Hurricanes, Storms and Tornadoes

PB93-137743

TT 75-52013

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Hurricanes, Storms and Tornadoes

Geographic Characteristics and Geological Activity

[*Uragany, Buri i Smerchi: Geograficheskie Osobennosti i Geologicheskaya Deyatel'nost'*]

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Nauka Publishers
Leningrad Section, Leningrad, 1969

Translated from Russian

Published for the National Oceanic and Atmospheric Administration,
United States Department of Commerce, and
the National Science Foundation, Washington, D.C.,
by Amerind Publishing Co. Pvt. Ltd., New Delhi
1982

Translated and published for the National Oceanic and Atmospheric Administration, United States Department of Commerce, pursuant to an agreement with the National Science Foundation, Washington, D.C., by Amerind Publishing Co. Pvt. Ltd., 66 Janpath, New Delhi 110001

Translator: Dr. B.B. Bhattacharya
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Available from the U.S. Department of Commerce, National Technical Information Service, Springfield, Virginia 22161

Photoset and printed at Raj Bandhu Industrial Co., New Delhi 110064, India

UDC 551.515 + 551.55

This book represents the first attempt in Soviet, indeed in world, literature to give an account of the origin and characteristics of hurricanes, storms and tornadoes. It deals with their effect on different natural processes. The monograph includes, in addition to a detailed account of the topic, a number of original contributions by the author, including a new classification of these atmospheric phenomena and an analysis of the geological activity of very high velocity winds.

Editor-in-Chief
M. I. BUDYKO

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Introduction

One of the main purposes of this book is to draw the attention of our geographers and geologists to one significant and important factor which has not yet received the attention it deserves. This factor is the extraordinarily fast, often catastrophic movement of the air currents variously called hurricanes, storms and tornadoes.

In the scientific world it is widely accepted that geological and geographical phenomena and processes occur slowly, gradually and over a very long period, i.e. they are evolutionary processes. Often this concept supplements another—that the history of the earth's surface abounds in such evolutionary processes.

The concept of the great significance of slow, prolonged and gradual processes is quite correct. A large number of phenomena have evolutionary processes as their basis. But the idea that these alone make up the history of the earth contains an inherent error, limiting and distorting our ideas.

Fast, sudden, sharp, violent and catastrophic processes, which may be termed revolutionary, also have a prominent place in the history of the earth. Often they are no less significant than the evolutionary processes. The history of earth's surface comprises the combined series of actions of evolutionary and revolutionary processes and phenomena.

Hurricanes, storms and tornadoes belong to the category of catastrophic phenomena.

The terms "catastrophe", "catastrophic" require some explanation. Usually they refer to men, their lives and buildings. Hurricanes, storms and tornadoes bring death to thousands, even hundreds of thousands of men and can destroy whole cities. But in the history of the earth man has appeared very recently. Were there such catastrophes before his emergence? Yes, of course. These catastrophes are rare in relation to the life span of man but in the life of the earth they are repeated so frequently that they form a common feature.

Layers of deposits related to them, usually in the sections, are revealed in the walls of pits, but we have only just started recognizing their presence. One of the fascinating problems facing geologists and paleogeographers is to understand such deposits thoroughly.

This book is divided into two parts—geographical and geological. The geographical part includes brief descriptions of hurricanes, storms and tornadoes mainly as geographical phenomena. It consists of three corresponding sections. The second part—geological—mainly concerns the effect of hurricanes, storms and tornadoes on sedimentation and the distribution of marine organisms. A brief description of the effect of atmospheric catastrophes on the static condition of the earth's surface, particularly on the earthquakes and formations of faults and anomalies, is also given.

Hurricanes, storms and tornadoes are mainly meteorological phenomena and a large amount of data can be found in meteorological literature. At the same time, they are geographical phenomena inasmuch as they radically change the surface of the earth—"the appearance of the earth". This aspect is dealt with in detail. However, the meteorological problems, especially theoretical, relating to the physical conditions of their formation are not dealt with in any detail.

While working on this book it was found that hurricanes, storms and tornadoes display many interesting and distinctive features. Descriptions of these features fill the major part of the book. They are mainly geographical but include the geological aspect.

Lastly, a detailed presentation of a wide range of new material required the description of some purely meteorological problems. Such problems are the horizontal vortex formations in thunderstorms and especially in tornado clouds, which attain quite unusual dimensions, and the very high wind speeds in hurricanes and tornadoes. This last often exceeds the speed of sound.

On the whole the book falls whithin the range of disciplines dealing with the science of the earth. It will be of interest to geographers, meteorologists, geologists and a wide circle of students of Soviet local lore.

The book is of the popular science type in respect of meteorological topics but the geographical and geological data may be of interest to specialists. Special attention has been paid to new problems that have not yet received the attention they deserve.

A bibliography is provided for those who desire to deepen their knowledge in one or other topic. Almost all of it has been utilized in writing the book.

The author acknowledges the help of all the meteorologists who have helped him in writing this book.

He is especially indebted to M.I. Budyko and L.A. Vitel's for going

through the manuscript and offering a number of suggestions. L.A. Vitel's provided much interesting and important information which has been incorporated in the text. This is included in the chronological index at the end.

DEFINITIONS

Cyclone: This is a gigantic atmospheric vortex with air pressure decreasing to the center. The circulation of the air around the center is anticlockwise in the northern hemisphere and clockwise in the southern hemisphere. Near the earth's surface (up to an altitude of 1–1.5 km) the wind has a component directed inward into the cyclone along the pressure gradient and the cyclone converges to the center of the vortex. Cyclones arising and developing in nontropical latitudes—*nontropical cyclones*—have lateral dimensions of the order of a thousand kilometers in the initial stage of development and of a few thousand kilometers in the stage of the so-called frontal cyclone. The speed of the wind in deep cyclones with large pressure gradients may attain the strength of storms and often hurricane force, although in most cases it does not exceed 6–8 units.

Tropical cyclones occur in tropical latitudes. The average width of a tropical cyclone is a few hundred kilometers, and its height varies from 6–8 to 12–15 km. The central part, the "eye of the storm", displays the lowest pressure, weak wind and little cloud. The "eye" is surrounded by rings of the cyclone walls, consisting of dense cloud rotating at fast, even hurricane speed. The walls change more or less sharply in the peripheral parts, where the wind gradually weakens to total calm.

Tropical cyclones of the Atlantic Ocean are generally known as hurricanes and those of the western part of the Pacific Ocean as typhoons.

Tornado (in Europe—spout, in America—tornado): This is the strongest vortex of atmospheric formation. It is somewhat akin to a tropical cyclone. It differs, however, in its dimensions: the width ranges from a few meters to 2–3 km, on an average 200–400 m; the height ranges from a few tens of meters to 1,500–2,000 m, on an average a few hundred meters. The central part is sharp and high. The walls are more or less sharply defined, seldom blurred or indistinct. A tornado is characterized by the tremendous speed of rotation in the walls, reaching supersonic speed. The peripheral part is not very big; it is irregular or even absent. Often a tornado is associated with a tropical cyclone (hurricane).

WIND SPEED

The speed of wind mentioned in the above formations fluctuates from total calm to supersonic speed. The speed of sound in air is 331.8 m/sec = 1,194 km/hr.

In 1806 the English admiral Beaufort suggested 12 scales of speed (strength) of wind. This scale, with slight modifications, remains in force today. In 1946 the last unit, the 12th (hurricanes), was subdivided into six divisions because hurricanes can differ widely in strength.

Beaufort scale

Beaufort No.	mph	Description	Effects observed on land
0	0–1	Calm	Smoke rises vertically
1	2–3	Light air	Smoke drifts
2	4–7	Light breeze	Leaves rustle
3	8–12	Gentle breeze	Leaves in constant motion
4	13–18	Moderate breeze	Dust and leaves raised
5	19–25	Fresh breeze	Small trees begin to sway
6	25–31	Strong breeze	Larger branches of trees in motion
7	32–38	Moderate breeze	Whole trees in motion
8	39–46	Fresh gale	Twigs and small branches break
9	47–54	Strong gale	Slight structural damage occurs
10	55–63	Whole gale	Trees broken or uprooted
11	64–75	Storm	Damage all over
12	Over 75	Hurricane	Large-scale damage, calamity

Often the numbers are expressed in metric measurements—meters per second or kilometers per hour. The adjusted numbers are as follows (Khromov and Mamontova, 1963):

Nos.	m/sec	km/hr	Nos.	m/sec	km/hr
0	0	0	9	22.6	79.41
1	0.9	3.24	10	26.4	95.00
2	2.4	8.64	11	30.5	109.8
3	4.4	15.84	12	34.8	122.28
4	6.7	24.12	13	39.2	144.60
5	9.3	33.48	14	43.8	157.68
6	12.3	43.3	15	48.6	174.90
7	15.5	55.8	16	53.5	192.6
8	18.9	68.4	17	58.6 and more	210.96 and more

It is evident that the scales for hurricanes are insufficient. In the Atlantic a speed of 150 mph = 241.5 km/hr for a hurricane is not rare. Speeds of 200 mph = 322 km/hr, 250 mph = 402 km/hr and even 400 mph = 644 km/hr have also been observed. In tornadoes the speed exceeds the speed of sound, i.e. 1,200 km/hr. A wind with such a high speed destroys all measuring instruments and therefore accurate measurements cannot be obtained.

PART I

HURRICANES

1
Tropical Hurricanes

FUNDAMENTAL LAWS

Tropical cyclones originate over oceans, primarily in their western parts, in the equatorial zone of calm, but quite far from the equator (10–15° latitude). In the beginning they take the form of small, shallow depressions and the force of wind is weak. After forming they start moving to the west, at first slowly. The dimensions and depth increase with the movement. The speed of the wind increases as well. In some cyclones this process is very fast and as many as 40–50% develop into hurricanes. Of 591 tropical cyclones originating over the Atlantic from 1887 through 1960 343 attained the intensity of hurricanes.

After some time the trajectory of the cyclone veers to the northwest, then to north and finally to the north-east (Fig. 1). Some of them strike land—islands or continents—causing large-scale destruction. Others remain over the sea throughout their passage.

Figure 2 depicts the typhoon of September 20, 1934, approaching Japan. Next day it caused large-scale destruction and vast loss of life.

According to recent data obtained from satellites, the tropical cyclones of the North Atlantic often form over Africa, but the winds attain storm or hurricane proportions only over the ocean (Khromov, 1964, p. 393). The track resembles a parabola in shape.

The hurricanes of the Atlantic have been described in detail in the books by Tannehill (1956) and Dunn and Miller (1960). Popular but informative and interesting reviews have been published by Z.M. Tiron (1964) and Sloane (1956). Descriptions of Japanese typhoons and their consequences have been presented by a group of authors and these have been translated into the Russian language (Okuta Minoru, 1963).

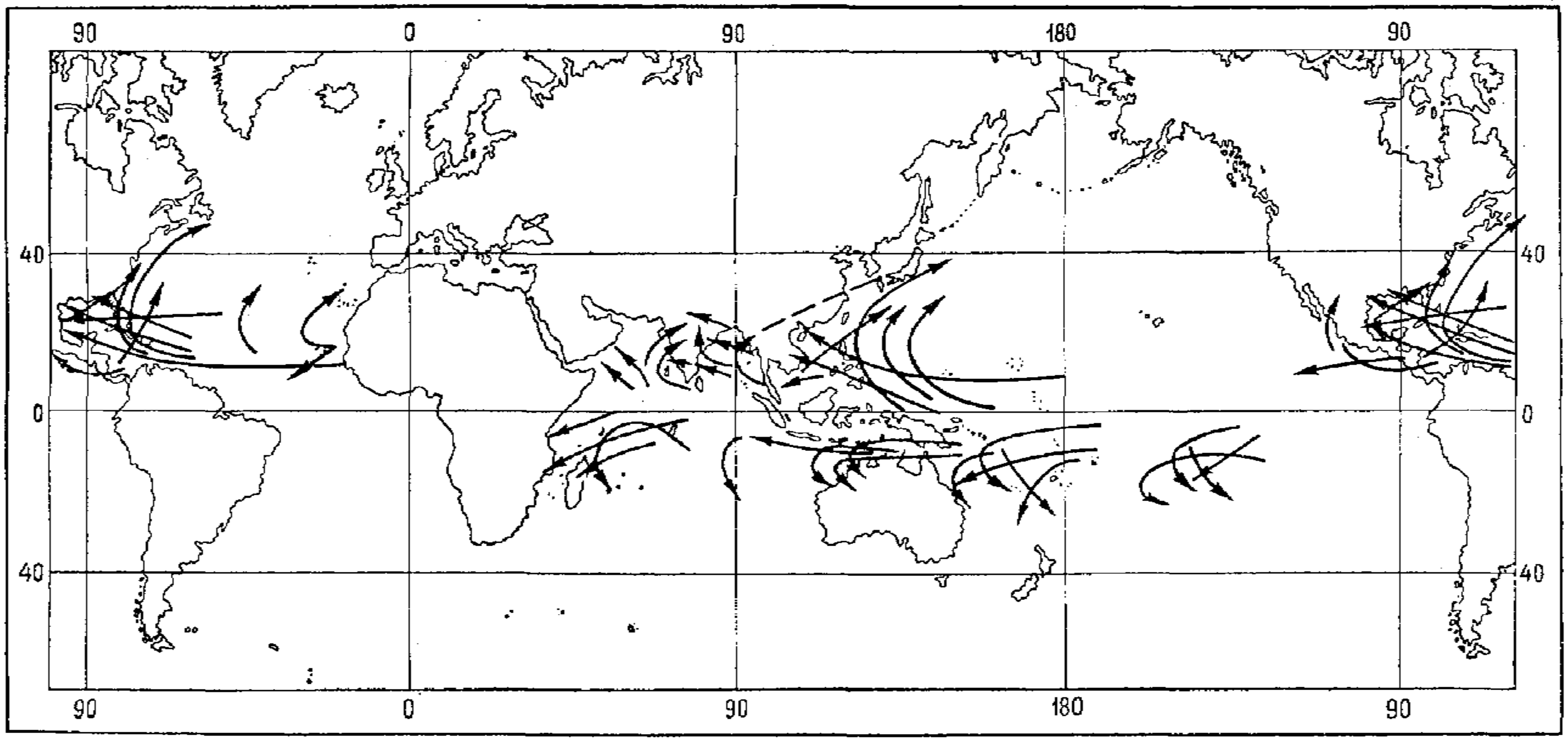


Fig. 1. Main tracks of tropical cyclones--hurricanes and typhoons (Khromov, 1964, Fig. 101).

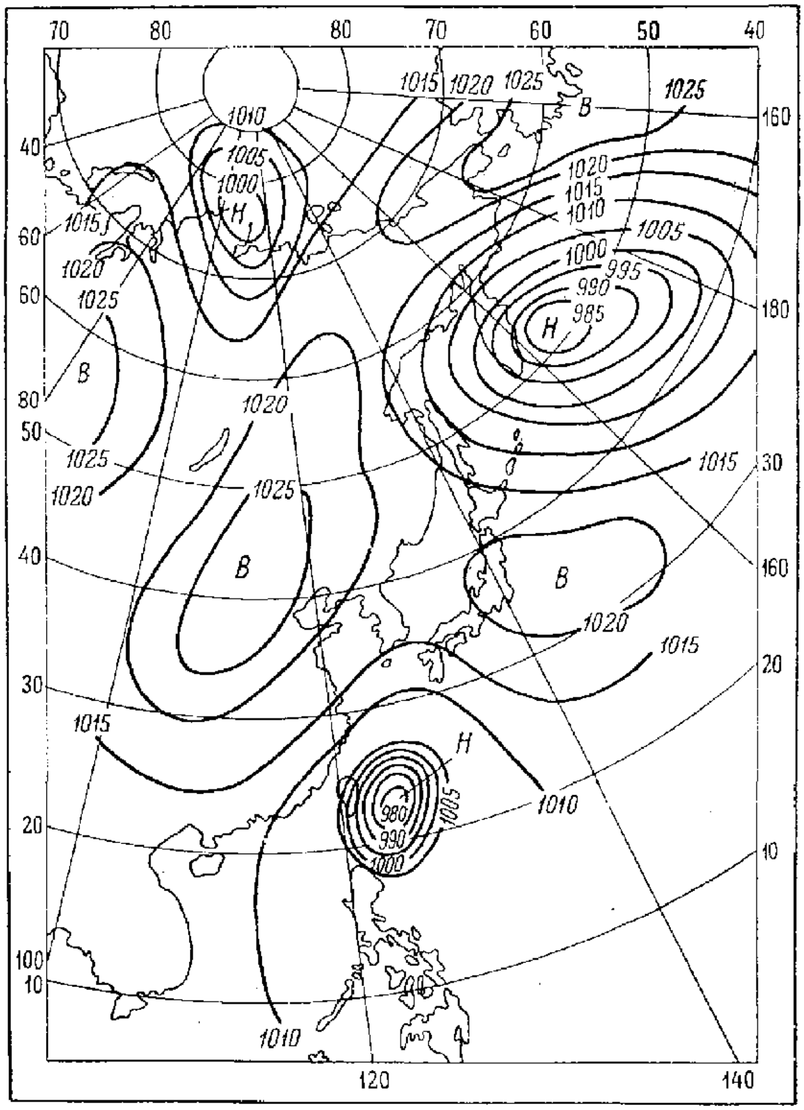


Fig. 2. Typhoon in south, near Taiwan, and nontropical cyclone in north, over Kamchatka. Synoptic map (Khromov, 1964, Fig. 100). *Figures*—pressure (mb); *H*—cyclones; *B*—anticyclones.

The hurricanes of the Pacific Ocean have been described in the monograph by Visher (1925).

A general review of the hurricanes of the world is given in the monograph by Newham (1922). It is a meteorological work and does not include data on destruction.

Among the earlier literature, Fassig's (1913) work deserves attention. Much information on the tracks, origin and destructive action of hurricanes is to be found in this book.

There is an interesting and informative book by P.A. Molyen (1967). Like many French popular science works, it is lively and gives a graphic account. Most fascinating is the description of flights inside hurricanes, particularly in the "eye of the storm" of typhoon 'Ruf' of 1962 (see below).

Apart from the review, hundreds, even thousands of other studies and descriptions of individual hurricanes and related problems are referred to.

The characteristic feature of the tropical hurricane is the spiral wind flow. This was established in the last century and vividly depicted in the book by Davis (1899). Figure 3 shows the pattern of wind in the hurricane over Cuba in 1888: the picture on the left depicts the hurricane on September 3, that on the right the same hurricane on September 5. The movement of the hurricane and the increase in its dimensions can readily be seen.

The spiral structure of hurricanes can be seen more distinctly in the photographs taken with the help of radar, the Tiros satellite and the U-2 airplane.

Many scientists of the last century termed the characteristic change of wind to the hurricane stage the "law of the storm" (Dove, 1869).

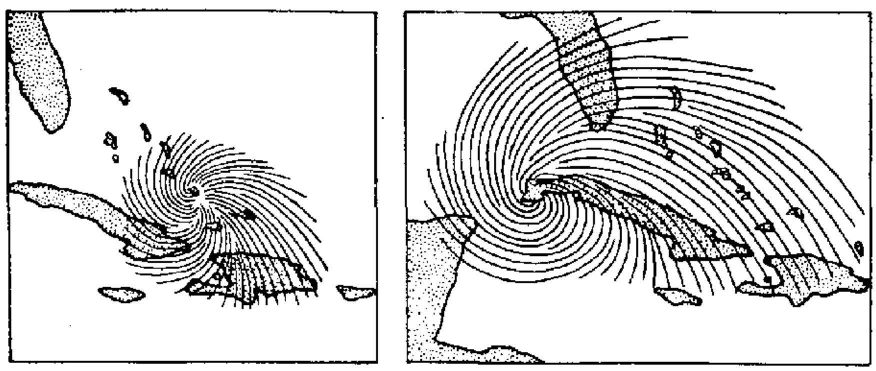


Fig. 3. Sketch of direction of winds in hurricane, Cuba, 1888. Spiral structure (Davis, 1899, Fig. 54).
Left—September 3; *right*—September 5.

STRUCTURE AND FORM

A hurricane is a tropical cyclone in which the pressure in the center is extremely low and the wind attains very high speed and destructive force. Characteristic of the hurricane is the high funnel (up to 10–14 km) with steep side walls rotating at very high speed. A sketch of the structure of a hurricane is given in Fig. 4, taken from the interesting and informative monograph by Tannehill (1956). At the top is a sketch of the direction of the rotating air; the middle diagram shows that the hurricane has a well-defined central funnel in which the movement of air is directed downward while at the sides it moves upward. The bottom diagram shows a section of the funnel of the hurricane of 1882 over Manila. It can be seen that up to a height of 8 km the side of the funnel is quite steep, becoming more gentle higher up.

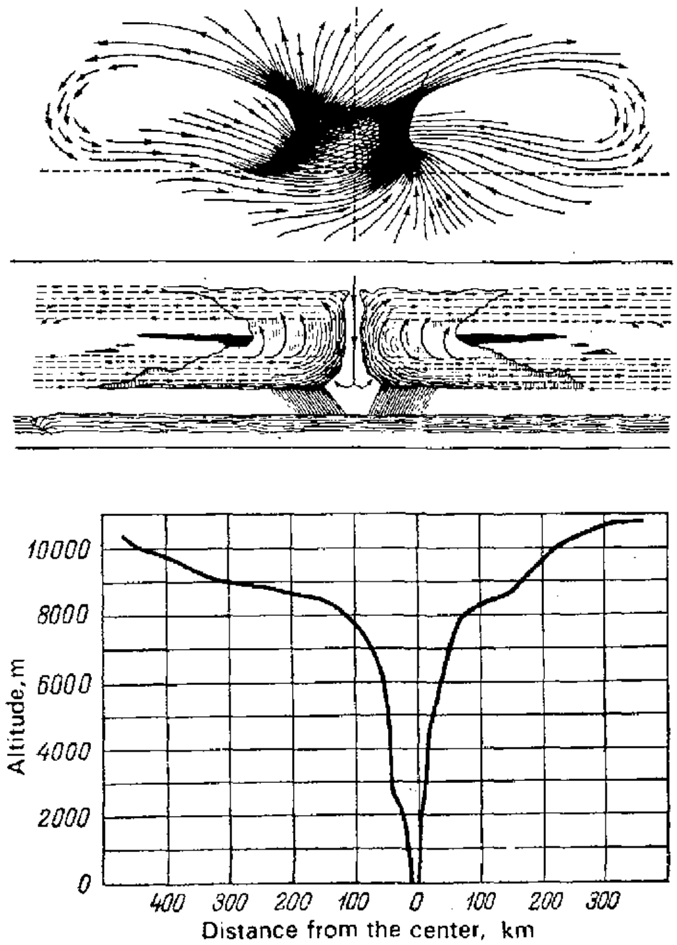


Fig. 4. Sketch of structure of hurricane
(Tannehill, 1956, Fig. 8).
Top—direction of wind; *middle*—cross section of hurricane
("eye of storm", central funnel, its walls and periphery);
bottom—funnel of typhoon of 1882.

The data on the width of the funnel are interesting. On the surface of the earth it is around 20 km, at a height of 2 km—40 km, at a height of 6 km—100 km, at a height of 8 km—175 km and at 10 km—700 km.

An interesting section of the cyclone (Fig. 5) is given in the book on meteorology by S.P. Khromov (1964, Fig. 102). The hurricane in this case is related to the gigantic, almost continuous, black thunderstorm cloud 14 km in height and around 800 km in width. It has a circular or oblong-oval form. In the center we have the funnel, the "eye of the storm"; its width is 20–25 km. The funnel is open at the top, almost without cloud, and wind is either absent or very weak. On the other hand, the walls of the funnel are a zone of very strong rotation and wind. This is essentially what we call a hurricane. Although the wind continues beyond the boundaries of the walls its speed

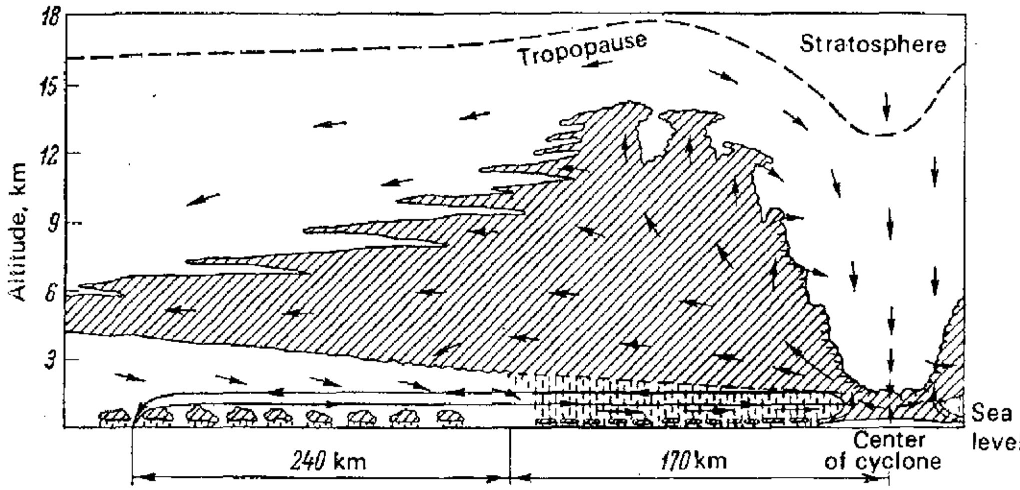


Fig. 5. Section of half of tropical cyclone (hurricane) (Khromov, 1964, Fig. 102). *Arrows* show movement of air, descending in central funnel and ascending to spiral along wall; *slanted dashes*—primary and secondary clouds; *vertical dashes*—rain.

falls sharply outward, i.e. the hurricane ceases and the height of the thunderstorm cloud decreases.

The thickness of the walls of the funnel varies widely. Generally it is in the range of tens of kilometers, but sometimes can be of the order of 100 km or more. It is well shown, though somewhat primitively, in Fig. 4 and can be seen in the photographs taken by Tiros (Figs. 10, 18), radar pictures (Figs. 14, 16) and in the sketch by Braun (Fig. 6).

A lively account of the central part of a typhoon has been given by Molyen (1967). The Meteorological Department aircraft he was aboard crossed typhoon 'Ruf' of 1962 (Fig. 7). He writes: "We are located in the wall of the typhoon, in the zone of maximum wind, in the zone of convergence, meeting the air jet where the accumulated, skewed, compressed wind bursts furiously into the gigantic funnel of the depression and cannot escape from the mysterious boundary of the walls.

"All of a sudden, when the Boeing has been captured in the last outburst, a dreadful mood sets in and abruptly there is silence.

"This is the eye.

"This is the zone of least pressure and highest temperature.

"This void, this abyss in the atmosphere where, as if at the summons of a Prophet, a fantastic order of millions of cubic meters of air is rushing, vanishing impatiently, warming up, howling and whirling, lifting ocean in waves and foam, like the travelling dust bursting back and forth, jostling in millions, enveloping the same mystic deadly material...

"Before us appears the most majestic, the most thrilling phenomenon such as may have appeared only when Nature was created. All this happens in the eye of the typhoon. The return brings a mixed feeling of delight and horror, which cannot be described in words. We hear the roar of the engines or, rather, we sense the calm. It is so unexpected and dramatic that according to one sailor it is preferable to hear once again the roar of Nature in her enraged mood.

"All around us is the wall, the fort, which is there to make us captive in this totally magical and fascinating country.

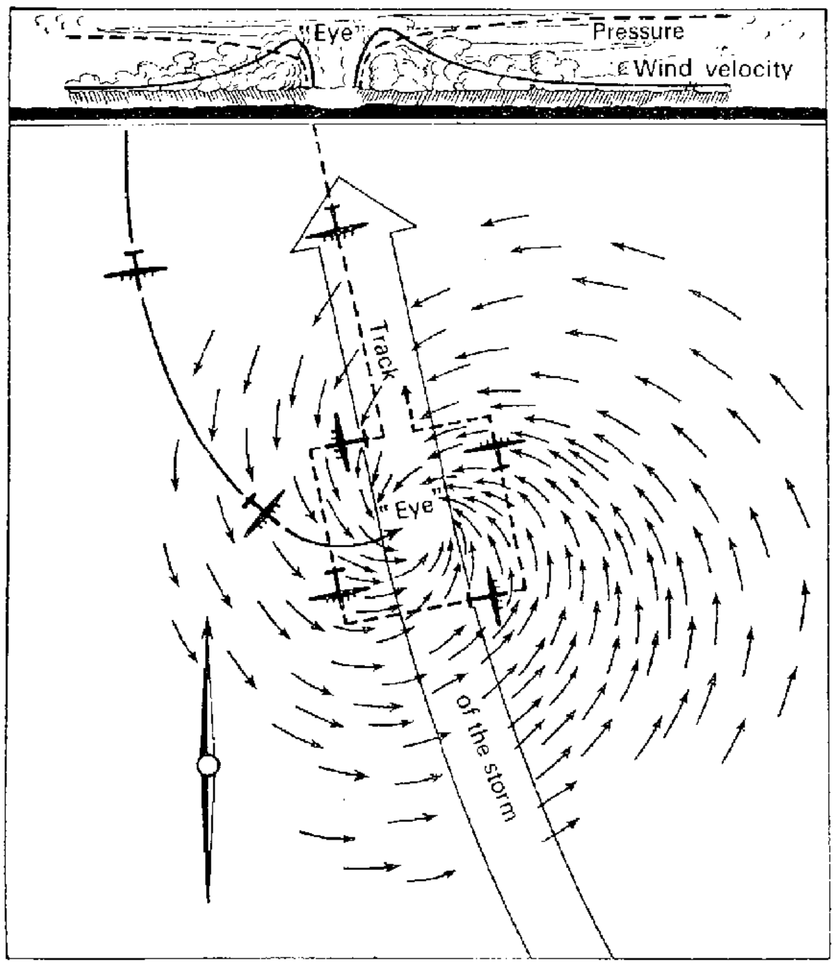


Fig. 6. Sketch of structure of hurricane (Lane, 1966).

"We are flying at a height of 3 km in a well 22 km in diameter, in which some cirrus clouds float as peacefully as dolls. The walls of this well constitute the core of the storm, held confined by some mysterious cause. It is full of seething clouds enveloping terrible convulsions . . .

"When the aircraft banks to turn our eyes glimpse the top of the wall, the mouth of this well, 15 km above us. Before our amazed sight this seething 15 kilometer wall develops this gigantic abyss, this circular aperture which is known as the 'eye of the typhoon'.

"One should not imagine that the typhoon is clearly defined, that it looks like whirling earth being ground to fine powder by a millstone or like a rotating column. It has no distinct boundary—it is a mass with a vague outline and twice as high as Everest with a crater in the center. One does not forget it if he has once seen it. This is a world of violent forces, a world of inevitable destruction, a world of energy, equal to the energy of three atom bombs in a second" (Molyen, 1967, pp. 207–216).

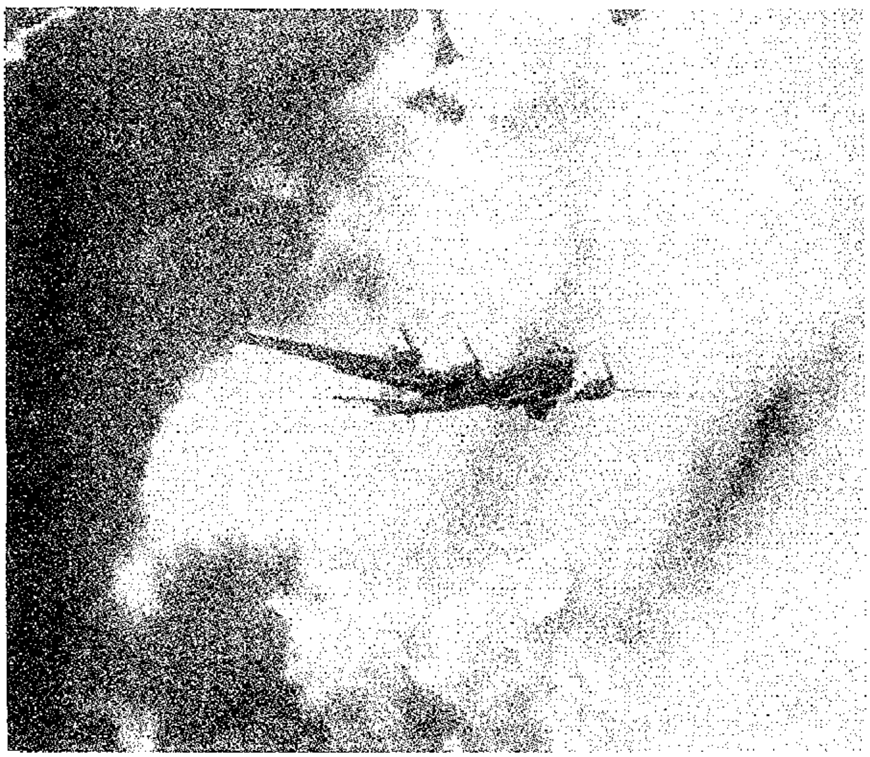


Fig. 7. Aircraft emerging from hurricane (Lane, 1966).

DIMENSIONS

The dimensions of different hurricanes differ widely; they also differ according to the method used for estimation. Often the width of the zone of catastrophic destruction, i.e. the zone of hurricane wind force, is taken as the width of the hurricane. As has already been mentioned, this zone has a width of 20 to 200 km or more. Often the zone of wind of storm strength with relatively less destructive power is added to this zone; then the width of the hurricane is measured in hundreds of kilometers, often up to 1,000 and even 1,500 km. The work done during the last hundred years contains material which provides the following information:

"From the determination over Redfield City, the diameter of hurricanes near West Indies islands changes from 150 to 225 km, and with further movement it widens so much that the diameter becomes 900–1,500 km. G. Tom states that the diameter of the hurricane is 600–900 km in the southern part of the Indian Ocean. According to G. Piddington, the diameter of cyclones in the Arabian Sea is around 350 km and in the Bay of Bengal from 450 to 550 km" (Dove, 1869, p. 300).

According to the latest data, the Atlantic hurricanes have an average diameter of 150 km and a diameter of the storm zone of 450–600 km. But these figures can vary. The fierce hurricane of October, 1950, in Miami, Florida, comprised in all a 23 km zone of destruction and an extraordinarily sharp boundary of the walls, reminding one of a tornado. The famous violent hurricane of 1935 in Florida also left a sharp belt of destruction, 50–65 km wide. Hurricane Hazel of 1954 left a zone of destruction more than 200 km wide and 500 km wide storm zone. Carol (1953) measured 240 and 640 km respectively and the big Atlantic hurricane of 1944, 320 and 960 km respectively (Dunn and Miller, 1960, p.76).

More significant are the dimensions of typhoons. For the Pacific Ocean the average dimension of the cyclonic belt of the strongest storm is of the order of 500–600 km. The least dimension is around 80 km, the largest about 1,600 km. In tropical areas the dimensions increase to nearly 3,000 km. The belt of destruction over which the "eye of the storm" passes is usually 15–45 km, but in the contiguous belt of approximately the same width of zone of destruction is quite small. For some storms the zone of destruction from wind and waves is around 40–80 km wide, but the destructive cloudbursts affect a larger area (Visher, 1925).

The structure, formation, growth and movement of typhoons have been described in a series of papers in the collection "Proceedings of the UNESCO Symposium of Typhoons, November 9–12, 1954" (1955). The collection contains a variety of material, mainly of synoptic character, along with maps, sketches, diagrams, figures and photographs.

Among Soviet publications the work by A.P. Barabashkin and E.A. Leskov (1958) on typhoons passing through the Primorsky region (the work is synoptic in character) and the review work by T.F. Batyaev and L.S. Minim (1967) deserve mention.

LIFE SPAN

The average duration of Atlantic hurricanes is around nine days, although in August it may be around 12 days. The hurricanes developing over Africa and the Cape Verde Islands are of longer duration. They cross the Atlantic Ocean twice and move farther to the north. Their duration is in the range of three to four weeks, for example, the famous New England hurricane of 1938 and the hurricanes passing through the Altantic circle. The famous hurricane of San Ciriaco (1899) lasted for five weeks. Often tropical hurricanes, without losing strength, change to nontropical hurricanes and then the duration of their life becomes considerable. The hurricane of 1900, which killed 6,000 people in Galveston on September 8, originated on August 27 in the middle of the Atlantic Ocean, crossed the Carribean Sea and the Gulf of Mexico and penetrated deep into the continent. In the region of the Great Lakes it transformed into a nontropical cyclone, but retaining its strength, moved right across North America, the Atlantic Ocean and the whole of Europe and moved on into Siberia. According to Tannehill, the lifespan of this hurricane was 27 days (August 27–September 22).

SPEED

The speed of translational movement of hurricanes and typhoons varies widely. Often they remain at one spot, though not long, or move at a speed of a few kilometers per hour and then accelerate to tens of kilometers. The figure of the order of 50–60 kmph may be taken as average and 150–200 kmph as maximum.

The speed of the vortex wind inside the hurricane, especially in its walls, is very high. The maximum figure is for the famous Florida hurricane of 1935. From the destruction it caused engineers calculated the wind speed to be 320–400 kmph. Speeds of the order of 250 kmph have been observed in many strong hurricanes and can be considered as typical (Dunn and Miller, 1960, p. 62; Harding, 1965, p. 42).

The maximum vortex speed approximates the vortex speed of a tornado. It is of interest that such speeds are observed in hurricanes of very small diameter and in the densest walls. Apparently a higher vortex speed gives the vortex a denser wall, and sharp boundaries are found not only in tornadoes but also in hurricanes. This underlines the close similarity between them.

DATA FROM RADAR, SATELLITES AND AIRPLANES

Hurricanes differ widely in dimensions and they cannot be covered entirely by the usual observations. Radar, satellites and high altitude aircraft are of great help in providing information (Kiss, 1960).

RADAR means Radio Detecting and Ranging. The radar beam penetrates the hurricane, is reflected from the stream of air with a large quantity of moisture and forms a white strip on the screen. Air streams without water remain black. The "eye of the storm" is always clear, without cloud or rain, and therefore on the radar screen it has the form of a small black spot, often of circular form. This is surrounded by a white ring of continuous rain. From this ring white spiral rings radiate, gradually widening and disappearing into a black background (Fig. 8). The diameter of the spiral belt is the diameter of the hurricane. Usually they are a few hundred kilometers wide.

The spiral nature of the air stream shows that the entire body of the hurricane imparts spiral rotation to the air mass, consisting of the air stream, at first saturated with water and subsequently almost dry. Radars show that vertical motion is displayed not only by the central part of the hurricane but also by the entire mass—the whole gigantic thunderstorm and rainclouds. It is interesting that thunderstorms in the central part of the hurricane are very rare and usually appear only at its boundaries.

Observations by radar are made from stationary stations and from aircraft. They yield very important factual material and are indispensable for determining the location and movement of hurricanes. Radar is widely used in the Air Force and the Navy of the United States for predicting hurricanes (Battan, 1959, 1962). Radar data are also used in the Far East, especially for predicting typhoons.

Vital data have been obtained using fighter planes and planes of the Meteorological Department. At first such flights were rare: they were made in ordinary aircraft at great risk. Now specially built aircraft are used for the purpose. Unfortunate accidents are rare but do occur.

The most extensive large-scale observations from aircraft are made in the United States, which suffers most from hurricanes. The aircraft penetrates deep into the hurricane to its center, flies around the hurricane and above it. The "eye of the hurricane" was photographed for the first time from an aircraft. Airplanes fly many hundreds of kilometers over the ocean to determine the location and speed of movement of the hurricane and provide important information for hurricane forecasts.

Molyen (1967, pp. 237–38) observed the following while flying in an American plane: "I went to the pilot's cockpit and with difficulty suppressed a scream. Yes, theoretically I knew that I was in the midst of these spirals of clouds, but now it was there in front of me, as if I could reach out and touch it—not displayed on the radar screen but in reality . . .

"The cyclone swings toward us so that its spiral cloud and the empty space in between separate in a long curved path, resembling a race track, 20–25 km long, stretching away about 300 km in the bright, unusual light of the setting sun . . .

"We are flying, moving along the corridor of the typhoon as if on the marble walk of a submerged, deserted palace."

The majestic picture can be seen in the photograph (Fig. 7). The plane comes out of the hurricane and behind it rises the wall of black cloud.

To study the hurricane the airplane first flies to its left where the wind speed is lowest, penetrates into the "eye"—the central zone—and determines its position and dimensions. Then it flies into it along the track of the hurricane (Fig. 6), describing a square around the "eye", and again flies along the track of the hurricane. In this process all the features of the central—the most important—zone are determined (Brown, 1950).

The most dangerous part is to fly into the "eye" of the hurricane. In the process the wall enclosing the "eye", where the wind is very strong, is crossed. The arrows in the diagram show the direction of the wind. The thicker the arrows, the stronger the wind.

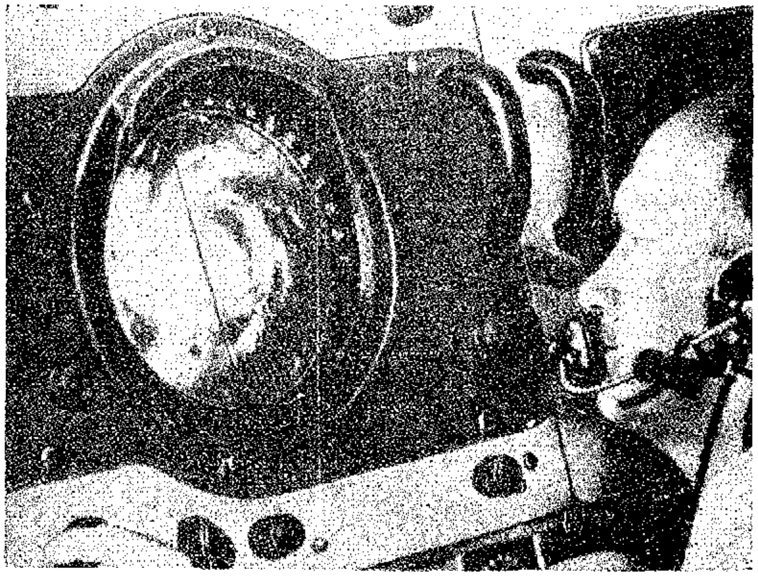


Fig. 8. Form of hurricane on radar. Spiral structure is well shown (Knight, 1964, p. 40).

The top of Fig. 6 shows a section of the hurricane along its track. The continuous bold line represents the strength of the wind and the broken line the pressure. In the wall of the "eye" the wind strength is maximum and the pressure is minimum. The short inclined lines represent rain. The spiral structure in the diagram is as vivid as the description given above by Molyen.

Interesting material has been obtained from the photographs taken by the television camera of the special Tiros satellite (Fig. 9).

The first satellite, Tiros I, was launched in 1960. In 1965, photographs were obtained from the ninth satellite—Tiros IX. The first satellite, orbiting at a height of 697 to 737 km, took 6,000 photographs of different types of cloud (Fritz and Wexler, 1960). A lar · number of photographs were taken by subsequent satellites. These photographs covered a very large area. For the first time such large-scale phenomena as tropical and even extratropical cyclones and hurricanes, were photographed. These photographs showed such details that in some cases tornadoes accompanying the hurricane could also be distinguished. In these photographs clouds saturated with water appear white and clearly show the general spiral structure of the hurricanes (Figs. 10, 26), the center of the hurricane ("eye of the storm") in the form of a round black spot and the continuous white wall of the rainy cloud surrounding it (Figs. 10, 14). In general, the photographs taken from the Tiros satellites contain extremely valuable material. They are used to advantage in many types of meteorological work.

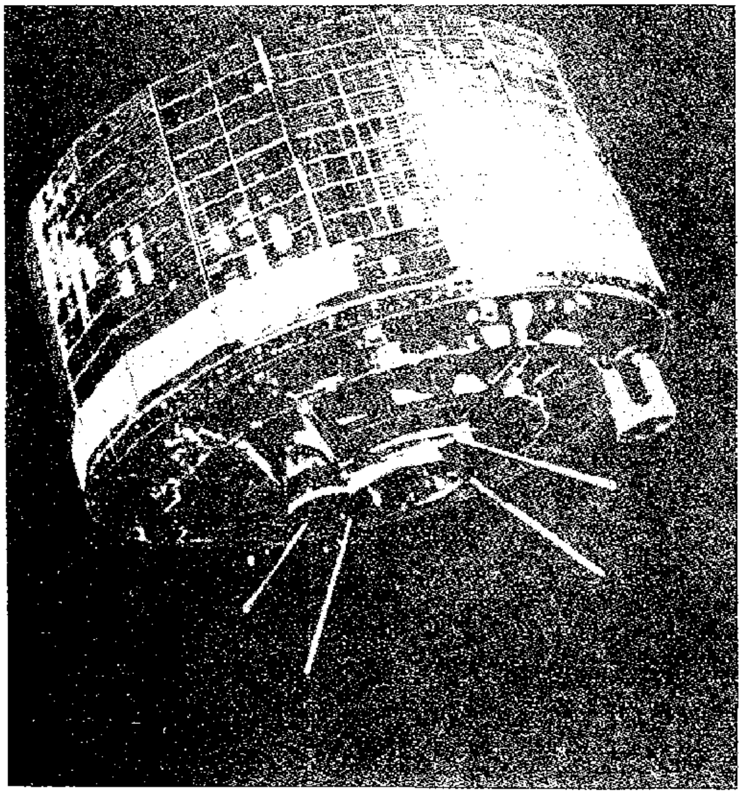


Fig. 9. American Tiros satellite (Knight, 1964, p. 50).

Atlantic and Pacific ocean typhoons were photographed with the help of Tiros satellites. The photographs showed them in their totality. Typhoon Opal of 1962 (Fig. 10) is not different from the hurricane Daisy (Fig. 18). The form, dimensions and track of typhoon Opal can be seen in Fig. 11. In six days it passed the Philippine islands and Taiwan and crossed into the territory of the Chinese mainland.

When cloud is absent the photographs depict the earth's surface in great detail. Adequate enlargement of such photographs is of reconnaissance value. For this reason our press often refers to the Tiros satellite as a spy satelite.

The American reconnaissance plane U–2 is notorious as a "spy plane". One such was shot down by a rocket from Sverdlovsk during a reconnaissance flight. These planes reach a very great height of the order of 20 km or more. They can easily photograph the top of any hurricane or typhoon.

Many interesting photographs were taken during the flights of the satellites Mercury and Gemini, either by the astronauts or using the automatic telecamera. The later photographs are especially clear and contain im-

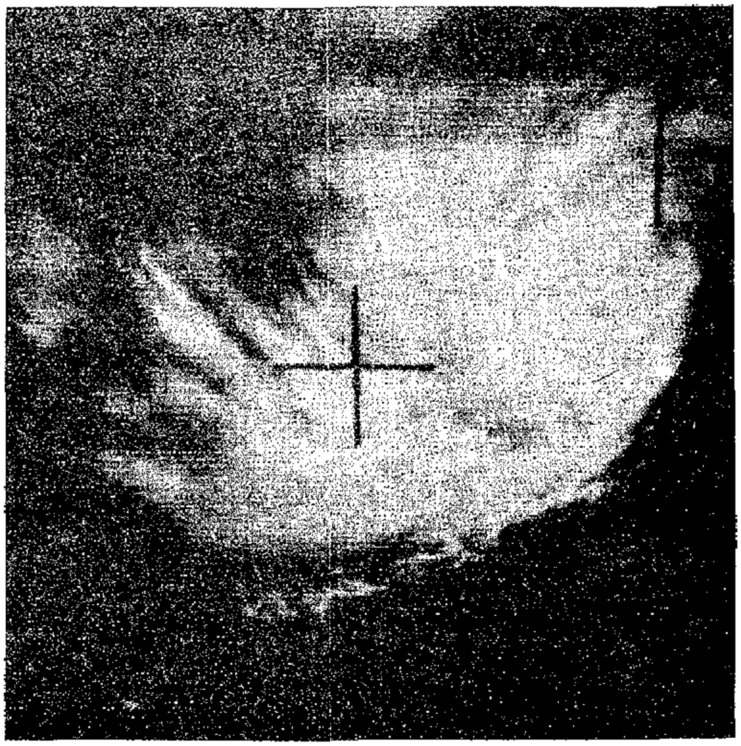


Fig. 10. Typhoon Opal, 1962. "Eye of the storm"—small circular black spot between cross and boundary around white wall of rain. Photograph from Tiros V (Weather, v. 20, 1965, p. 144).

portant geographical and geological data (Lowman, 1966). The large-scale tectonic structures in the Atlas Mountains in Morocco, the extremely distinct structure of Rihat in Mauritania (meteorite crater?), pyramidal dunes in the northern Sahara, the strikingly correct delineation of dunes of pinkish sand in the desert of Namibia (Southern Africa) and the fabulous amount of golden loess silt carried to the sea by the great Chinese rivers can be distinctly seen in these photographs.

Many Soviet satellites have carried out meteorological observations and photographed and teletransmitted the information to ground stations; for example, the satellite Cosmos-122, which went around the earth 15 times a day. The panorama of the weather in a 1,000 km wide belt was photographed by cameras aboard the satellite. More than 25 million km^2, constituting 5% of the entire planet, was surveyed in one hour.

Cosmos-122, orbiting over the Pacific Ocean and Japanese islands, located two typhoons simultaneously. The first, Alice, was already known and was duly observed. The second, Cora, was noticed for the first time. The photograph showed that it had already formed and had a diameter of 900 km. The spiral structure was distinctly visible. Information on Cora was rapidly transmitted through the International Weather Service.

Cosmos-122, orbiting over the central belt of the Pacific Ocean, photographed the gigantic hurricane Grace moving toward the west (Dmitriev, 1966).

The meteorological satellite Cosmos-122 functioned continuously for four months and regularly supplied a large amount of meteorological information. Experience shows that the decision to launch meteorological satellites in our country, providing prolonged simultaneous measurements of several parameters of atmospheric conditions, was correct and effective.

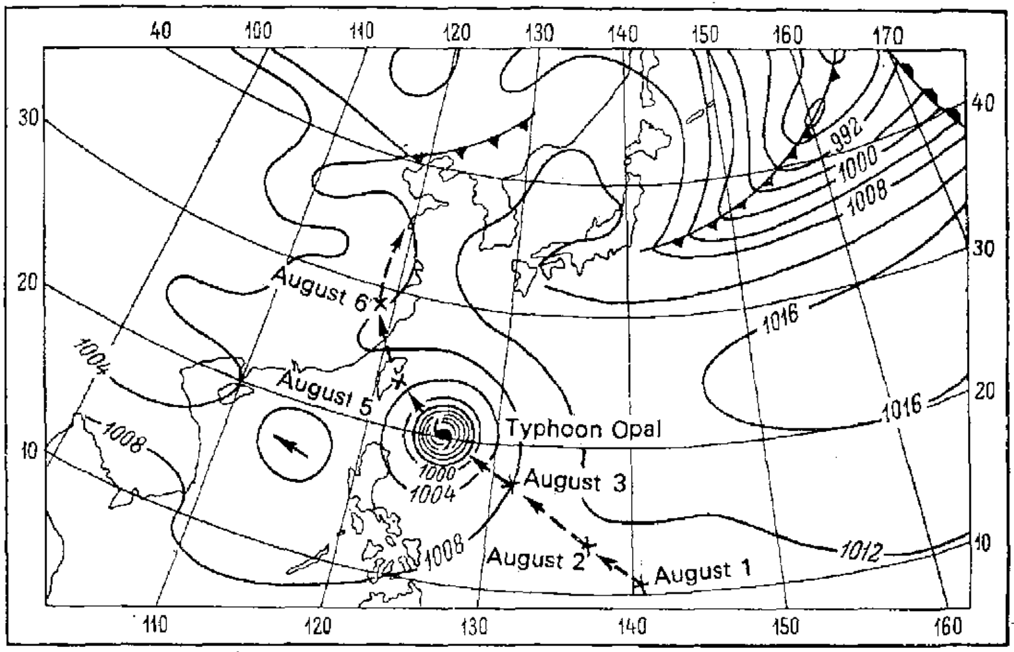


Fig. 11. Typhoon Opal, 1962. Synoptic map showing track of typhoon (Weather, v. 20, 1965, p. 144).

For this purpose a new meteorological sputnik, Cosmos-144, was lofted on February 28, 1967, to an altitude of 625 km in a circular transpolar orbit. The diagram depicts it and a short account is given in the paper by G. Golyshev and I. Andronov (1967). At the time of the flight the satellite was accurately oriented with respect to the earth. One of its axes was oriented to the center of the earth, the second along the trajectory and the third perpendicular to the plane of the orbit. The width of the zone of observation was around 1,000 km.

A television camera was used for observation of the illuminated side of the earth. Observation of cloudiness on the dark side was carried out by infra-red photography. Photographs of the clouded parts obtained with this system show less detail than television does but are adequate for analysis of large-scale atmospheric phenomena—cyclones, typhoons, fronts, etc.

Cosmos-144 showed cloud, snow cover and ice-covered areas on both the illuminated and the dark halves of the earth. Even the first photograph was of very high quality: not just not inferior to but in many ways superior to the American photographs.

In October, 1967, another meteorological satellite, Cosmos-184, was launched. The plane of its orbit was almost perpendicular to the plane of Cosmos-144's orbit. This enabled us to obtain meteorological data at the same point of the earth twice a day and thus to trace the development of atmospheric processes in time.

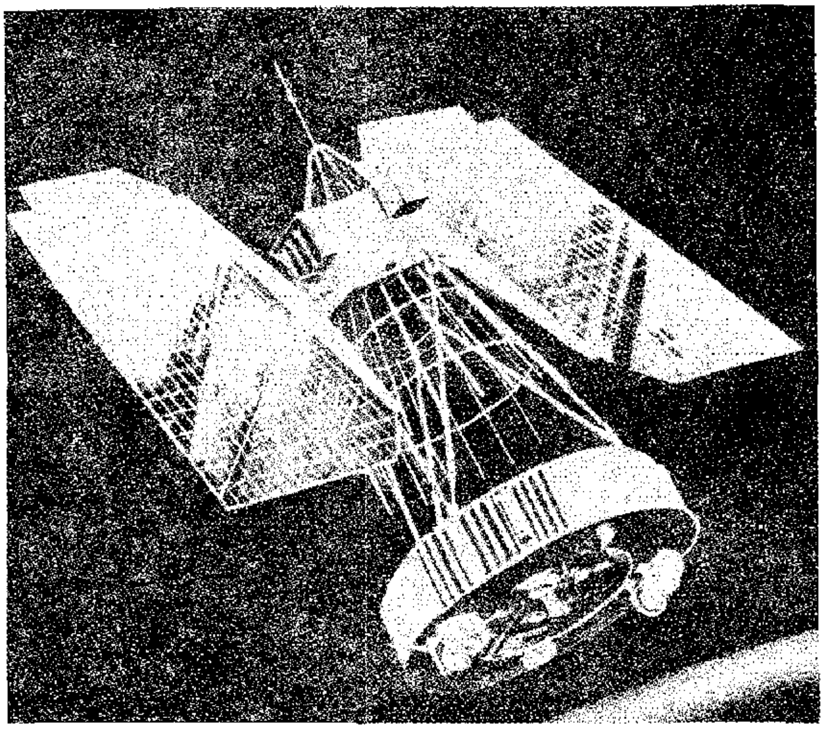


Fig. 12. Satellite Nimbus (Knight, 1964, p. 57).

On March 14, 1968, another satellite, Cosmos-206, was added to the family of satellites. Its orbit was quite close to that of Cosmos-144. It helped in objectively verifying the information coming from Cosmos-206 by re-examining the same region covered by Cosmos-144 after an interval of 20 min.

The three satellites—Cosmos-144, Cosmos-184 and Cosmos-206—together with the Meteor ground control system give exceptionally important information on the weather.

The volume of information is measured in multimillion binary units. This large amount of material is processed by computer and other automatic devices. The results are obtained in the form of maps and graphs, elucidating the atmospheric processes on a worldwide scale. The photographs of hurricanes obtained with the help of the infrared system are of great significance (Golyshev and Andronov, 1967).

A short description of the American satellites Tiros I, II and III is given in the interesting paper by Tepper (1961). Other satellites such as Nimbus and Aerus are also described therein. The first carried a camera always oriented toward the earth and the orbit of the second was at such an altitude that its position with respect to the earth did not change and the same region could be photographed continuously. This is important for observing Atlantic hurricanes during the entire period of their existence. For Nimbus the characteristic is the solar rudder, thanks to which it retains its position in space (Fig. 12). Nimbus is equipped with television cameras and automatically transmits pictures to earth (Widger, 1966).

Atlantic hurricanes cause such destruction that a special institute has been set up in the USA—the National Hurricane Center—to study, observe and forecast them. It is closely connected with aviation and is housed in the aviation building in Miami, Florida. The structure and activity of the Hurricane Center are described in the paper by Hawkins (Hawkins, Purdue and Reber, 1961).

A review of the latest work on hurricanes is given by Gentry in his paper (Gentry, 1964). It is said in this review that one of the unsolved problems is the origin of hurricanes. The place of origin is not always certain. Surveys from aircraft showed that the altitude of the clouds reaches 12–15 km. In a number of hurricanes the speed of the wind was more than 120 kmph and they maintained an altitude of more than 11 km.

The meteorological conditions favoring the origin and growth of hurricanes is well described by Pierce (1939) with the example of the famous hurricane of 1938 in New England. The text is illustrated with numerous maps.

GROWTH

Observations with the help of ground-based radar and from aircraft and the study of photographs from Tiros have provided a huge amount of material with which the development of tropical hurricanes has been reconstructed.

The initial stage shows the spiral rotation of the rainclouds. Neither the center of the hurricane nor the closed ring of clouds surrounding it is yet to be seen. The clouds form a characteristic hook (Fig. 13). The form of a hurricane is to some extent similar to that of a comet. The speed of the wind is less than that reached in a hurricane. Figure 13 shows hurricane Abbey of July 9–11, 1960, at the beginning of its passage to the west of the Antilles Islands:

Only in the mature stage, which is quite prolonged and characteristic of a hurricane, does the "eye of the storm" appear. It is completely surrounded by the white ring—the wall of rainclouds, rotating at the speed of the hurricane (more than 30 m/sec). The body of the hurricane is compressed and concentric and acquires an open form, almost that of a round spiral. All these features can be seen in Fig. 14 depicting the same hurricane Abbey. But on July 15, when it was approaching Honduras (Fig. 15), it is already at the end of its mature stage.

No less typical is hurricane Donna of 1960, one of the most mature hurricanes of all time, when it approached Florida (Fig. 16). Its track can be seen in Fig. 15. Hurricane Ether of September 14–16, 1960, differed in the minor axis of the central zone and massive wall of rain-clouds. Radar revealed hurricane Karl of September 10, 1961 (Fig. 17), and clearly depicted the large circular "eye of the hurricane" and wall of clouds surrounding it. At the periphery of the hurricane a small tornado (shown with arrows) can be seen. Often the central region is partly covered with thin cloud and is not noticeable, as can be seen in the photograph of hurricane Daisy of October 5, 1962 (Fig. 18).

The final stage has been thoroughly studied. The translatory speed decreases. The spiral structure becomes less and less distinct and ultimately disappears. Then it is replaced by an irregular pattern of clouds. The rain wall disappears and the central zone widens. This phenomenon was well studied for hurricane Hilda (October, 1964). This hurricane is discussed in

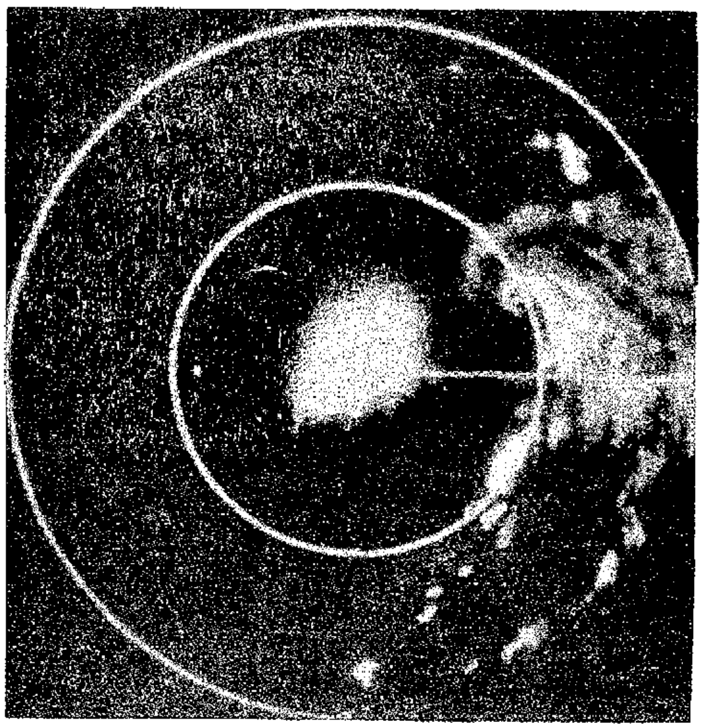


Fig. 13. Hurricane Abbey, 1960. Initial stage of growth. Radar echo in hook form is distinctly seen (Dunn and Miller, 1962, Fig. 3).

the work of Schulz and Hill (1965) and its development is shown with a number of diagrams. Hurricane Abbey (Dunn and Miller, 1962) gradually dissipated after penetrating southern Mexico. It is quite likely that part of it crossed the Gulf of Mexico and further developed into a new hurricane, Celeste. Hurricane Donna became an extratropical hurricane and dissipated near Greenland (Fig. 15).

The above examples, however, do not exhaust all the varieties of growth of hurricanes. Some details are given in the work of Fett (1964) and Frank (1963). The latter author makes extensive use of Tiros data. He writes: "Launching of the first satellite Tiros opened up new avenues for the study of the weather. No system had received so much attention since the discovery of radar. Of all the meteorological instruments it has been most used for forecasting tropical hurricanes. The first Tiros detected a cyclone which went unnoticed by the usual methods of observation" (Frank, 1963, p. 355).

This observation is fully confirmed. As an example the work of Fritz (1962) can be referred to, where in a series of photographs taken from Tiros III the formation of hurricane Anna can be seen. This hurricane originated in a region of low pressure over Africa. On July 16, 1961, over the central part of the Atlantic Ocean the concentration of cloud and the first sign of spiral circulation were noticed. On July 17 these features were confirmed. On July 18 it was established but the center of the hurricane was not yet closed, and on July 20 the hurricane was fully formed and caused destruction in the Barbados Islands.

In another work, Fritz (1965) shows photographs taken by Tiros III and IV of fully grown hurricanes (Fig. 19) and their dissipation. The continuous sharply defined spiral zones of cloud saturated with water break up in one part and remain diffused. The spiral structure is quite distinct and the center of the hurricane disappears. In one more day, the hurricane changes into an irregular accumulation of individual clouds of relatively small size.

Photographs from Tiros V taken on August 4, 1962, gave the complete picture of typhoon Opal over two days as it crossed Taiwan with a wind speed of 270 kmph. The typhoon was observed from a spy plane as well, but Tiros photographed the entire typhoon and determined the position of its center (Fig. 10). The path of the typhoon is shown in the accompanying map (Fig. 11).

The Tiros satellite photographed hurricanes from a great altitude and therefore a large number of details of structure are missing. Greater detail was obtained in the photographs taken from the spy plane U-2.

On September 25, 1958, typhoon Ida was photographed (Fig. 20) from a U-2 flying at an altitude of more than 20 km. The spiral structure and "eye of the storm" partly covered by light cloud can be distinctly seen. The width is around 20 km, height 17,300 m, base 2,200 m and top 19,500 m. When it was over Japan, 900 people were killed, 556,000 people made homeless and 211,000 acres of cultivated land inundated. The wind attained a speed of 240

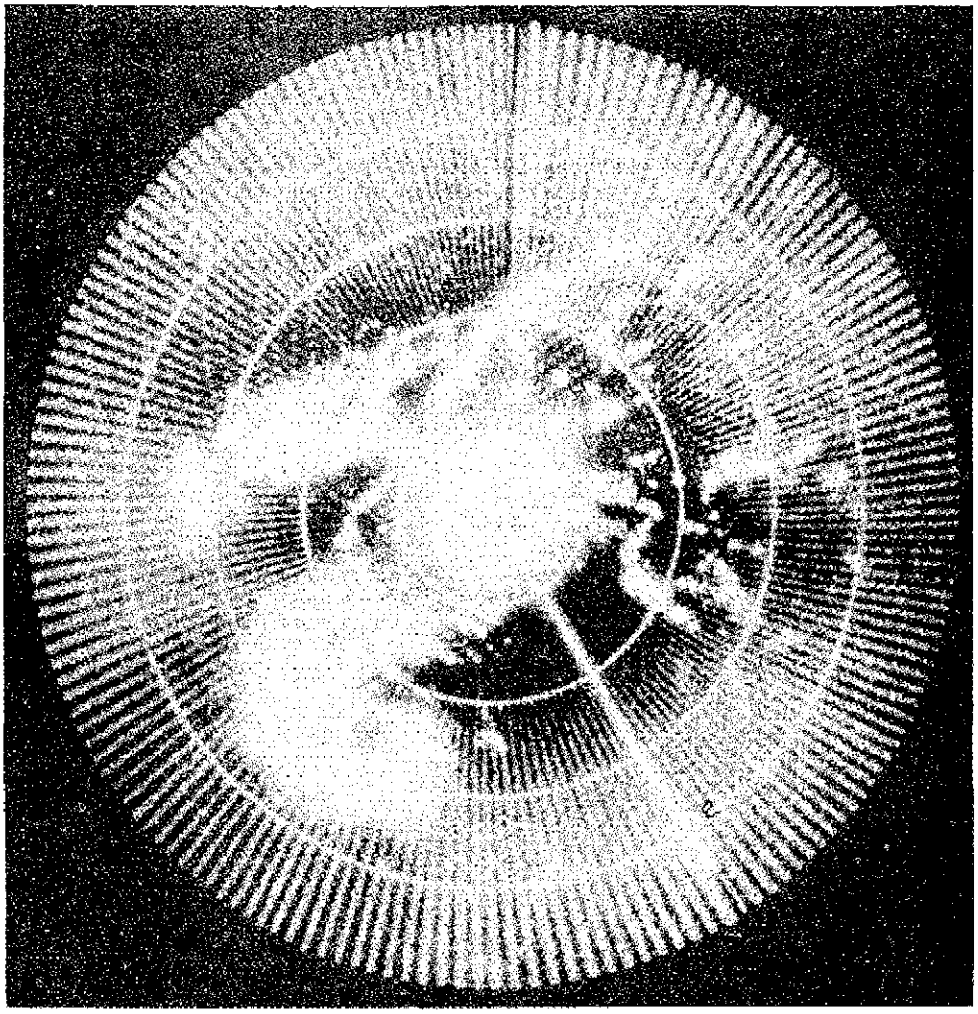


Fig. 14. Hurricane Abbey in fully grown stage. Circular "eye of the storm" is surrounded by a white wall of water (Dunn and Miller, 1962, Fig. 4).

knots (444 kmph); the average speed was 145 knots (268 kmph) (Fletcher, Smith and Bundgaard, 1961).

In 1957 the first photograph of the top of a typhoon was taken from this airplane, flying above typhoon Kit, over the Philippine islands. The pilot photographed the center of the typhoon. This clear, fascinating photograph shows that the typhoon had started dissipating. The "eye of the storm" was a small area dividing the wall of cloud (Bundgaard, 1958).

An exceptionally interesting vortex structure—possibly still in the formative stage and without the typical "eye of the storm"—was photographed by an American astronaut at the time of his flight over the Atlantic Ocean in 1965 (Lowman, 1966). In the colored photograph the western part of the Anti-Atlas is tinted brick red and is strikingly bright. The cloudy mass of the hurricane with the characteristic spiral structure can also be seen. The

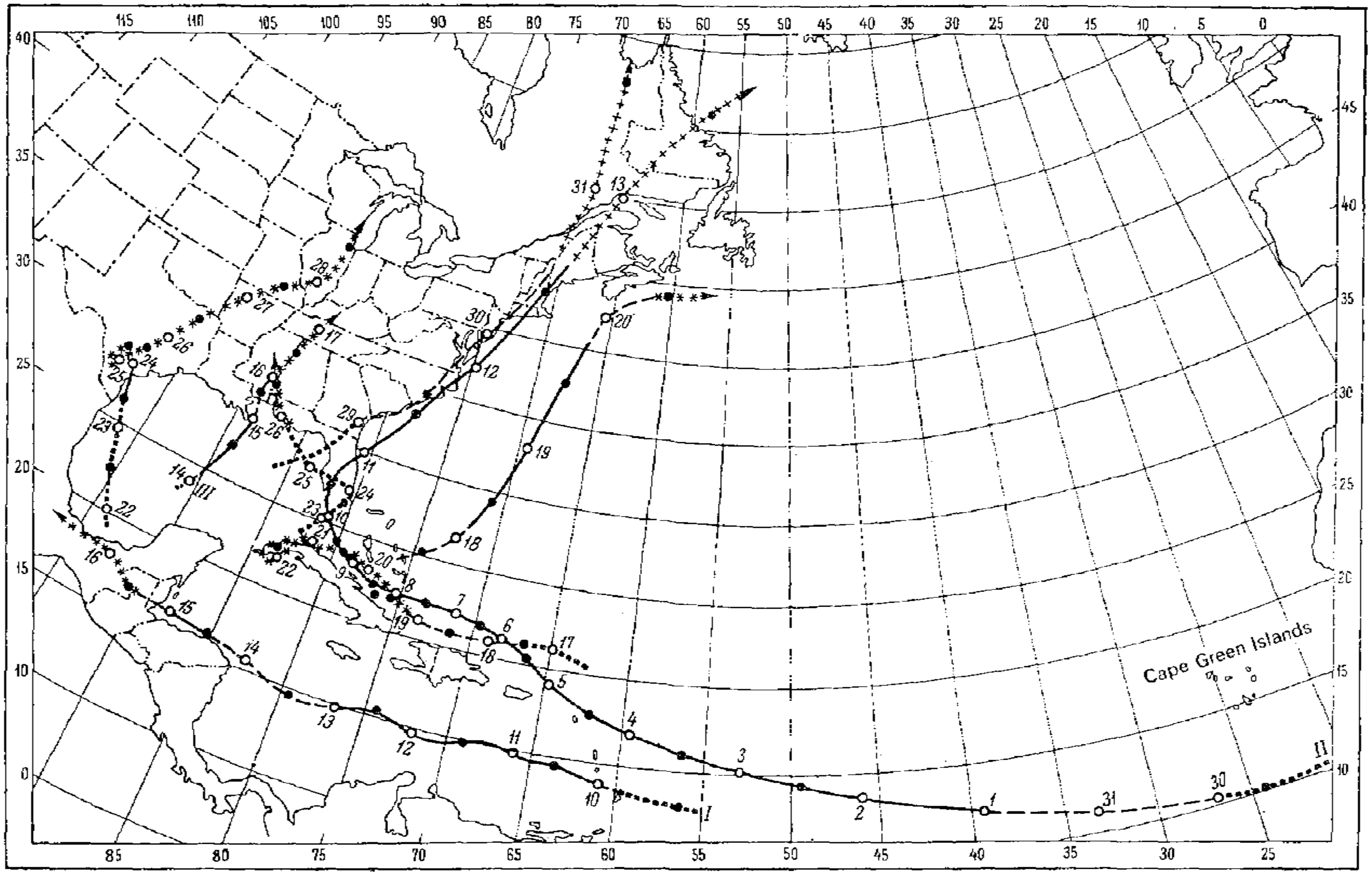


Fig. 15. Track of cyclones of 1960 (Dunn and Miller, 1962, Fig. 1).

I—Abbey; *II*—Donna; *III*—Ethel. *Continuous black line*—stages of hurricane; *other marks*—initial and final stages, rather weak; *open circles*—position of hurricane in morning (figures denote number of days elapsed); *distance between consecutive circles*— track of hurricane in course of one day; *number of circles*—life of hurricane, days.

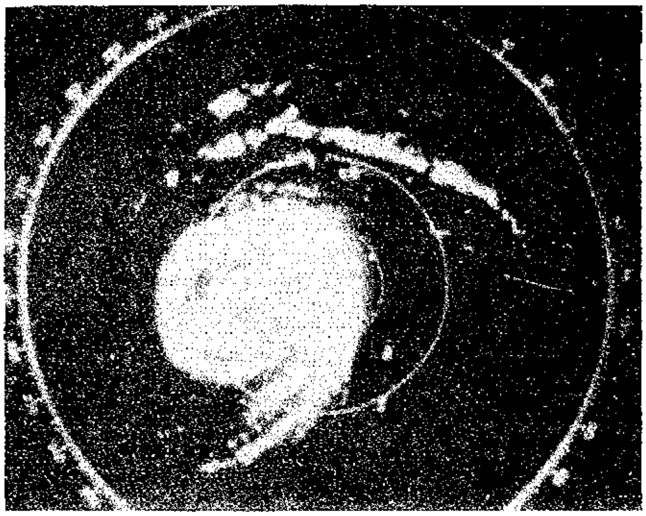


Fig. 16. Hurricane Donna of 1960. Small "eye of the storm" and thick massive wall surrounding it. Track of hurricane is shown in Fig. 15 (Dunn and Miller, 1962, Fig. 5).

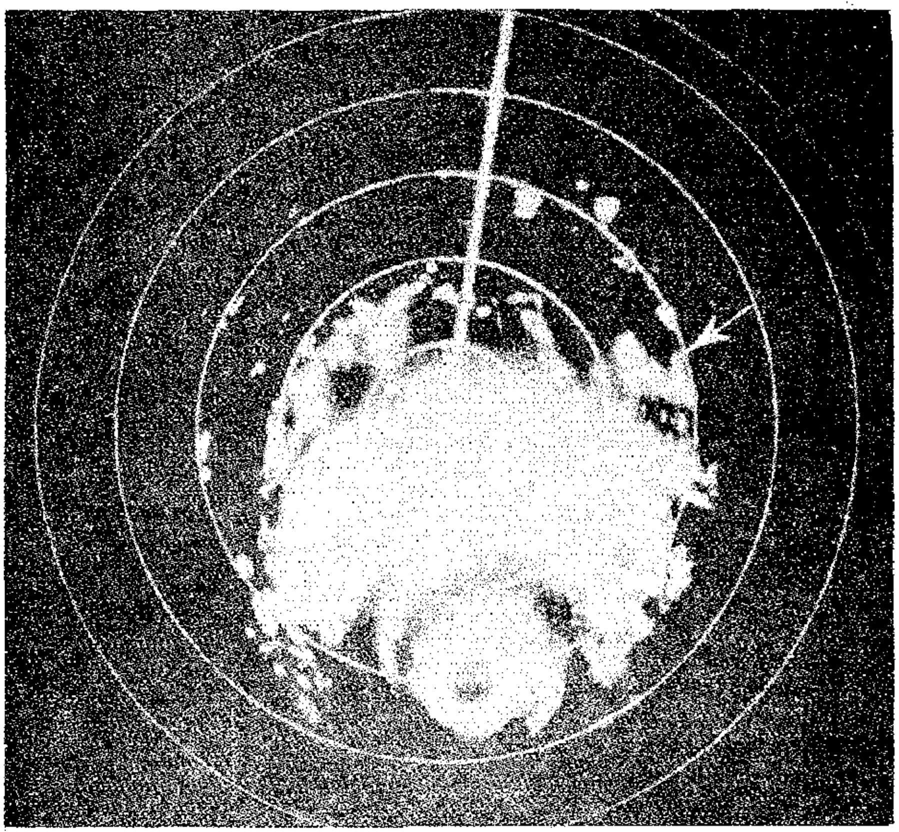


Fig. 17. Hurricane Karla of 1961. Large circular "eye of the storm" and wall of cloud surrounding it. In neighborhood of hurricane cloud system is accompanied by tornado of almost cylindrical form. Tornado is shown by arrow (Sadowski, 1961, Fig. 3).

Fig. 18. Hurricane Daisy of 1962. Partly closed "eye of the storm" is marked by cross. Spiral system of cloud (Dunn, 1963, Fig. 4).

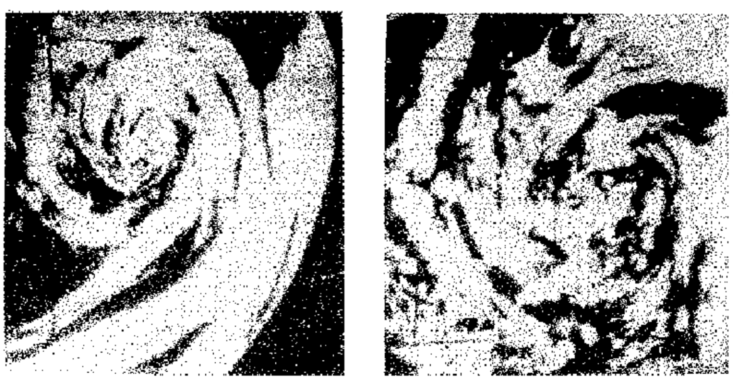


Fig. 19. Comparison of hurricanes in full growth (left) and dissipation (right). Photo from Tiros (Fritz, 1965, Fig. 7).

cloud is similarly tinted red. It is located over the so-called Red Sea (pages 502–525) where there is a massive accumulation of red dust on the sea bottom.

The photographs taken by the astronaut are interesting in that they furnish new information on the origin of a few tropical cyclones over the Sahara or the immediate vicinity.

The photographs taken by astronauts during the flight of satellite are exceptionally important. These are certainly better and more informative than the photographs taken from Tiros or Nimbus. But their number is

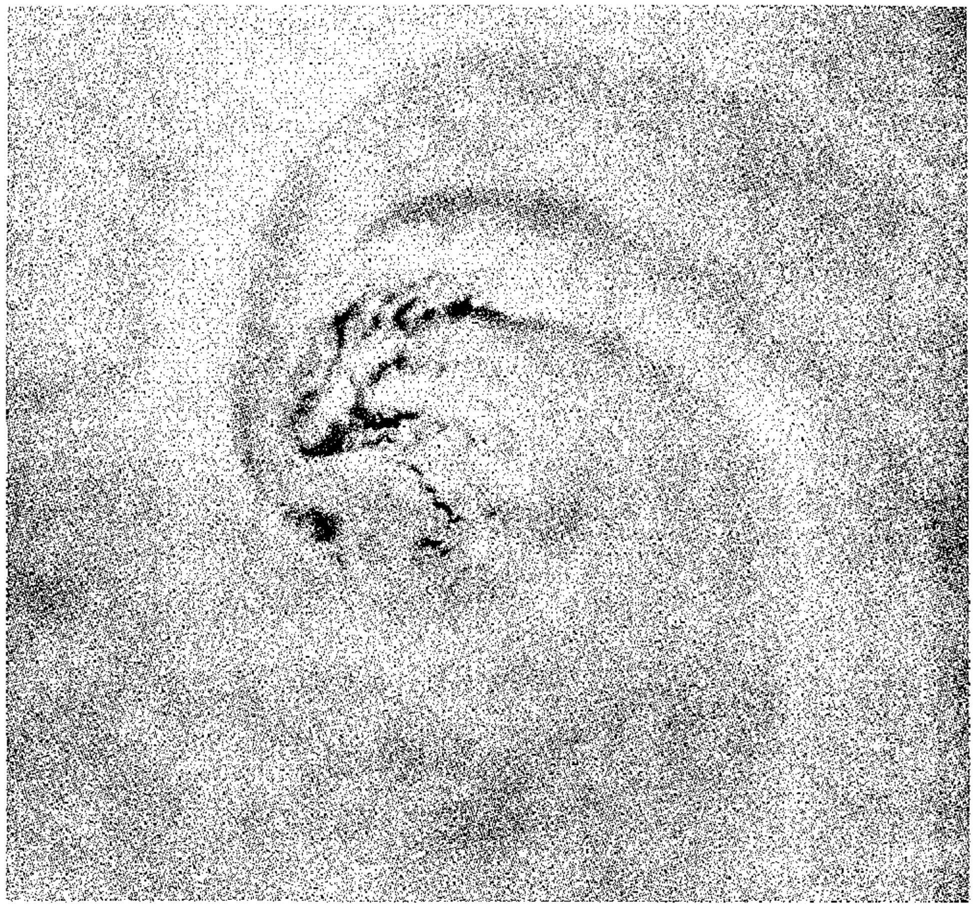


Fig. 20. Typhoon Ida of 1958. Structure at top is partly closed by "eye of the storm". Spiral structure can be clearly seen. Photograph was taken from high-altitude spy plane U-2 (Fletcher, 1962).

limited.

The new satellites which automatically transmitted pictures, Essa II and Nimbus II, provided a series of important pictures of hurricane Judy. In the initial stage of growth the "eye of the storm" is absent but the hook can be seen clearly. At the fully grown stage the center is dense and the "eye of the storm" can be clearly seen. In the final stage the center disintegrates, the "eye of the storm" is not distinct and the hook reappears (Fett, 1966).

MOVEMENT AND TRACKS

The paths of tropical hurricanes are governed by the rotation of the earth and local conditions. Due to the rotation of the earth, the tracks take the form of a parabola, always open to the east. On the southern trajectory the arm of the parabola is almost parallel to the latitude, from east to west. At the top of the parabola it is almost meridional and in the northern tip it has a northeasterly direction.

The parabolic nature of the path was shown in an interesting way in the almost forgotten work of A. Mikhailov, *On storms* (1888). It can be seen clearly in the map (Fig. 1).

Local conditions, especially cold fronts, distort the parabolic shape of the track, especially the northern arm, often orienting it in a meridional or near-meridional direction. Often hurricanes describe loops, sometimes several loops. All these distortions can be seen clearly in the maps in Figs. 15 and 21–24. It was because of loops that the dangerous hurricane Flora (1963) brought about such devastation in Cuba (see pages 54-56).

The movement of tropical cyclones-hurricanes has been studied in detail. A schematic representation is contained in Fig. 1. Some regions of development of hurricanes and storms can be seen in the figure. The first is the Yellow Sea and the Pacific Ocean in the region of the Philippine islands. The maximum number of cyclones originate here, around 28 in a year, and one-half of them have a wind strength of 12 units. They are known as typhoons. Initially they move in a northwesterly direction and then northeast, quite often affecting Japan, Korea and once in a while touching parts of the USSR, including Kamchatka (Visher, 1925).

The second region of origin of storms is the Mexican Gulf, Carribean Sea, Antilles and West Indies islands in general. Here cyclones with wind speeds of 10–12 units are known as hurricanes. The West Indian and Antilles hurricanes often penetrate into the southeastern plains of the USA and carry with them the marine microfauna of the Mexican Gulf.

The third region of origin of storms is the Indian Ocean to the east and west of the Indian subcontinent. On an average 10 hurricanes originate here in a year. They cause large-scale destruction in India and West Pakistan and penetrate far inland over the Arabian desert.

The fourth source of storms is in the southern hemisphere, in the Pacific Ocean, off the coasts of New Guinea and northern Australia. The number of cyclones is 10 to 20 per year. They carry marine microfauna to the deserts of northern Australia.

There are more centers of origin of hurricanes, of a secondary nature, in the Pacific Ocean.

In all, not fewer than 70 tropical cyclones with stormy and hurricane winds originate in the world every year (Khromov, 1964, p. 396). The frequency of hurricanes in the Atlantic and Pacific oceans is dealt with in detail in the paper by Jordan and Ho Te-chun (1962).

The number of extratropical cyclones is several hundreds in a year but cyclones with hurricane or storm winds are much fewer.

It can be said that tens of cyclones, hurricanes and storms move from the sea to the land, primarily in the subtropical and temperate zones. Where there is a large tract of alluvial plain adjoining the sea hurricanes and storms penetrate into continents hundreds or even thousands of kilometers, carrying marine microfauna with them.

The paths of hurricanes over the western part of North America, the Caribbean Sea, the Gulf of Mexico and the Atlantic Ocean have been shown in a number of maps in the interesting work of Tennehill (1956). They cover a period of 60 years, from 1874 to 1944. One of the maps, for the second half of August, is shown in Fig. 21. Another, for the first half of September, is given in the book by Reihl *Tropical Meteorology* (1963, p. 340). The map in the work by Z.M. Tiron (1964, p. 46) and the data of Aquirre (1963) and Alexander (1902) deserve attention.

A more detailed account of the tracks of recent hurricanes is given in the work of Cry (1965). This work contains 82 maps of the northern Atlantic Ocean in which the tracks of hurricanes are shown yearwise, starting from 1871 and ending in 1963. There are also five maps for the period from 1871 through 1900 monthwise and 25 maps of different periods from 1901 through 1963. This rich material provides a comprehensive picture of the lengths and trajectories of the tracks of hurricanes and their seasonal variations.

The majority of hurricanes occur in August and September. In these two months hurricanes are not only numerous but also attain maximum strength. They cover longer paths and the parabolic curvature is most defined (Fig. 22). It is during this period that hurricanes originate over Africa and the Cape Verde Islands and travel farther north along the Gulf stream.

In July and October hurricanes fall sharply in number and length of track. In the remaining eight months hurricanes are rare and the tracks are shorter and irregular (Fig. 23). Actually hurricanes are periodic, seasonal phenomena. All the other phenomena, e.g. geological and otherwise, associated with them are similarly periodic and seasonal.

In the months of maximum activity the number of hurricanes is so large that the thin lines showing the paths of their centers completely fill the belt of hurricane growth. If we recall that the width of an average hurricane is 200–600 km (as the map is approximately to a scale of 1 cm), then the entire belt could be filled by the tracks of hurricanes, at places several times over.

During the period from 1871 through 1963, in all 512 hurricanes occurred, of which 46, i.e. about 9%, occurred in November–May (Cry, 1965, p. 5). According to another source (Dunn and Miller, 1960, p. 50) 331 hurricanes occurred from 1887 through 1958, of which 280 occurred in August–October and 16 in May–November.

From the maps it can definitely be said that Atlantic hurricanes following all the various tracks obey a law of planetary nature. Taken together, the tracks of these hurricanes form a huge parabola, well defined in the south, west and northwest and branching off in the northeast.

It is generally believed that the region of origin of many hurricanes is not the Cape Verde Islands but the western Sahara. Many workers have advanced this argument and it can be accepted as a fact if the huge amount of red dust the hurricanes bring every year from the Sahara to the Cape Verde

Islands is taken into account. The latest account of this phenomenon is given in the monograph by the well-known oceanographer Kuenen (1950) and in my book *Studies on Facets* (Vol. 1, 1955, Fig. 101). From this figure it can be clearly seen that the dust carried from the Sahara by strong winds penetrates the Atlantic up to the 20th, the 30th and the 40th meridians. Many of these winds constitute the initial stages of the development of hurricanes (Erickson, 1963).

The regime of hurricanes varies in different parts of the Atlantic parabola. The western part is the region of maximum growth of hurricanes; here hurricanes are quite frequent and strong and cause maximum damage. In the northeastern part of the parabola they are relatively rare and weak.

The regions of origin of Atlantic hurricanes are dealt with in detail in the work of Haggard (1958). Studying the hurricanes from 1886 through 1957, he concluded that most hurricanes originated in the western part of the Atlantic parabola, the Gulf of Mexico in the south, the Caribbean Sea in the west and in the Atlantic Ocean between the Antilles Islands and South America. Hurricanes originating over the Sahara and Cape Verde Islands were rare (Henry, 1939).

Hurricane Carrie of September 2–24, 1957, can be considered a representative example of all past hurricanes of the Atlantic circle. It started from the coast of Africa, crossed the Atlantic Ocean twice and dissipated over southern England. The length of the path was 11,000 km. It was tracked thoroughly by airplanes and radar. The wind attained a speed of 150 kmph. The five-masted sailing vessel *Pamir* with 80 people aboard was caught in the track of the hurricane and lost (Davis, 1958).

A second example is the destructive hurricane Donna of August 29–September 13, 1960 (Figs. 15, 16). On August 29 it originated off the coast of Africa. By September 4 it had reached the Antilles Islands accompanied by high tidal waves, causing large-scale destruction and death (114 people). On September 10 it crossed Florida, causing huge destruction. During this time, according to the radar picture (Fig. 16), it was an "ideal" hurricane. The "eye of the storm" was around 30 km wide and was surrounded by a thick wall of cloud 25–30 km in diameter. For four days Donna traveled along the coast of the USA, causing unusual destruction, though the loss of life was relatively small (51 people). Donna dissipated over the coast of Greenland on September 13, after becoming an extratropical hurricane (Moore, 1961).

The number of hurricanes having such long tracks as Carrie and Donna is relatively small. Mitchell (1924, 1930) has prepared a list and shown that some hurricanes cross Europe and penetrate into Siberia, covering a track of 20,000 km. In Australia some hurricanes have been tracked from the west coast to New Zealand, covering a distance of not less than 15,000 km (Visher, 1925, p. 85).

The tracks of hurricanes, especially in their final phase, are shown in great detail in the work of Mitchell (1924, 1930). In the period 1887 through

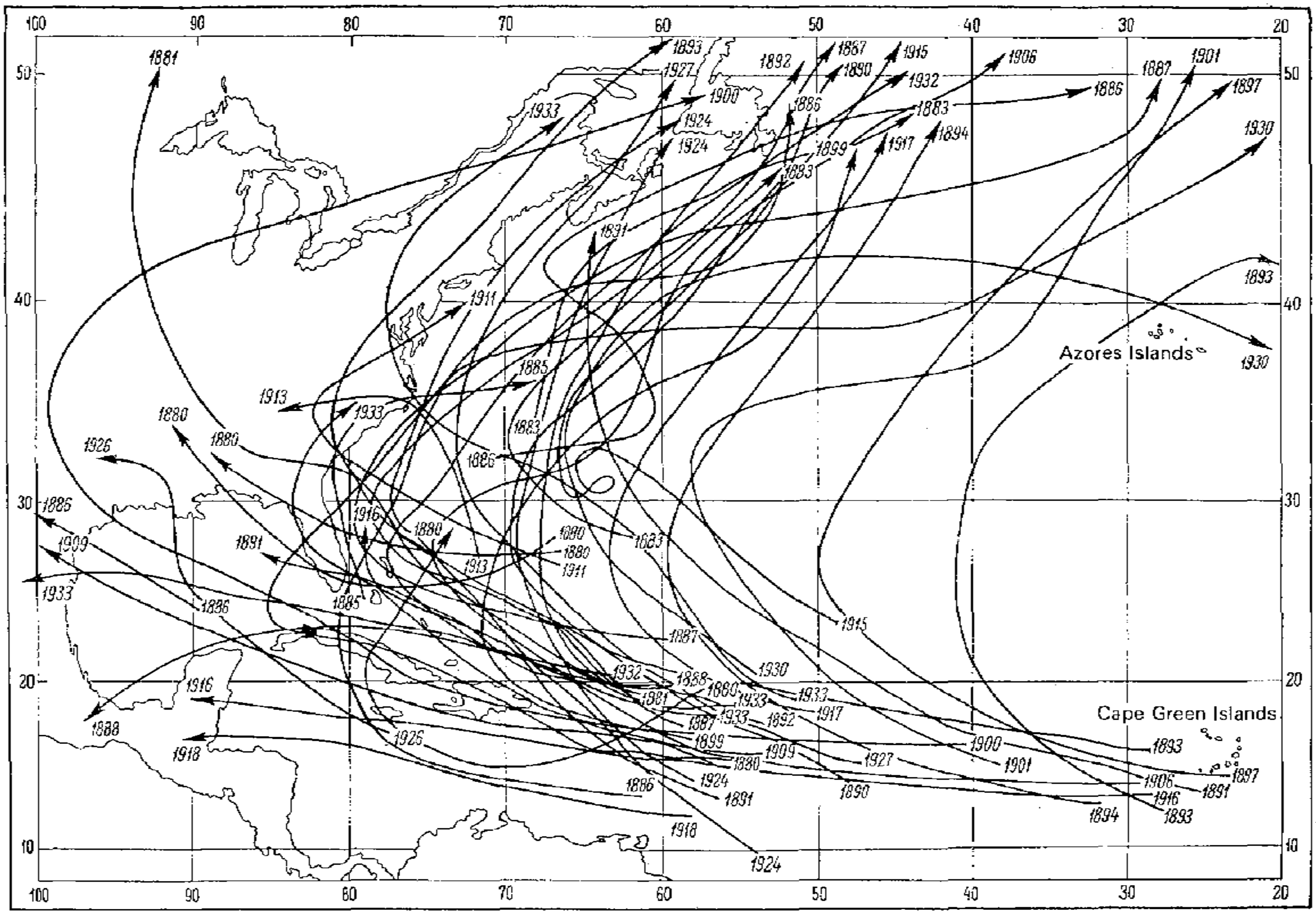


Fig 21. Tracks of Atlantic hurricanes, August 16–31, 1874–1944 (Tannehill, 1945).

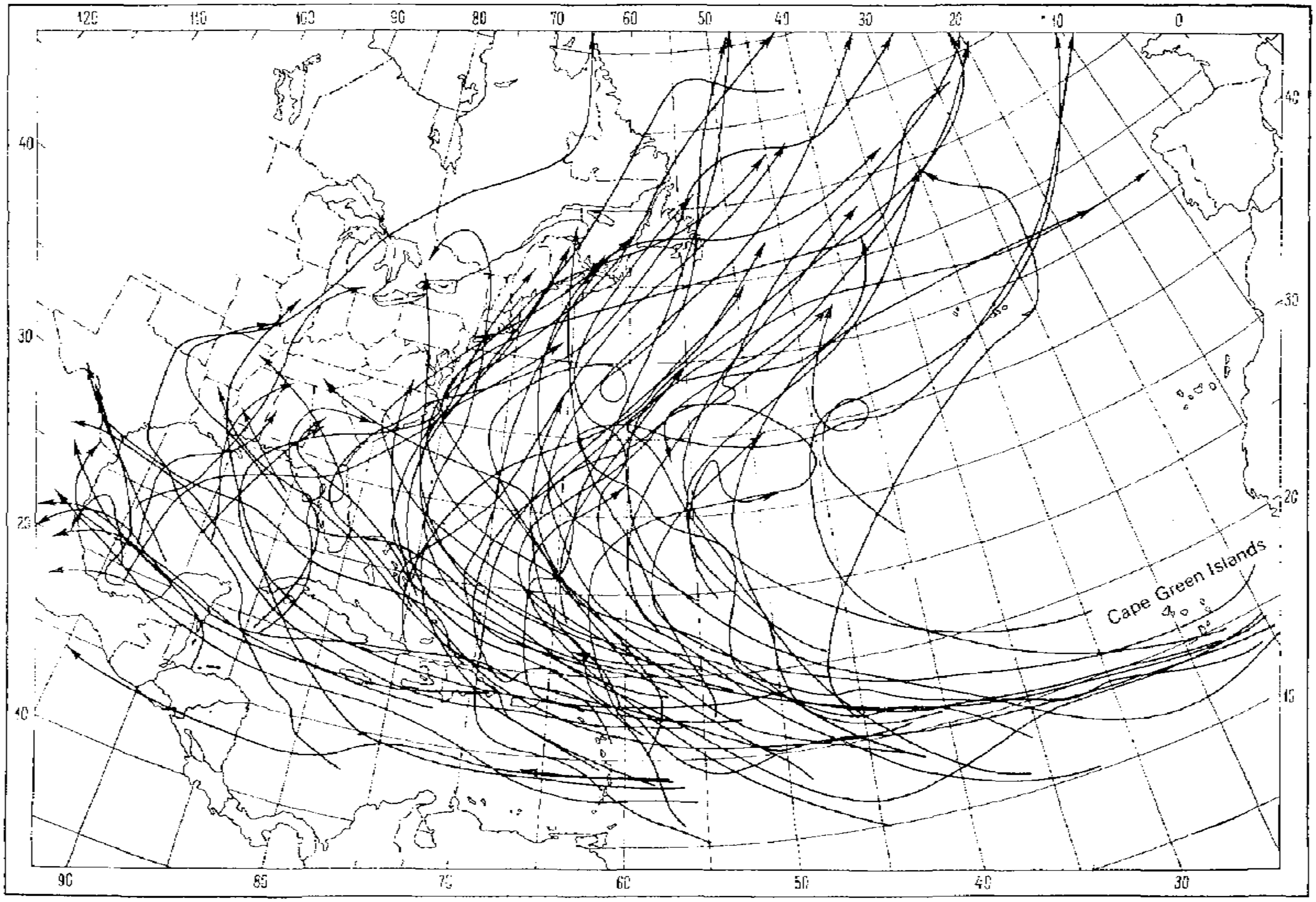


Fig. 22. Tracks of Atlantic hurricanes, September 1–10, 1901–1963—period of maximum growth of hurricanes. Many originated off African coast. Tracks show parabolic form. They traveled to northern Atlantic (Cry, 1965, p. 141).

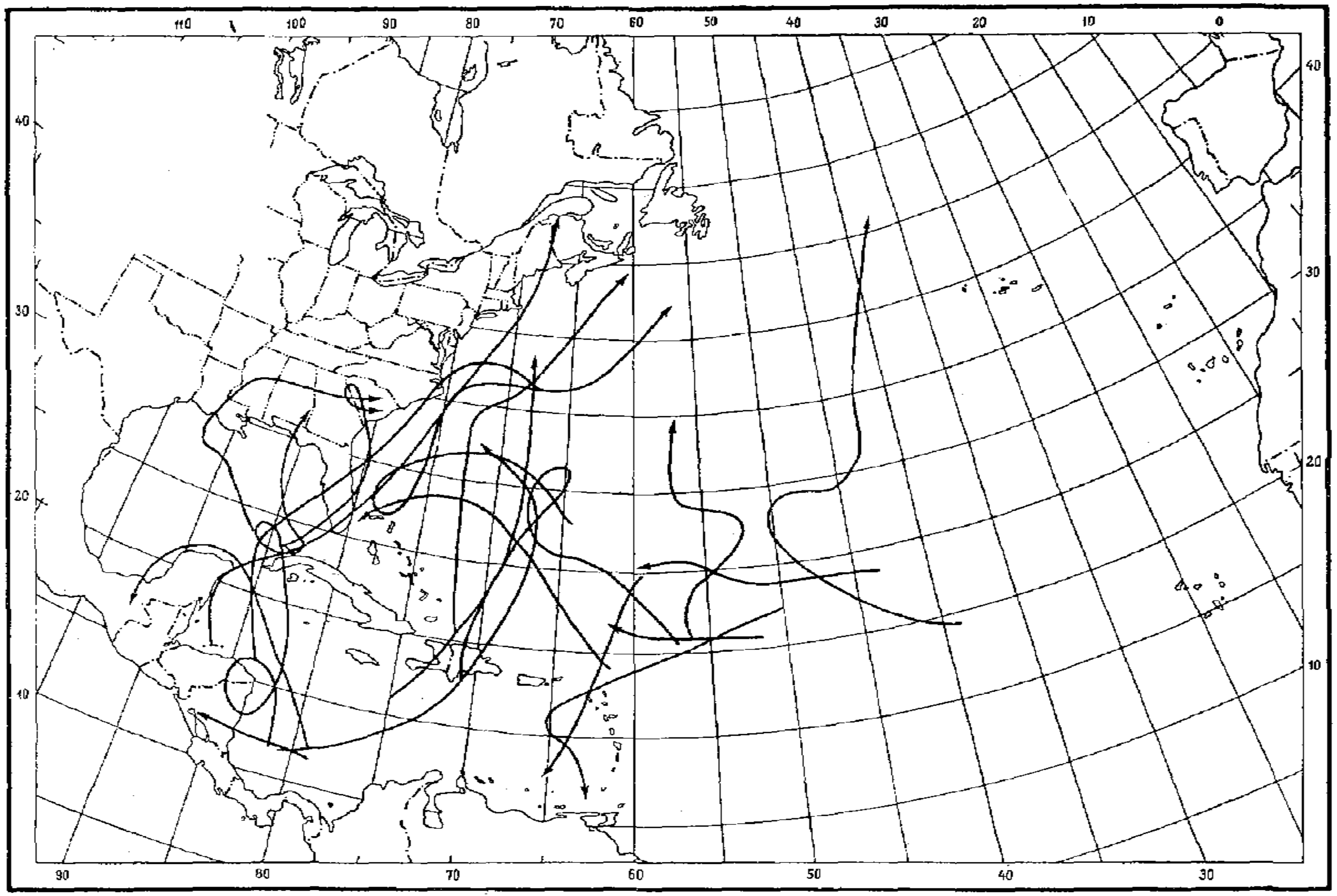


Fig. 23. Tracks of Atlantic hurricanes, November 16–May 31, 1901–1963—period of least growth of hurricanes. Tracks are of irregular form and of short length (Cry, 1965, p. 148).

1923, in June and July, three hurricanes reached Iceland, a fourth reached England, a fifth crossed England and moved on up to the 60th parallel and a sixth reached Copenhagen. In the maximum intensification epoch of hurricanes in August and the first half of September, 11 hurricanes crossed Labrador, 12 hurricanes reached Iceland, and nine reached Northern Europe. The amazing hurricane of 1899 originated off the coast of Africa over the Cape Verde Islands, crossed Haiti and Florida and then formed two loops in the middle of the Atlantic Ocean, traversed France and reached the foothills of the Alps. It traveled a record distance of 16,000 km. Its duration was 37 days (August 3–September 8). In all 19 hurricanes originated in the Cape Verde Islands, of which eight penetrated to the 65th parallel in the north. During the second half of September and October the region of growth of hurricanes moved west to the Antilles Islands and only two hurricanes originated off the African coast. However, penetration to the north remained significant. Four hurricanes penetrated to the north of Scandinavia, two reached Stockholm, 11 Iceland and five Greenland. The hurricane of 1893 traveled from Africa to central Greenland in 22 days.

All these examples show that the northern part of the Atlantic parabola of the hurricane path is fairly well defined. Numerous hurricanes approaching Iceland and the coast of Norway closely follow the northern branch of the Gulf Stream.

The map of the tracks of cyclones and anticyclones in the northern hemisphere prepared by Mitchell (1930) and the maps prepared by Cry (1965, Figs. 22, 23) deserve attention.

The tropical cyclones (typhoons and hurricanes) of the Pacific Ocean are described in the interesting monograph by Visher (1925). It gives maps of the tracks of typhoons (normal and abnormal) and hurricanes off the coasts of Mexico and California, over the Hawaiian Islands, Fiji Islands, New Zealand and Australia (Visher, 1922b). In the map of the tracks of hurricanes (Fig. 24) each line represents approximately 25 typhoons.

The latest account of hurricanes is given in the interesting work of Harding and Kotsch (1965) intended for sailors. It gives the following information: Typhoon: a tropical cyclone in the western Atlantic Ocean with winds of 64 knots (115 kmph) or more. It observes that one is safer, the farther one happens to be from it—a statement certainly meant for sailors.

Important detailed data on the tracks of typhoons are accompanied by numerous maps. The majority of typhoons originate over the Pacific Ocean in the region of Guam Island and to the east of it. Many tracks lie entirely over the sea, not touching land, especially in January–May when typhoons are rare and weak. In June, July and the first half of August the tracks move to the northwest; many of them cross Korea and Japan. At the end of August the typhoons start moving south. In the beginning many of them cross Japan but quite a large number immediately move west toward China. In November and December they mostly strike the Philippine islands and Taiwan.

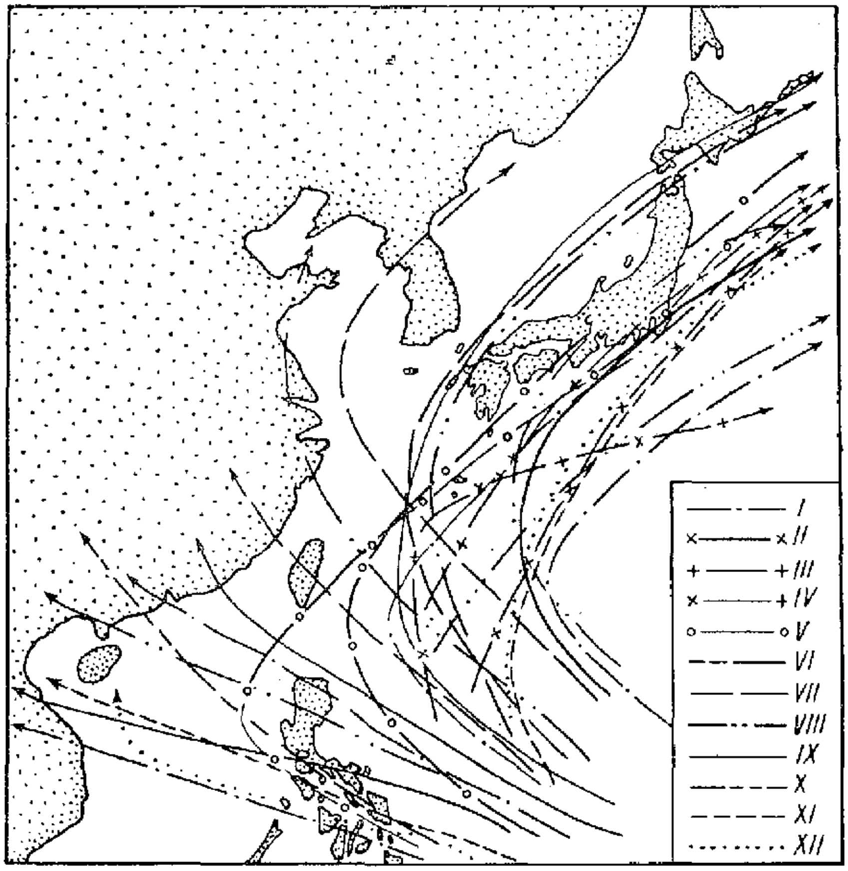


Fig. 24. Tracks of typhoons in Atlantic Ocean. Each line corresponds to approximately 25 typhoons (Visher, 1925, Fig. 9).
I–XII—months.

Quite a large number of typhoons cross southern China too.

According to Kotsch (Harding and Kotsch, 1965), the typhoons of the Pacific Ocean are more numerous and stronger than Atlantic hurricanes, although they are essentially of the same type.

Typhoons rarely penetrate the Far East of the USSR. They travel to the south of this region. Over the continent, the typhoons quickly change to extratropical cyclones.

Hurd has described the hurricanes off the western coast of Mexico (1929). The greater part of these travel along the coast, but some cross the coast and cause large-scale destruction on land. There were 95 cyclones in 19 years. The latest figures are given by Kalstrom (1952).

A detailed account of the tracks of tropical cyclones is given in the annual report of the journals *Monthly Weather Review* and *Weatherwise*. Some of these reports, in the last few years, have been prepared by Gentry, Hardy, Mure, Frank and Davis. Important data are contained in numerous papers on individual hurricanes.

Data on Australian hurricanes are published in the *Australian Meteorological Magazine*.

NUMBER AND FREQUENCY

From the map prepared by Tannehill it can be said that no fewer than 118 hurricanes penetrated the United States and Mexico from the sea over a period of 60 years. Practically the entire length of the coast of central and North America up to Newfoundland experienced the effect of winds of hurricane strength. The extent of penetration inland is of interest.

The region of the Great Lakes is at a distance of 2,000–2,500 km from the sea. The distance is considerable but no fewer than 14 hurricanes penetrated the region. The Appalachian Mountains form a great obstacle and the majority of hurricanes travel along them, between the coast and the mountains. Yet 15 hurricanes crossed the Appalachians. Many hurricanes (42) cross the alluvial plain 100–300 km wide adjoining the Gulf of Mexico. Some of them (18) travel farther inland, 1,200–1,500 km, up the valley of the Mississippi.

All these figures are quite important. If it is remembered that they concern an interval of time of 60 years, which is insignificant on the geological scale, then it is clear that the penetration of hurricanes inland anywhere from 100 to 1,500–2,000 km is a common phenomenon. Some hurricanes travel inland to a distance of 3,000 km or more. Between September 10 and 27 the hurricane of 1906 covered the major part of a track from the Atlantic to the USA via the Gulf of Mexico and traversed a distance of 4,000 km in the USA from the mouth of the River Colorado to Newfoundland (September 30).

All these hurricanes freely carry marine microfauna, particularly diatoms and foraminifera, distributing them in large areas adjoining the coast. Due to this these two groups practically lose their significance as an index of the marine regime.

The presence of one of the marine diatoms or foraminifera in sandy clay deposits not related to the normal marine fauna cannot serve as a definite index of the presence of the sea in the past. In the majority of cases these deposits will be continental.

It has already been stated that the number of cyclones, hurricanes and storms is about 100–120 a year. In a thousand years it will be 100–120 thousand, in a million years 100 million and for a larger unit, billions. Thus we find that a rare and accidental phenomenon becomes an important geological factor requiring serious attention.

This is of special significance for the study of large coastal alluvial deposits and deposits in continental plains. If one hurricane, coming from the sea, carries inland to the surface of the plain a small amount of diatoms and foraminifera, then billions of hurricanes can be responsible for quite a substantial admixture in continental fauna. In individual layers it will be so high that we will be correct in relating it to marine deposits. In reality these layers are formed hundreds or even thousands of kilometers from the sea.

If one hurricane deposits 2–4 mm of dust in the plains, then for billions of hurricanes it will be many thousand meters. The high frequency of an insignificant phenomenon makes it a possible geological factor. This can be used reliably for estimating the geological activity of hurricanes and storms.

2
Nontropical Hurricanes

FUNDAMENTAL LAWS

Extratropical hurricanes are cyclones in which the velocity of the wind is 30 m/sec. They differ from tropical cyclones in their larger diameter and higher frequency.

In both the northern and the southern hemishperes cyclones move primarily from west to east. In the northern hemisphere (especially in Europe) the cyclones show greater variation in the trajectories than in the southern. Cyclones frequently shift from southwest to northeast and from south to north. The cyclones move as an entity, independent of the system of winds. The movement of hurricane winds determines the movement of the center, as in the case of the tropical hurricanes.

The speeds of cyclones vary widely. They are on an average 30–40 kmph, although sometimes much higher, reaching 100 kmph. Often cyclones remain stationary for nearly two days.

Often extratropical cyclones have winds of a stormy nature. A sudden strengthening of wind accompanied by a change of direction is known as a squall. Occasionally cyclones are termed "storms", especially over the land.

STRUCTURE AND FORM

The structure of cyclones is similar to the structure of tropical hurricanes but the form and pressure gradient differ considerably.

The extratropical hurricane is a gigantic system of clouds, from a distance appearing like one enormous black cloud. There is a sharp fall in pressure in the center. The center is surrounded by a zone of storm and hurricane winds, showers and thunderstorms. In the border zone weak winds and rain occur.

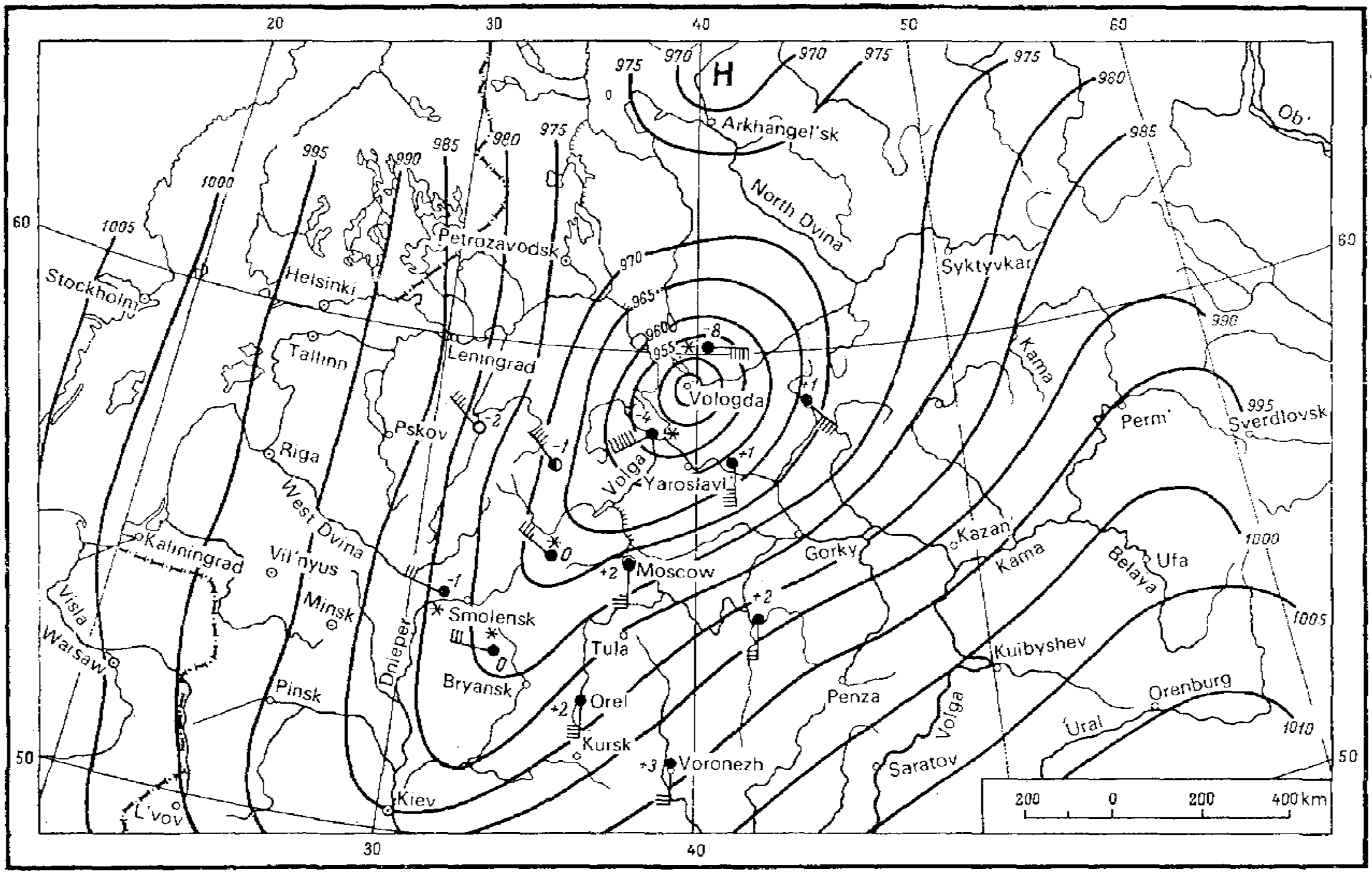


Fig. 25. Stormy cyclone in January, 1923 (Kolobkov, 1975b, p. 160).

The form of all these formations is different. The cyclone has an appreciably larger diameter. Its center is considerably higher and, as a rule, is covered by cloud. The "eye of the storm" characteristic of the tropical hurricane is absent and the zone of wind and rain belts is wide and less well defined. The speed of the vortex wind in this zone is quite high but is less than that in a tropical hurricane.

The special feature of northern extratropical cyclones is the heavy snowfall and hailstorms, often of unusual magnitude. The cyclone itself often originates in winter (Bjerknes, 1951). The stormy cyclone (Fig. 25) that occurred in the northwestern European part of the USSR in January, 1923 (Kolobkov, 1975b, p. 160) can be taken as an example. This storm covered more than 2,400 km in a day.

Fig. 26. Extratropical cyclone, 300 km east of Moscow, May, 1965. Spiral structure is quite distinct. Photographed from Tiros (*Monthly Weather Review*, vol. 93, 1965).

The form, dimensions and structure of extratropical cyclones can be distinctly seen in the photographs taken from the American satellite Tiros. The first photograph (Fig. 26) shows an almost stationary vertical, sharply-defined cyclone located 300 km east of Moscow on May 6, 1965. The spiral structure can be clearly seen. The size can be judged from the lake covered by unthawed snow—a white spot to the northwest of the spiral.

The second photograph (Fig. 27) is rather strange. Here two curved zones can be seen to the north and south of the spiral cloudy mass (white spot) of a vague internal structure. This photograph was taken on November 20, 1963. The main white zone situated to the west of the spiral is the main Caucasus range, covered with snow. At the eastern end of it the outline of

Fig. 27. Cyclone over Caspian Sea, November, 1963. Spiral structure can be seen. Photograph from Tiros (Shenk, 1965, Fig. 1).
White zone on left—Caucasus mountain ranges; *black spot on right*—Karabogazgol; *to south*—southern part of Caspian; *white*—cyclone.

the Apsheron Islands can be seen. On the other side the spiral outlines Karabogazgol and the Krasnovodsky Islands equally clearly.

Opinions differ regarding the nature and conditions of formation of the cloud spiral. One group of scientists believes that there was a cold front situated to the north. This is the opinion of V. A. George and O. A. Lyapin. Others believe that the spiral body was formed during movement along the Caucasus range. The third group (Shenk, 1965) rejects the theory of a cold front and longitudinal movement. Analyzing the synoptic conditions, Shenk (1965) put forward the theory of a vertical vortex of air rising over the mass of warm sea water in the same way a vortex of smoke rises over a big fire.

These theories are interesting in that they underline the various conditions conducive to the formation of the spiral vortex of cloud. Usually such vortices are regarded as cyclones but it is quite likely that not all of them exhibit the properties of extratropical cyclones. They may exhibit the transitional form of the dust vortex or tornado.

The third photograph (Fig. 28) is of an extratropical cyclone over the Pacific Ocean, 1,280 km west of California. The diameter of the cyclone is 1,500 km. In the top right of the photograph the circular black spot—the center of the cyclone—can be seen; it is surrounded by the white wall of

Fig. 28. Extratropical cyclone over Pacific Ocean, 1,280 km to west of California. Spiral zone of white cloud. Photograph from Tiros (Fritz and Wexler, 1960, Fig. 7).

rainy thunderclouds; the spiral rotation of the cloud zones can also be seen.

MOVEMENT AND TRACKS

Extratropical cyclones move anywhere, but like tropical cyclones they have definite regions and tracks of movement.

Such regions cover the subpolar latitudes. Here one finds the main tracks of cyclones. It is here that maximum growth and strength are attained, often accompanied by storm or even hurricane winds.

Cyclones originate in the fronts at the boundary of warm and cold air. European cyclones often originate in the Iceland region where the cold air current coming from Greenland meets the warm air coming from the Gulf Stream.

Many storm- and even hurricane-stage cyclones over the west coast of Europe behave more or less like tropical cyclones. They travel up the east coast of North America and cross the Atlantic Ocean. After reaching Europe the majority of them exhibit the features of extratropical cyclones. Some cross the whole of Europe and often reach Siberia (Abercromby, 1887, p. 423). Earlier (see page 33) we mentioned hurricane Carrie (1957), which followed a track starting from the coast of Africa, traversing the

Atlantic Ocean and then moving over England. Approximately the same track was followed by hurricane Debbie of 1961. Many hurricanes originate in the region of the Caribbean Sea, travel up the coast of North America and reach Europe with all the features of extratropical hurricanes.

An interesting problem arises with a third group of cyclones—storms and hurricanes that penetrate Europe from the south. It is often assumed that some of these cyclones originate over the Mediterranean Sea, from where they move north or northeast. Observations from satellites, as already mentioned, show that tropical cyclones which were supposed to originate over the eastern Atlantic Ocean actually originate over the Sahara. This may also be the case with many extratropical cyclones which are supposed to originate over the Mediterranean Sea. They may originate in the same way over the vast deserts where there are sharp variations in temperature.

This is first of all shown by the composition of the soil which is brought to Europe by the cyclones moving in from the south. Detailed investigations by Ehrenberg (1849) showed that the composition of red dust collected on a ship in port in Malta, in the streets of Lyons, in Sicily and Calabria showed dust and clay particles with encrustations of iron oxide. In these particles a large number of silicious skeletons of freshwater organisms, especially diatoms, were found.

Cyclones originating over the Mediterranean Sea could not carry such dust. Cyclones originating over North Africa, specifically over the Sahara, could. It should be remembered that among the surface deposits of North Africa, especially in the Sahara, freshwater deposits occur extensively. The presence of freshwater organisms in the transported red dust confirms that they have been carried from the direction of the Mediterranean Sea.

It should be noted that after full development hurricanes show extraordinary strength and persistence. They surmount big barriers and turn up far beyond the region of their origin. Hurricanes originating and forming in the Sahara move right across the Mediterranean Sea and strike hundreds of kilometers into southern Europe. They mainly travel up the valleys of big rivers but the stronger ones even cross such high mountains as the Alps. According to the detailed data of Ehrenberg (1849), Saharan red dust with freshwater diatoms and marine foraminifera was found on the snow in the Tyrol, near Salzburg, in 1847. How far north southern hurricanes can penetrate can be seen from the presence of red dust in Silesia (Wroclaw) and Austria (Vienna) after the hurricane of January 30–31, 1848.

The southerly and southeasterly storm or hurricane wind on the shores of the Mediterranean Sea is known as the "Sirocco". The red dust serves as a good indicator since it gives rise to "red" rain. The "red" rain used to cause superstitious panic; it has been recorded in literature and chronicles from ancient times down to the present era. Such data were collected in the monograph by Ehrenberg (1849) and a brief account is given on pages

502–509. From this it can be seen that the southern hurricanes affect the whole of southern and a large part of central Europe, spreading to southern England, Holland, south Germany, Switzerland, Austria and south Poland. "Red" rain occurred in Lvov in 1716. The bishop ordered a mass fast and continuous prayer.

Central, especially northern, Europe is a region of traverse of many Atlantic cyclones moving in from the region off Iceland in an east-northeastern direction. Analysis of 300 storms carried out by P. I. Brounov (1884) yielded this result. The tracks of some storms striking Europe during the period 1876–1880 are quite interesting (Fig. 29). All of them started over the Atlantic Ocean.

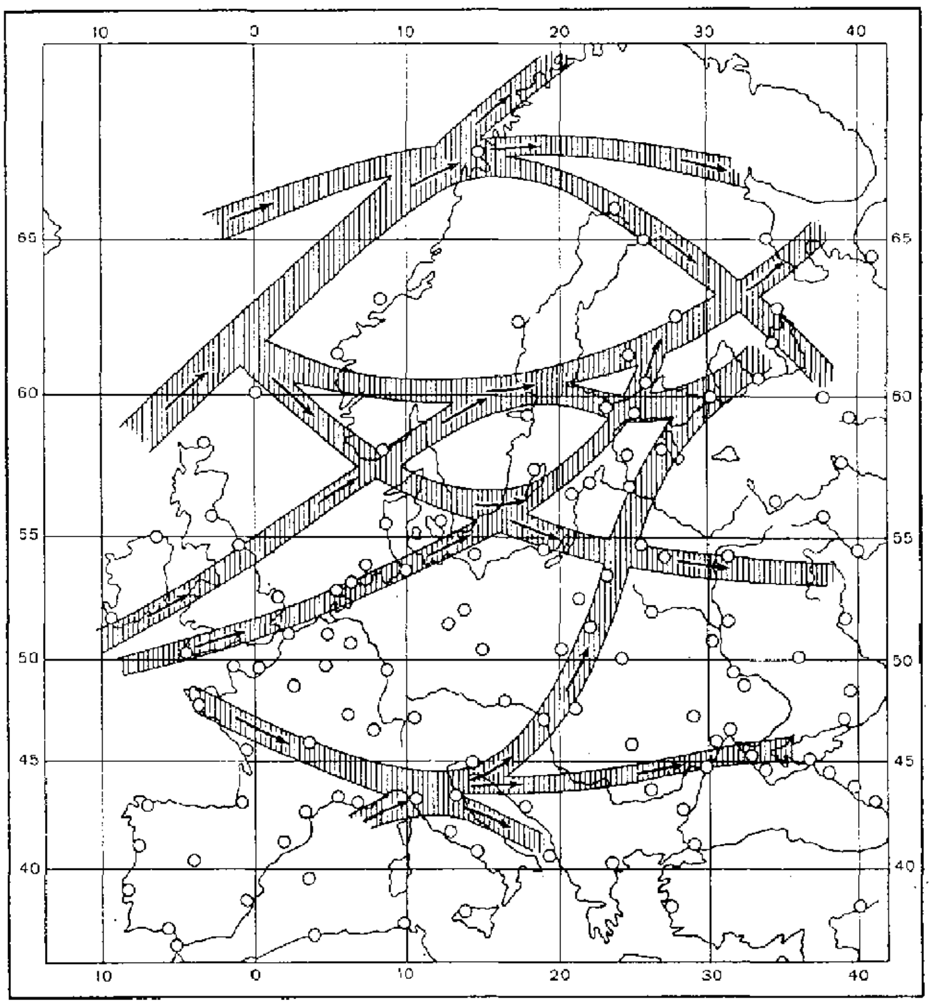


Fig. 29. Tracks of extratropical cyclones in Europe, 1876–1880 (Brounov, 1884, map VIII).

November of 1893 was quite stormy in Europe. The stormy spells were active for almost a month with occasional cyclonic storms. Ten strong cyclones crossed Europe during this one month. The seventh was especially stormy. It originated in the Gulf of Genoa on November 18 and crossed Europe from the Riviera to Vyatki. A strong storm attaining hurricane strength crossed England, France and Spain, churning up the Atlantic Ocean and the Mediterranean Sea in the span of three days. This cyclone reached Russia on November 20 and caused snowstorms in the central belt (excluding Moscow) and in the south. Movement of trains was halted in many places by the snow cover. A violent storm broke out over the Black Sea.

The cyclones described above caused havoc in the countries of western Europe. In England and France telegraph and telephone lines were broken due to snowfall and snowstorms; in many places railroads were damaged. In Scotland 3 m of snow was found on the rail track in some places. Many trains were held up by snow.

The hurricane caused large-scale devastation along the coast of France. In the neighborhood of Calais the sea swamped the dike and the stone lighthouse was destroyed. At Le Havre the front was littered with the wreckage of ships and the bodies of seafarers.

The total number of ship losses was 144 according to Lloyd's of London. A very large number of people died. Around 200 people died on the coasts of England alone (*Meteorologicheskii Vestnik,* 1893, No. 12).

The map of the tracks of storms in the northern hemisphere prepared by Lumis in 1886 is quite interesting. It is shown in Fig. 30. Here the storms associated with extratropical and tropical cyclones are shown. The sharp decrease in the number of cyclones in the subpolar region and the concentration in the form of rings in the middle latitudes can be clearly seen. Attention is drawn to the two curved projections of the ring: the projections are situated almost symmetrically in the Atlantic and Pacific oceans and represent hurricanes and typhoons.

The symmetrical, strikingly correct trajectories of the storms show that the origin of storms is of a planetary nature.

Although the Atlantic cyclones do not carry red dust, the transportation of Atlantic microorganisms deep into central and north Europe does not appear to raise doubt.

The last group of extratropical hurricanes and storms relates to the polar latitudes—the Arctic and especially the Antarctic. Over the mountainous regions of the Antarctic continent anticyclones are a regular feature. The air current blows over the sea with great force. On the other hand, over the sea and the coastal regions of the continent exceptional development of cyclones occurs, often with storm or hurricane force winds. The speed of the wind in hurricanes attains very high values—50–60 and even 90 m/sec. The wind literally carries away everything present on the surface and polar explorers bury themselves deep in the snow and ice to escape it. A large number of hurricanes and storms are persistent. Adel experiences storms and hurricanes for nearly 340 days in a year. The number of storms fluctuates from 20 to 30 in a year. There was not a single day without hurricane force winds in 1957 and 1958 at the station Oasis. In 1959 the station Lazarevskaya had 89 days of storms and 36 days of hurricanes from May through October.

Due to the almost continuous ice cover the geological activity of this fierce wind is inconsiderable. Even the drift of marine organisms onto the continent is limited by the distribution of hurricanes along the coastline and the continuous activity of the strong, constant storm flux.

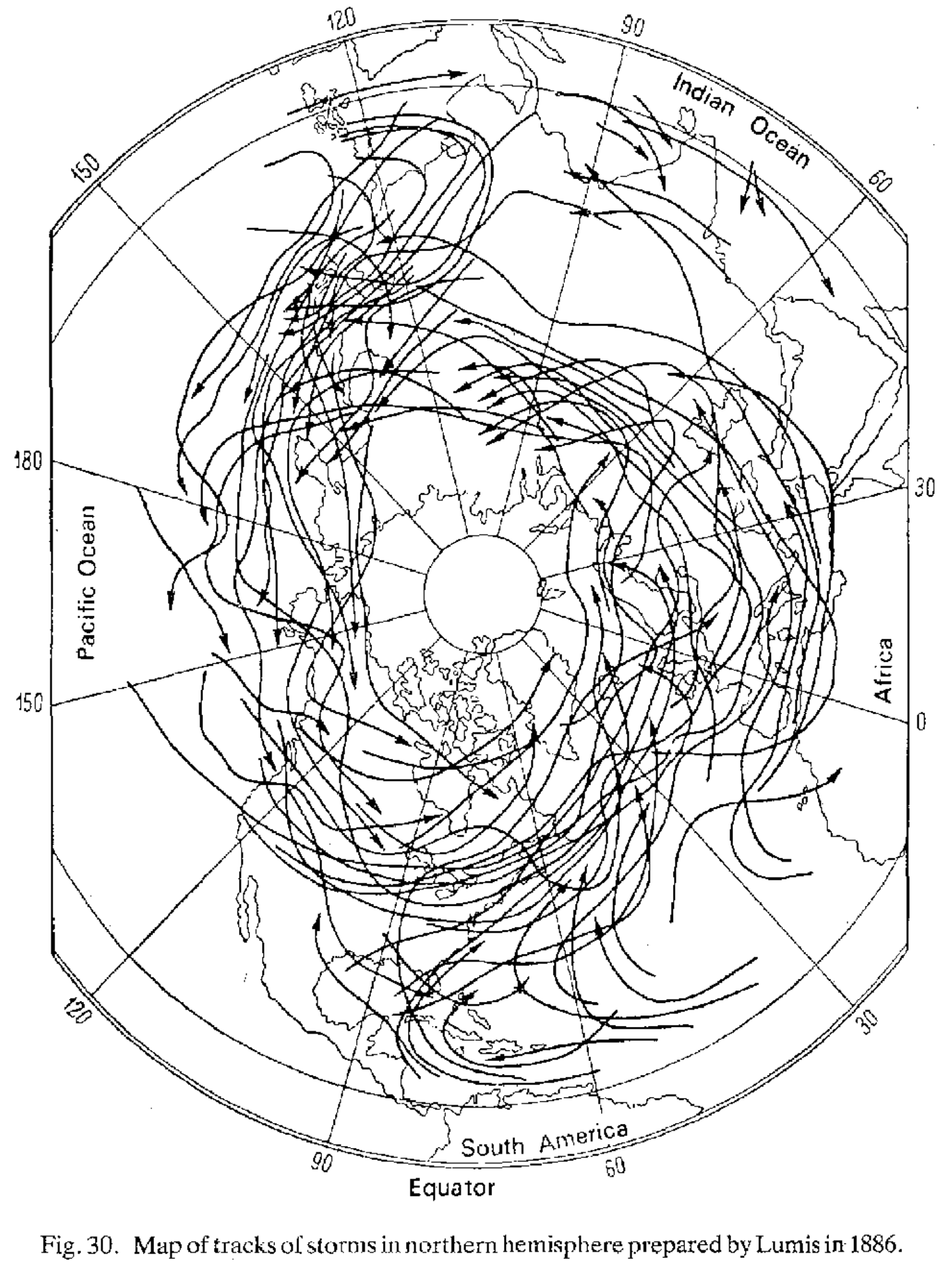


Fig. 30. Map of tracks of storms in northern hemisphere prepared by Lumis in 1886.

In the Arctic cyclonic activity is observed at all seasons of the year, especially on the southern border. The earlier idea of stable anticyclones in the Arctic is not correct. In the Arctic only the high plateau of Greenland with its ice sheet is a region of regular anticyclone (Khromov, 1964, p. 476). The cyclone of February 1962 that struck the mobile scientific station Severnyi polyus-8 and destroyed it totally can be taken as an example of hurricane winds. The cyclone was centered on Severnaya Zemlya.

Strong regular winds, often of storm strength, transport a huge amount of marine microorganisms to continents and islands.

There is no doubt that in the Arctic the hurricane waves associated with hurricanes and storms attain a considerable height. They are not very well known due to the low density of population in the polar region.

3
Destructive and Creative Activity of Hurricanes

The destructive activity of hurricanes-stage cyclones is catastrophic and well known but their creative activity, although important, is ignored. In Nature, along with destruction something is always created. The accumulation of the products of destruction takes place simultaneously with the destruction. The destruction takes place before us and therefore it strikes us but the accumulation of new deposits often takes place under water and we do not notice them. Here the two processes will be considered together.

Many phenomena accompanying hurricanes are as powerful and dangerous as the actual hurricanes. Often they surpass the hurricanes in intensity. Undoubtedly the maximum destruction, often with death on a large scale, is due not to hurricane winds but to hurricane-caused waves.

The hurricane wind is dangerous due to its own strength and destructive activity but the question arises: which is more destructive—the wind or the precipitation accompanying it? Which should be assigned second place? If we remember the huge, sudden inundation of very large areas accompanied by landslides it is clear that second place goes to precipitation and the wind takes third place.

The violent and destructive hurricane tornadoes, hailstorms and electrical phenomena take next place, forming a second group.

The significance of the hurricane as an overall geographical phenomenon is often overlooked. Many assume that hurricanes, like other catastrophes, are rare and occur at long intervals. During this interval of time slow evolutionary phenomena usually give rise to results that are greater than the effects of the hurricanes themselves.

This assessment has to be revised. Actually, it has more basis than is generally assumed. Specialists, well knowing the actual facts, believe that the changes and destruction caused by hurricanes are much greater than all the other ordinary changes and destruction. The evolutionary phenomena only transform and modify what is created by hurricanes.

The important feature of hurricanes is that they are closely connected with the oceans. Hurricanes develop over the ocean and much of the track, often the entire track, lies over it. Hurricanes lose their strength once they arrive over the continent and many dissipate while others transform themselves into extratropical hurricanes. Hurricanes are mainly marine and oceanic phenomena.

Therefore the maximum intensity of the activity of hurricanes is on and near the coast. In coastal regions the destruction from hurricanes attains very high magnitude.

Abrasion is an important geographical and at the same time geological phenomenon. It can now be said that abrasion is mainly due to the activity of hurricanes and hurricane waves.

Abrasion is also an important factor giving rise to marine transgression and angular nonconformities of the deposits accompanying it. The close relationship between hurricanes and accompanying inundations with transgressions has been noted by the eminent geologist E. Zuss.

All these problems will be considered in detail in the following account.

The large scale of the destruction due to hurricanes reflects the unusual magnitude of the energy of hurricanes.

ENERGY OF HURRICANES

Dunn and Miller (1960, p. 123) mentioned that different calculations show (Hughes, 1952; Miller, 1958a), that an average hurricane releases $2.0 \times 6.0 \times 10^{26}$ ergs in the form of heat in a day. The maximum figure is approximately equivalent to 16 trillion kilo-watt-hours per day. This energy is sufficient to supply electricity to the whole of the United States for half a year.

A comparison of hurricanes and nuclear explosions showed that the energy of an ordinary summer thunderstorm is equal to the energy equivalent of 13 atom bombs of the type used over Nagasaki. The energy of an average hurricane is equal to 500,000 atom bombs. The nuclear explosion over Bikini Island lifted 10,000,000 tons of water into the air, but a hurricane over Puerto Rico brought 2,500,000,000 tons of rain in a few hours—250 times more than the water lifted in the Bikini explosion.

The main source of energy of the hurricane is the release of heat from the condensation of vapor.

The extraordinary energy and power of hurricanes have been described in great detail by Dunn and Miller in their monograph (1960), where measures to combat hurricanes are discussed. The most powerful atom bomb is weak and insignificant as compared to the strength of vortex formations having diameters of 500–750 km or more.

Interesting data are given in a paper by Holzman (1951) which discusses the effect of nuclear explosions on the weather. He shows that the energy generated during the life-cycle of a hurricane is inconceivably great. The kinetic energy of an average hurricane is equal to 1,000 atom bombs. Small storms with rain release a quantity of energy not less than that of three atom bombs in one second. According to the latest calculations by Lane the heat released from a big hurricane is equal to the heat arising from the combustion of 2–3 million tons of coal. In one day such a hurricane expends energy equal to the explosion of a 13,000 megaton nuclear bomb (Lane, 1966, p. 5).

The energy comparable to that of gigantic natural phenomena such as frontal storms and hurricanes has not yet been attained in man-made bombs.

DESTRUCTIVE FORCE

The destructive force and the power to transport materials of hurricanes are enormous. They generally give rise to winds of enormous speed and the wind carries a mass of water, dust and sand. The main destruction and human "catastrophe" are caused by hurricane waves and tides. These add to the violence of the hurricane in association with the action of wind and movement.

It is known that air moving at a speed of 40 m/sec sets up a pressure of 100 kg/m^2. With an increase of speed to 80 m/sec the pressure increases to 400 kg/m^2. A surface area of a few square meters experiences a pressure of 1000 kilograms. At the time of strong hurricanes individual gusts attain still higher values, say of the order of 120 m/sec with a pressure of 900 kg/m^2. Such terrific pressure cannot be transferred and consequently all buildings, even stone buildings, are destroyed (Rue, 1940, p. 46).

On the seashore of North Carolina (USA) at the crest of the sand dunes, a few hundred meters from the water, there was a two-storied, fairly big reinforced concrete house. Hurricane Hazel (1954) struck and practically nothing was left, just the dunes, the foundation and the ground floor. The upper story was caught by the waves and wind and was tossed into the lagoon on the other side of the dune after the hurricane.

The same hurricane crossed part of the island of Haiti and destroyed everything in its path—structures, gardens and forest. The vortex, attaining a speed of 300 kmph, picked up green coconuts, pieces of bamboo, heavy tropical shells and even a cup made of ebony engraved "Made in Haiti". All these were carried in the wall of the hurricane for three days, transported over the sea for a distance of 1,500 km and dumped on the shore of North Carolina.

The most terrible Florida hurricane of 1935, resembling a gigantic tornado in form and speed of rotation (400–500 kmph), carried sand at such speed that the people taken by surprise on the open beach suffered holes in their clothes and skin. The corpses were left with only leather belts and shoes. A big log of wood, 5–6 m long, lifted into the air horizontally, hit a two storied frame house and passed through it. In the light house 40 m tall the lenses and thick shield glasses were destroyed by water (McDonald, 1935). This hurricane carried two large land tortoises through the Gulf for a distance of 30 km. The weight of one was 66 kg, i.e. comparable to the weight of a man (Lane, 1966, Townsend, 1936).

At the time of strong hurricanes the transporting strength of the wind shows unusual magnitude. This can be seen from the fact that a one-inch thick plank was transported by the wind with such force that it pierced through the trunk of a palm tree. Such an incident was first reported during the hurricane of 1825 in Guadalupe but 100 years later similar cases were photographed in the hurricane of October 20, 1926, in Havana and September 13, 1928, in Puerto Rico (Fig. 31). In other cases road metal and pieces of metal pierced the trunks of solid trees. The Barbados hurricane (August 10, 1831) carried a piece of lead weighing 60 kg a distance of more than 500 m and another weighing 160 kg a distance of 400 m.

For its staggering strength the "Great Hurricane" of 1780 in the West Indies islands is considered the biggest in the last 300 years. The famous Admiral Rodney, commanding a British fleet, wrote to his wife: "It will be difficult for you to realize my surprise and grief when I saw the devastated condition of the island (Barbados) and the destructive force of the hurricane. The strongest buildings and a number of houses, the majority of which were made of stone, yielded to the fury of the wind from the foundations. The entire fort was destroyed and many heavy cannons were carried a distance of more than 100 feet (30 m). If I had not seen all these things myself it would have been difficult for me to believe it. More than 6,000 people died and whole settlements were destroyed" (Tannehill, 1945, p. 125). The total number of victims was around 20,000. Tens of ships with their cargoes were sunk.

Admiral Rodney himself saw cannons move but he did not see them flying through the air. It is difficult to credit the flight of lumps of lead weighing 60 kg and 160 kg but the flight of heavy tiles, road metal and pieces of metal is plausible.

We will cite a description of the hurricane in Barbados on August 10, 1831: "At seven in the evening the weather was calm and clear and it continued so till nine in the evening, when a northerly wind started blowing. Lightning started at half past ten over the northern horizon. Around midnight a squall accompanied by rain started and then changed to calm. The temperature fell. After midnight bright flashes of lightning became almost continuous and a fresh wind started blowing from the north and northeast. At one in the night the strength of the wind increased to the order of a storm, which blew from the northeast and then suddenly veered northwest. During this period the lightning sharply illuminating the clouds showed up in all

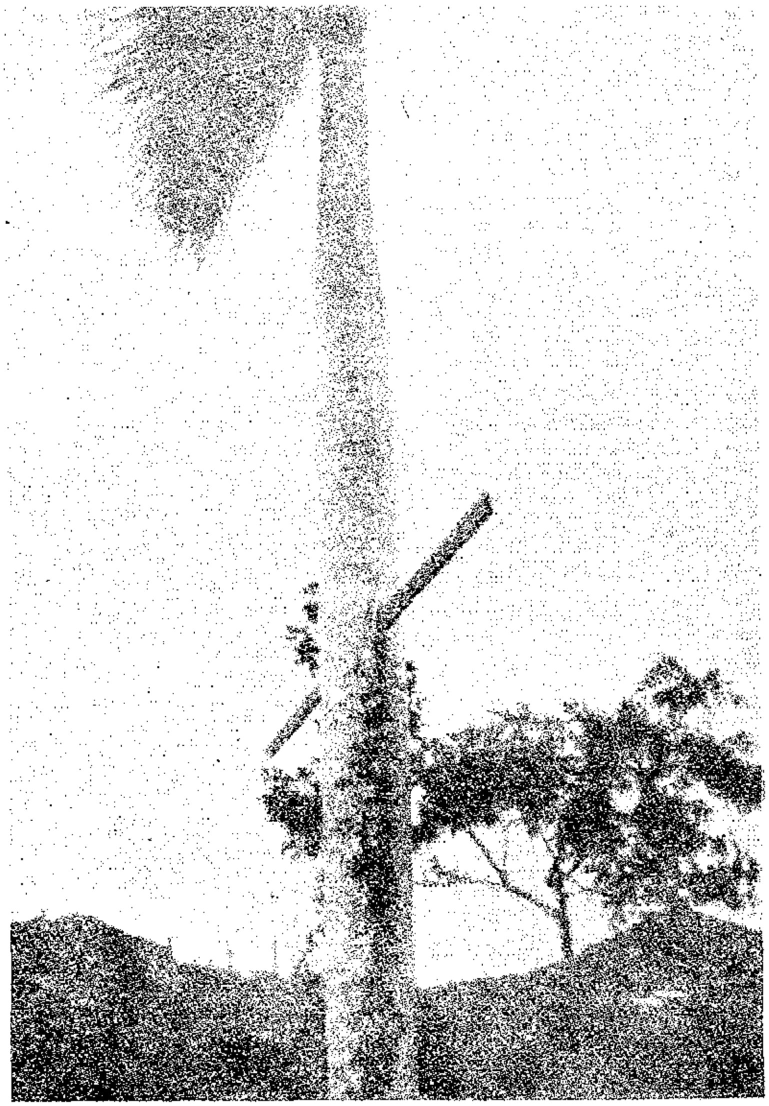


Fig. 31. Palm tree pierced by one-inch-thick pine plank during hurricane of 1928 in Puerto Rico (Tannehill, 1956, Fig. 66).

directions and was accompanied by terrible thunder. After two, the storm attained the strength of a hurricane, which blew with such a deafening roar that it is difficult to describe. Colonel Nichel took shelter in the arch of the ground floor to avoid the wind and rain and did not hear the sound when the first floor collapsed, but he realized it from the dust and rubble falling from above.

"At three the wind was slightly less noisy but blew a terrible squall. With the weakening of the wind the flashes of lightning stopped for some time and the city was submerged in impenetrable darkness." It was at this time that the center of the hurricane passed. Soon the hurricane revived and the "deafening noise of the wind changed to bellowing or, to be exact, to a distant roar which is difficult to express in words, and now the lightning illuminated the entire space between clouds and earth and this continued for half a minute. It appeared as if a huge fire erupted in flames next to the houses, which went up immediately.

"Immediately after this terrible phenomenon, shown by the lightning, the hurricane again started from the western bearing of the compass with such a terrific force that it carried everything that could not withstand its pressure. It is not only that solid buildings started shaking but even the surface of the earth was vibrating. It was not possible to hear the peal of thunder at this time. The terrible howl and roar of the wind, the noise of the sea waves threatening total destruction of the city, the noise due to the fall of walls, windows, fencing, etc. cannot be conceived and it was a terrible rattle. It is difficult for those who live far from this terrible, agonizing situation to visualize the condition and suffering of the people living in this city.

"After five in the morning the hurricane started weakening and it was possible to hear the noise due to the fall of building materials carried by the hurricane. At six the wind started blowing from the south, at seven from the southeast and at eight from east-southeast; nine the weather cleared up . . .

"Climbing the tower of the church, I surveyed all sides and had a view of a desolate scene of total destruction. The entire island around the city appeared to me to be naked, without any sign of vegetation. Some of the surviving trees had no buds and no green leaves" (Dove, 1869, p. 222–225).

In addition to the electrical phenomenon witnesses noticed saline rain, actually sea water carried by the hurricane, deep inside the island. Marine microorganisms were transported along with the water.

Pieces of heavy shells, not accompanied by other marine microfauna, have been found in the upper chalk layers of the Caucasus and Carpathia. They are regarded as marine deposits but the important facts described above show that they could have been transported by hurricanes and storms and their presence in continental deposits is easily explained.

Among recent hurricanes, our account concludes with hurricane Flora of September 26–October 13, 1963 (Dunn, 1964, p. 133–136; Frank, 1964, p. 17). On Septembr 26 the satellite Tiros VII photographed an accumulation of cloud in the middle of the Atlantic Ocean, indicating the formation of a hurricane, but the spiral belt had not yet formed. It was not there on September 27 either. On September 28 and 29 observations were not made but on September 30 the hurricane started its destructive activity. The special "hurricane hunter" plane flew to meet it and encountered the well-defined central belt, the wall of cloud 12 km wide around it and wind speeds of more than hurricane force. In short, the hurricane was fully formed. At two in the afternoon it struck Tobago Island, causing the first destruction and killing 17 people. On October 1 and 2, Flora went out over the sea and gradually intensified. The reconnaissance plane found the wind speed to be

260 kmph. The hurricane attained terrible strength at seven units in the evening and struck the western fringe of Haiti. The strength of the wind was violent: the speed in gusts exceeded 300 kmph.

The destruction of highlands was complete. Some of the cities were immediately inundated while other cities faced landslides. Three-meter-high waves destroyed everything on the sea front. The standing crop was completely destroyed. More than 5,000 people died and loss of property was more than a million dollars.

Next day, without weakening, Flora struck the eastern end of Cuba. The hurricane raged violently for four days over the island. The hurricane winds uprooted trees, destroyed structures and interrupted the transport system. Floodwaters inundated large areas. As many as 1,750 people died and the loss of property was of the order of 500 million dollars.

At last, on October 8, the hurricane crossed Cuba and the Bahama Islands. Still its strength was enormous: it was one of the worst hurricanes in the history of the area. On October 9–11 the hurricane moved rapidly over the ocean. On October 12 it reached Newfoundland and became an extratropical cyclone. On October 13 Flora dissipated over the central Atlantic Ocean.

Based on wind strength, the magnitude of destruction and the number of deaths (7,200 people), Flora occupies the second place after the "Great Hurricane" of 1780 in which 20,000 people died. N.N. Kolobkov (1964) and Z. M. Tiron (1964) have described it in great detail.

The geological significance of Flora is unquestionable. The large-scale floods, numerous landslides, sand flux during the storm and storm waves on the seashore cause substantial changes in the deposition pattern. These changes cover a large area and thus significant changes take place in the recent deposits. There is no doubt that interchange of marine organisms from sea to land and from land to sea occurs.

Hurricane Audrey of 1957 attained enormous speed (Ross and Blum, 1957) while crossing the USA during its passage from the Gulf of Mexico to Canada. It crossed Canada and almost reached Greenland as an extratropical cyclone. It killed 600 people and the loss of property was of the order of 150–200 million dollars It almost approximated hurricane Donna of 1960.

Hurricane Diana of August 10–14, 1955, carried away 1,200 people in tidal waves and the associated flood caused a fantastic loss of the order of 2 billion dollars.

Special attention is drawn to the above mentioned hurricane Hazel (1954), one of the most terrible and best studied hurricanes of the recent past (Dun and Miller, 1960). The first sign of it, in the form of tidal waves, was noticed on October 3. On October 5, at a point 75 km east of Grenada Island a reconnaissance plane detected the cloud vortex system with a blurred eye and a wind speed of 150 kmph. At the end of the day the hurricane, still weak and not yet fully developed, crossed the island, causing the first destruction and loss of life. On October 6 the hurricane went out over the sea still not fully developed. Aerial observations showed that the speed of the wind in squalls had already attained 200 kmph. From October 7 through 11 the hurricane moved slowly in zigzag fashion over the sea. At the end of this period the "eye" was fully formed and the wind in the surrounding wall attained unusual strength: the reconnaissance plane narrowly escaped destruction.

On October 12, after attaining full strength for the first time, the hurricane struck densely populated Haiti. The small settlements in its path were totally destroyed and the bigger towns were badly damaged by the wind and tidal waves. The rain caused floods and landslides. One landslide annihilated a village of 200 people. The estimates of dead ranged from 400 to 1,000. The speed of the wind was 220 kmph. On October 13 and 14 the hurricane moved over the Atlantic Ocean, inundating the Bahama Islands on the way. The "eye" was of small size, around 10 km in diameter, but the strength of the wind was violent. It was observed from the reconnaissance planes that below the hurricane there was an uninterrupted cover of white foam on the waves.

On October 15 the hurricane approached the coast of North Carolina. Storm signals were immediately raised and people were alerted by the radio and other media. The entire population was evacuated from the coastal zone but still a large number of people died.

In the afternoon Hazel struck the coast. The coast was sandy, the low-lying area being covered by dunes with a large number of islands, gulfs, lagoons and straits. In these places towns had developed. All these were destroyed. All along the coast there were 3 to 6 m high sand dunes with green scrub. Along almost the entire belt there were buildings, for a distance of 8–10 km. All these were destroyed—the dunes, the concrete foundations and the green belt. The shore line receded by several tens of meters. Where in the morning there had been thousands of buildings, gardens and roads, in the evening there was only sand. The entire complex was destroyed. The loss was of the order of tens of millions of dollars, but because of the timely warning the death toll was only 20. The height of the hurricane tidal wave reached 5 m.

Destroying and eroding the coastal zone, the hurricane moved inland into the continent, gradually changing to extratropical form but with the same strength, destruction and threat of death. It approached Lake Ontario, crossed it and entered Canada. In the United States, Hazel caused a loss of 251 million dollars and killed 95 people. All this continued in Canada. There was large-scale destruction here, too, due to strong winds, heavy rains and floods. Seventy-eight people died. Loss of property was of the order of 100 million dollars.

Gradually Hazel lost strength and, changing to the usual type of storm, crossed Canada. On October 18 it moved out across the Atlantic and was last observed to the north of Scandinavia (Dunn and Miller, 1960, p. 245–257; Knox, 1955).

The recorded life of Hazel was 15 days. It attained maximum strength between October 12 and 15. During these days its wall contained coconuts, bamboos, shells and glass, which it transported from Haiti to Carolina (Gentry, 1955b; Boughner, 1955).

A rather peculiar hurricane passed over the islands of Florida Keys on September 2, 1935. It killed more than 400 people. The large-scale destruction it caused was accompanied by hurricane waves more than 6 m in height. It is described in the book by Douglas (1958).

Its uniqueness lay in the unusually narrow belt of destruction—the total width being 15–20 km—and in the tremendous wind speed of 400–500 kmph. The wind literally wiped out everything in its path and overturned 10 Pullman coaches. These two features of the hurricane of September 2, 1935, show that it was similar to a tornado in character and width.

The destructive force of the hurricane-tornado of 1935 was startling. Air carrying sand blew at such a speed that it gouged holes in the faces of people and caused bleeding. The train that was overturned was empty and no one died. It had been sent to bring war veterans living in a camp on one of the islands. Anticipating the hurricane, they abandoned the train and took shelter under the embankment. The hurricane waves destroyed the embankment; 120 veterans were drowned, 90 could not be traced and 100 were severely injured.

The hurricane of 1935 showed a minimum pressure of 892 mb (26.35″, 569 mm) when measured over land (Moore, 1961). This was recorded on September 2, 1935, at the coastal station of Florida. The lowest-ever pressure of 877 mb was recorded over the ocean on September 24, 1958, in the center of typhoon Ida between the Marianas and the Philippine islands.

We will describe the hurricane waves of 1935 observed at the meteorological station. Let us start with a description of the center of the hurricane, the "eye of the storm": "During the calm period the sky was clear. Bright stars could be seen and a light breeze was blowing. It was not total calm, though. During the middle of the calm period, which continued for 55 minutes, I saw that the sea had started rising quite fast. I could see a wall of water a few meters high. I immediately ran to the cottage but it overtook me and I was immersed in it. The water flooded the cottage. The first onset of wind with high force was at 10.15 a.m. Houses tumbled down. The wind became stronger than during the earlier hours. I recorded a barometer reading 26.98″ (674.5 mm). Then I was immersed and carried away by the wind out to sea, where I caught hold of coconut leaves to save my life. I was hit by something and lost consciousness. I regained my senses at 2.25 p. m. and found that I was stuck in the branches of a palm tree 20 feet (6 m) above the ground" (Duane, 1935, p. 238).

It may be added that 400 people died in Florida.

According to Lane the destructive activity of hurricanes in the USA alone during the last 60 years has caused 17,000 deaths and a loss of 5 billion dollars. Every 12th hurricane killed 100 people and was responsible for the loss of 1 million dollars (Lane, 1966, p. 3).

The Pacific Ocean typhoons are not inferior to the Atlantic hurricanes in destructive power. The name "typhoon" means "the wind that kills", and it really kills. Even such a small typhoon as Ruby of 1964 caused large-scale destruction and killed 31 people in Hong Kong. Typhoon Wanda of 1962 killed 178 people and gave rise to hurricane waves 3 m in height (Wood, 1965).

The description of a Japanese typhoon by Molen is quite interesting (1966, p. 27): "The gigantic typhoon approached Japan, developed tremendous energy, carried billions of tons of water and inundated the entire province. It raised waves as high as multistoried buildings and caused winds like there was a fusillade of stones and the wind was blowing projectiles . . . As if a gigantic turbine had been dumped on the earth, sweeping away everything in its path." Four hundred km away from the "eye" of the typhoon the speed of the wind was 25 m/sec—sufficient to uproot nearby trees.

For more than 4,000 years vessels have plied the seas and oceans the world over. Every year sea-going vessels face tens and often hundreds of hurricanes, storms and typhoons. Every year tens and often hundreds of vessels of different types and sizes, from rowboats to the sailboats of the Phoenicians, Egyptians, Romans, Vikings, Chinese, Indians, Arabs, etc. have been sunk and tens or even hundreds of people drowned. Then these small vessels gave way to large sailing frigates, clippers, brigs and hundreds of other varieties of vessel in the last hundred years with crews of hundreds. Even in the second century the size of vessels and their crews had increased but they still could not withstand the terrific pressure of a rotating air mass of huge size and strength. The vessels were often destroyed and with them thousands of people drowned. We do not know how many people have died in the last 4,000 years and we will never know. We do not know how many sailors died and we will never know, but it is certain that the number would add up to hundreds of thousands of people of various nationalities.

The book *Guide to Stormy Weather* written by the American sailor-meteorologists Harding and Kotsch (1965) gives a large amount of statistical data and lively description of the plight of vessels facing hurricanes in the chapter "Deadly Force of Hurricanes". The French and British fleets were caught in the Great Hurricane of 1780. Forty ships were destroyed and 4,000 soldiers along with the crew were drowned.

Nowadays the size of vessels is enormous, the speed very high and they can withstand great hurricanes, but any carelessness can cause severe damage.

There was a large concentration of the American fleet in Japanese harbors after the end of the Second World War. The commander of the fleet relayed the movement of a typhoon but the Admiral ignored it and went ahead with his planned operation. The loss was severe! Two torpedo boats and a few small boats were sunk with their crew. The majority of the ships survived but all were damaged, some considerably. The entire fleet was driven out to sea and the operation had to be abandoned.

Even the biggest liners quickly change course to avoid a hurricane.

The destructive force of nontropical hurricanes is less than that of tropical ones, but still it is something to reckon with. The great destruction caused by hurricane waves on the west coast of Europe has been described earlier. The destruction is no less by the wind when it reaches hurricane strength. It is immaterial whether the hurricane is tropical or extratropical. The destruction is caused by the wind force and the impact of the waves. The destruction is similar to that of a wind of hurricane strength. Extratropical cyclones rarely become hurricanes of the tropical type and therefore the destruction due to them is less than that caused by tropical hurricanes.

Any hurricane, independent of its place of occurrence, shows tremendous destructive force. The hurricane that hit Cherbourg on the French coast on January 11, 1866, can be taken as an example. There were 32 ships in port. Twenty-two of them were hurled against the harbor wall (Fig. 32). Huge boulders weighing 2–3 tons lying on the main pier were lifted to a height of 8 m and blown away. The waves striking the pier splashed 50–60 m high. The violent wind caught the foam and carried it in a horizontal sheet deep into the city.

Fig. 32. Hurricane of 1866 at Cherbourg on French coast. Twenty-two ships were driven onto harbor wall (Zurcher and Margolle, 1883, Fig. 36).

Strong storms were active in different parts of the world during the autumn-winter season of 1967–68. Many cyclones had hurricane winds and were accompanied by heavy rain.

At the beginning of September strong monsoon rain caused catastrophic floods in North India and East Pakistan*. In Uttar Pradesh, 7,500 villages were inundated and more than one million people were affected. Thousands of people were rendered homeless and 377,000 acres of land under crop were flooded. The rivers Ganges and Jamuna inundated many parts of the city of Allahabad at the confluence of these two rivers.

Between September 10th and 20th the Caribbean Sea and the Gulf of Mexico were struck by the violent hurricane Beula. It moved over Haiti after crossing Martinique and Puerto Rico. In the territory of the Dominican Republic the hurricane damaged the dam of the port San Pedro de Makarios. The tidal waves gushed into the city. The electric transmission line was damaged and the city was plunged into darkness.

Beula passed over Cuba and then struck the coast of Mexico. Maximum damage occurred in the city of Merida. The speed of the wind was as high as 120 kmph. Reaching the territory of the USA, the hurricane caused great damage to coastal towns and crossed Texas, destroying thousands of houses. According to newspaper reports, the port city Isabel looked like it had been bombarded. Near the city of Corpus Christi the hurricane literally lifted an automobile with two passengers and threw them in the ditch.

Beula continued on its course for 13 days. The loss to agriculture in Texas alone was of the order of 50 million dollars.

At the end of September, another tropical hurricane, Chloe, traversed a course of 7,000 km over the Atlantic Ocean. It gave rise to stormy winds on the coasts of Europe (Spain, the Bay of Biscay, France). It gradually dissipated but was responsible for the growth of another powerful cyclone which gave rise to stormy winds in the south Baltic Sea and heavy rains in the GDR, Poland, Czechoslovakia and Hungary.

In the first half of October storm and hurricane winds hit the east coast of India. A hurricane caused great damage in the state of Orissa. Around 600 people died at sea and on the coast. Almost one million people were without shelter. In Cuttack alone 700,000 people were rendered homeless. A large number of cattle perished.

In the middle of the month reports of cyclones, rain and floods in different continents were received. In Guinea, floods affected nine administrative regions and this flood was considered to be the biggest of the last 100 years. On the American continent floods caused the greatest loss in Buenos Aires. On October 12–13, the Primorye territory was hit by a cyclone with an unusual downpour. Many of the streets of Vladivostok looked like mountain torrents. This region had not seen such rain in the last

*Now Bangladesh—Translator.

50 years. There was heavy rain in many parts of England. It caused floods in Wales. Hurricane winds caused large-scale destruction in Denmark, Sweden and West Germany.

Hurricane activity was violent over the North Sea and the Baltic Sea. In the Kaliningrad area the hurricane wind (up to 30–35 m/sec) uprooted big trees, damaged fishing boats and carried away light structures. There were similar strong winds in the northwestern regions of the RSFSR, BSSR and Pre-Baltic republics. On the eastern shore of the Baltic Sea gusty winds attained a speed of 40–50 m/sec (Klaipeda, Liepaya).

The cyclone raised the level of the water in the Baltic Sea as well as in the Gulf of Finland. This water reached the mouth of the Neva River and on October 18 Leningrad was flooded (p. 77–79).

On October 22 a hurricane force cyclone struck Burma and East Pakistan. The speed of the wind reached 150 kmph. In the Burmese city of Akyab 60% of the houses were destroyed. The hurricane caused maximum damage in the city of Rathedaungu, where 90% of the houses collapsed. The same hurricane caused havoc in Ceylon* as well. Around 50,000 people were without shelter.

On October 27 the powerful typhoon Diana struck Japan. Dozens of people died due to the storm and floods. Twenty thousand houses and large areas of agricultural land were under water.

At the beginning of November storm winds with heavy rain and thunderstorms struck the Mediterranean and the coast of Africa. In the middle of the month unprecedented rain fell in arid Kuwait. The water washed away roads, disrupting lines of communications. The nomads of the desert suffered badly.

By the 20th of the month (November), strong winds, thunderstorms and heavy rain had affected the central part of Tunisia. Heavy showers caused floods in Europe and America. Twenty-six people died and thousands of families were made homeless due to floods in Columbia.

On the night of November 25–26 a cyclone with a heavy downpour caused heavy floods in Lisbon. According to an unconfirmed figure, 367 people died.

The level of water in the rivers in Java went up alarmingly. The dam around the city Bombong was damaged and more than 100 people died.

It is noteworthy that in November, 1967, cyclonic activity was unusually intense over all the seas surrounding northern Europe as well as the western sector of the Arctic. Twenty-six stormy days, against the normal seven, were recorded in the Norwegian Sea (*Meteorol i Gidrol.*, 1968, No. 1).

There were many natural calamities in the winter of 1967–68.

At the beginning of December a heavy downpour caused floods in the eastern part of Algeria. Roads were washed away, disrupting traffic, and

*Now Sri Lanka—Translator.

20,000 people lost their homes.

A hurricane struck the coast of Venezuela on December 6–7, damaging the port La Guaira. The loss due to the hurricane was more than ten million bolivars (more than three million dollars).

Heavy snowstorms struck various parts of Europe in the first 10 days of the month (December). Traffic stopped on the Adriatic coastal route of Yugoslavia and also in some parts of England. In December cyclonic activity was intense in both hemispheres. Even in Antarctica—normally a region of anticyclones—a well-developed cyclone was observed on the night of December 19. It was photographed by the satellite Cosmos-184. The same satellite recorded a powerful cyclone in Antarctica on January 3, 1968.

On December 20, a snowstorm struck the Indian reserve in northeastern Arizona. Many tribal settlements were cut off from the outside world. An epidemic started in the area. Food was in short supply. Many were frostbitten. According to the leader of the tribes, tens of thousands of Indians suffered.

In Mexico, due to a cyclone with heavy rain an area of hundreds of square kilometers was inundated in the state of Sonara. Roads, bridges and a large number of buildings were damaged. Many lost their lives or were made homeless.

The hurricane struck Veracruz, damaging the roofs of buildings and uprooting trees and telegraph poles. About 50 fishing boats did not return from the sea. The wind attained a speed of 66 m/sec.

At the end of December snowstorms and cold wave affected Turkey and Iran, damaging gardens and vegetation on the shores of the Gulf of Persia.

January, 1968, was quite cold and stormy. On New Year's day a violent storm was seen over the Black and Azov seas. For a few days blizzards raged over south Sakhalin. Accumulations of snow on hills precipitated avalanches and had to be cleared by snowplows.

On January 7, Ankara was hit by a snowstorm with a thunderstorm. This was the first thunderstorm in Ankara in January in 40 years.

On January 8, the Cosmos-184 showed several strong cyclones. One of them passed over the Adiatric Sea in southeastern Europe. It struck the Ukraine with heavy snowfall. A very strong cyclone with winds of hurricane force crossed the North Atlantic. A still stronger cyclone was observed over the north Pacific Ocean. Several strong cyclones were recorded in the southern hemisphere.

On January 7–8, gales with heavy downpour raged over many parts of France. The storm brought down the newly built rail station at the Olympic village near Grenoble. It shook like the curtains in a house. Quickly a new rail station had to be built for the opening of the Tenth Winter Olympics.

During this period the level of the water in the Seine at Paris rose by 3.5 m. Parts of the bank were inundated. The Paris newspapers reported that the water had "reached up to the ankles of the statues", i.e. up to the base of the sculptures of Almee on the bridge. This is vivid reporting of a flood. In one of the suburbs of Paris the wind toppled a big lift crane and swept away the roofs of many houses.

A violent snowstorm struck Switzerland. In many places road and rail communications were disrupted. The St. Bernard pass was covered with 3 m deep snow. In western and southern Switzerland the speed of the wind was 100–111 kmph.

In Basel the elephant Jumbo from the local zoo was employed for the removal of snow. It energetically transported snow on its sledge.

On January 9 the people of London did not hear the traditional chimes of Big Ben. The gigantic clapper in the bell tower of Westminster Palace was covered with snow and so Big Ben stopped. The correspondent of *Izvestiya,* M. Sturua, reported that the snowstorm paralyzed the transport system in many parts of England. According to the Automobile Association of Great Britain, 100,000 miles of highway were out of commission and only one-fifth of the railroads was operational. Almost all the airports were closed. Industry suffered badly as the workers could not report for duty. In London the stock exchange was closed and the post office stopped mail deliveries.

Snowstorms swept many parts of European territory—Sweden, GDR, FRG, Denmark, etc.—from January 11. The wind speed over the Baltic Sea was 11 units. In Denmark, GDR and FRG the railroads and highways were under 1 m deep snow. Vehicles could not ply in the streets of Copenhagen. Air traffic between different regions was disrupted.

In the GDR the snow accumulation 4–5 m deep could not be removed with the usual snowplows and tanks were deployed. For snow clearing thousands of army volunteers were employed. Soldiers cleared the snow in Czechoslovakia and Bulgaria. In Czechoslovakia even airplanes were mobilized. It was necessary to clear not only snowdrifts but also icebergs in the river. In Tatra an avalanche buried a big group of students. It was reported from the GDR that a tank had to be used to reach a maternity home as no other form of transport could negotiate the snowed-up highway.

On January 13 the satellites Cosmos-144 and Cosmos-184 detected a powerful cyclone in the South Atlantic. It moved east at a speed of 1,100–1,200 km per day and approached the marine and aviation routes linking South America with the eastern hemisphere. The World Meteorological Center in Moscow radioed urgent storm signals to the countries concerned. Over the USSR Cosmos-144 located a cyclone over the central and lower Volga. It gave rise to strong winds and snow.

Throughout one week a cyclone moving in from the Mediterranean and Black Seas swept the southern half of the European territory of the USSR. Hurricane winds with snow penetrated the Ukraine, central and eastern regions. In Volgograd the speed of the wind reached 145 kmph.

During this period the northern half of the European territory of the USSR was very cold, at places 20° below normal. Even in Moldavia and southern Ukraine the temperature dropped to −22° to −24°.

The average monthly temperature in Leningrad was −18.1°, 10.6° below normal. There was record cold in January. In the last 100 years only the January of 1942 was colder, when the temperature was 0.6° lower. In the last 200 years January temperatures lower than that of 1968 were recorded in Leningrad on only four occasions—1783 (−18.8°), 1809 (−18.6°), 1814 (−21.4°—the coldest) and 1942 (−18.7°). A very big negative anomaly of temperature was recorded over the entire northern half of the European territory of the USSR.

From the middle of January to the end of the month hurricanes and snowstorms continued in many countries and affected not only Europe but also Turkey, the Arabian peninsula and North Africa.

A correspondent reported from Ankara that in all corners of the country snowstorms had disrupted all forms of transport. The cities were hard hit by the unusual winter and could not cope with the snow. In Istanbul snowplows were not available for clearance. Besides the snow cover, ice was responsible for many accidents.

Turkey was struck by a hurricane force cyclone with a wind speed of 150 kmph in the middle of the month. It destroyed bridges and roofs and uprooted trees and telegraph poles.

An unprecedented snowstorm occurred over the Mediterranean Sea. In Cyprus snowfall occurred for the first time in 17 years. At Moft (not far from Nicosia) the hurricane wind carried away the big top of a circus and there was panic among the spectators. In Syria and Lebanon traffic was disrupted on mountain roads due to snow. The lighthouse of the Syrian port Latakiya was destroyed by the hurricane wind and many Turkish craft including fishing boats capsized. At Beirut the wind caused two-meter-high waves, destroying some of the piers and other waterfront structures. The port and airport were closed.

There was snowfall in eastern Algeria and the route to the city Suk-Ahras was covered with snow. Snow blizzards even struck the northern part of the Sahara for a few days. On January 22, in the small Algerian settlement of Ain Skruna, Soviet agronomists and 200 technicians were trapped by the snowstorm. Two-meter deep snow accumulated in a few hours.

Heavy snowfall and violent snowstorms struck Jordan in the middle of the month. The loss was quite heavy in a camp city of refugees from the occupied territory of Israel.

A powerful cyclone with dust storm struck the Arabian peninsula via Iran and Ashkhabad on January 16–17. The hurricane whirlwind, similar to a tornado, was accompanied by thick clouds of yellow dust. The dust covered the city in a 5 cm thick layer. The government set up a commission to handle the hurricane damage. Next day Ashkhabad functioned on a war footing, cleaning the city, repairing the water supply, erecting new electric poles and repairing the roofs of houses.

On January 19 the tropical hurricane Georgette lashed the north coast of Mozambique. It damaged large areas under cultivation, uprooted thousands of trees and capsized dozens of small vessels. There was loss of life as well.

The snow continued until the end of January and the beginning of February in Turkey, Iran and Syria. Traffic on many roads, especially the highways connecting Ankara and Istanbul, Damascus and Beirut, was repeatedly disrupted by snowstorms and snowdrifts.

In concluding this incomplete review of the catastrophic phenomena of the autumn-winter season of 1967–68, it may be stated that many regions of the northern hemisphere suffered from the worst snowstorms and cold in 50–100 years, and the southern hemisphere experienced anomalous summer weather.

A report from Canberra said old people could not remember such a long summer. Rivers dried up and pastures were parched. Forest fires broke out from one end of the country to the other. The reserves of water in the big cities were greatly reduced. Life in Melbourne and Canberra was particularly threatened. Much of Australia faced drought and wheat production fell by 41% as compared to the previous year.

An exceptional summer, often with tropical rains was also experienced by Brazil*.

HURRICANE WAVES

Hurricane waves are startling phenomena and frequently occur when a hurricane crosses a coastline and strikes land. A wave of low force begins but over the water it attains unusually high pressure, literally pressing the water out. Very long waves are formed, moving at great speed either ahead of or at the edge of the hurricane. The frontal waves always travel with the hurricane and are generally accompanied by very strong winds, downpour and thunderstorms. The waves at the border travel sideways from the hurricane and often strike the shore with the full force. In Japan this is known as "unyere". It is something similiar to hurricanes (Okuta Minoru, 1963, p. 183).

Huge waves are formed in the open sea (Fig. 33). According to V. V. Shuleikin (1960) hurricanes with a speed of 60 m/sec form waves 12.5–13 m in height and 230 m in length.

As such colossal waves approach the shore the level of the water rises slowly and continuously. At a particular instant the water level rises high enough to topple the wave and the water rushes ashore. This sudden spurt is caused by the waves at the center of the hurricane, attaining great heights (Ponyavin, 1965, pp. 19–21).

The size of the hurricane waves varies from a few tens of centimeters to

*The note on the activities of storms in the autumn-winter season of 1967–68 was contributed by L. A. Vitel's.

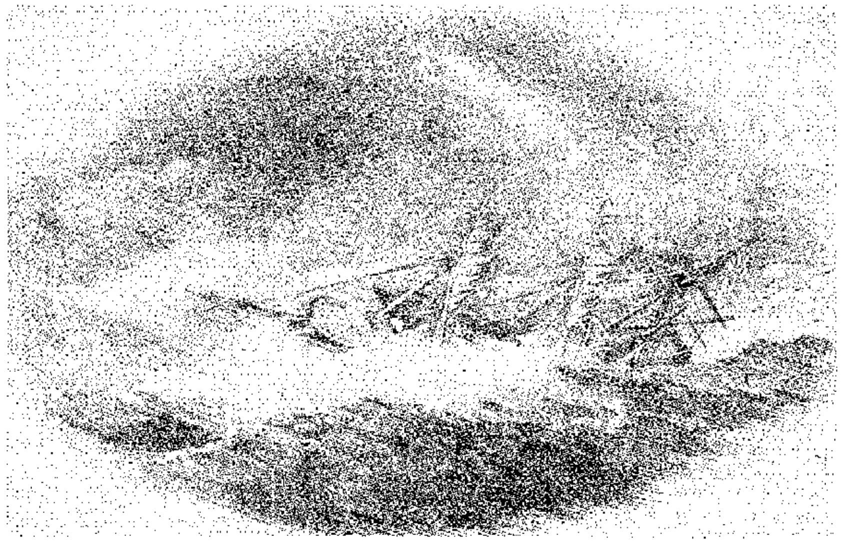


Fig. 33. Waves accompanying hurricane attain height of 12–13 m. Wind flattens crests of waves (Reid, 1850, p. 292).

12–14 m. It depends on the strength of the hurricane and the particular sector of the hurricane (the center or the periphery) striking the shore. The topography is very important.

The Bay of Bengal

In the Bay of Bengal hurricane waves attain enormous dimensions, especially when they coincide with tidal waves. In such cases the height of the waves reaches 11 m or more. The height of a four-storied building is 12 m. The sight of a wall of water of this height, seething and turbulent, strikes terror (Fig. 34). Few who see it will survive. A record loss of human life of 30,000 was caused by the hurricane of October 7, 1737, in the Gangetic delta (River Hooghly). The storm waves rose to a height of 12 m in the Bay of Bengal. About 20,000 vessels of different types were lost. The hurricane of May 21, 1833, killed 50,000 people. The Calcutta hurricane of October 5, 1864, carried away 50,000 people and drowned 100,000 head of cattle. The height of the waves reached 12 m (Fig. 35). During the Bakhergunj hurricane of October 31, 1876, a wall of water inundated the land up to the south of Calcutta and all the islands and low-lying areas were under 3 to 9 m of water. More than 100,000 people died and 150,000 people died of hunger and epidemics after the flood.

The hurricane of September 21, 1885, brought stormy waves 7 m high and rolled up the shore in the form of a continuous water front of irresistible force, carrying away structures, cattle and people.

In 1891 a small-size hurricane 80–100 km in diameter, but powerful

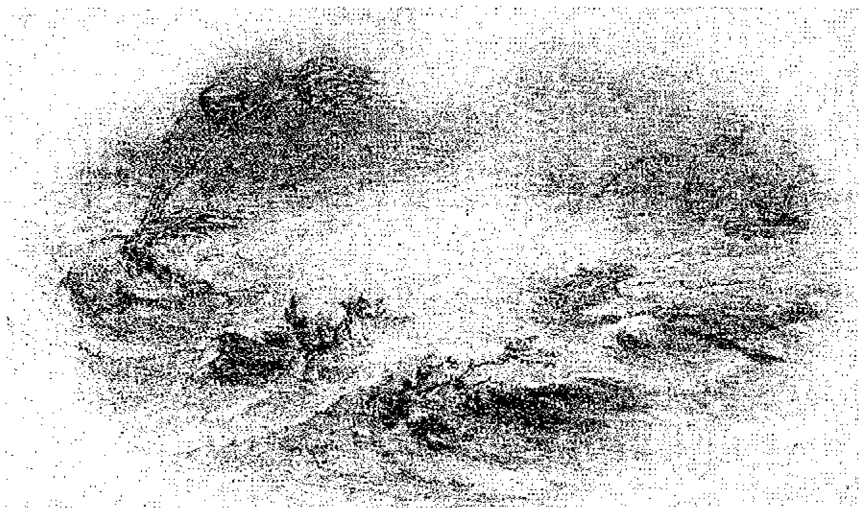


Fig. 34. Tidal waves in Bay of Bengal during hurricane of 1833. Only tops of trees can be seen. Tens of thousands of people died (Reid, 1850, p. 292).

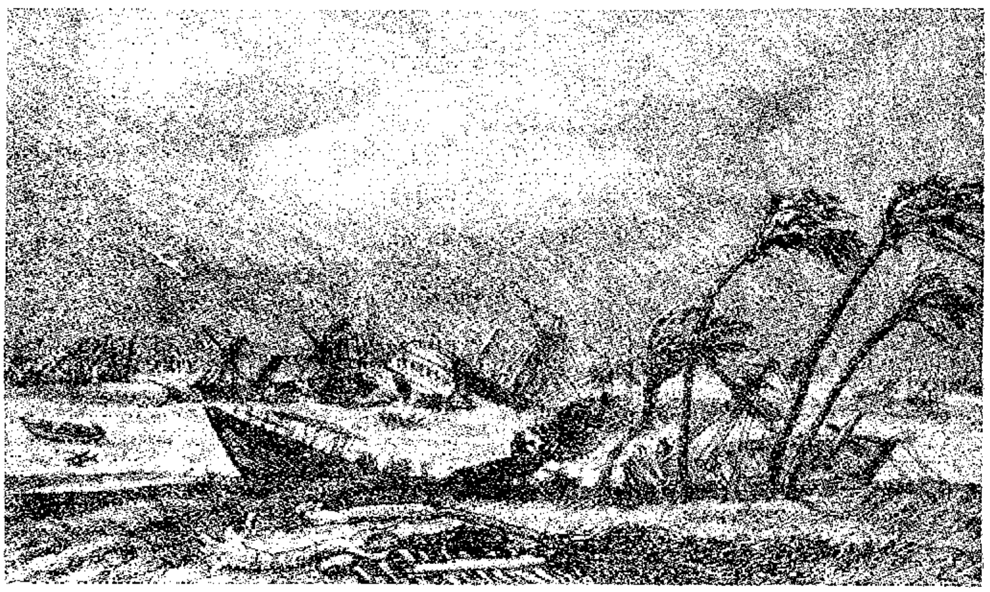


Fig. 35. Hurricane in Calcutta, 1864 (Zurcher and Margolle, 1883, Fig. 39).

enough, developed in the Gulf of Thailand, crossed the Malaysian peninsula and produced a great surge in the Bay of Bengal. It retained its strength for seven days. The enormous tidal waves associated with it killed a large number of people.

The next hurricane lashed Chittagong on October 31, 1897, and killed 1,000 people, mostly women and children.

Thereafter, there is a break in the records and data on severe hurricanes are missing. The last catastrophic hurricane occurred at the end of 1960 and beginning of 1961. It has been described by Dunn (1962). He states that four big and numerous small islands are situated in the upper part of the Bay of Bengal. These are all low-lying areas and very fertile. About one million people live here. The islands are without telephone or electricity and highways are practically absent. The shores of the bay are also low-lying and densely populated. Conditions are highly favorable for the formation of very high storm waves with frightful consequences.

The first two hurricanes struck on October 10 and 31, 1960. The population was unprepared and about 15,000 people drowned. The last two hurricanes of May 9 and 30, 1961, were weaker, the inhabitants were warned either 24 or 36 hours ahead and so a smaller number of people died (about 450 people in the first case).

The hurricane of October 10, 1960, passed over Bhola, Hatiya and Ramgati islands, not far from the city of Maji. The wall of water over the last was 3–4.5 m high. At this height it struck the shore but the water did not enter the city. The island of Ramgati suffered extensively. Though there was no individual wave, the level of water rose quickly by 4.5–6 m and carried away 2,764 people. The speed of the hurricane was 160 kmph. The island of Hatiya was completely submerged by 3.5–4 m high waves. About 3,450 people died.

The hurricane of October 31, 1960 was still stronger. It had a speed of 180 kmph and Hatiya was again hit hard: 1,377 people died. The center of the hurricane crossed the coast to the north of Chittagong. The duration of the hurricane was only 3–4 hours. It is interesting that the storm waves hit the coast two hours after the hurricane. The flood was started by individual waves following each other. The highest level of 6.6 m was maintained for 15 minutes. It then dropped to 5 m and continued to fall gradually during the following 6–8 hours.

On May 9, 1961, another hurricane crossed the same point as the hurricane of 1960. The speed was 150 kmph. Thanks to the timely warning only 450 people were killed, mainly due to a gigantic landslide (Tiron, 1964).

The hurricane of May 30, 1961, was strong but of small size. The storm wave in Chittagong was very high—6.3 m, but the loss of life was small thanks to the timely warning.

In 1963 three hurricanes passed over East Pakistan and Western Burma. They caused tremendous loss of life: 10,000 people died and 500,000 were homeless. Nowhere in the world have hurricanes taken such a toll of life (Tiron, 1964).

The hurricanes and storms of the Bay of Bengal are described in the book by Eliot (1900). It covers the entire 19th century but is essentially meant for sailors. Data on the destruction on land are meager. The maps of the tracks of storms and hurricanes are interesting. Almost all of these storms developed in the Bay of Bengal and traveled toward the shore accompanied by hurricane waves, often of very large size. Their number is considerable. The majority of the storms crossed the coast of the Indian subcontinent between Madras and Calcutta. Here the activity of the hurricane waves is considerable and the seacoast undergoes significant changes as a result.

Only a small number of hurricanes hit the coast between Calcutta and Rangoon but the destruction they cause is considerable.

Some of the hurricanes were of large size 500–600 km in diameter, e.g. the Calcutta hurricane of 1864 and the Bakhergunj hurricane of 1876. The destruction and loss of life were enormous. The other hurricanes were of relatively small size with diameters of 60–80 km but the tremendous force of the wind caused huge waves and large-scale destruction, e.g. the Chittagong hurricane of 1897.

The Pacific Ocean

The maximum size of storm waves is attained along the western shore of the Pacific Ocean. A record loss of life (300,000 people) was caused by the typhoon of 1881 on the coast of North Vietnam, in the region of Haifong. The maximum height (14 m) of waves was attained on June 30, 1905, in the Marshall Islands (Visher, 1925, p. 64).

Hurricane waves reach a height of 2–3 m quite often on the coast of China. The nature of the coast decides the order of destruction caused by the waves. The destruction is considerable, especially in low-lying and densely populated areas. For example, in the low-lying delta of the River Han, in the city of Shantou, the hurricane of August 2–3, 1922, was accompanied by a relatively small increase in the water level—2.5 m—but individual waves attained a height of 7.5 m. The water covered the entire delta. The flood was aggravated by a heavy downpour. The wind attained tremendous force: during two hours it reached a speed of 150 kmph. The destruction was enormous and about 60,000 people died (Visher, 1925, p. 155).

In 1910, in the islands of Fiji, a hurricane was accompanied by 10.5 m high waves but the loss of life was small due to the elevated coastline.

In the Hawaian Islands hurricane Dot of 1960 was also accompanied by enormous tidal waves (6–9 m high). The photograph is quite clear and vivid (Stearns, 1960).

The famous hurricane of March 5, 1899 in Australia produced waves 12–13 m in height (Whittingham, 1958). The hurricane started from the east and crossed the northern part of the Great Barrier reef. Its center passed over the harbor of the fleet of Pearl divers, destroyed it and drowned 307 people. The width of the track was 120 km. The vegetation over its entire length was almost completely destroyed.

Sergeant Kenny with four colleagues was camping overnight on a sandy cliff 40 ft (12 m) high 1 km from the shore. The hurricane started in the night. First one tent was blown away and then the others. The party held onto trees, shielding their faces from the rain lashing them like small pebbles. Amid the noise of the wind and the crashing of trees they noticed with awe that waves were coming nearer and nearer to the crest of the cliff. Soon the water swept over the crest. Already half-dead, they hung onto the trees and fortunately for them the water started receding after two hours. Their horses were killed by falling trees in the wood and the party had to walk to the nearest post.

If Sergeant Kenny's estimate that the cliff was 40 ft high is correct, then the height of the waves was quite unusual. At other points of the shore it was around 4 m.

The hurricane waves that struck the shores of the New Hebrides Islands were a few meters in height (Fig. 36).

Fig. 36. Hurricane waves 6 m high moving toward shore of New Hebrides (Rue, 1940, pl. IX).

The hurricane waves and their destructive activity are described by Okuta Minoru (1963), who cites Japanese typhoons only. The typhoons of recent times are dealt with in detail. The most terrible among them was typhoon Isevan (Vera, No. 15) of September 26–27, 1959. The height of the hurricane waves was of the order of 5.2 m; they crossed the 4.8 m high dam near Nagoya and killed 5,500 people (Arakawa, 1960). In all, an area of 350 km^2 was inundated and the sea water remained for a long time over an area of 240 km^2. The highest wave (10 m) was recorded on the coast of Gotsen Iva in August, 1956 (Unoki and Nakano, 1958).

In the Gulf of Osaka, typhoon Muroto (September 21, 1934) gave rise to waves of 4.58 m height, inundated an area of more than 100 km^2 and killed 2,900 people. A number of other typhoons, accompanied by waves 2–3 m in height, killed hundreds and thousands of people (Arakawa and Suda, 1953; Wadati and Hirono, 1955).

The frequency of hurricane waves is quite interesting. It was 5 and 9 in the gulfs of Tokyo and Osaka, respectively, for a period of 50 years (from 1900). In the Gulf of Suruga, not far from Tokyo, the number of waves was 8 over a period of 35 years. The maximum number of waves was in the Gulf of Toyama: 28 gigantic waves over 30 years.

Japanese scientists, considering the enormous size of hurricane waves, named them "Tsunami", analogous to the waves generated at the time of earthquakes. A detailed bibliography on them has been compiled in the work of Wadati and Hirono (1955).

The inundation due to the annual floods caused by hurricane waves is of considerable geological significance. Although the thickness of each deposit is small, the number of deposits over a period of 10,000 years is significant and the thickness attained during this period in some cases may be a few meters to tens of meters.

In the flood zone the continental layers may alternate with marine deposits. Therefore it is possible to have cyclic layers of deposits.

The sea water striking the coast contains marine organisms and in the geological context causes real marine transgression. The area occupied by hurricane transgression is relatively small. The thickness of the deposit is also small and the quantity of fauna also is insignificant. By examining the deposits of hurricane layering contemporary transgression can be diagnosed and erroneous explanation of it as due to tectonic uplift or submergence can be reduced.

The Atlantic Ocean

The tidal waves on the coast of the Gulf of Mexico attain enormous strength. The small town of Indianola, slightly north of the Mexican border, was lashed twice (September 16, 1875, and August 19, 1886) by hurricane waves. The first wave of September, 1875, with a hurricane wind of 100 mph killed 176 people and damaged three-fourths of the town. It was restored, but in August, 1886, it was destroyed once again. Enormous destruction was recorded after the storm. There was not a single undamaged house and whatever remained standing was dangerous for living. Many houses were destroyed and the debris was littered all around the city. Others were lifted up whole and carried away to a great distance. The lowlands of the city were covered with the debris of the houses, fragments of carriages and a large number of animals. Only a few could be salvaged and as all the houses were useless the town was abandoned (Tannehill, 1945, p. 35–36). To this day the town has not been restored.

In the Gulf of Mexico hurricanes exhibit the usual phenomena. The hurricane waves attain small heights of 1 to 3–6 m but cause large-scale destruction. Over the 20 year period from 1900 through 1919 the loss due to these waves was 105,640,000 dollars with a death toll of 7,225 people. The striking force of the waves is enormous because they are accentuated by the hurricane winds. At the lighthouse near the mouth of the Mississippi an iron plate 1.5 m thick was bent by the waves although it was 8 m above sea level (Cline, 1920, p. 140).

The maximum height (3.5–6.0 m) and strength of hurricane waves are attained in the path of the center of the hurricane; on the sides the height is reduced, but over the entire gulf the level is raised by 0.5 to 2.5 m. The height of the water level in the hurricane of September 11–14, 1919, is given along with data in respect of two other hurricanes of 1915 in an interesting map incorporated in the work of an American meteorologist (Cline, 1920).

Some data on the waves accompanying recent hurricanes are given by Pore (1957). In 1938, on the coast of New England, hundreds of people relaxing on the long low-lying beach observed a dangerous, black thunderstorm cloud moving in from the sea. All of a sudden long waves 3–4 m high struck the beach and completely inundated it. The waves flooded the beach and carried away hundreds of people lying on the beach.

Hurricanes Carol and Edna of 1953 were accompanied by 12–13 m high waves. The famous hurricane Audrey of 1957 was responsible for 3.5–4 m high waves. Hurricane Greta of 1956 struck Puerto Rico with 6–9 m high waves.

The European Seas

Hurricane waves are formed more by tropical than extratropical cyclones and do not bring such colossal disaster as in the Bay of Bengal. However, they attain large dimensions and cause large-scale damage, inundating large areas along the seacoast. The main destruction is caused by the storm waves accompanying the hurricanes. They are very long and attain a height of 3–4 m or more. The maximum area is inundated by rivers, whose flow comes to a stop due to wind pressure; at times their course is even reversed.

One of the strongest hurricanes of recent times churned up the North Sea on January 31 and February 1, 1953 (Fig. 37). A natural calamity of huge proportions struck the east coast of England and the coasts of Holland and Belgium. Foreign reports said that it was one of the worst catastrophes in Europe in 100 years. The huge waves struck the east coast of England and the northwest coast of Europe. The entire east coast of England was flooded. Many residential areas were wiped from the face of the earth. Holland was particularly affected. The dams and dikes were damaged. The water burst through the breaches and penetrated 65 km into the country. The depth of the water reached 9 m. Many protective structures on the islands were breached. Many of the big ports, e.g. Rotterdam, were destroyed or badly damaged.

In Belgium the coastal belt between Ostende and the Dutch border was badly affected. The rafts and embankments were damaged and houses were under water. Kurorty, Ostende, Geiste and Knokke were badly damaged.

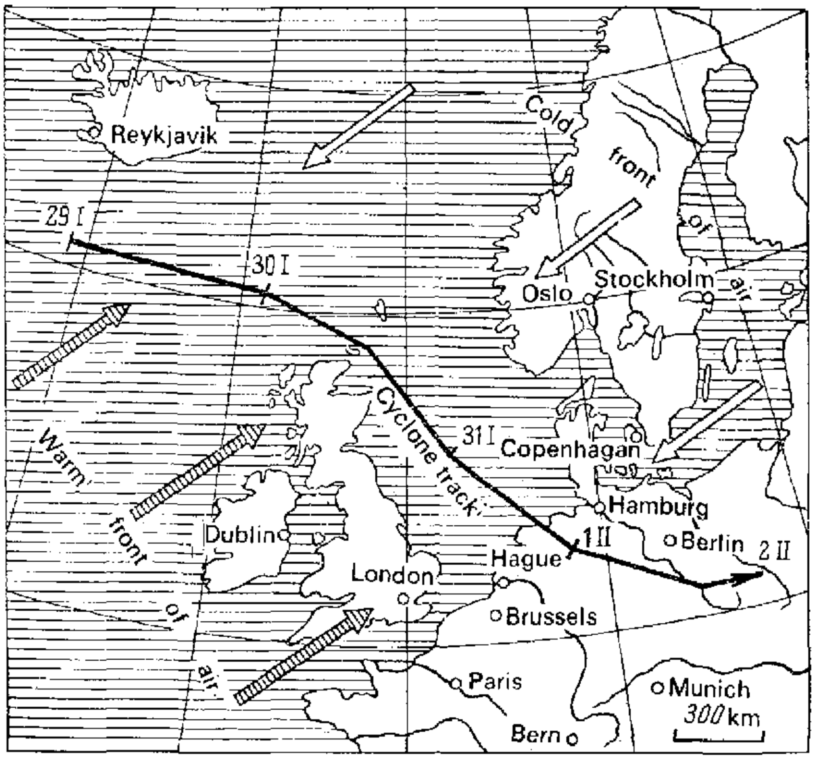


Fig. 37. Track of "Dutch" hurricane of 1953 (Kolobkov, 1957b, p. 167).

About 3,000 people died. Hundreds of thousands of people were homeless. The material loss was incalculable (Kolobkov, 1957, p. 166–167).

The rise in the water level at the coast was 2.7, 3.4, 2.4 and 1.4 m in England, Holland, GDR and Denmark, respectively. On the coast of Holland the hurricane waves reached a height of 10 m and nothing could withstand them. The speed of the wind was 35 m/sec. The hurricane dissipated on February 2 after reaching Berlin.

The quantity of water carried by the hurricane from the North Sea was of the order of 15 billion cubic feet (King, 1959, p. 286).

Tidal waves were generated by the small but deep cyclone passing over the North Sea from northwest to southeast. On January 30 the center of the cyclone with a pressure of 986 mb was situated north of Scotland. Due to its movement the pressure dropped and on January 31 it dropped to 966 mb over the northern part of the sea. The speed of the wind was unusually high (280 kmph) and it caused havoc in Scotland.

Further on the pressure started increasing on the morning of February 1 and when it reached Holland (Fig. 37) it was 979 mb. The storm waves caused such large-scale destruction on the coast of Holland that it was often referred to as the "Dutch hurricane".

The hurricane of 1953 and its destructive activity are described in the works of King (1959), Douglas (1953), Barnes and King (1953), Rossiter (1954), Robinson (1953) and a number of other popular articles. Contemporaries still remember it.

The flood accompanying the hurricane of December 31, 1904, covered a large area along the western Baltic and inundated large areas in Denmark, southern Sweden and north and west Germany. The extent of the floods and the height of the waves are described in detail by Rabot (1905).

Zuss' view, quoted by Rabot, expressed after the disastrous flood of November, 1872, is interesting. Zuss stated that the flooded area was so large and the area under sea water so big that the fossils from the deposit of this flood, with its marine fauna, would give the impression that it was due to marine transgression.

The opinion of so well-known a geologist as Zuss was important, but it did not receive the attention it deserved even after it was cited by Rabot. This is explained by the fact that the meteorologists Zuss and Rabot did not know about the deposits left behind by floods due to hurricanes. Without this knowledge it was difficult for the geologists to locate such deposits in the fossilized forms.

Another serious flood occurred on the coast of West Germany in 1962. In the Hamburg region water penetrated 100 km inland. The water level went up so quickly that many people could not escape and 540 people ultimately drowned.

Exceptionally high storm waves were recorded on the coasts of Germany in 1164, 1334, 1362, 1509, 1570, 1717, 1825 and 1906 (Tiron, 1964, p. 186). The storms over the North Sea were responsible for the origin of the wide Gulf of Zuider-Zee which formed in 1282 due to a breach of the sea wall. The terrible storm of 1825 eroded the sandbar separating Lim-Fiord from the sea, making the northern tip of Jutland into islands and Lim-Fiord a strait. This is a minor example of such significant changes in the distribution of sea and land caused by hurricanes and storms on the shores of the North Sea.

Considerable flooding was caused by hurricanes on the shores of the Barents and White seas. In 1635 the Solovetsky Islands were struck by a storm and the water rose to such a level that the ground floor of the monastery was inundated. Such a high level of water has not been recorded since.

The violent storm of 1808 raised the level of water in the city of Mezeni by 4 m. The floods recurred in 1914 and 1925 although the water level did not rise to such a height.

The storm of June 13–17, 1915, lashed the White Sea for four days. It raised the level of the sea in Archangel, Kandlash and Solombal by 2 m or more. The storm was associated with a cyclone (Sysoeva, 1916).

The hurricane of November 16, 1957, approaching the White Sea attained a speed of 40 m/sec and raised the level of water over Mudyung Island by 2 m.

Neva floods: A typical example of floods associated with a cyclone is the Leningrad flood. It can be said that it is difficult to think of a place more favorable for the occurrence of floods than the delta of the River Neva, where the major part of Leningrad City is situated. The wide, deep river with constant flow debouches into the narrow, long, shallow Gulf of Finland. It is important to note that the Gulf of Finland roughly coincides with the usual path of cyclones from west to east, and the cyclones coming from Scandinavia accentuate the westerly wind.

A rise in the level of the Neva by 1.7–1.8 m inundates Leningrad slightly, i.e. the water inundates basements and low-lying areas. If the level rises by 2.0–2.1 m whole sectors are also inundated. Any rise in level by 2.5–2.6 m causes inundation of parts of the suburbs—Lakhta, Sestroretsk, Strel'na, Petrodvorets and considerable parts of the islands and coast.

Since 1703 there have been more than 50 occasions when the water rose more than 2.0 m. Eight of these were around 2.5 m and four around 3.0 m and more. The last great flood was in 1824 in Pushkin's times, and it formed the theme of his well-known poem "Copper horseman".

But the force of the wind from the gulf
Blocked the way of the Neva,
Went back raging and seething
And inundated the island.
The weather furious;
The Neva swelled and roared;
It boiled and rolled
And suddenly the Beast became enraged
And threw itself on the city.

The rise in the water level in the Neva started with a strong westerly wind on the evening of November 6. On the night of November 7 the wind reached hurricane force. At 10.00 hours the river crossed its banks and inundated the streets. By 12.00 hours two-thirds of the city was inundated and the water was still rising. The strong wind blew away the wooden barges in the River Neva as well as roofs, trees, people and cattle. All the floating bridges were destroyed. The maximum rise (3.75 m) was recorded on November 7 at 14.00 and 15.00 hours. After this the wind abated, the hurricane ceased and the water started receding rapidly. It was possible to move on the streets at 19.00 hours. In all 208 people were drowned.

The flood of September 23, 1924, was the second biggest in intensity in the last 100 years. The water level rose by 3.69 m during a hurricane blowing at a speed of 42 m/sec. All the islands and the coast of the city were inundated. From the window of my flat on 21st street on Vasil'evsky Island I watched a steam tug drifting. The flat was on the second floor and we kept running to the stairs to see how many steps were still left to our floor. When only four steps remained, the water started receding at a fast rate. The hurricane then abated.

The flood of 1777 was the third in intensity; the water level rose by 3.1 m. It was also accompanied by hurricane winds. At midnight the water level rose very fast and a large number of people drowned.

In the fourth flood of October 15, 1955, although the level of water rose by 2.82 m (only 28 cm less than that of 1777), the material loss was relatively smaller than in the previous flood and there was no loss of life at all. Precautionary measures were taken, thanks to the timely forecast.

The flood of 1955 was not as destructive as those of 1777, 1824 and 1924. It was only because the speed of the wind was less and did not attain hurricane force. The maximum recorded speed was 24 m/sec (10 units). R. A. Nezhikhovsky records another significant reason. In his book *The River Neva* (1955, p. 100–103) he mentions that in the early years of Petersburg a rise in the water level by 130–150 cm above normal was considered dangerous. Afterward, thanks to the periodic increase in the height of the embankment and the streets of the city, the "danger level" also rose. At the beginning of the 19th century the danger level was further raised by 150–179 cm and at present a rise in the water level by 180–200 cm inundates only a few low-lying areas (mainly parks and gardens). Such floods are considered minor.

The flood of 1955 is graded as "major" (250–300 cm). An area of 34 km^2 of the city was inundated, but such a flood might have inundated 45 km^2, two hundred years ago.

The last major flood in Leningrad occurred recently—on October 18, 1967. It belongs to the "average" category. The level of water in the Neva was above normal by 233 cm. The low-lying areas, mainly the health resort zones (Sestroretsk, Ol'gino, Repino) were inundated. The flood of 1967 ranks thirteenth in the life of the city.

The flood of October 18, 1967, was associated with a hurricane moving in overnight from England, Denmark and West Germany. In Leningrad the wind was weak: it attained a speed of 23 m/sec.

For a long time it was believed that the floods in Leningrad were due to these winds. Recent studies show that the main cause of the flooding of the River Neva is the long waves originating in the Baltic Sea. A definite role is played by the fluctuation of the water in the high waves.

The waves are rapidly generated when they enter the narrow, shallow part of the Gulf of Finland. Serious floods occur when the long waves are accompanied by a strong wind.

It is well known that before Petersburg was founded the mouth of the Neva regularly flooded. From the historical documents and chronicles we know that catastrophic floods occurred in 1300, 1541 and 1691. In 1300 and 1691 the Swedish forts Landskron and Nienshanns, situated at the mouth of the big River Okhta, suffered badly. It is interesting that after the founding of Petersburg (1824 to 1924), the mouth of the Okhta was not inundated. From this the specialists estimate that the rise in the level of the Neva in 1300 and 1691 was as much as 4.0–4.3 m above the mean level.

Storms are rarely encountered in the Black and Azov seas. On the night of March 12–13, 1914, an unprecedented hurricane broke out over the Azov Sea. The hurricane force wind struck the eastern shore of the Azov Sea and raised the level of the water disastrously. Waves 3 m in height washed away 1,500 fishermen on Achuevsky spit. All of them drowned. On Yasensky spit, near the rail station, the waves washed away 200 workers. Only 50 people were rescued. Many people drowned in Eisk and Temryuk.

Geomorphological and Sedimentation Activity of Hurricane Waves

Hurricanes and hurricane waves destroy structures and kill people. They also change the coastline. Straits change into islands and islands are connected with the mainland. New gulfs and straits are created, new dunes are formed and the old ones are shifted. Often all these changes remain unnoticed by observers. We have already mentioned the big changes in the coastline due to the hurricane of 1938 in New England and the hurricane of 1953 on the shores of the North Sea. Such changes on the shores of the Azov Sea went unnoticed in 1914.

At many places in the eastern USA the outline of the coast and the relief of the coastal belt changed during the dreadful hurricane of 1938. The sandy spit west of Rhode Island was divided into many islands. On Long Island new gulfs were formed and some of the old gulfs were extended. At many places on the coast dunes up to 6 m high were reduced to sea level (Tiron, 1964, p. 74).

Hurricane Audrey of June 27, 1957, struck the shore of the Gulf of Mexico at the western mouth of the River Mississippi (Morgan, Nichols and Wright, 1958). The significant changes that it wrought on the coastline have been described in detail. This study was easier because the coast had been photographed from the air in 1955–1956 in search of oil. Aerial photography was repeated immediately after the hurricane, in July, 1957. The accurate photographs on the scale of 1:20,000 yielded exceptionally important and interesting findings.

Hurricane Audrey was one of the strongest hurricanes in the history of Louisiana. Its "eye", about 50 km wide, crossed the coast at the border of Louisiana and Texas. It packed winds of 170 kmph and brought hurricane waves 4 m high. Before the hurricane at least 75,000 people were evacuated from the coast. But even then the loss of life was more than 500 and the loss of property was of the order of 150–200 million dollars.

The low-lying marshy coast, running over 100 kilometers at 1.0–1.5 m above sea level, was inundated. At many places the flood penetrated 50 km inland. An extensive area was inundated. The work by Morgan, Nichols and Wright (1958) gives a detailed map of the area. The depth of the transgression of the sea is given in isobaths at intervals of 0.6 m (2 ft).

The inundation was almost continuous. Only the tops of individual hills, the coastal dikes and salt massifs (domes) remained above water. Often even these were covered by individual waves rolling in from the advancing sea, reaching a height of 2.5–3.0 meters. The advance of the sea did not last long. The withdrawal began 10 hours after the start and after one-and one-half days the sea returned to the original mark. In individual isolated swamps it took over a month for the sea water to retreat: this was revealed by aerial photography.

Analysis of the aerial photographs taken before and after the hurricane showed that 50% of the entire belt along the coastline retreated; 29% of this belt changed either due to sedimentation or erosion, 19% did not undergo any significant change and 2% of the coastline moved forward due to the deposition caused by accidental obstacles.

Part of the coastline did not change, but the morphology of the coast changed considerably due to sedimentation and erosion. The most characteristic form of sedimentation was mud flats. They occurred on the surface of coastal marshes and on dike banks. Their dimensions varied but the total area covered was considerable. The thickness of the deposition was 0.4–0.6 m. The surface was slushy and gelatinous; after 6 months it had dried to form a network of cracks. But at a depth of 15–20 cm, the deposition was still soft and fluid.

Only a small part of the area was covered by sand and shell deposits from the damaged dikes. Even so, the deposit covered the marshes and formed a marshy deposit of considerable size.

In many cases the erosion and transportation of soil and sand are caused by winds attaining tremendous speed. Aeolian soil, though thin, spreads over a large area. It does not affect the relief and in the work of Morgan et al. it is hardly mentioned. The work describes the number of forms of relief that arise due to erosion during the retreat of hurricane waves. Often they are relatively small, due to the density of the marshy deposits adjoining the coastline.

Approximately one-fifth (19%) of the coast remained unchanged. This was on the edge of the hurricane where the hurricane wave was small and the wind was of insignificant strength.

The work of Morgan et al. deals with many other phenomena of a more specialized nature. The problem of deposition is not dealt with. Nor is the change in the distribution of fauna and flora discussed.

Their data on other hurricanes crossing the coast of Louisiana are interesting. Three weak hurricanes of 1918, 1936 and 1940 literally passed over the same point on the border of Texas and Louisiana as Audrey did. In geological time they occurred at the same time and their activity was also the same.

The results of the action of hurricane waves at Koring, a town on the coast of the Bay of Bengal, deserve attention. In December, 1789, a hurricane started at the time of high tides and the inhabitants noticed with awe three incredibly high waves moving toward the town. The first, destroying everything en-route, inundated the city to a depth of 1–2 m; the second covered the entire city and penetrated deep into the plain; the third inundated everything that remained. The town and 20,000 people were annihilated. All the boats anchored on the shore were driven far into the plains and the sailors drowned. While retreating the waves left behind heaps of sand and aeolian soil. The mouth of the River Yanon became inaccessible to big vessels. Similar waves struck this place in 1839 and the city was abandoned.

For us the indications that storm waves raise and transport considerable amounts of sand and aeolian soil are important. This shows that the strong hurricanes lift and transport large quantities of sand and dust together with microorganisms hundreds of kilometers deep into the continents.

As already mentioned, the terrible hurricane of September 21, 1938, struck the coast of New England. Rhode Island lay first on its path. In the evening about 300 people of the State died when an entire town was destroyed; the borderline of sea and land changed radically. The main part of the town was under 3 m of water.

So great were the topographical changes caused by the hurricane that the authorities announced that the coastal map had lost all meaning (Douglas, 1958).

On the night of September 16, 1959, the southern part of Korea was struck by a typhoon and the associated hurricane waves caused havoc. On Kochzhedo Island all the houses were buried under sand and pebbles. In Miryan district "the terrible typhoon and flood destroyed everything; there was no sign of life anywhere. Everything around was dead. People had no shelter in their ancestral villages. About 119,000 houses were destroyed; 128,000 hectares of land under crops was damaged due to the incursion of salt water" (Tiron, 1964, p. 132).

In September, 1964, the coasts of Florida, Georgia and South Carolina were struck by hurricane Dora. The tidal waves reached a height of 3–3.5 m and in the open sea 6–8 m. It was an average hurricane in terms of intensity, but the coast underwent considerable change. At one point the coast was severely eroded, the coast highway was eroded and the sea encroached into some houses; on the other hand, at other places new sand spits and banks were formed. The sea penetrated deep inland, and the lagoons inundated low-lying areas and river valleys. The sea left behind a deposit containing marine fauna. A minor marine transgression had occurred. The magnitude of the flood varies with different hurricanes and the depositions have not yet been studied, but such deposits can be seen in the sections of transgression.

The erosion potential of the waves in a hurricane is not imaginary. They can erode 10 to 15 m of shore in a few hours. A strong hurricane can erode many kilometers of sand dune 3–6 m in height and 30 m in width in 5–6 hours. In a day a hurricane can destroy a coastline which was there for hundreds of years. The waves severely affected the coastline of North Carolina in hurricane Hazel of 1954. Many settlements on the coast were destroyed. Of 357 buildings on Long Beach only five remained (Dunn and Miller, 1960, p. 221).

It is interesting that even relatively weak hurricanes accompanied by hurricane waves of average size (3 m) cause large-scale destruction and significantly change the coast. "It was March 7, 1962. I was returning from sunny, warm, quiet Italy. But as my plane approached the coast of my native land it encountered very heavy, continuous cloud. To bypass it the altitude of the flight was suddenly reduced. We flew just over the sea and as there was no storm or rain visibility was very good. I started looking out of the window, expecting to see the well-known sandy island, Long Beach and the cottages. Now I can see the coast, but what is this? The houses are surrounded by raging waves; before my very eyes one of them collapsed into a heap of rubble. One very big wave tossed it far back from the shore. Another house was also destroyed but the plane had already crossed the coast and reached the airdrome, not far from Washington. The customs officials told me that the plane had flown over one of the strongest storms in the last 50 years" (Kenney and Stewart, 1962, p. 860).

This information was not strictly correct. The customs official was not a meteorologist and did not know that the storm was weak and that the wind did not cause the destruction. The storm did not rate a name but it was accompanied by tidal waves 3 m high. The waves and the flood accompanying it continued for four days and were the cause of large-scale destruction. It killed 40 people and brought large-scale changes in the coastline and in the relief of the sandy islands.

The observer in the plane was a geographer, a member of the editorial board of the National Geographic Magazine. He along with Stewart wrote an interesting paper with rich illustrations (Kenney and Stewart, 1962).

Many sandy islands running along the coast for hundreds of kilometers were in the low-lying zone and the 3 m high waves and the hurricane wind not only completely inundated the islands, but penetrated the lagoons as well.

The sea water gushed out between the islands with great force, carrying a colossal mass of sand and aeolian soil. The flow was so strong that enormous cavities were formed and at one place a big strait appeared. Figure 38 shows the strait, which is of considerable size. A bridge has already been constructed and automobiles can be seen waiting for clearance; to the left, Atlantic Ocean surf; to the right, an enormous lagoon with marsh and a growth of thicket. In the far distance can be seen the tallest lighthouse in the

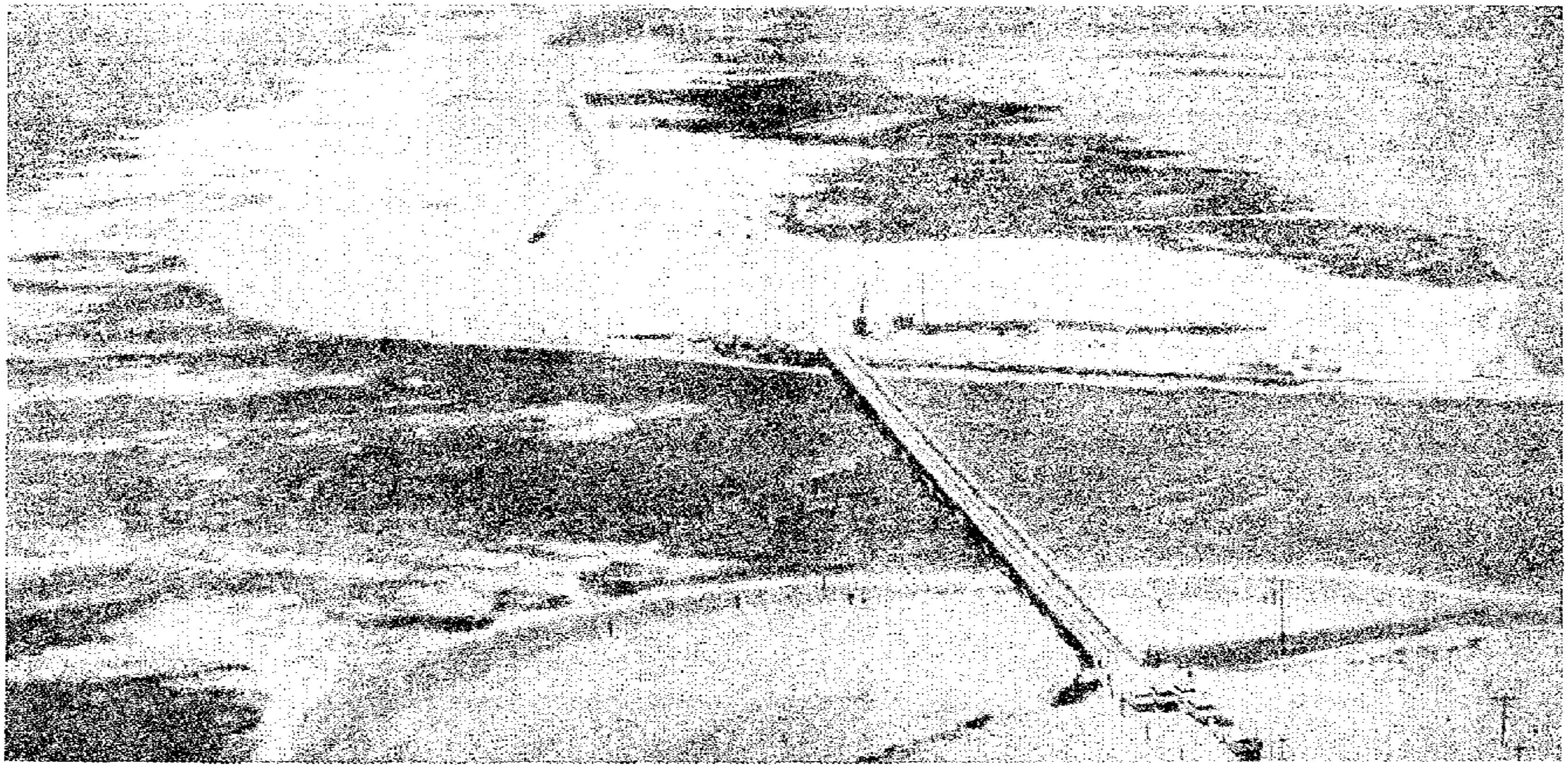


Fig. 38. Aftermath of hurricane and 3 m high waves on coast of USA near Cape Hatteras on March 7, 1962: newly-formed strait. Strait and bridge built over it can be seen (Kenney and Stewart, 1962).

USA, at Cape Hatteras.

The marshy land on the edge of the lagoon had a width of 1 kilometer or more. In a number of areas it was completely covered with sand and soil. Such beaches can easily be seen in the aerial photographs accompanying the paper by Kenney and Stewart (1962).

The outline of the seacoast changed considerably. The coastline moved tens of meters and at places hundreds of meters. The relief of the sea bottom and the shore both changed. The director of the Coastal Geodetic Branch hired 300 specialists to map and publish the changes caused by the storm. Some of them had already started work when the storm entered its fourth day.

While eroding and transporting soil and sand at the bottom of the sea, hurricane waves also transport shells. Kenney shows very little interest in shells but mentions that in many areas the oyster banks disappeared and these areas were covered with sand. On the other hand, there was an exceptional accumulation of bivalves, forming a thick layer at the bottom of the sea and even covering a considerable portion of the shore. Figure 39 shows the mass of bivalves surrounding the rubble on the beach. At the sea bottom they live by burying themselves in the sand and at some distance from one another. Here they lie above sea level on land, crowding each other and with entire shells from other sections. In fossilized form these are called cockle shells by paleontologists. It is interesting that the mass was

Fig. 39. Mass of bivalves on beach due to waves and hurricane of March 7, 1962 (Kenney and Stewart, 1962).

formed not by ordinary surf but by the hurricane waves that cast them up on land.

Bivalves appear after hurricanes at the bottom of the sea. Figure 40 shows a fisherman in a boat collecting bivalves in huge quantities in a special bucket at a point where they were not found previously.

Such redistribution of shells caused by waves is extremely interesting for paleontological reconstruction. It demonstrates the occurrence of hurricane waves and consequently of hurricanes of a past epoch.

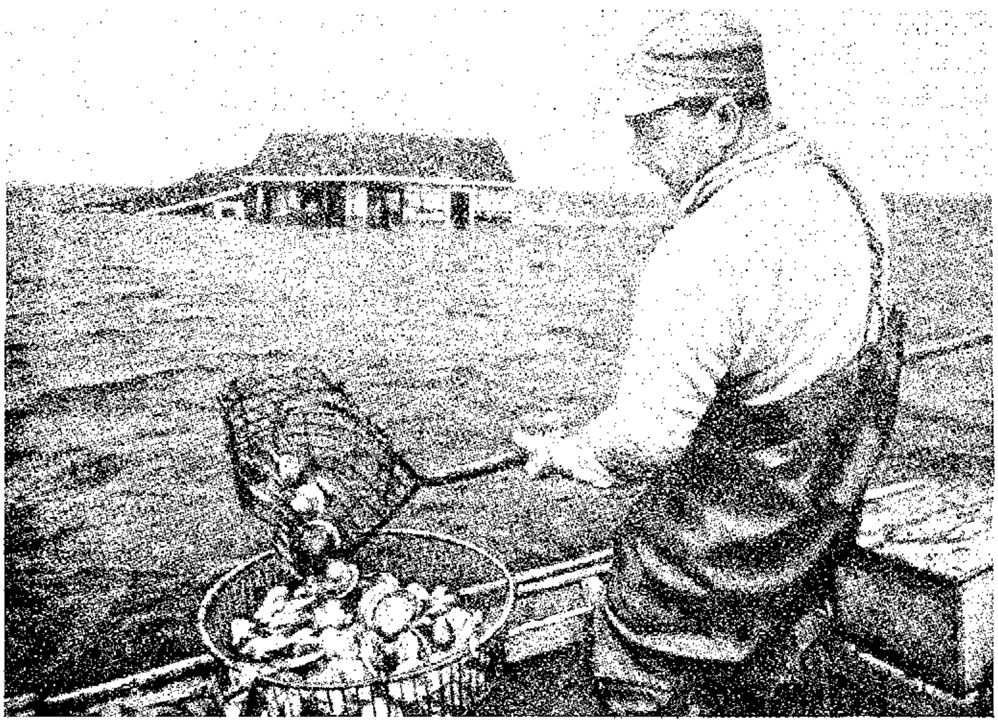


Fig. 40. After hurricane of March 7, 1962: Fisherman collects bivalves transported by hurricane waves in special bucket (Kenney and Stewart, 1962).

In the paper by Kenney (Kenney and Stewart, 1962) the focus is on the destruction of structures, highways, swamps, etc. The photograph of the flood caused by the hurricane wave is interesting (Fig. 41). The flood inundated the island and the houses were surrounded on all sides by water. After a few hours all of them were either destroyed or were under the sea. One house was lying in the sea at a place where bivalves had lived and the bivalves were lying on the shore where the house had stood (Fig. 39).

The photograph of the cottage uprooted, moved and twisted by the tidal waves is very telling. The housewife is trying to save anything she can (Fig. 42). It should be mentioned that after five months the house was still standing where it was and the housewife gave a vivid description of what happened after the hurricane.

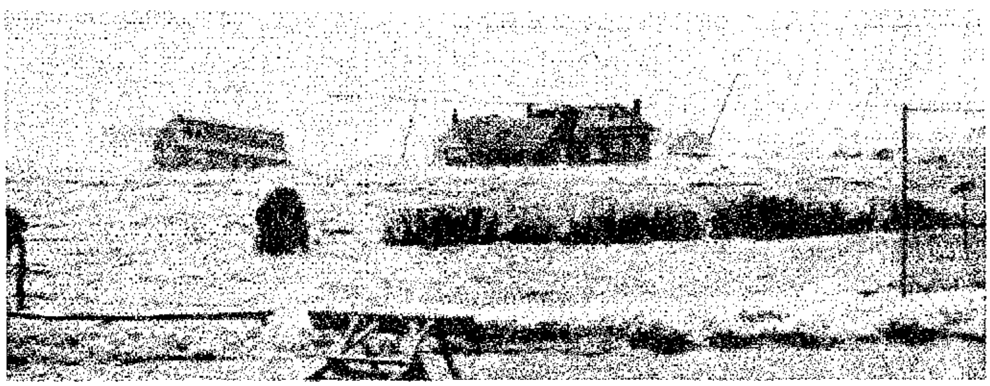


Fig. 41. Flood caused by hurricane waves of March 7, 1962 (Kenney and Stewart, 1962).

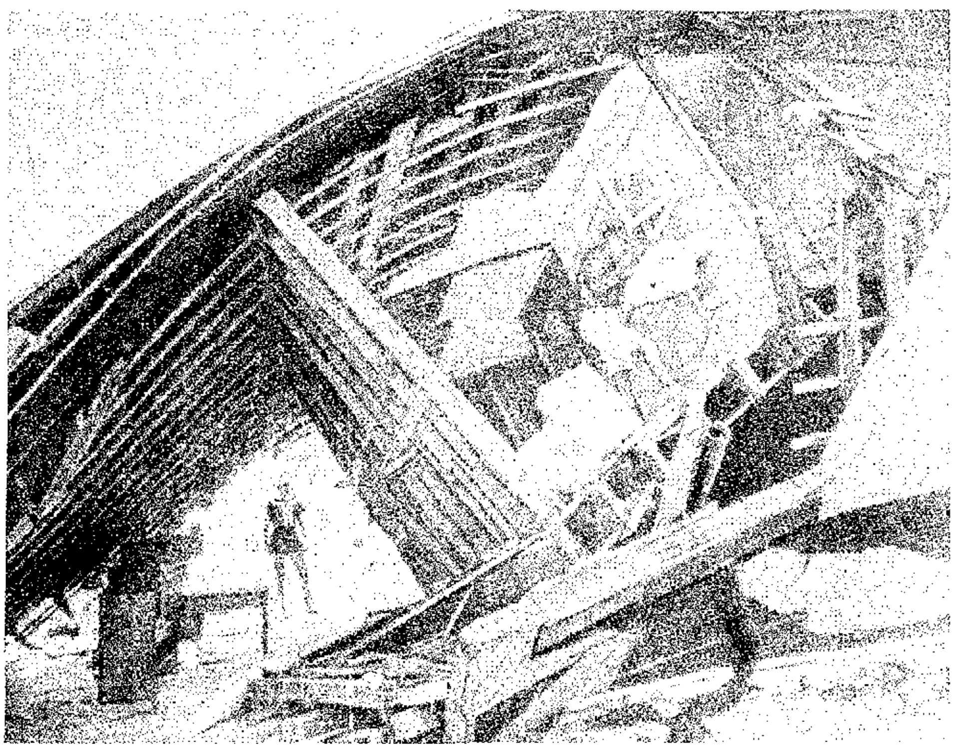


Fig. 42. Coastal cottage after hurricane of March 7, 1962 (Kenney and Stewart, 1962).

The monograph by V. P. Zenkovich (1962) gives a number of examples of reconstruction and destruction of sandy coasts by storm waves. The storm waves in the Baltic Sea attain a height of 1.5–2 m and cause large-scale erosion of the coast. During the storm of September 18–21, 1957, V. P. Zenkovich observed how a sandy shoreline 20 m high, covered to 12 m by old dunes with a thick vegetation of old pine trees, was eroded.

The effect of storm waves on the shore of the Black Sea is no less where its height reaches 3–4 m. The entire abrasive activity of the sea in Odessa is due to storm waves reaching a height of 2 m. In the Gulf of Taganrogsky the waves on the shore show many features of interest. In Anapy, waves 1 m in height change the profile of the beach considerably.

Very severe erosion takes place on the clayey west coast of Kamchatka. One autumn sea storm destroyed a 40 m belt of coast of the Mitogi region.

"Often catastrophic floods occur due to the erosion of low-lying parts of the land, separated from the sea by the coast dunes" (Zenkovich, 1962, p. 139–140).

Additional data on the destructive activity of storm waves on steep rocky coasts are given below in the section "Abrasion".

In his interesting book Douglas (1958) discusses the destructive activity of hurricanes and raises the question of the significance of hurricane dust. Hurricane waves generally surpass the normal height of the surf. They penetrate to a distance which is generally inaccessible to normal waves. So when the hurricane crosses shallow water it lifts a huge quantity of soil which under normal condition is static. The quantity of the soil lifted is so great that the clear, transparent sea water becomes muddy. The soil in the water fills the gills of fish and they are suffocated and die. Douglas (1958) gives a long list of fishes that died during the hurricane.

Fish are tossed ashore by the hurricane waves along with numerous animals buried under the soil. The animals find the new environment difficult for survival.

Hurricane waves most adversely affect denizens of the soil that are slow-moving. Among fishes, the fast-moving ones swim out to the open sea. On land a huge quantity of fish die, littering a large area. In the zone of maximum wind even such big fish as sharks are tossed ashore. This was observed in the coral reefs on the coast of the Florida Islands. The coast was littered with shells and a thousand types of shell fish. The small fishes, crabs and sand worms were destroyed. Even the parasites in the oyster shells were dead but many oyster banks remained undisturbed (Fineg, 1917). It should be added here that during the hurricane of 1938 the coast of New England, including the oyster banks, was hard hit. It was eroded and shifted in the form of an enormous plateau.

Coral reefs are widely distributed along the coasts of Florida, the Bahamas and other islands. Often the alluvium lifted by hurricanes is deposited on the surface in such huge quantities that reef-forming organisms are killed and a layer of clay is deposited on the surface of the reef. When fossilized this will be assumed to be due to the marine regression.

Hurricanes inundate coastal dunes and beaches and penetrate into fresh-water lagoons and lakes. Afterward everywhere a layer of clay with marine microfauna and often macrofauna can be found. After fossilization this situation will certainly be interpreted as due to typical marine transgression.

The recurrence of hurricanes will cause repetition of such "transgression".

Douglas (1958) described how one hurricane penetrated from the sea to the famous Everglades swamp and Lake Okeechobee. A wide belt away from the mangrove swamp was destroyed. A large area on either side was inundated. Everywhere the clayey mass at the bottom of the swamp was covered by a layer of clay with marine fauna.

The penetration of hurricane waves into coastal swamps occurs repeatedly. It is quite possible that often the layer of clay with marine fauna in coastal sediments is not related to the lower region, as is often stated, but to the spread of sea water due to hurricanes.

The propagation and height of hurricane waves in respect of Atlantic hurricanes are discussed in detail in the work of Harris (1963). The area inundated by the sea during strong hurricanes is shown.

Hurricane Karl of 1961 caused large-scale floods. The entire shore of the Gulf of Mexico was inundated by the sea. The width of the inundated zone on the coast of Texas was 60–70 km. The average height of the waves was 3.5 m, though they attained a maximum height of 6.5 m at places. In the mouth of the Mississippi the flooded zone was much higher, even though the height of the waves was much less (1–2 m). The Mississippi delta, lagoons, straits, gulfs, mangroves, etc. were all inundated. The remnants of the vegetation, which was quite dense in this region, had a blanket of alluvial soil and sand with typical marine fauna transported by the hurricane. The length covered by the sea was of the order of many hundred kilometers, greater than many big lakes.

Earlier, in 1957, hurricane Audrey had approached the mouth of the Mississippi and had caused a higher flood in the low-lying areas. Although the height of the waves in this case was slightly greater (2.0–2.5 m) than in hurricane Karl the width of the inundated zone was 40–65 km (Dunn and Miller, 1960, p. 260).

In the geological sections the layers of marine alluvium transported by hurricanes Audrey and Karl will be so insignificant that they will not be taken into account.

Among the hurricanes the strong hurricane Donna of 1960, which inundated the northern coast of the USA, is worth mention. It passed over the coast starting from Florida and ending at New England. The length of the inundated zone was thousands of kilometers and its width 80–100 km. Lagoons, estuaries, swamps and lakes, etc. were inundated.

From the work of Harris (1963) it can be seen that serious floods accompanying hurricanes often recur. The frequency varies from a few years to 20–30 years. On the geological scale this period is insignificant and the thin layers of marine alluvium and sand are also insignificant. The section on the coast of the USA consists of alternate bands of thin layers of continental and marine deposits of different composition.

Coastal floods associated with hurricane waves are not confined to the

USA. They occur wherever tropical hurricanes cross the coastline and such regions are large in number (Fig. 1). Severe floods occur over large parts of the Pacific Ocean rim from the Philippine islands to Japan. The disastrous floods in the Bay of Bengal have already been described.

Even such distant places as England, far from the main path of hurricanes, are affected by hurricane floods. In January, 1607, enormous waves, rolling over one another, hit the shores of the estuary of the River Severn, terrifying observers. Soon they lashed the coast, eroding and destroying everything in their path. The flood moved so fast that in five hours the entire low-lying coast was inundated. Hundreds of people died.

From Bristol to Gloucester the coast was inundated up to 10 km inland. The waves raged around and over the town of Barnstaple. Only the top of the church tower remained above water like a cliff in the sea (Laughton and Heddon, 1927).

This flood also deposited alluvium containing marine microfauna.

Hundreds and thousands of such examples can be cited, but the important point is that such floods, over a long period, are repetitive phenomena.

Destruction of Coral Reefs

One of the important consequences of hurricane waves is the destruction of coral reefs. The destruction assumes large proportions. The reason for this is the structure of such reefs. The top of the reef is constantly subjected to wave action and only very highly stable corals and hydras, having massive skeletons, can survive. Grouped together, these form a continuous dense panel which can withstand normal waves. The thickness of the panel is not very much: 1–2 m. Branches grow downward, causing cavities and holes. The size of the caverns in reefs is considerable, of the order of 6–10 m wide. The panel virtually hangs over it, forming a small cornice.

Normal waves strike the cornice without penetrating the void zones. Their strength is also relatively weak. Hurricane waves are of larger size and move at great speed. The main impact is on the lower part of cornice, on the caverns, the brittle and less stable parts of the reef. Under the tremendous impact of gigantic waves and the immense strength of the wind (Fig. 43), not only individual branches but small parts of the coral structures are also damaged. The panel cracks off in large blocks. The waves and wind pick up these blocks and bring them to the surface of the reef.

On Kaukura Island (Tuamotu archipelago), the hurricane of 1878 struck the island and destroyed all the structures and the houses. The coconut plantations and other trees were uprooted. Earlier, from a distance, the island looked like a green spot. After the hurricane, the island could not be identified from a distance and only a few large blocks more than 10 m in height could be made out from a distance of 15 km. Such strange, enormous blocks on the surface of reefs can be seen on a number of coral islands. Often they are as high as a building (Visher, 1925).

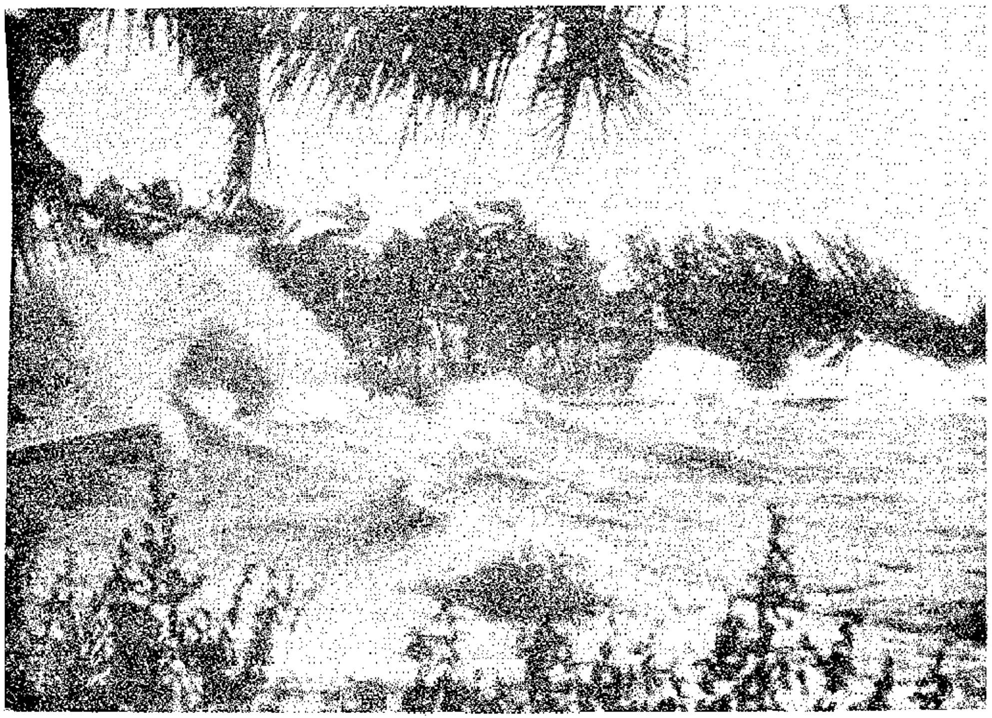


Fig. 43. Gigantic waves during hurricane. Coral reefs of Miami on coast of Florida.

Stoddart (1962a) gives a detailed description of the destruction of coral reefs and islands caused by hurricane Hattie, which crossed the coast of British Honduras on October 30–31, 1961.

The hurricane was very strong. At a distance of 25 km from the center the speed of the wind was 250 kmph and gusts reached 320 kmph. The height of the hurricane waves was 3–4.5 m and some of the islands were completely inundated. The destructive activity diminished rapidly at the periphery, away from the center of the belt; at a distance of 50 km from the center the destructive activity ceased almost completely.

About 80% of the coral reefs disappeared in the center of the path of the hurricane. The surface of the reef was left without life. The entire panel was destroyed and the old surface with cracks and fissures was exposed. Some coral islands with palm plantations were totally eroded. At the edge of the big islands the sand was eroded to a depth of 0.3–0.9 m and the roots of palm trees were exposed. At places patches of new sand and clay zones 1–1.5 m thick were found. The outline of the coast changed considerably. In fossilized form all these changes will be interpreted as changes of land into sea, i.e. as typical transgression.

Stoddart (1962b), in his second paper, describes the destructive activity of hurricane Janet of 1951, also on the coast of British Honduras. The general picture is similar. A large number of islands were lost and new ones appeared at other places. Gaps were formed in the continuous belt of the coastal reef, giving rise to new straits. Big dunes were shifted. The features of the near-shore belt changed considerably.

The observations on the destructive activity of the strong hurricane Betsy of August 27–September 12, 1965, carried out by two geologists well-versed in the deposition process, are important and interesting.

The center of the hurricane passed over the Bahama Islands and caused large-scale destruction on the reefs. The destruction in shallow water and transportation of coarse rock fragments by one hurricane is equal to the changes over many years under normal conditions, i.e. what the hurricane does in one day would have been done only over long periods under normal circumstances.

The destruction was rather severe on the exposed coast. The open reef of Berry Island was exposed to the thrust of the right-hand margin of the hurricane. Massive corals were uprooted and the colonies were disturbed. Large fragments were shifted by not less than 10 m.

On other islands the hurricane waves uprooted and shifted massive colonies of coral up to 1 m in diameter. The projections in the reef were broken to a depth of 3 m. Even in the shielded part of the reefs protruding colonies were everywhere broken, but the massive rounded colonies remained undisturbed.

Aerial photographs of the Bahama reefs were taken two years before the hurricane and again after the hurricane. This helped in mapping the changes due to the hurricane (Easton, 1966).

Another geologist studied the changes caused by hurricane Betsy on the reefs of Florida and offshore islands. The hurricane passed to the right of the region and only its left, rather weak, margin struck the area. The speed of the wind, in any case, was 215–250 kmph but the height of the hurricane waves was only 1–1.5 m.

The geologist anticipated greater changes than actually occurred. But the changes were quite significant. His interest was not only in the reefs but also in the carbonate clay deposits, formed in the shallow water between the reefs and the continent, outside the carbonate bank.

In all the banks situated below the level of the straits and the ebb tide, the erosion and deposition were of "insignificant" magnitude, around 1 cm.

The sections lying above the level of the strait had depositions up to 2.5–5 cm and more at places. The deposition consisted of calcareous clay and fine-grained sands mixed with small or large quantities of thalassia and the residue of vegetation. These deposits occupied an irregular zone 6–30 m wide and 100 m deep. The thickness of the deposit decreased sharply inland and there was a deposit of a thin film of clay over a large zone covered by the hurricane waves. The microrelief of the inundated area greatly influenced the deposition due to hurricanes (Pray, 1966).

It should be noted that a thickness of hurricane deposit of 5–2.5 cm or even 1 cm is not "insignificant", as the hurricanes are a continuing phenomenon and recur often. Over an interval of a few years to tens of years the thickness of the deposit will gradually increase.

It is important that the repeated layers of hurricane deposits inevitably show up as thin layers in the section as a whole.

We are glad to note that soon after Pray's account, Ball, Shinn and Stockman in their paper (1967) described not only the layering in calcareous deposits caused by the hurricane but compared it quite convincingly with the calcareous layers of Permian and Ordovician age (Fig. 44). The photograph shows the recent deposits as alternate bands of thin black layers and relatively thick white layers. The black layers are formed during the calm period and consist of calcareous soil and residues of vegetation transported by the normal wind. During hurricanes the hurricane waves cover the shore and deposit a considerable quantity of white calcareous soil to form the white layer. After a few days, when the waves retreat, the surface of the trans-

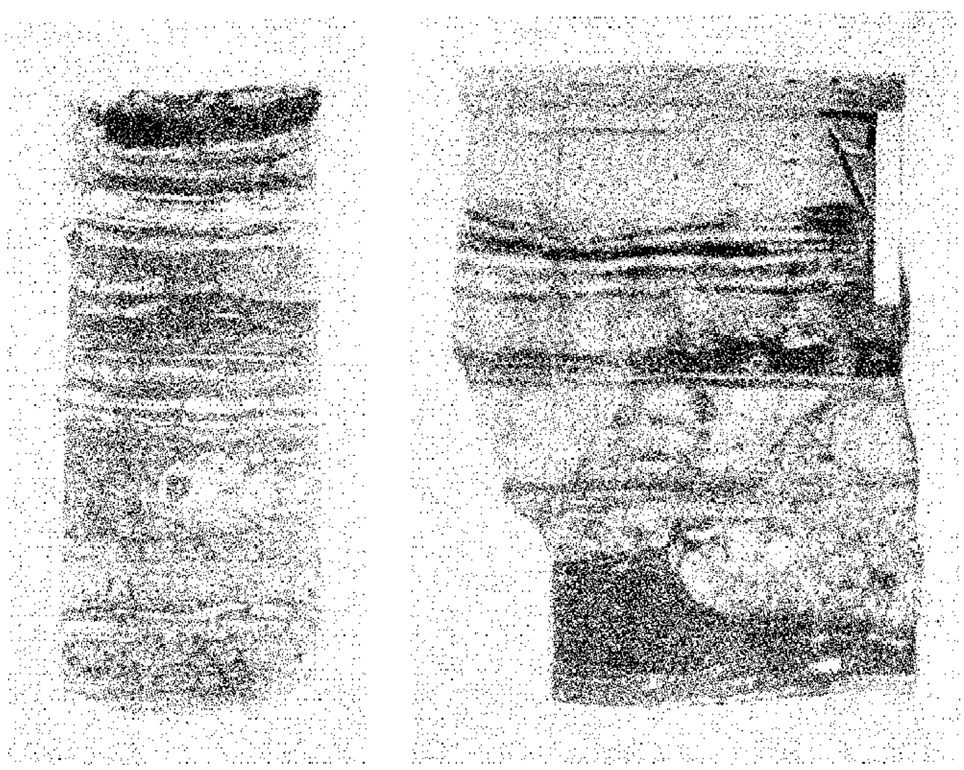


Fig. 44. Layers formed in carbonate sand bank in reef zones (Ball, Shinn and Stockman, 1967).
Left—recent alluvial deposits on coast of Florida; *Right*—Analogous Ordovician limestone.

ported soil layer dries up, shrinks and forms a network of cracks. This is well seen in sections. Calm conditions prevail again and the black layer forms. When hurricane waves again cover the shore a new white layer of calcareous soil is formed, developing cracks on drying.

Repetition of these deposits gives rise to a banded structure. This is due to the recurrence of hurricanes and the calm periods in between.

The material of Ball et al. has been collected from the wide alluvial bank situated between the massive reefs of Florida and the offshore islands and the continental shelf. The activity of hurricane Donna of 1960 helped to promote an objective study.

The paper by Ball et al. is illustrated with numerous interesting photographs.

The relative duration of hurricane deposition is an important consideration. The total thickness of the band is 2.5 m. If it is assumed that one hurricane wave in a day deposits 2.5 cm of silt, then it will take 100 days to form a 2.5 m thick layer. The age of the layer (^{14}C) is 4,000 years. Naturally, he raises the question: if 100 days are sufficient to form the layer, then what happens on the other days? Ball believes that the interval corresponds to a break in deposition (Ball, Shinn and Stockman, 1967, p. 504).

This is not at all correct. The section does not consist of one white layer from hurricanes over the course of 100 days. In addition to it there are thin black layers deposited during calm periods. A considerable time elapses during their formation. Calculations show that for each layer the intermediate period is 10,000 days. This intermediate period is the break conjectured by Ball. Ten thousand days are equal to 30 years, which is the intermediate period between two big hurricanes.

It is interesting that the thick white layers are formed 10,000 times more quickly than the thin black layers. This is valid not only for the recent deposits of Florida but also for the reef limestones of the Ordovician and Permian and many others.

Ball, Shinn and Stockman (1967, p. 592) correctly state that although the catastrophic effects of hurricanes are rare in the life of man, they are frequent and repetitive when considered on the geological scale.

It should also be noted that the layer in reef limestones of the lagoon type caused by hurricanes (Fig. 44) shows a microrhythmic structure. Similar structures in recent and fossilized limestones are explained as due to tectonic causes and seasonal changes. They are actually caused by hurricanes. Geologists should give serious attention to this aspect.

In their work Ball et al. studied a number of other phenomena caused by hurricanes—displacement of calcareous sand, large debris and change in the form of reefs, etc.

Silt debris, even of considerable size, mostly does not change due to hurricanes. Solid reef structures, especially frontal ones, are severely damaged, more than the big debris. The stability of the debris is due to the fact that a special type of marine grass grows over it, making a continuous cover and special packing.

In the fossilized form the silt debris will be dense and extremely fine-grained and may look like limestone. Such limestones are expected at a depth. Some types of limestone, however, may be formed on the surface of the sea with the growth of grass.

Typhoons also cause large-scale destruction of coral reefs in the Pacific and Indian oceans. On January 7, 1958, typhoon Ophelia hit the Marshall Islands. The speed was 225 kmph and the hurricane waves were 4 m high. The leeward side of the Jaluit Atol underwent significant changes forming new straits, capes and spits. Many islands disappeared and new islands were formed at other places. At a number of points coarse debris a few meters thick accumulated in the form of lenses on the surface of the reef. Huge blocks were displaced from the main reef and lifted to the surface. Layers of soil and cultivated ground were completely eroded and transported by the hurricane. Dozens of people died. Where healthy trees with houses and gardens had been there was now barren earth and the massive naked surface of the old reef (Blumenstock, 1958).

Coral reefs are quite large in number in tropical seas and can be found everywhere. Hurricanes blow over these places quite often. Destruction and reef formation are natural phenomena occurring over large areas. There is no doubt that similar destruction occurred in the past, not rarely but often.

Destruction is less in the fossilized reefs. The easiest of all to locate is the irregular lens type accumulation of coarse debris and individual massive blocks on the surface of the reef. Of course, these have been repeatedly observed, but we will briefly explain the tectonic uplift of reefs, their rapid erosion and the time factor in the formation of reefs.

The most important signs of hurricane intervals and coarse debris are the boundaries, local growth, localized distribution and thickness. Longitudinally the path is usually 200–300 km, the length of the lens 100 m, the thickness a few meters and occasionally more.

4
Atmospheric Phenomena

HURRICANE DOWNPOUR AND THUNDERSTORMS

All the phenomena accompanying tropical hurricanes have their characteristic strength and size. While crossing the sea hurricanes suck in enormous amounts of moisture and with condensation the moisture forms thick clouds—the source of catastrophic phenomena, often continuing for several days (Shoner and Molansky, 1956).

There was 116.8 cm of rain over the Philippine Islands during the typhoon of 1911. Rainfall of 75 cm has frequently been recorded.

The downpours, over many days, yield more striking figures. The rainfall over Jamaica during a hurricane lasting four days was 241 cm. In 1913, over Taiwan, the rainfall for three days was 203 cm (Fassig, 1916).

In Missouri, USA, 30 cm rainfall was recorded in an area of 10 sq miles, 20 cm in 100 sq miles, and 10 cm in 4,000 sq miles, all during a period of 42 minutes (Lott, 1954). All these are record figures.

When hurricane Hazel passed over Canada 16 cm rainfall was recorded in a day and this caused devastating floods, killing many people (Knox, 1955).

In Puerto Rico the hurricane of August 8, 1899, accompanied by downpour gave 25 cm of rainfall over the entire island. The total amount of water in the downpour was 2,600 million tons (Fassig, 1916).

On September 4, 1923, 101.1 cm rain fell in a day in Japan in one downpour. This figure is one of the highest in the world.

For comparison, it may be noted that in Paris the total precipitation including snowfall is 52 cm, in London 62 cm, in Chicago 82 cm, in Leningrad 57 cm. It should be remembered that these are annual figures, but half as much as the highest figure for a day mentioned above.

More devastating rain occurred over the island of Reunion and over Taiwan (Paulhus, 1965) in recent times. The island of Reunion is situated in the Indian Ocean, 600 km east of Madagascar. During the hurricane of March, 1952, 184 cm of rainfall fell in a day, and in eight days, from May 11 through 19, the total rainfall was 406 cm. This is a world record.

In Taiwan, during typhoon Gloria, from September 9 through 12, 1963, the total rainfall was 160 cm in two days.

Hundreds of people died during these devastating rains; rivers swelled and damaged thousands of buildings. Gigantic landslides partitioned the river valleys and created new lakes.

Hurricane downpours and floods cause other changes and sedimentation on a very large scale. Among these the appearance of a layer of clay that forms a network of cracks on drying is of interest. During floods these are generally formed in new places. During the exceptional flood of 1950 the streets of Kansas had depositions of clay. When it dried up the deposit formed a typical network of cracks. During the downpour an area of 20,000 sq. miles had an average of 25 cm of rain in 72 hours and at places the figure was 40 cm.

Clay with patchwork cracks is generally explained as due to an epoch of drought. But often they are due to floods caused by the downpour accompanying hurricanes and storms. The layer of clay with patchwork drying is a definite sign that the area was struck by a storm or maybe a hurricane.

Such huge masses of water cause substantial changes in the deposition. Numerous flows develop, carrying coarsely fragmented materials of different sizes to the plains. In sections this will be explained as internally formed breccia and conglomerates.

Away from the mountains rainwater occasionally overflows river banks and inundates large areas, causing large-scale destruction and loss of life.

The sandy clay material formed at such times is of considerable thickness —tens of centimeters or more—and covers large areas. The surface of these layers dries up and contracts when the water recedes, forming the correct layering of continental deposits.

The typhoon floods in Japan have been described by Okuta Minoru (1963). The floods in the USA have been described in the monograph by Hoyt and Langlein (1955).

The worst flood occurred due to rain accompanying hurricane Diana of 1955. The hurricane was of medium intensity but the accompanying rain broke all records. The hurricane penetrated quite deep into the USA and caused large-scale floods everywhere. The destruction was considerable and Diana was called the "first billion-dollar hurricane"—so enormous was the loss it caused (Dunn and Miller, 1960). Ten years later hurricane Betsy traversed Florida and Louisiana. It destroyed many health resorts and settlements, as already mentioned (p. 89-93), and the loss was one-and-one-half times greater (Lane, 1966, p. 27).

Floods spread over a large area and transported an enormous amount of sand and clay. The water saturated with sand and soil traveled at great speed. It could have been correctly termed a mud current and compared with the mud currents at the bottom of the sea.

The geomorphological and sedimentation changes due to floods caused by hurricane waves have been described above. These changes are considerable but the biggest changes are due to the floods caused by hurricane downpours.

The main process is displacement. Erosion takes place on high ground and on slopes, while sedimentation takes place at the base and on the plains. The displacements are of two types—by current and by landslip.

The channel current transports relatively less material and the erosion due to it is small, of the order of a few centimeters, although the area occupied is large. The length is of the order of a few tens or hundreds of kilometers.

The thickness of the layer formed by a rain current, in geological section, is small: it varies from a few centimeters to tens of centimeters. The layers contain large grains as compared to the subsurface and underlying layers but not as large as those due to landslides. It is something like gravel or large-size sand grains. Large-size debris is rare. Such layers are generally known as unconformable layers. The area they cover is enormous.

The thickness of the layer formed by a landslip is generally not less than 1–2 m. Sometimes the thickness is tens and hundreds of meters. It is generally coarse-grained and at times contains clay material. A landslip originates due to large-size boulders.

The depositions due to a hurricane downpour do not contain marine microfauna and exhibit typical continental formations. This is the main difference from the depositions due to hurricane waves.

These depositions are generally found in well-developed hurricane zones and cover large areas. The geologists and geomorphologists have not yet been able to separate the deposits in sections, even in the case of the youngest deposits, which are only tens of thousands of years old.

Thus an indication of a peculiar and interesting, though not necessarily welcome, phenomenon, has been obtained. There is no record of the geological history of all the hurricanes and storms but there is no doubt that they have a history. This is one of the weak areas for geologists to investigate. They dread catastrophic phenomena but are unable to locate them in the evidence of the past.

Hurricane downpours and thunderstorms in extratropical cyclonic regions are characterized by lower wind speeds than in the tropical zone. The heavy downpour is rare and of small magnitude and the thunderstorm is not that intense. But the rainfall is quite significant and floods occur over large areas. All the aspects described above hold good for extratropical hurricanes but to a lesser degree.

The characteristic features of extratropical hurricanes are that they often occur in the winter, accompanied by strong storms and winter thunderstorms. Spring snow during the thaw makes channel currents which are of considerable geomorphological significance.

ATMOSPHERIC ELECTRICITY

The electrical phenomena associated with hurricanes differ widely in intensity, magnitude and character.

Ball lightning is extremely rare but during the hurricane of August 18, 1891, considered one of the strongest-ever in the West Indies islands, continuous flashes of lightning were observed from Martinique Island. "The villagers, who fled from their damaged houses, described numerous instances of ball lightning flashing in the air and bursting noisily 50 cm above the ground" (Tiron, 1964, p. 57).

On Barbados, during the hurricane of 1831, as described above (pages 53–56), the hurricane revived after the center passed over and "the deafening noise of the wind changed to bellowing, to be exact like a distant roar, and the lightning flashes filled the space between the clouds and the earth and continued for half a minute. It appeared that the mass of hot vapors came in contact with the houses and flames erupted from the earth and shot skyward" (Dove, 1869, p. 222).

The maximum strength and frequency of electric discharges are attained in the vortex of the cloud ring surrounding the "eye of the storm". In September, 1947, during the passage of the hurricane over Miami, lightning flashed around the "eye" uninterruptedly and with unusual strength. According to the meteorologists such an event had never before been recorded.

During the famous hurricane of 1935 over Florida, the strongest of all the well-known hurricanes, a huge mass of sand was lifted into the air and transported at inconceivable speed. Due to the friction of the particles with each other "myriads of small electrical discharges occurred, looking like a million glowworms" (Dunn and Miller, 1960, p. 165).

In addition to these unusual phenomena, numerous cases of normal lightning have occurred. As usual, they started fires and caused loss of life.

HURRICANE TORNADOES

In addition to thunderstorms and downpour, hurricanes and typhoons are often accompanied by tornadoes, which can be called hurricane tornadoes. They are not different from the normal ones except for their small size. They move in the direction of the hurricane. The speed of the hurricane determines the speed of movement.

The origin of the hurricane tornado is entirely natural. The hurricane displays a vortex movement and often exhibits a well-formed vortex body, oriented toward the base of the cloud system of the hurricane. The funnel is detached from such a vortex body, often reaching to the surface of the earth.

The existence of a horizontal vortex, usually of circular form, at the base of the hurricane clouds has been established long since. The existence of such a formation in the clouds over a tornado is still debated. The hurricane tornado confirms the existence of such a formation.

For example, a hurricane tornado may have been responsible for the tornadoes that accompanied hurricane Karla of 1961, as described in the work of Sadowski (1961). According to Sadowski, the total number of tornadoes was 16. Most of them, 13 in all, were located in the zone of strong wind and the other three in the zone of weak wind. The tornadoes did not form in the zone of hurricane wind. The tornado nearest to the center of the hurricane was at a distance of 200 km and the farthest at a distance of 450 km. The first tornado originated when the center of the hurricane was over the Gulf of Mexico, at a distance of 200 km from the coast, and the next four when the center approached nearer to the coast. The other 11 tornadoes were formed when the center of the rapidly decaying hurricane passed over Texas. The last of them passed over Oklahoma when Karla changed to an extratropical hurricane. A picture of the tornado was obtained with radar (Fig. 17).

The paper by Smith (1965) describes hurricane tornadoes in great detail. According to him, 98 hurricane tornadoes occurred during the period 1955 through 1961. Their distinguishing feature was that they were half the width and traveled only half as far. The destruction, though considerable, was somewhat less in magnitude.

In 1962 and 1963 hurricane tornadoes did not occur in the USA but in 1964 (Pearson and Sadowski, 1965) there was a rash of them. Four hurricanes were accompanied by 39 tornadoes. Of 94 tornado conditions caused by hurricanes 28 attained the tornado stage. The weakest hurricane, Isabella, had the maximum number of tornadoes.

A summary of earlier hurricane tornadoes in the USA is given in the paper by Malkin and Galway (1953). In the 141 years up to 1952, in all 24 tornadoes were recorded. This shows the lack of attention devoted to this aspect by earlier observers. Often it was mentioned that the hurricane was accompanied by a tornado, but without any data on the latter.

Tornadoes accompany hurricanes not only in the USA. They are no less common in the deserts of Africa, Asia and Australia. They are generally related to haboobs. A fantastic but memorable picture of a hurricane tornado is due to Flammarion (Fig. 58).

The latest summary on hurricane tornadoes in the USA is given by Sadowski (1966). Based on the available material, he concludes that the overwhelming majority of tornadoes form in the right quadrant of the front, in the wind zone of the storm. This information may be used for forecasting tornadoes, if they are considered as heralding the center of the hurricane.

Tornadoes are not formed in the center of hurricanes or in the wind zone. In spite of their small number and localized area of activity, considerable death and destruction are wrought by hurricane tornadoes. Of 46 tornado conditions associated with hurricane Karla only 11 developed into actual tornadoes.

5
Transportation of Organisms

Hurricanes and typhoons, because of their tremendous strength, long track and duration, as well as their enormous span, greatly influence the widely distributed species of plants and animals.

Their role in the distribution of organisms is considerable. Without exaggeration it can be said that wherever hurricanes pass the diatomites cannot serve the purposes of paleogeography. The marine forms mix with the freshwater forms and vice versa, to such an extent that the index condition of existence ceases. The same can be said of spores and pollen. (This is considered in detail on pages 509–511.)

Foraminifera, ostracods and higher-order microorganisms are undoubtedly transported in large quantities and to great distances. But data regarding this are meager.

"In 1967, the ship *Vidal* encountered rain with fresh-water diatomites in the middle of the Atlantic. It was found that a large portion of the dust collected at Barbados came from Africa or the Alps" (Lyman, 1968, p. 17).

The scanty data on the transportation of organisms, though not sufficient, are important and interesting.

The data are mainly related to animals with wings. In a number of hurricanes described by Visher (1925), data on birds and butterflies in the central zone of hurricanes are provided. As soon as a ship enters this zone ("eye of the storm"), birds and butterflies, carried away by the storm, take shelter on it. During one hurricane, hundreds of dragonflies were transported from Borneo to Palm Island, a distance of 1,100 km.

Leaves and branches with animals and plants on them are transported to great distances.

During the floods accompanying hurricanes many treetrunks are transported to the sea, where ultimately the current engulfs them. It has been mentioned above that many warm currents coincide with the main tracks of hurricanes and can be traced for thousands of kilometers. Treetrunks with larvae and eggs on them are transported to such distances.

The paper by Hurd (1917) describes in detail the transportation of insects by hurricanes. At a distance of 2,000 km from the African coast, in the Atlantic Ocean, clouds of locusts fell onto a ship. The insects were normal and alive. In another case large number of insects were dropped on a ship in the middle of the Atlantic Ocean. These two cases, however, are dissimilar. They only show that huge mass of flying insects can be engulfed by hurricanes and storms and can be transported several thousand kilometers.

When insects and birds are transported from the land to the open sea they die. When the transportation is over islands or continents the distance of mass transportation reaches several hundred or even thousand kilometers. These insects and birds will be buried in climatic zones not natural to them. This may give misleading information in the reconstruction of the paleogeographic conditions. The only consolation is that insects and birds are rare in fossilized form and therefore their transportation may hardly interfere with the work of paleogeographers.

So far, only one case of transportation of shells and other matter to a great distance has been noted and this has already been mentioned. The very strong hurricane Hazel (1954) struck the coast of North Carolina and left behind green coconuts, pieces of bamboo, a cup with the engraving "Made in Haiti" and, most important of all, tropical shells weighing 3–3.5 kg. The track of the hurricane showed that after striking Haiti it moved over the sea for a distance of 1,500 km before hitting the coast of the USA (Gentry, 1955b). It is not yet clear how a hurricane can transport such heavy, compact objects a distance of 1,500 km.

It has been stated above that the transportation potential of big hurricanes is extraordinary and can exhibit unusually striking phenomena. From the paleogeographical point of view the transportation of heavy tropical shells a distance of 1,500 km to the north is exceptionally important. The journey took three to four days.

Transportation by hurricane waves has a distinct form of its own and penetrates deep inland. The waves transport different types of fauna and deposit them on the land amid continental deposits. Thus a peculiar combination is obtained: marine fauna around continental deposits. In the fossilized form such a combination will be wrongly referred to as a marine deposit.

During the hurricane of 1927 on the coast of Florida at Miami it was found that the hurricane waves transported fish deep inland. The house of one observer located a few hundred meters from the shore was very near to the sea water. Standing on the porch, he could observe the movement of the waves penetrating far inland. After one wave withdrew he found a big jellyfish in front of his house. His most important observations concerned the numerous fish scattered all over the place covered by the waves. There was a variety of fishes. It is interesting that the wave seldom retained its form when rising to a considerable height. Surf-borne, fast-moving fishes, however, were relatively rare (Schubert, 1927).

The strength of the wind was tremendous. The air was saturated with sea water spray, like a thick fog. The foggy spray moved horizontally over the ground at great speed. Marine microfauna accompanied the spray.

The hurricane of September 21, 1938, caused large-scale changes on the coast of New England. The sediments near the coast were mixed up and the colony of oysters was transported to places where it had not existed earlier. Due to the tremendous speed of the hurricane window panes in Montpelier, Vermont, 220 km from the seacoast, were covered with salt particles from sea water (Tiron, 1964, p. 71), and these contained marine microfauna.

6

Planetary Laws of Propagation

For the last 100 years it has been assumed that cyclones are rare in the equatorial belt and totally absent in the Arctic regions. This is seen in the map prepared by Lumis (Fig. 30) and is repeated in the book by Davis (1899, Fig. 62).

The research of the last 10 years shows that cyclones, though somewhat rare as compared to middle latitudes, do occur in the equatorial belt and in the Arctic regions. This complicates the general rule, although the main theme is confirmed.

The theory has received unexpected support from the study of vortex atmospheric formations—thunderclouds and tornadoes. It appears that these do not propagate in the Arctic regions and weaken in the equatorial belt.

This important and natural phenomenon has a planetary character and depends primarily on the rotation of the earth.

Mitchell (1930) wrote an interesting paper on the propagation of cyclones and anticyclones. According to him anticyclones penetrate into the northern belt but cyclones do not. The path of cyclones spills over the New World, Taimir, the northeastern fringe of Greenland and Alaska. Data on cyclones farther to the north were not available at that time.

Observations of the last 10 years in the Arctic and the Antarctic have revealed a sharp decrease in the frequency of cyclones, at least near the poles, but have shown the occurrence of cyclones at extreme high latitudes (see p. 51).

In short, we find that the Arctic cap and the equatorial belt differ sharply in causing a reduction in cyclonic activity.

This rule is not a casual aspect. Its universal nature suggests that the cause of this phenomenon is planetary and the chief cause is the rotation of the earth.

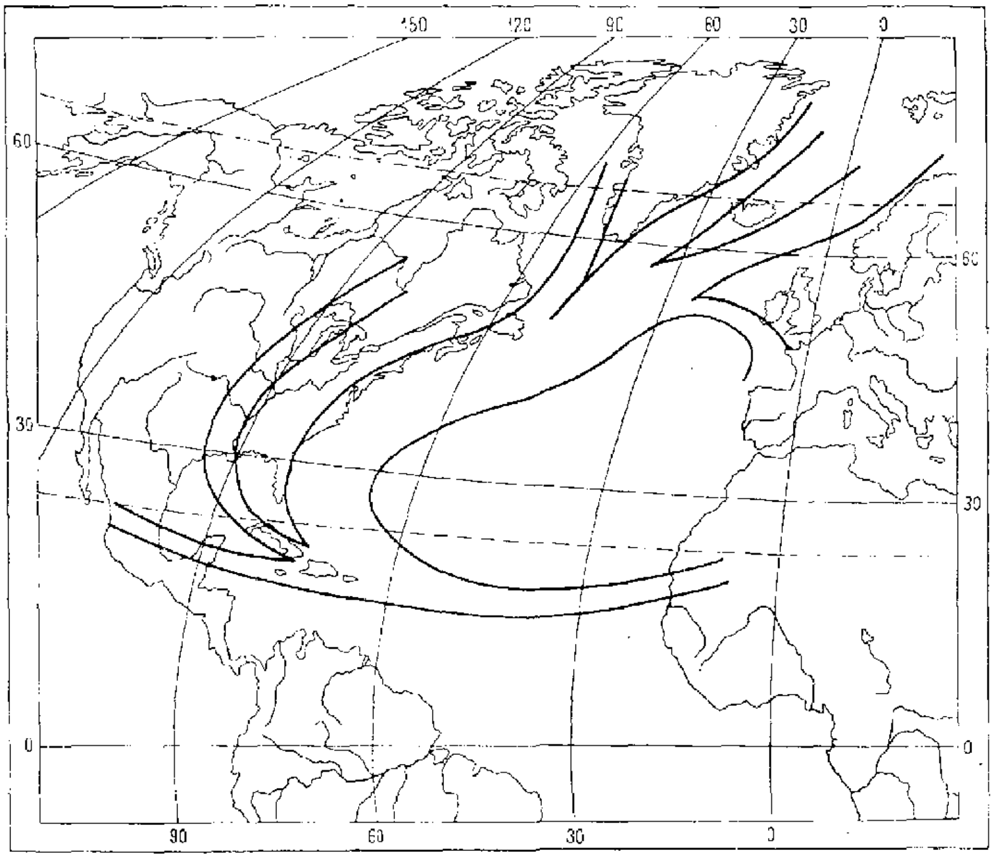


Fig. 45. Atlantic belt of hurricanes.

The second rule is similarly related to the rotation of the earth. This is the observed direction of rotation of the vortex of atmospheric circulation. All these vortices—cyclones, hurricanes, whirlwinds and tornadoes—rotate in one direction: in the northern hemisphere anticlockwise, in the southern clockwise.

The third rule is the restriction of the overwhelming majority of the tracks of hurricanes to a belt of parabolic form, to produce "parabolic hurricanes". Two such belts have been studied in great detail—the Atlantic and the western Pacific.

The Atlantic belt includes hurricanes passing over the northern Atlantic Ocean and striking the Atlantic islands and the United States of America. They cause large-scale destruction and have been studied in detail. Their tracks have been accurately mapped.

As mentioned above, analysis of the tracks of hurricanes shows (Figs. 22, 23) that they are restricted to a particular belt having mainly parabolic form. The southern half of the parabola begins in the western Sahara, passes over the Cape Verde Islands, proceeds across the Atlantic Ocean to the West Indies Islands and ends in Cuba. Within these limits the tracks of hurricanes

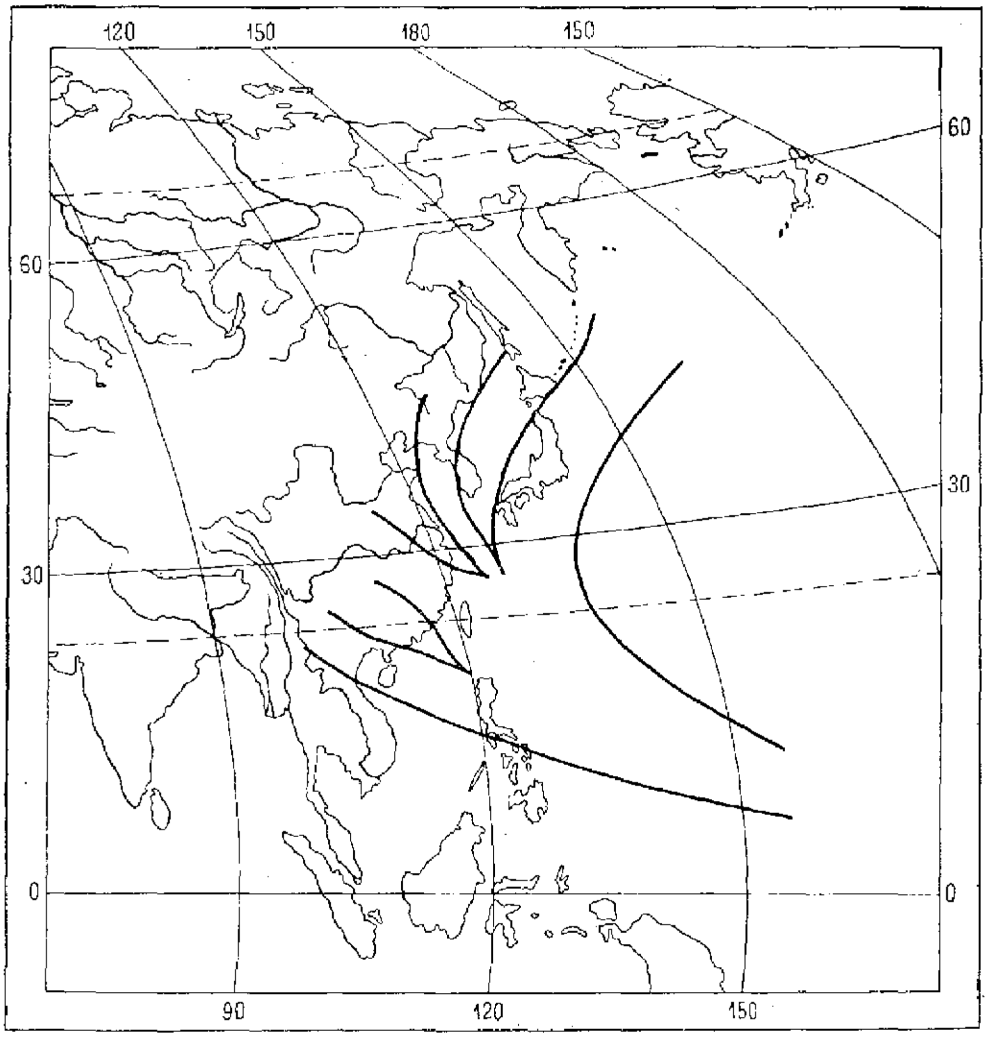


Fig. 46. Pacific Ocean belt of hurricanes.

are close to each other and the lateral spread is relatively small. The northern half of the parabola is fan-shaped, widening to the north (Fig. 45). Here it has several branches. One of these approaches the Greenland coast, the second extends to the northern edge of the Atlantic, the third to the coasts of Norway and Scotland and the fourth to southern England and France.

It is interesting that these branches correspond to the offshoots of the Gulf Stream, and the axis of the northern half of the parabola coincides with the Gulf Stream.

The southern half of the parabola at first coincides with the north trade wind flow and then with the Atlantic flow. In the north it passes over the Gulf Stream. The Antilles track branches into the Caribbean Sea and the Gulf of Mexico and these also correspond to the tracks of hurricanes.

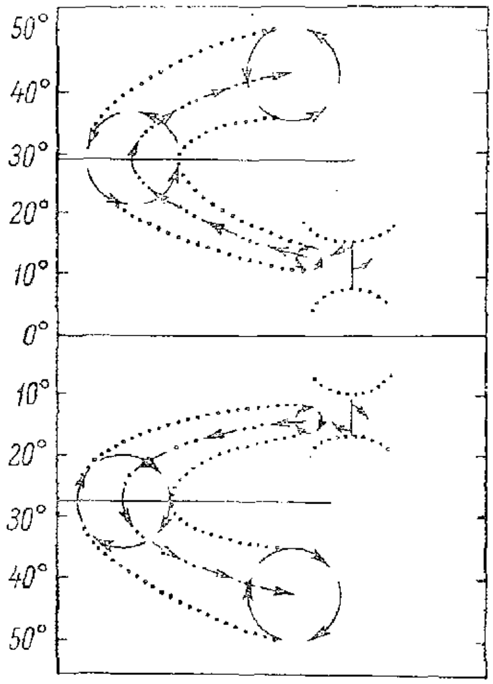


Fig. 47. Tracks of tropical cyclones in northern and southern hemispheres (Zurcher and Margollé, 1883, Fig. 26).

The second parabola, in the western Pacific, also has been studied in detail. The tracks of typhoons are no less numerous than the tracks of Atlantic hurricanes. The western Pacific belt is more distinct and crowded than the northern Atlantic belt. It too, comprises northern and southern halves. A typhoon starts in the southern half and ends in the northern (Fig. 46).

The beginning of the belt is located around the Marshall Islands but here typhoons are few in number. Their number increases in the Caroline Islands. The belt is well-defined and develops fully over the Philippine Islands, progressing over the South China Sea and as far as the Bay of Bengal. A number of typhoons penetrate into China. The northern half of the belt starts around Taiwan and covers Japan and Korea. It deviates to the west, approaches the Kuril-Islands (Fig. 46) and ends over the Pacific Ocean.

The western Pacific belt of hurricanes, like that of the North Atlantic, coincides with the course of the major warm current, including the course of the Kuro-Sivo.

The tracks of hurricanes in the southern hemisphere have not been studied in detail but their concentration in a parabolic belt has been established (Fig. 1). The location of these belts and their shape are the mirror image of those of the northern hemisphere. Here, too, they coincide with the course of the major warm current.

The parabolic form of the tracks of hurricanes and their symmetry with respect to the equator can be explained by the planetary factor—the rotation of the earth (Fig. 47).

Thus it can be said that the rotation of the earth together with the position of the continents and the oceans determines the main tracks of movement of cyclones. At the same time, these factors cause the definite movement of water masses—the currents.

The nature of movements of the air (atmosphere) is well known. That of the movements of the water medium (hydrosphere), though not so well known, is known well enough. But the nature of movement in the solid medium (lithosphere) is not only not fully known, its existence is often overlooked altogether.

The rotation of the earth sets up a large force, moving enormous masses of air. This force moves a considerable amount of water. This force operates on the solid core too.

The magnitude of the force which causes the movement in the atmosphere has been calculated (see the section "Energy of the hurricanes"). It is exceptionally large. It is no less in the hydrosphere and, of course, in the lithosphere. It should cause changes in the solid medium. Ignoring the occurrence of these changes is unrealistic and regrettable.

Thus we conclude the section on hurricanes, the most dangerous phenomenon on the surface of the earth, affecting a large number of human beings and causing large-scale shift of organisms and deposits.

It is to be hoped that geologists and geographers will pay more attention to hurricanes. The most important aspect is the study of hurricanes of the distant past, which are still not very well known.

PART II

STORMS

Storms are of various types and they travel everywhere. They have special names in many parts of the world. These names have been listed in detail in a number of works. Some of the names are given in the monograph by V. Fett (1961) and in the Meteorological Dictionary. In the work of Becker (1948), 220 names are listed in alphabetical order. Some of the names are given in the popular scientific work of L.J. Prokh (1961). Some 30 main types of storm are listed below by name.

No generalized classification of storms is available. Qualitatively they are classified in two different groups: vortex storms and flow storms.

Vortex storms are mostly of complex nature and move over a large area. It is quite likely that movement of air currents also plays a part in their formation, along with the vortical motion. It is necessary to analyze the synoptic conditions over large areas in order to understand their characteristics fully.

Flow storms are local phenomena of limited movement. They are distinct and isolated and identification is not difficult. They can, however, be less intense than vortex storms.

1
Vortex Storms

Vortex storms differ from the regular vortex formations which are often of considerable diameter and have a distinct identity. The speed of the wind in a vortex storm, although considerable, is less than that in hurricanes. The sizes of vortex storms vary widely—from thousands of kilometers to tens of kilometers. Vortex storms, originating over large areas, are generally associated with cyclonic activity. The storms over a small area may be due to local conditions and are intermediate between cyclones and tornadoes.

Tornadoes are similar to some vortex storms in size, but differ distinctly in their sharply limited rotating body.

These comparisons are generally correct but a number of deviations also occur. Some storms occur over large areas and some tornadoes have diffused and ill-defined bodies. These deviations underline the close relationship between hurricanes, vortex storms and tornadoes. They show the occurrence of a number of transitional formations.

A firm classification of vortex storms does not exist at present. Qualitatively they can be divided into: dust storms, dustless storms and squalls.

The dust storm is characterized by the presence of dust in the air; when dust is absent the storm is innocuous and goes unnoticed.

Squalls are a distinct meteorological phenomenon. They can be identified distinctly, but are akin to short-lived dustless storms, differing in their strength and large-scale destruction. They differ from the dust storm in the absence of dust, but if the squall passes over a region covered with dust it picks up dust. It is of short duration and limited strength (Battan, 1961).

On the other hand, squalls are closer to tornadoes, which they resemble in the transitional formations described below in the section on squalls.

The synoptic conditions for the formation of dust, dustless and squall storms are akin, often identical, despite their variety. Their effects are quite different. This allows us to distinguish three varieties of storm.

DUST STORMS

Classification

There is considerable geological significance in a dust storm. Even in 1917 the well-known American scientist Keyes (1917, p. 57) wrote: "A dust or sand storm is as much a transporting agent as any river. In comparison to big rivers it is gigantic in the transportation of deposits. Its width is 300–500 km as compared to the width of 2–3 km of big rivers. It transports at a speed of 60 kmph as against 5–10 kmph. It transports a hundred thousand times more eroded material, a huge quantity of which is from the arid parts of semiarid and humid regions. An enormous quantity of transported products of erosion can be seen in the deposits of loess in large amounts in the black soils of the steppe and in the large areas covered by marls in the periphery of deserts in our country.

"At the bottom of a dust storm, at a height of a few tens of centimeters, coarse sand and road metal move. The fine sand grains fly at the height of a man. Above this moves the dark, dense dust, rising to an altitude of 1.5 km. When the dust storm is seen from the top of a peak, it appears at a distance to be thick, sharply defined by the flux, quickly rushing to the bottom. The air current saturated with dust descends like an enormous flow of water."

This description reflects the activity of dust storms. Under this name numerous storms have been classified in different latitudes. They exhibit large lifting and transporting strength, have longer or shorter duration and carry a mixture of soil, dust and sand. Often they attain the strength of hurricane but differ in structure by the absence of any zonal formation. The central part of the hurricane ("eye of the storm"), the zone of wind and heavy rain and the peripheral zone are well-defined in hurricanes, but in the dust storm they are not distinct and may be absent. Dust storms occur often and have been studied in detail but no "eye of the storm" has ever been recorded. The different zones of wind and downpour are not well defined and the exact location of the center is not clear.

Dust storms can have a duration of several days. During this time they cover thousands of kilometers, spreading hundreds of kilometers in width. The height of the dust cloud is not more than a few hundred meters and often the sun's rays are visible through it. In the case of large dust storms the height of the cloud is 2 km or more and the sun's rays cannot be seen through it, often causing total darkness.

Dust storms are of various types and frequencies. In Central Asia, over five years (1951–1955) 3,882 storms occurred. They originated under several quite different synoptic conditions. N.N. Romanov (1961) divided dust storms into four categories:

1. Short-lived with considerable deterioration in visibility; duration is of a few minutes only.

2. Short-lived with considerable deterioration in visibility; duration is from a few minutes to tens of minutes; the clouds of dust are dense, gray and of different heights.

3. Long-lived and pulsating storm with considerable deterioration in visibility; duration is from a few hours to a few days.

4. Strong prolonged storm with considerable deterioration in visibility; with considerable vertical thickness and prolonged duration—from 2–4 hours to a few days.

This classification is meant for aviation purposes, for pilots flying over Central Asia to whom dust storms pose great danger. For us it is of interest for the gradations of strength of dust storms.

A classification based on the color and composition of the dust is given by M.M. Zhukov (1964). For geologists this is convenient and the classification is as follows:

1. Dark storm; occurring in the European part of the USSR; displays dark color due to the transportation of black soil; occurs also in the USA and other countries.

2. Yellow storm; transports yellow sand and dust; all the storms of Central Asia described by N.N. Romanov belong to this category.

3. Red storm; transports red material of the same composition as that of the yellow storm, but the red color is due to iron oxide.

4. White storm; occurs over broad salt zones; salt gives the white color to the transported dust; relatively rare.

The name "dark storm" has been known for a long time and is widely used. Dark storms are related to areas of black soil of agricultural regions. They have been studied in detail and a great variety of literature is available on the subject.

Yellow and red dust storms, as classified by M.M. Zhukov, occur widely over desert regions. They are typical storms of the desert, traveling thousands of kilometers away from the desert. Most of them have local names (Khamsin, Simoom, Haboob, Harmatan, Sirocco) but often they are referred to as just "dust storms". It would be quite rational to combine all these under one name. The best name of all is "yellow-red storms". Often the same storm transports red and yellow dust. Often the color of the dust changes, depending on the nature of the locality over which the storm is passing. The name "yellow-red" comprises all the main colors of the dust of deserts.

The white storm is a new and special name, but its occurrence is rare.

Frequently the subdivision of dust storms is local and widespread or just local, changing with the locality, and mixed, depending on the origin of the dust flux encountered (Ostrovskii, 1963). All dust storms are mixed, propagating from one region to another. They start out as local and then become widespread or transitional.

The transportation of atmospheric dust is discussed in detail in the paper by K.P. Makhon'ko (1960).

In two wide geographical zones dark storms gradually change to yellow-red storms, where a distinction between the two types is not always possible.

The first region is the virgin land of Kazakhstan, the deserts of Kazakhstan and Central Asia. Over the virgin land dark storms predominate; over the deserts yellow-red storms are common and over Central Asia mainly yellow storms prevail. There are, however, intermediate zones where it is difficult to say whether the storm is yellow or dark.

The same is true in the second region—the central and western states of North America. The dark storms cause great loss of crops in this region. In the southwest the yellow-red desert storms occur. They differ very much from one another in the composition of the transported material. Consequently their effects on depositions are also different. However, American meteorologists refer to them simply as dust storms. Often it is not difficult to distinguish the dark storms from the yellow-red by the place of origin: in the northeast, in the agricultural lands, dark storms occur; in the southwest, in the desert region, yellow-red storms are the rule. Often the storms envelop the intermediate zones and any distinction is difficult and at times impossible. Therefore some of the American storms described in the section on dark storms may belong to the yellow-red category.

The spread of a dust storm is quite wide. It originates anywhere, wherever there is dust and strong wind. It is relatively rare in the polar regions and along the equator.

Sand and dust storms almost always display a vortex structure and are related to the group of vortex storms. They carry mainly aeolian terrigenous material, primarily dust and sand.

It should be noted that the storms occurring in the desert and arid zones are related to the group of flux storms, and similarly lift and transport sand and dust. It is sufficient to cite the description of the storms Santa Ana and Chinook (see p. 197): the "enormous river of dust" flowing down the valley.

Essentially such storms are also dust storms but they are never so called. They transport dust a short distance and in limited quantities. The flux dust storm is essentially a local phenomenon of secondary nature and small dimensions.

Vortex dust storms, on the other hand, display regional propagation and have enormous dimensions and significance. They are known as "dust" and "sand" storms.

Dark Storms

Dark storms occur in the southern arid zones of Siberia, the European part of the USSR, western Europe and the United States of America. The name "dark" depends on the color of the black soil and the chestnut-colored soil which is eroded and transported by these storms. The zones of occurrence of these soils are the zones of origin of dark storms. The black soils are transported many hundreds, even thousands of kilometers, far from the range of the black soils.

The wind erosion and depletion of soil occurring with dark storms often attain catastrophic proportions and cause large-scale loss to agriculture. Therefore they have been well studied and hundreds of papers are available on the subject. The latest summary is given in "Dust Storms" by P.S. Zakharov (1965) with a detailed bibliography.

Among the important data given in the work of M.M. Zhukov (1964) is a description of the storm of March-April, 1960, over the southern European part of the USSR. He writes that the maximum objective cognizance of the storm is due to stormy wind and loss of visibility. The field of vision is reduced to 10 m and sometimes even less. Even during daytime the light has to be switched on in houses.

The regions of prevalence of dust and haze should be distinguished. The haze or "dry cloud" spreads far beyond the range of propagation of dust.

The direction of the wind in the regions of development of dark storms during the spring of 1960 as a rule was found to be easterly or southeasterly; only in one case was it northeasterly. The area of the storm was bounded by the 15 m/sec isotach, but the speed of the wind reached 28 m/sec and in one case 40 m/sec. The duration of the storm was up to five days. The speed of the wind during this period varied: it changed in different isolated areas. The turbulence of the vortex was not temporary (Fig. 48). Often the storm was referred to as a "dangerous vortex".

The area of spread of the storm of 1960 was 1 million km^2. It is partly shown in Figs. 48 and 49 and there is no doubt that it extends to the east, quite likely to the deserts of the Caspian. This can be seen clearly from the open 15 m/sec isotach in the east (Fig. 49). The altitude of the layer of dust, according to fliers, was more than 1,500 m. Only at a height of 2,000 m did the aircraft climb above the cloud of dust. In the neighborhood of Odessa the altitude of the dust reached 2,400 m. The quantity of mixed black soil was 25 km^3.

The storm of 1960 started over the Caspian, enveloped the entire lower Caucasus and southern Ukraine and extended up to Odessa. The length of this region is approximately 3000 km. The most frightening of all is the winter storm known as "dark winter" in Ukraine.

The synoptic situation responsible for the dark storm of 1960, and of other similar storms, is not very clear. Earlier it was believed that they originate in the deserts of Central Asia, travel in a northwestern direction carrying hot, dry air and thus cause the dry wind. M.M. Zhukov, studying the data of the storm of 1960, came to the conclusion that it originated to the north of the Caspian due to the mixing of a cold anticyclone moving from the north and a warm cyclone moving from the southwest. Quite likely the warm cyclone had the main role in that the influence of the desert in forming the

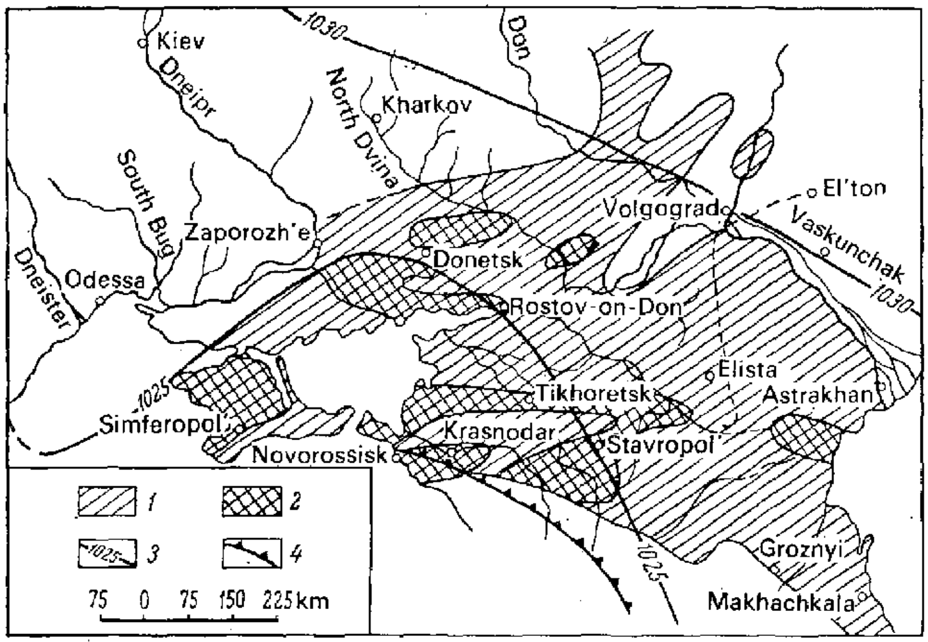


Fig. 48. Wind speed during period of dust storm in April, 1960. Centers of wind speed change (Zhukov, 1964, Fig. 2).
1—Wind speed from 15 to 20 m/sec; *2*—from 21m/sec and more; *3*—isobars; *4*—occlusion.

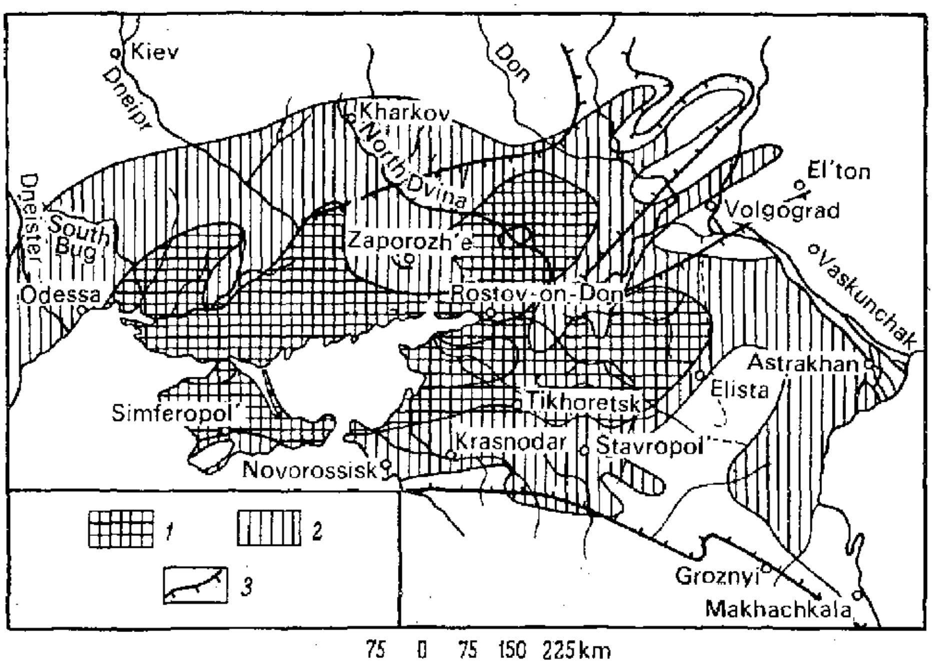


Fig. 49. Duration of dust storm in April, 1960, and area of its extension (Zhukov, 1964, Fig. 4).
1—Duration of storm up to five days; *2*—five days or more; *3*—contour area with wind of more than 15 m/sec.

hot wind cannot altogether be ruled out. This is shown by the nature of the 15 m/sec isotach opening wide in the Caspian Sea region, and also by the fact that the dust at Kiev and other points was not related to the black soil. It is likely that the wind from the deserts was superimposed on the wind formed by the mixing of the cyclone and the anticyclone and thus the dust storm formed.

But it is clear that the storm of 1960 does not belong to the category of the ordinary extratropical cyclone. It has to be included in a special group: "cyclonic dust storms". There was the growth of vortex motion in it, but this motion was more akin to that of tornadoes, although almost all these storms resemble extratropical hurricanes and storms.

Geologically the dust storm is an important factor, significantly influencing deposition on the continents as well as on seacoasts. A considerable quantity of sandy-clay material, transported by the northwesterly wind from the desert to the Caspian Sea, has been repeatedly recorded and is discussed below.

Much information on the dark storm of 1960 and on storms of 1928 and 1892 is to be found in the monograph "dust storms and dangers due to them" (1963) compiled by the Institute of Geography, Academy of Sciences, USSR.

In an interesting review paper A.G. Doskach and A.A. Trushkovsky (1963) state that very strong storms occurred in 1928 and 1892. Ehrenburg (1849) mentions a dark duststorm in Kiev in 1847. Dust storms depend mainly on the location of cyclones and anticyclones and on the aridity and looseness of the soil due to lack of vegetation over the soil cover. The frequency of all these complex phenomena has not yet been established. It can only be said that the strongest dust storms recur every 30–40 years. Geologically the strongest dust storms, despite their catastrophic strength, are quite frequent phenomena.

Dust storms are relatively rare in the Caucasus steppe. The grass cover prevents the formation and blowing of dust. Dust storms are formed, however, when the steppe is plowed virgin land. After a few years some of the fertile virgin lands are transformed into barren sandy tracts (Fig. 50).

What is a dust storm? "Dry, easterly wind continuing for a few days—driving a mass of sand, soil and dust. Clouds of dust are lifted one after the other and nothing is visible through them. The wind, roaring with tremendous strength, destroys everything it encounters. Crops, withered by the dry wind, are uprooted and the soil with the roots is lifted. Soil to a depth of 18 cm is removed and the subsoil is exposed; soft, fertile fields suffer most. Not long ago the green cornfield turned into a black parched valley as though after a fire" (Popruzhenko, 1893, p. 57-58). The strongest dust storm is much more dangerous than this description in the eyewitness account of the storm of 1892 in Ukraine.

In 1928, from April 26 through 28, a dust storm caused devastation over a large area. It enveloped the entire steppe and part of the forest steppe. The wind lifted more than 15 million tons of black soil from an area of 1 million square kilometers to a height of 400–750 m. The enormous quantity of dust settled partly in Ukraine and partly in Rumania and Poland. The area on which the dust settled (in our country and abroad) was of the order of 6 million km^2. Soil 12 cm thick and at places 25 cm thick was blown away (Babichenko, 1965).

V.N. Babichenko (1965) considers the average duration of dust storms in Donbass to be 8–9 hours; in the steppe zone, 3–6 hours; in Poles'e, 1 hour. The strongest storm goes on for three to five days. The wind speed in such a case is 15–20 m/sec and in some cases reaches 4 m/sec. Then the storm is of hurricane strength.

Lifting the dust to an altitude of 1–2 km, and often more, the storm transports it west and northwest.

On May 3, 1892, at many places adjoining the Baltic Sea a peculiar "clayey", "dusty" rain occurred. These places were almost contiguous with south Denmark, via south Sweden, Oland Island and south Finland up to Vyborg. Within one night, the area extended over the southern shore of the Baltic Sea. This phenomenon attracted the attention of the well-known Swedish scientist Nordenskjold (1894), who wrote a few papers on it.

Fig. 50. Virgin land turned into sandy tract (Zemlyanitskii, 1957, Fig. 3).

The fall of dust was accompanied by rain, strong wind and often thunderclouds. The sky became overcast with gray, dark or yellow clouds. The air was filled with a thin haze. In Vil'nyus there was so much dust that it looked like there was a solar eclipse.

The dust was fine gray or yellow powder. It comprised mainly colorless angular fragments of quartz and feldspar 1 to 10 microns in size. A considerable amount of the dust consisted of clayey material rich in organic matter. The water contained salt, in a limited quantity, along with different materials and the residue of organisms (diatoms, spores, silicious sponge). Chemical analysis showed three major components: silica (50–70%), clayey material (12–20%) and iron oxide (5–6%).

The calculation showed that 1–2 g of dust accumulated over 1 m^2 and that the total mass was 500,000 to 2–4 million tons.

Nordenskjold could not determine the origin of this dust. He was not able to relate it to the dust storms of the northern Caucasus and Ukraine, although this relationship would be no surprise for us.

A similar fall of dust was observed in Minsk, Kovno (Kaunas) and Pinsk. The dust traveled southeast.

It is interesting that in 1960 no dark storm was observed over Stavropol plateau, although hurricane force wind was experienced over the entire territory clear to the Caspian Sea. This shows that for the occurrence of dust storms storm strength wind alone is not enough: dust is also needed. This dust was not present east of Stavropol. There the land was still frozen and the arable land was of small area.

The transportation of dust, as is seen from a number of observations, was less than that in 1928, although the wind speed was higher. This shows that the damping effect of a forest-covered area is considerable.

Vortex circulation, spiraling up, plays an important part in lifting dust. The transportation of dust in a suspended condition is dealt with in the paper by I.M. Ostrovsky (1963), and the meteorological conditions in the paper by M.E. Lyakhov (1963). According to the latter, the maximum speed is observed at an altitude of 200–1,600 m. Above and below, the wind speed falls rapidly. For example, on April 8, at Divnom, at the level of the windvane the speed was 12 m/sec, at a height of 1,000 m 36 m/sec, at 1,600 m 54 m/sec, at 3,000 m 9 m/sec. The hurricane speed wind transported the dust to a great distance. The zone of strong winds in the near-surface layer was 2,000 km long and 500 km wide.

According to A.V. Voznesensky (1930) particles more than 0.5 mm in size were not found in the air during the storm of 1928 (Fig. 51). Particles 0.02–0.06 mm in size and sometimes bigger—0.15–0.5 mm—were generally found. In the regions of settled dust in western Ukraine the dimensions were 0.003 mm on an average, with a maximum size of 0.005 mm.

In Odessa (Akimovich, 1963) two types of sample of dust, falling in March and April, 1960, were studied. Both samples were dark gray powder, capable of scratching glass. They darkened with water and this showed the presence of humus. The damped powder smelled of clay. The samples were similar. The April sample differed mostly in organic content. The dust contained mostly clayey material and quartz and the remaining material constituted only 2–3% of the samples. The particles were angular. Among minerals, feldspar, carbonate, tourmaline, biotite, etc. were found. The organic matter was of plant and animal origin: small seeds, plant residues, shell splinters, etc. The air was polluted severely by bacteria—an increase of

7 to 30 times and even 75 times above normal. The quantity of dust increased 9–22 times. The quantity of bacteria increased due to the spores.

An exceptionally strong, even catastrophic dust storm occurred over the virgin lands of Kazakhstan and adjoining areas. The dust storm attained high speeds of 22–25 m/sec and at times 34–40 m/sec. This is hurricane strength. The sky became overcast with dust and the sun could hardly be seen through it. In Priirtish, on May 19, 1960, the dust storm continued for 12 hours from the southwesterly direction. The wind speed at a height of 2 m was 13–17 m/sec. The air was so saturated with dust that a man could not be seen at a distance of 3–4 m (Chakvetadze, 1962, p. 71). After the storm the thick vegetation had turned into desert, littered with the roots of plants.

In the virgin lands of Kazakhstan the soil layers are thin and can easily be blown away. The black, organic material is quite meager and the dust storm, on M.M. Zhukov's classification, occupies an intermediate position between black and yellow. The coloration is dark yellow. The composition of the transported material is also mixed: organic and sand.

A summary of the dust storms in Kazakhstan is given by E.A. Seredkin (1960). It supplements the summary of dust storms in Central Asia by N.N. Romanov (1961). Short-duration storms (15–45 minutes) occur in Kazakhstan. Numerous storms continue for 10–12 hours but rarely over 15 hours. The wind speed is generally 4–10 m/sec but many storms attain a speed of 11–20 m/sec and on rare occasions more than 20 m/sec.

The main cause of the strong wind is the cold front. Storms with cyclonic features are rare.

The zones of depletion of soil are shown on the map (Fig. 52) prepared by P.S. Zakharov (1965). It is divided into a number of regions, starting from south Ukraine and ending in the Minusinsk depression. All these regions are situated in forest steppe, steppe and semidesert zones, having arid or semiarid climate, loose soil and sparse vegetation. The strong winds cause dust storms.

The regions of depletion of soil should supplement the regions of depletion of alluvial deposits, situated in the south, in the ranges of our deserts. Unfortunately these regions have not been studied well, nor mapped properly. As such, the economic importance of the region is small. These are large-size areas and the surface of our deserts contains river and lake alluvials, loose and stratified. The growth of aeolian sand zones is a secondary element subject to depletion by dust storms.

In the aggregate zone depleted soil and desert depositions occupy an enormous area. The dust storms are numerous and are of considerable geological significance.

Dust storms in the USSR cause great harm to agriculture and hence a considerable amount of literature is available on them. The most recent review is by P.S. Zakharov (1965). The main bibliography and short characteristics of the main regions of incidence of dust storms are given. The locations and sizes of these regions are given in a schematic map.

Dust storms in the south European part of the USSR, North Kazakhstan and Central Asia have been described above. The nature is the same in other regions, but the strength and extent of the area affected are less.

The dust storms of Zavolzh'ya are described by N.V. Bova (1957), of the Ukraine by G.N. Vysotski (1894) and S.O. Vorob'ev (1930), of Bashkir by T.F. Yakubov (1946), Sh.A. Gaishin and G.I. Lysak (1958) and M.M. Turovtsev (1964), of the Kulundinsk steppe by L.N. Gribanov (1954), of the Omsk and Novosibirsk regions by L.N. Gribanov (1954) and P.S. Denisov (1964).

Dust storms occur in the Far East and in the Prikhankaisky valley. Here, on April 14, 1956, a strong dark storm occurred. It spread over an area of 20,000 km^2 and wrought havoc for 5–8 hours. The wind speed was 22–24 m/sec. Visibility fell to less than 50 m and at places to 5–10 m. An enormous quantity of dust was transported (Sokolov, 1957).

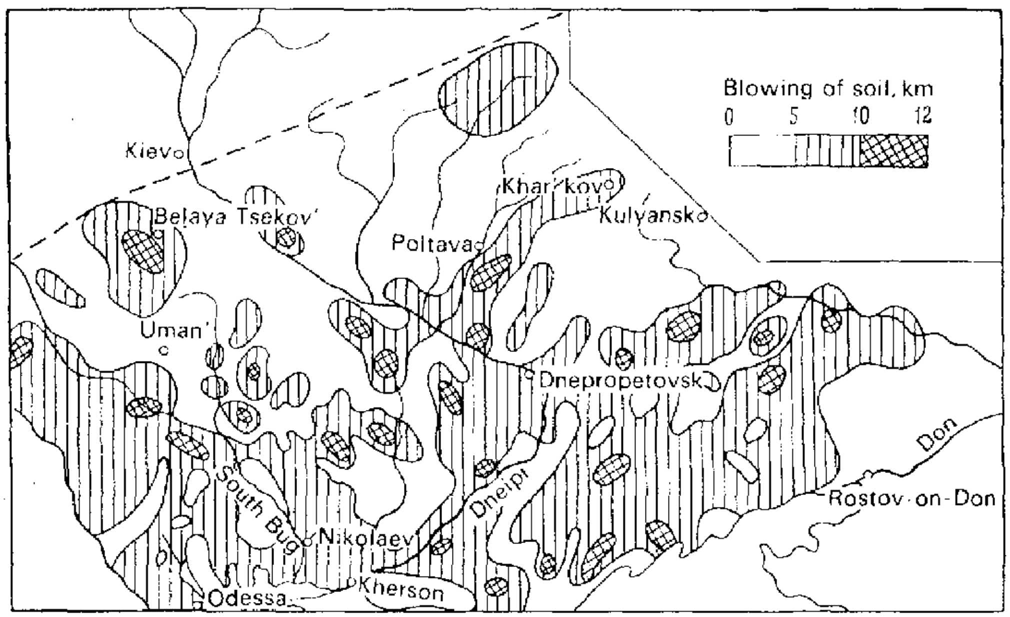


Fig. 51. Blowing of soil during dust storm of April 26–27, 1928 (Zhukov, 1964, Fig. 6 after A.V. Voznesensky, 1930).

A comparison of the data given in this work and in others shows that the dust storm is a widely distributed phenomenon in the USSR, causing large-scale damage to our country. Necessary measures can be taken to tackle it, but the most important thing is to get rid of the dust. There can be no dust storm in the absence of dust. The most important method of controlling dust is the growing of plant covers of different types, including barriers.

Depletion of soil and dark dust storms are not limited to the USSR. They occur, on a considerable scale, in the central States of North America: North

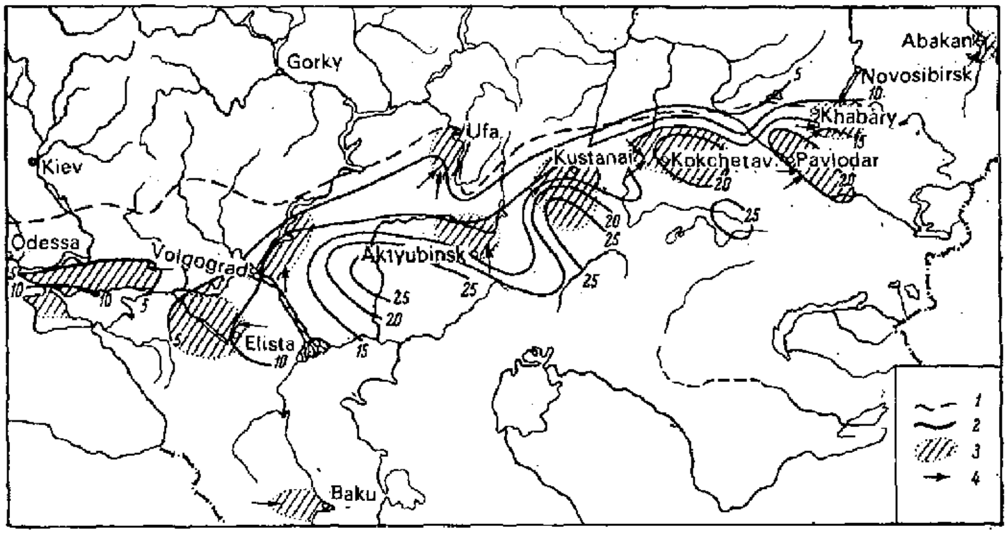


Fig. 52. Schematic diagram showing distribution of dust storms in the USSR (Zakharov, 1965, Fig. 25).
1—Northern boundary; *2*—number of days with dust storms per year; *3*—regions of strong depletion; *4*—direction of dust storms.

and South Dakota, Nebraska, Kansas, Iowa, Tennessee, Missouri and Wisconsin. The dark sandstorms attain an exceptionally big size (Figs. 53, 54) during prolonged drought and hurricane force winds. The dust transported from the central States reaches the shores of the Atlantic Ocean at New York, covering around 2,000 km. The dust from Nebraska penetrates the Gulf of Mexico, a distance of more than 1,300 km. The bigger particles are transported within the continent. The dust piles up in enormous quantities in the presence of any barrier.

The losses due to dark storms are enormous. A short review of the losses

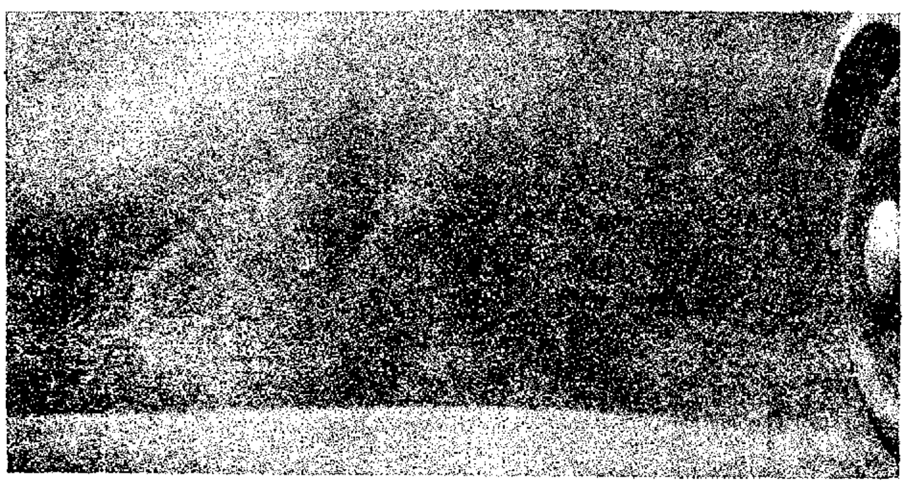


Fig. 53. Dust storm, South Dakota, April, 1934. Front view: *right*—wheel of automobile (Mattice, 1935).

due to the strong storms of 1933-34 is given in the work of Mattice (1935). The erosion of soil in 1933 and 1934 and in the broad plains was considerable. Millions of acres were subjected to depletion and over thousands of acres the soil in the plains was removed to the depth to which it had been plowed the previous year. The soil-covered area was completely eroded. The loss to agriculture was of the order of many millions of dollars (Free, 1917).

Fig. 54. Dust storm, South Dakota, April, 1934. Side view: *white*—warm air, lifted over cold clouds with dust (Mattice, 1935).

The character of the dark storm in the USA is the same as that of the Ukraine, described in detail above, or the red-yellow storm of the Sahara. Everywhere it follows the advance of a cold mass of air (Fig. 55).

The dust storms of the USA are described by Konke and Bertran (1962, p. 158–176). The interesting point is that soil particles 0.5–3.0 mm in size roll over the surface, particles 0.1 to 0.5 mm in size take off and particles less than 0.1 mm in size are transported upward. Particles more than 3 mm in diameter are dislodged only in hurricane force dust storms.

The dynamics of the wind erosion of soil is dealt with by Chepil (1945, 1946). The main data in regard to such erosion are given in the work of T.F. Yakubov (1959). The quantity of moving particles in the wind and the density of the soil-wind current attains the maximum value on the surface of the earth and decreases sharply with height. For a wind speed of 6–10 m/sec (at a height of 30 cm), 60–80% of the soil mass is carried to a height of 0–5 cm; more than 90% stays below 30 cm and a very insignificant quantity is lifted to a height of more than 1 m (Yakubov, 1959, p. 47). The height of transportation increases considerably during the transition to hurricane strength, with speeds of 30–40 m/sec, but the exact figure is not given by T.F. Yakubov.

Fig. 55. Dust storm, Kansas, 1935. Movement is from left to right. Black, dusty cold cloud consists of individual vortex formations merging together. *Top*—warm air (Knight, 1964, p. 116).

Intensive wind erosion of soil took place in 1933–1935. Due to this, crops of different types were damaged over one-third of the total agricultural area of the USA. Starting from 1930 soil erosion affected the great plains and 160,000 farmers were thrown out of work. In the USA, soil erosion has now affected 100 million acres, of which 10 million acres have become useless for agriculture.

An analogus situation developed in Canada, where the wind erosion of soil acquired a massive character, especially in the central agricultural regions.

In the USA and Canada the governments had to tackle the problem of wind erosion of soil (Yakubov, 1959, p. 42).

We will now look at some specific figures. On March 19, 1930, strong dust storms occurred over Idaho, Washington and Oregon and the duration was 8 hours. According to Freeman (1930), on an open balcony 2.03 g of dust accumulated on a piece of paper 1 sq. ft in area. This gives a figure of 62 tons for an area of 1 sq. mile and 3,000,000 tons for a storm covering an area of 50,000 sq. miles. This dust would have had to be transported by a 500 mile (800 km) long freight train.

In 1921 a very strong dust storm occurred in North Dakota. Calculations show that 320,000,000 tons of dust was deposited in an area of 400,000 sq. miles at the rate of 800 tons of dust per sq. mile. The length of a train to transport this amount of dust would be 10,000 km.

The dark storm of 1934, described by Mattice (1935), is shown in Figs. 53 and 54.

Before concluding this review of dark storms, we will recall the oldest description, from about 3000 B.C., M.I. Budyko drew my attention to it. In Sumer (the present Iraq) the horticulturist Shukallitud wrote:

Father, as I filled the furrows with water,
As I dug wells in the bed
I tumbled over the roots and they scratched me.
Furious wind all around
And wind with dust enveloped my face
My face . . . and my hands.
The wind brought dust
To my garden in five or ten inaccessible places.
In each of these places I planted trees for shelter in the shade.
The shelter of the shade of "sarbat" with thick leaves,
The shade that it gives in the morning
And at midday in Sumer—it never disappears.

(Kramer, 1965, p. 89)

Thus dust storms have been recorded for a long time and people have tried to counter them with the help of tree cover. The horticulturist Shukallitud wanted to do so, but this could not be done with the "sarbat" trees. The question is: How many dust storms occurred before and how many afterward?

Winter Dark Storms

The dark storms known as "dark winter" occur quite frequently in the south European part of the USSR. They do not attain the destructive strength of spring and autumn dark storms, but in any case they, too, are capable of causing great damage.

In winter the soil is generally covered with snow and the storms and dust are not that strong. In a snowless mild winter snow cover is either absent or meager and the soil is relatively loose and dry. It easily yields to depletion and therefore the storm carries large amounts of soil along with snow. Thus the peculiar snow-dust storm is formed.

One of the earliest descriptions of such a storm is presented by V.V. Dokuchaev. In his report for June through November, 1892, he writes: "Not only was the fine snow cover removed and carried away but the dry loose soil, exposed under the snow, flew like ashes in vortex form at a temperature of −18°C. The clouds of dark dust filled the frozen air spread over the highways, made communications between the villages difficult, entered the gardens. The tree-covered areas had clouds up to a height of 1.5 m. They formed dunes and mounds on the streets of the villages and badly affected railroad traffic. The trains had to be stopped due to the drift of black soil mixed with snow" (Dokuchaev, 1951, p. 138).

A number of dark snow-dust storms are described by P.S. Zakharov (1965, p. 65–69). In the Rostov region, in December, 1949, a wind of up to 20 m/sec with a very low air temperature started blowing across the thin snow cover over the soil and winter crops. Thus a dark dust-storm started.

In February of 1951, in Priazov, a strong storm occurred with a speed of 16–18 m/sec. It carried away the thin snow cover and started blowing away the exposed dry soil. The snow, along with the eroded soil, was deposited near obstacles, forming dark snowdrifts 1–1.5 m deep. The blowing away of soil and winter crops continued during the spring months.

The dark winter was observed in the Voronezh region during 1953–54. During the depth of winter in January and February, when the temperature fluctuated between –20° and –30°C, a strong wind (up to 16 m/sec) started blowing across the snow cover 8–12 cm deep. The snow deposited on the open fields started blowing away and depletion of the soil started. The areas of snowdrifts were covered with 2 cm thick soil. Blowing away of soil did not take place in forest-covered zones.

At the end of January, 1964, a strong snow-dust and at places pure dust storm occurred over the Stavropol region. Starting with a westerly wind (16–20 m/sec) at 7 in the morning, the storm strengthened to 34 m/sec, attained hurricane force and caused havoc until 23 hours. The dust storm was caused by a deep cyclone traveling up to Rostov and the north Caucasus. In the west, where there was snow, snowstorms occurred. In the east, over the Stavropol region, the wind blew with snow and soil, forming zones of snow-dust, dust and dustless storms. This is a good example of how the same storm can be dustless, snow-dusty and dusty, depending on the condition of the soil.

In other regions, e.g. over the Kustanaisky region (Yakubov, 1959), snow-dust storms are rare.

All these examples show that winter soil depletion is not a rare phenomenon. There are regions where the blowing away of soil takes place around the year, even in the snowy winter.

The descriptions concern dust storms of local origin, occurring wherever there is deflation of soil. Naturally, moving from the regions of deflation the storms occur where deflation has not occurred earlier and, conversely, accompany the settling of dust lifted earlier.

In winter, the dust is mixed with snow and the storm is accompanied by a fall of colored snow. A.D. Zamorsky (1939) describes such a snowfall in Rostov-on-Don that occurred on March 9, 1939. A large territory of several tens of thousands of square kilometers adjoining the River Don and Kubani had colored rainfall. In the Rostov region colored rain alternated with colored snow. The coloration of the snow was dirty gray. The white village cottages became dirty. In Rostov the sidewalks had a dirt cover. What was striking was that big dirty flakes fell along with dazzling white flakes.

The cyclone with which the snow-dust storm was associated developed a cold front on March 8 over Rumania. Moving at a speed of 50 kmph, it crossed the Black Sea and on March 9 struck Rostov-on-Don. From the morning the wind started growing stronger and at 11.00 hours attained storm strength. Low cloud covered the entire sky. Visibility started deteriorating and at 13.00 hours dirty rain fell. It became dark as if there were heavy thunderclouds. At 13.20 hours the rain was accompanied by wet snow of dark gray color. This lasted for two hours but the rain continued until 20.30 hours, gradually decreasing. At 21.30 hours the storm was over and moved to central Volga.

An analysis of the meteorological and soil conditions showed that the dust was of local origin. The main reason for the colored snow was the small depth of the snow cover. Such snow-dust storms have been observed repeatedly in the south European part of the USSR.

These, however, differ sharply from the red and rose snow formed on the Alps and other peaks. There one gets colored snow and colored dust transported from the desert far to the south.

Snow-dust dark storms occur in the plains of the USA. In 1938, in the well-known "dust bowl", a bed of dust 400 m in length and 1–2 m in depth was formed during such a storm.

An enormous quantity of snow, mixed with dark cloud, fell during the storm of 1895 in the states of Indiana and Kentucky. There was so much dust that a thick dark liquid, resembling ink, resulted when the snow melted. Study of the dust showed that it contained many diatomites. It was believed that the dust was transported from the west, from the State of Montana (Abbe, 1895a).

Accumulation of Dark Storms

The destructive and depleting activities of dust storms have been studied in detail. There are hundreds of reports on them: The quantity of soil transported by such storms, as mentioned above, is of the order of tens of cubic kilometers. The complementary side of the process, i.e. creative accumulation activity remains almost unknown, especially in the quantitative sense.

The bigger particles of the size of sand and small stone chips roll over the surface of the earth. The small barriers block their passage and accumulation of the material takes place in front of them. The rule of movement is the same as that of sand. The dust forms an irregular bed or hump with a height of 2–3 m. It fills up depressions, ditches, etc. All these depositions are of small size but in individual cases the area can be of considerable size. This area coincides with the area of activity of the storm. For many storms this area is well-contoured. It is also established that the area can attain large size. For the storm of 1960 this area extended to 1 million km^2 and for many other violent storms the area is of the same order.

The black sands do not show such thick continuous sedimentation as aeolian sands in the desert. The plains of the uninhabited desert have fewer barriers to continuous deposition. The regions with vegetation, on the contrary, are full of such obstacles. This is the region of irregular, discontinuous deposition of black sands.

The mass of these sands is enormous and differs very little from that of desert sands. They play an important part in the formation of ancient deposits. Unfortunately, this fact has not caught the attention of the specialists on Quaternary deposits. In sections repeated layers of "fossilized soil" occur but the layers of "black aeolian sand" are not seen.

In the southern regions, the regions of the growth of dark storms, there are always lens-type deposits of small size and a thickness from a few tens of centimeters to 1–2 m, mixed with sandy materials and rich in humus. So far they have not been classified. In the legends of maps the Quaternary deposits do not show "aeolian sand of black soils", although these certainly exist.

The black soil dust with particles of a few tens of microns is lifted into the air and transported beyond the range of the storms. Part of it remains in the region. The quantity is not large, and often it is mixed with other deposits showing red coloration. Only at the bottom of a lake or lagoon and on the surface of saline black soil does the dust form a thin layer of a few millimeters and, rarely, a thicker layer. These dark clays are quite distinct in the sections of halogen deposits (see the section "Aeolian—lake deposit").

The black soil haze, with particles less than 1 micron in size, remains floating in the air for a long time and spreads over a large area. It is not distinct among other deposits and only increases the dark coloration. Its presence can be recognized only under the microscope.

Descriptions of aeolian black soil deposits are rare. The work of P.F. Barakov (1913) on aeolian deposits deserves attention. The ancient Greek, later Roman, city of Ol'viya ceased to exist in the seventh century. Ol'viya was situated on the eastern shore of Bugsk lagoon, 35 km from Nikolaev, on a small hill, in the western part of the area of propagation of dark storms. This region has intensive accumulation of aeolian sand and dust.

P.F. Barakov showed the exposure of aeolian deposits at a number of points near the site of Ol'viya (Fig. 56). The thickness of the deposits differed in different areas. Near the city it was 2.2–2.5 m in 12 centuries, i.e. 20 cm per century. On the slopes of the hills the thickness was greater, of the order of 30 cm. It is interesting that the drains of the Ellinsk epoch (up to the second century) overlie the drains of the Roman epoch (second century). In four centuries, the overburden is 80 cm, i.e. 20 cm in 100 years. This figure is very high, i.e. 2 m in 1,000 years. It is true that over stone slabs the thickness was 1.0–1.5 m, but it is also quite significant.

Let us look at a typical section of the aeolian deposit: "The dark-colored soil horizon contains fine-grained structures with a mixture of limestones; thickness 75 cm. The lower coloration is more white-colored with imprints of podzol formations and this explains the considerable loose overburden. The thickness of the lower horizon is 1.6 m and the total thickness of the overburden 2.4 m. The general characteristic of the aeolian overburden and soil is its fine structure, approaching powder form, and this is the reason for its loose nature" (Barakov, 1913, p. 116).

The photograph shows the complete absence of layers and the vertical separation can be distinctly seen.

All the specimens are oxidized and the upper zones are comparatively strongly oxidized. The humus content fluctuates from 1.5 to 8%; with heating it fluctuates from 6 to 14.5%.

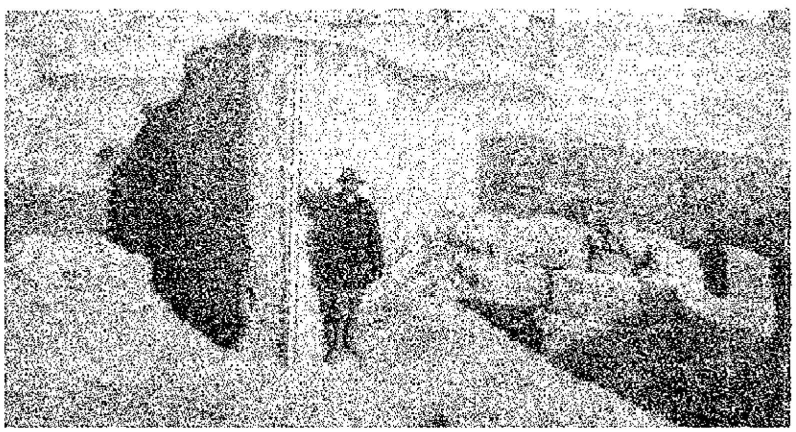


Fig. 56. Section of deposition due to dust storm. Excavations at Ol'viya. Worker is standing in front of section. *Right*—stones of ancient walls (Barakov, 1913).

The data of P.F. Barakov are scanty but give information on the rate of deposition of aeolian deposits and their composition.

Unfortunately more detailed research on aeolian depositions due to dark storms has not come to my notice.

One more observation is of significance. In the southeast Russian platform, to the west of Volgograd, at the watershed between Khoper and Medvedits, thick loess has developed. Its mineralogical composition shows the presence of hornblende. Its quantity is many times greater than the rocks of the adjoining areas but is identical with the rocks of a Turkish province (Karakorum). This permits one to conclude that the Khoper loess was transported from Karakorum by air to a distance of 2,000 km. The organic residue in the loess shows that its age is 15,000–20,000 years. The thickness of the loess is 10 m, i.e. 0.5 to 0.75 m per 1,000 years. This rate is nearer to the rate of deposition of loess in Central Asia—1 m in 1,000 years (see page 218).

Yellow-Red Storms

Gray or yellow storms originate where the soil consists mainly of yellow-gray clay and sand. It is characteristic of the steppe and semisteppe areas of the USSR. It has been partly described by A.I. Karpov (1939) under the heading "yellow" as a local storm occurring in lower Povolzh'. It occurs also in Central Asia due to the warm, dry wind known as "Afgan". One dust storm crossed Iran via Kopetdag to Karakorum in March, 1953. This storm transported dry loess dust whose weight was not less than 100,000 tons (Astapovich, 1955).

The lifting of sand into the air and its transportation, which cannot be considered as a dust storm, rates a special category. Sandstorms are quite well known, e.g. in Karakorum and Kyzylkum and especially in the Algerian part of the Sahara.

In subsequent sections we will consider dust and sandstorms together under the name "dust storms". Each sandstorm lifts an enormous mass of dust and is also known as a dust storm. Each dust storm during its maximum growth always transports sand particles.

Yellow and red storms are formed in all the deserts of the world over very large areas. The regions of development are thinly populated and therefore the loss of life and property is small. Therefore they have been studied much less than the dark storms. Their duration is a few days. They envelop areas a hundred kilometers in length. The track is long and the wind speed is that of storm strength and occasionally of hurricane strength. Therefore they can be compared with cyclonic storms.

The geological significance of yellow and red storms is very great. They determine the character of the desert surface, create massive aeolian sands and, most important of all, transport and deposit dust matter, forming aeolian loess—the most fertile soil in all of Central Asia.

Sandstorms

The important question is: How do storms transport sand? It is often thought that sand is lifted high in a cloud and that the cloud transports the sand. This is not at all convincing. It is known that during storms people feel the sting of sand on their faces. Usually the height of a man is less than 2 m. The storm actively transports sand and often small gravel to this height or even more. At a height of a few tens of meters the transportation of sand and small gravel is altogether absent. At that height and above, only dust is transported. The thick clouds—the wells of sandstorms—consist not just of sand but of dust. The sand transportation is just above the ground. Small obstacles contain it, forming sand beds, mounds and sandhills. The transportation of sand to small heights has been noted in previous works on this topic

For example, in Pribalkhan region (Caspian) of Turkmenia, I.A. Volkov carried out prolonged observations. He writes: "The transportation of broken materials by the wind takes place in two ways: in the form of raised particles near the surface (sand, gravel, small pebbles), and in the form of suspensoids lifted high (dust). The major part of the sandy material is transported by the wind near the surface (sandy wind current) and most of the sand rolls over the surface of the soil" (Volkov, 1964, p. 45–46).

In Pribalkhan region the dust storm reduces visibility drastically. The atmosphere is so saturated with dust that one can look at the sun with the naked eye. In the final stage of such storms everything is covered with a thin layer of fine dust. In subsequent storms this dust is again lifted up and transported farther in the air.

"In the suspensoids, sandy material moves less than dust. Though sand is mixed in the air, its transportation to a great distance occurs only in a limited quantity. Deposition of the sandy material does not occur far from its place of origin" (Volkov, 1964, p. 29).

On March 9, 1901, a dust storm accompanied by a tornado originated in the Sahara. An enormous quantity of sand and dust was lifted into the air, so much so that darkness prevailed at noon on March 10, and lights had to be switched on. On the same day, red dust fell on many parts of eastern European countries, and on March 13 it was detected over Ural. This dust formed a red film on the Alpine glaciers and was retained for several years.

According to the German meteorologists Helman and Meinardus (see page 159), this storm transported not less than 1.8 million tons of dust, and over the Mediterranean Sea the quantity was still greater. According to this calculation 150 million tons of sand and dust were transported across the African shores of the Mediterranean.

An explanation is needed in regard to these interesting data. In Europe, the dust settled and not the sand, as has been shown earlier by Ehrenburg (1849). A tornado may lift a considerable amount of sand into the air. The vortex cloud can transport it to a distance of tens and even hundreds of kilometers. Transportation of sand to thousands of kilometers, however, does not take place.

Important data on the transportation and deposition of sand in deserts are given by M.P. Petrov (1939) and A.G. Gael (Gael', 1957; Gael and Smirnov, 1963). They established that the dust storms in the virgin lands of Kazakhstan transport sand in a sandy wind layer 30 cm in height. Here 95% of the sand is transported in the height band of 0–15 cm, and the remaining 5% in the 15–30 cm high layer. In one hour, in a wall of 100 m, 1,330 kg of sand was transported at a height of 1 m at a speed of 8–10 m/sec and on the surface of the earth at a speed of 4–5 m/sec. Violent storms, with speeds of 20 m/sec and above, transport a considerable amount of sand but at a height of not more than 1–2 m.

Important and detailed data on the transportation of sand by the wind in the deserts are given by Bagnold (1935, 1941). The term "sandstorm" is relatively erroneous since it does not distinguish between sand and dust. In a desert area, for example in Iraq or Khartoum (Sudan), when a strong wind starts a dense cloud of dust is lifted to a height of 1–2 km and the sun cannot be seen for a long period. This is undoubtedly a dust storm, although it is quite often referred to as a "sandstorm".

The typical sandstorm looks like a simple dense low cloud with a sharply defined upper surface, grazing the ground like a carpet. The heads of people can be seen above this cloud as if the people are swimming in a pool. Over a coarse weathered surface the cloud may reach a height of 2 m but generally it is less. This is the real sandstorm, typical of the Libyan desert where the sand contains no dust.

During sandstorms the sand moves in suspended (fine-grained), rolling (medium-grained) or dragging (coarse-grained) condition.

To these characteristics mentioned by Bagnold and other workers, it may be added that during very strong storms and hurricane force winds, sand and dust storms get mixed up. The air, saturated with dust, forms an incredible wall rushing forward. Sand is absent from the cloud and moves only on the ground.

The face hurts when the particles strike. The sand particles polish everything on the surface of the desert, create three-cornered sanddunes and destroy the hardest rocks exposed on the surface of the earth. All this occurs on the surface.

Bagnold was a soldier and worked during the war period. No less interesting are the observations of another English soldier, Oliver, who fought on the North African front (El Alemein) from 1941 through 1945. He thoroughly investigated khamsin, dust storms and the movement of dust and sand. The sands lifted from the surface move ahead with the wind in the form of a series of small cascades. When the grains of sand fall they either bounce or toss other sand grains into the air. He explains that moving sand always forms dunes (Oliver, 1945, p. 28).

We all know that the aeolian sands accumulate mostly in the form of dunes but the explanation of this phenomenon was given only by Oliver. It is correct as well as interesting. Each grain of sand bounces individually, but at a distance it moves in association with other sand grains.

El Fandy (1953) provides interesting data on the physical phenomena accompanying dust storms. He shows that the typical dust storm described by Oliver (1945) develops only in deserts. It does not originate in the oasis city of Alexandria. Here one gets only the wind saturated with dust lifted from the desert.

The transportation of sand takes place in the form of a stream. The form of the transported accumulation is unstable and changes quickly.

The movement of sand in the Sahara has been investigated by Dubieff and others. Dubieff (1952), like Bagnold and Soviet specialists of whose work he was unaware, believes that the transportation of sand is effected only by strong storms and that it takes place at a height of not more than 2–3 m. Further, it has limited propagation.

He shows that movements of sand occur at different points of the Sahara and over small areas. The main massifs of aeolian sand are "dead", i.e. immobile. The gigantic immobile sandhills can be seen in the north as well. This observation is in full agreement with that of the Soviet geographers, who also believe that the huge masses of aeolian sands in our deserts are immobile. These are uneven sands. The mobile sandhills occupy small areas.

We know that the aeolian sands in the deserts are very mobile and are regularly transported by winds, especially by storms and hurricanes. In any case, the compressed part of the sand is immobile and is not affected even by powerful hurricanes. The walls of the "sand" storms are composed not of sand but of dust.

The immobility of aeolian sands is due to the plant cover. The areas of aeolian on the earth remain stationary due only to plant cover. This is valid for sands of deserts, marine dunes, lakes and river sands. Topographical maps show that the outline of the areas occupied by aeolian sands remains unchanged.

Central Asian Storms

Yellow sandstorms are frequent and widely distributed in Central Asia. Much data on them are given in the work of V.A. Bugaev et al. (1952, 1957) and in the reference work, although somewhat limited due to its mathematical treatment, of N.N. Romanov (1961). A dust storm, according to Romanov, is an intensification of wind due to which the dust is lifted into the air. It reduces visibility and affects the movement of airplanes. The entire phenomenon is treated from the point of view of pilots. Nothing is said about the dust: the place of origin, the place of deposition or the composition.

He believes that dust storms are caused by winds from the north and south directions, approximately of the same strength and frequency—the northerly wind being slightly more prevalent. The northerly wind transports dust to the south and the southerly wind to the north. He writes: "Due to the dust storm occurring in such circulatory conditions the larger part of the dust starts a unique rotation. Of course, large amounts of dust leave Central Asia, but we feel that the main mass remains in its domain" (Romanov, 1961, p. 113).

This observation draws our attention to an important phenomenon whose existence has not been emphasized in the literature. The products of depletion formed in Central Asia remain in that domain. This is undoubtedly the case in respect of aeolian sand. In regard to dust, it has been mentioned many times that it settles on hill slopes in the form of loess. The aeolian dust settles on the mountains, as high ranges surround the entire Central Asian region (including north Afghanistan) to the south.

The explanation of dust storms given by N.N. Romanov is somewhat primitive. If such movement really took place, then the greater part of the mass should have settled, although temporarily, in the central region of Central Asia. Such deposition is not found anywhere.

Sandhills in deserts always have a definite orientation, depending on the direction of the wind, as has been shown by B.A. Fedorovich. The orientation shows the prevalence of a northerly wind.

N.N. Romanov's assumption as to the equal strength of northerly and southerly winds is not always correct. The wind at the station Repetek, in the deserts of Karakum, was studied for six years by B. Orlov (1928). The northerly component gives the following annual figures in percentages: weak wind—30.6; moderate—16.9; fresh—1.5; strong—0.5; the southerly component: weak—7.1; moderate—6.1; fresh—0.9; strong—0.9. The northerly wind is more frequent in summer when the sand is loose and the transportation is substantial. The southerly wind is more frequent in winter and autumn when the sand and other materials are dense and transportation is difficult.

More convincing are the data of N.S. Orlovsky (1962) regarding the direction of dust storms in South Turkmenia. There northwesterly and northerly storms prevail. At Tejen 62% of the storms are northwesterly and only 10% are southeasterly. At Bairam Ali 72% are northwesterly and northerly storms and only 14% are from the opposite direction. Owing to the "Afgan" wind this ratio is 54% and 30% at Cherjoy and 33% and 45% at Kerkakh.

N.N. Romanov's book contains many other useful data. It records a large number of dust storms—about 4,000 storms over five years. This is certainly a large number. It underlines the significant depletion in the general geology of the country. This completely supports the data of L.E. Anapol'sky (1961) on the wind regime (see p. 138).

The majority of these storms are local phenomena. The height the dust is lifted to is not more than a few hundred meters and the area of distribution is not large. Their duration is not long either—from a few minutes to a few hours. Storms lasting a few days, of great altitude and covering large areas, are relatively rare and localized in specified regions.

All the works undoubtedly show that an enormous quantity of dust is transported over a large area of Central Asia. The high peaks situated to the south serve as a barrier to the movement of dust. On the foothills and slopes the speed of the storm falls sharply and the dust settles, forming a thick layer of loess, the rich soil of Central Asia.

The "dust storms of Central Asia" is an important geological factor having special significance.

Dust storms of Turkmenia: Work similar to that of N.N. Romanov, with both its merits and deficiencies, was carried out by N.S. Orlovsky for Turkmenistan (1962). According to him, in the 25 years from 1936 through 1960 altogether 9,270 dust storms occurred. The speed of wind recorded in the storms was: 1–3 m/sec—2, 4–6 m/sec—127, 7–10 m/sec—3,921, 11–14 m/sec—4,086, 15–20 m/sec—1,120, more than 20 m/sec—14. Storms with a speed of 1–3 m/sec or even 4–6 m/sec are not really storms. If these dust winds are excluded, then there were 9,000 dust storms. This is quite a large number and N.S. Orlovsky correctly labels Turkmenistan the region of maximum dust storms in Central Asia. Unfortunately data on the quantity of dust were not collected. The areas of the origin and deposition of dust are not clear. The greater part is transported to the southeast, to Afghanistan, due to the direction of the prevailing wind.

The duration of the dust storms, as is shown by N.N. Romanov (1961), is not long, not more than a few hours, but often the strongest storms have a continuous duration of two or three days. In November, 1910, a storm started in the evening. The very first night, the wind attained enormous strength and raged continuously for three days. During this period the people did not leave their tents. Along with the mass of dust, sand and snow, small pieces of stone were also found in the air. The wind blew over the steppe, where most of the cattle died. In the Mangyshlak region 500,000 sheep and goats, 40,000 horses and 30,000 camels died.

The strong dust storm that hit Ashkhabad on March 13, 1953, is described below (p. 195–196). In March, 1958, in Kazanjik, the layer of dust on insulators was 8 mm thick.

The direction of the dust storm is quite interesting. The main flux of the dust follows Kopetdag, traveling into Afghanistan. At Ashkhabad, 55% of the storms with a speed of 10.3 m/sec are from a northwesterly direction, at Bairam-Ali 51% and at Tejen 62%. At Serakhs 76% have a speed of 11.2 m/sec. In the south, 62% of the dust storms at Charjoy, 60% at Charshang and 55% at Repetek have a speed of 13.5 m/sec.

In the north of Turkmenistan most storms recorded are easterly, carrying dust to the Caspian Sea and lower Caucasus. At Nebit-Dag 70% have a speed of 14–15 m/sec.

This may be inferred from the detailed data obtained by I.M. Ostrovsky (1960). In the northwestern part of Karakoram easterly and northeasterly winds are prevalent, obviously associated with the anticyclones often referred to as the "Voeikov axis". The mountain massif, bounded by the desert to the west, changes this direction. The Uzboi pass is situated in a narrow passage which, in turn, is situated between the great Balkhan and Kopetdag massifs standing out prominently from the enormous sand desert. The very strong wind blowing through this passage also has an easterly direction and transports dust to the central part of the Caspian.

At the same time, at the foot of the great Balkhan, shielding it, at Jebel the wind circumvents the massif and acquires a meridional, i.e. northerly direction. A north-easterly storm approaching from Karakoram turns toward Kopetdag and travels, as already mentioned, along the foothills to the southeast.

On the whole the map showing the distribution of cyclonic winds and storms is quite complex. It becomes much more complicated with the wind flow locally known as the "garmisel" (p. 195–196), coming from the mountains in the desert and often debouching into the mountain valley in the form of a dust storm.

The dust carried by the "garmisel" is picked up, along with the Karakoram dust, by the meridional wind and carried to the southeast.

Afghan storms: Often strong dust storms occur over the southern part of Central Asia, especially on the upper course of the Amu Darya, in Termez. The wind associated with them is known as the "Afghan wind" because it blows from the southwest, from Afghanistan. The local people call it "Karaburan", i.e. "dark or bad wind". This wind is really bad, as I found in my experience of 1927. Termez is generally hot, but one particular day it became unbearable. The hot, gusty wind blew from the south to the Amu Darya. The local people lamented: "The Afghan wind is here". At first I did not understand. When I saw that everything was being closed down, that everyone was going inside the house from the courtyard, I realized that a hurricane was coming. All of a sudden it became dark at noon and the lights had to be switched on. An enormous dark brown cloud covered the entire sky. The wind became stronger and stronger and all of a sudden it became hot due to the baked dust. The wind blew like a wild animal and a frightening roar was heard all around. Everyone hid as best he could. The windows were covered as much as possible but still the hot dust penetrated everywhere. There was no escaping it. Due to the movement of the burning dust, all the surrounding objects, buildings and air were charged electrically. I touched the samovar and got a shock with fairly big sparks. It became sultry, but the hurricane wind did not weaken. Only in the evening did it quiet down slightly, but it regained strength again next morning. The storm continued for two days and a thin layer of dust was found everywhere, in the streets and inside the houses. I was so tired that I forgot to measure the thickness of the layer of dust. Afterward I came to know that Afghan dust penetrates deep into the north, right up to the Aral Sea. The streets of Termez showed nothing but dust. Sand and small-sized road gravel remained in the boundless semi-desert of northern Afghanistan. What happened there is not clear, but it is quite likely that the hurricane winds did not transport even a speck of dust. It is possible, however, that the surface of the semidesert was so dense and clayey that the storm managed to tear off only a fraction of the dust.

Important data on the origin of the "Afghan wind" are given in the work of K.A. Karetnikov (1935). An enormous mass of cold air pushes in from the north and northwest. It has an altitude ranging from a few hundred meters to 5–6 km. With the onset of the cold air mass warm air rapidly rises, causing a strong vortex movement, sucking dust up in high columns. A very large number of vortices are observed at the beginning of the "Afghan wind". The first vortex is thin and has the structure of a column. The vortex becomes dense with the proximity of the cold front and attains bigger diameters. Rising over the front, the wind saturated with dust blows north at very high speed.

K.A. Karetnikov believes that in this way the dust is transported very great distances. The dry dust cloud gradually covers the valley of the Amu Darya, Surkhan, Kafirnigan and Vakhsha. It is observed in Dushanbe, Garme, in the valley of kyzylsu and in some cases in Naryn, Tien Shan and even in Jarkent. N.N. Romanov (1961) doubts the distribution of dust to such far-off places as the valley of Kyzylsu. In the west the dust travels up to the western shore of the Caspian and even up to the northern shore of the Black Sea. Unfortunately K.A. Karetnikov does not cite data on the quantity and composition of the dust.

The observation of the effect of dust storms on atmospheric electricity is interesting. Illumination of the radio tower was observed within a few hours from the start of the "Afghan wind". The receiver set gave off a continuous discharge and at the beginning of the phenomenon the numerous wires of the radio room became live, flashing blue sparks. The wireless operators were stunned and could hardly throw off their earphones.

Wind speed: The speed of the wind is considered in detail in the authoritative work of L.E. Anapol'sky (1961). It is interesting that at the meteorological station Repetek, situated in the central part of the south Karakoram, the maximum wind speed over 20 years (V_{20}) is relatively low—26 m/sec. Even in Ashkhabad, which is somewhat higher, it is 28 m/sec. At Nebit-Dag it increases sharply to 42 m/sec. It is significant in Kyzyl-Arvat—up to 38 m/sec. But at Krasnovodsk and Jebel drops to 26 and 27 m/sec. It is quite likely that these figures are not for the strongest storms, but even then the speeds are not likely to be more than 40–50 m/sec.

Greater speeds were observed at Jungarsky Vorot, where prolonged violent storms called "ibye" occur. They attain a speed of 50 m/sec. In the passage between Jungarsky Alatan and Tarbagat the speed is almost the same—48 m/sec. At Termez the "Afghan wind" dust storm attains a speed of 41 m/sec. The speed of the wind at the exit of Fergan valley (the Ursatevsky wind) is considerable, 43 m/sec. Unfortunately, data are not available for the central region of Karakoram and Ryzylkum, where the main storms occur.

At Pamir the speed of the wind is average (24 to 26 m/sec) but is sufficient for the movement of a dust vortex, e.g. in the famous Tornado Valley. The speed of the wind at the western end of Issyk-Kulya is considerable. The westerly wind attains a speed of 42 m/sec.

The maximum speeds at the eastern edge of Kyzylkum, in the valley of Syr-Dari, are as follows: in Kazalinsk 30 m/sec, in Chiili 26 m/sec, in

Turkestan 31 m/sec.

All these figures show that for dust storms in Kyzylkum and Karakoram the speed of the wind is 40–50 m/sec and the figure is quite reliable. Such a speed is typical of cyclonic storms and hurricanes.

Chinese Storms

The dust storms in the deserts of northwestern China show the usual features and often attain great speed. They have been described in the monographs of explorers, for example that by Swen Gedin (1904). Among the Russian explorers, N.M. Przheval'skii (1883) gave a short description of the dust storms of Tsaidam. The description carries an illustration by V. Roborovskii (Fig. 57). The wide variety of meteorological information collected by N.M. Przheval'skii during the expedition was compiled by A.I. Voeikov (1895).

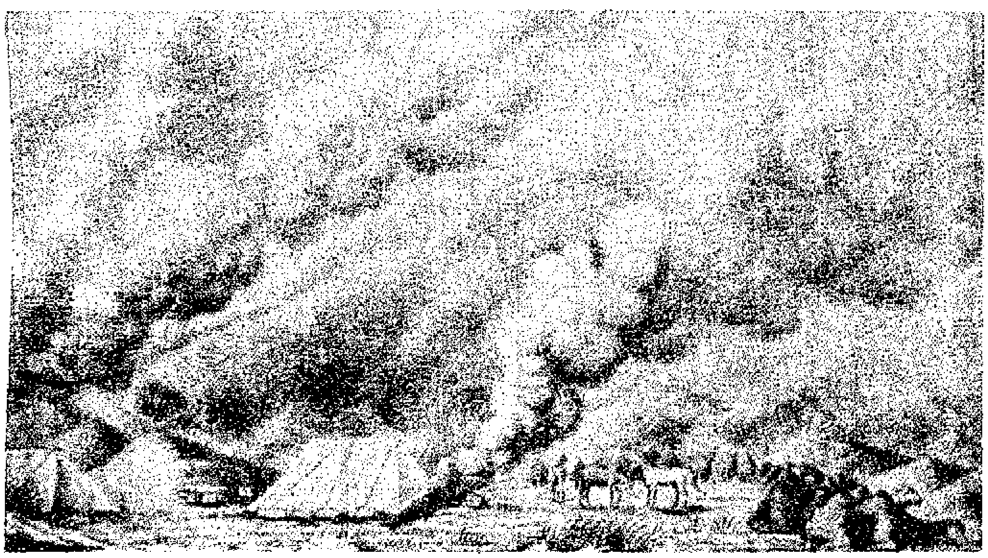


Fig. 57. Dust storm, Tsaidam, 1883. Against background of enormous dust cloud, individual vortex lifting and spiraling upward can be seen (Przheval'skii, 1883; drawing by V. Roborovskii).

A.I. Voeikov was the first to describe the Mongol-Siberian anticyclone and show its significance in the development of dust storms over all Central Asia. His concept is still valid for many meteorological processes.

A brief account of dust storms can be found in the work of other explorers leading expeditions undertaken at the end of the 19th and beginning of the 20th century.

V.A. Obruchev paid considerable attention to dust storms. In one of his papers, "Role and significance of dust in nature" (1951), he writes that the vertical vortex has a big part in the transportation of dust. The vortex lifts the dust high into the clouds, where it is transported great distances in the form of haze.

In any case, the main transportation is by dust storms. These are numerous in China, often attaining hurricane strength and enveloping large areas. They have special names: Huan-Fyn ("yellow wind") and Hyi-Fyn ("black wind"). North China is affected by strong and frequent storms coming from the northwest, from the deserts of Central Asia. They are frequent in spring and at the end of winter.

Considerably more information was obtained by joint Chinese-Soviet expeditions. The winds of the desert Takla-Makan and their activity are described by B.A. Fedorovich (1961) and that of Kuvilum by Ye.M. Murzaev (1961). A short description in respect of Beishan, Alashan, Ordos and the whole of Central Asia is given by V.M. Sinitsyn (1954, 1959a, 1959b). Valuable data are provided in the works of P.I. Herasimov (1959a) and Haude (1940).

But fairly complete material, covering all of Central Asia, has been collected by Chinese workers in the last 10 years. Unfortunately it is inaccessible, partly unpublished and partly published only in the Chinese language.

Apparently the well-known drawing of a dust storm with tornado (Fig. 58) in the desert of Takla-Makan appeared in the book *Atmosphere* by

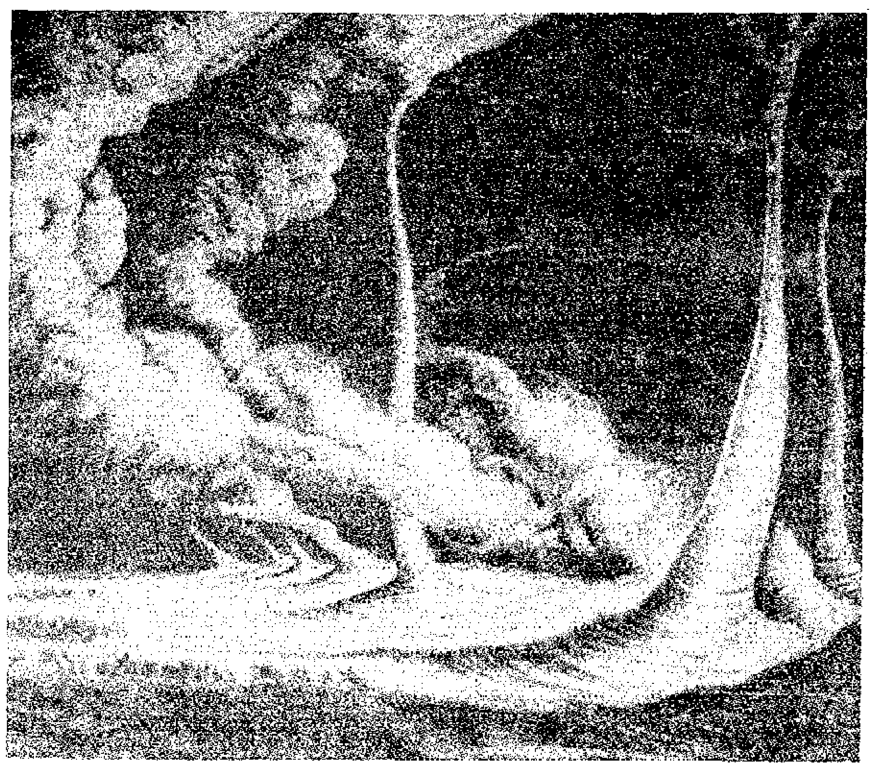


Fig. 58. Dust storm with tornadoes in desert of Takla-Makan (Flammarion, 1888, Fig. 240).

Flammarion (1888, Fig. 240) from the description of the exploration of 1850 given by T. Atkinson. This drawing is based on imagination but it shows an interesting similarity with the dust storms of Tsai-dam drawn by N.M. Przheval'skii (Fig. 57).

One of the first descriptions of a dust storm in southeast China, during the Russo-Japanese war of 1905, is included in the "Proceedings of Meteorology" (*Meteorological Vestnik,* No. 15, 1905, p. 182). The quantity of dust in the air was so great that war operations became difficult. Visibility became so poor that men could not be seen even at a hundred steps away. The dust was yellow, fine and of the loess type. During rain it fell in enormous quantities. In Tyan'-tszian, 4–5 mm dust was precipitated in four hours of rain. Such dust storms are common in Peking, Tyan'-tszin and even in Shanghai. They generally terminate over the sea and in isolated cases penetrate up to Japan.

In a short review of the Chinese climate, Koeppe and Bangs (1928) say that the main wind system is the monsoon. In summer it blows from the sea to the land and in the winter from the land to the sea, from west to east. The winter winds attain great speed, often changing to dust storms, and transport an enormous quantity of dust. There is no doubt that the monsoon system has a very important role in the deposition of loess.

Numerous typhoons strike the Chinese coast, moving from the southeast, from the sea to the land. These are more numerous and stronger than those of the USA. There were 54 typhoons in 12 years, from 1904 through 1915. They became extratropical cyclones over the land and gave rise to heavy rain, not only in central but also in north China.

Often they were accompanied by tornadoes, for example, the typhoon of August 11–14, 1923 (Barbour, 1924).

Typhoons and tornadoes have an important role in the transportation of marine microorganisms deep inland. This does not have much significance for the formation of loess.

The wind system has been considered in detail by the workers of the meteorological department of China (Staff members, 1957).

Important data are given in the "Proceedings of the Joint Soviet-Chinese Expedition" published by the Chinese Academy of Sciences (No. 1, 1958, Peking, in the Chinese language). Part of it is included in the monograph by M.P. Petrov *Deserts of Central Asia,* Vol. I, "Ordos, Beishan', Alashan' " (1966). Earlier material has been summarized in the works of V.M. Sinitsyn (1954, 1959a, 1959b).

The most important factor in the origin of dust storms of Central Asia, as already mentioned, is the Mongol-Siberian anticyclone. This enormous atmospheric circulation extends over a large area, from the Siberian plateau to Mongolia, but displays relatively small altitude. Its position over Central Asia is shown in the diagram prepared by V.M. Sinitsyn (Fig. 59). In this region a high pressure (810 mm) has been observed on the surface (Voeikov, 1895).

The anticyclone determines the direction of the wind in the deserts of Central Asia. The speed is relatively low and the wind is mainly northeasterly, crossing the desert and easily surmounting peaks of 1–2 km height. But very big mountains such as Kun'lun' and Nan'shan cannot be surmounted. The cold air mass rises up the slope, weakening gradually, while the major portion circumvents the ranges, acquiring a northwesterly direction.

The prevailing wind in Central Asia is generally northwesterly, northerly or northeasterly. Dust storms from these directions are strong and frequent. Haude (1940) carried out observations at two meteorological stations at Alshan in 1932. According to him, among 47 dust storms, 44 had a northwesterly direction and three easterly. Five storms in January and two in March attained hurricane strength and came from the northwest.

In summer and autumn the anticyclone dissipates and is replaced by monsoon winds of southeasterly and southerly direction. They are weak and rarely cause dust storms. Nonetheless they influence the transportation of dust and sand. They create the unique pyramid sandhills (Fig. 60). It is interesting that even in summer the occasional gusty northwesterly wind is stronger than the southerly winds.

The data on the antiquity of the Mongol-Siberian anticyclone are interesting. In the valleys of Kun'lun' and Nan'shan the aeolian loess covers the moraines of the last ice age. The aeolian sands were deposited as fluvial sediments in the valleys of the mountain base. This shows that the anticyclone obtained "throughout earlier epochs, i.e. over the last 12–15 thousand years" (Sinitsyn, 1959b, p. 1328). To this, another 20–30 thousand years should be added as the moraines were formed before the last epoch. Therefore an earlier accumulation of loess and aeolian sands and the still earlier occurrence of the anticyclone are quite possible.

The storms associated with Mongol-Siberian anticyclones are strong and quite frequent but not unique. The formation of pyramid sandhills by the southeasterly wind in Alashan has been discussed earlier. Such sandhills are found in the northwestern part of Central Asia (Fedorovich, 1961) and in the deserts of Takla-Makan (Fig. 61). These are formed due to the meeting of the wind from a northeasterly direction, coming from the anticyclone, and the stormy winds from a northwesterly direction, coming from Alaisk valleys.

A schematic diagram of the direction of gusty winds in Central Asia is given in Fig. 62. It is related to the deserts, mainly in the valley regions of Beishan (in the west), Alashan (in the center) and Ordos (in the east). The wind to a great extent is determined by the position of the southern mountain massifs (Petrov, 1966).

At Beishan one finds variable wind directions due to its distance from the sea, which weakens the effect of the easterly Chinese monsoon, and also due

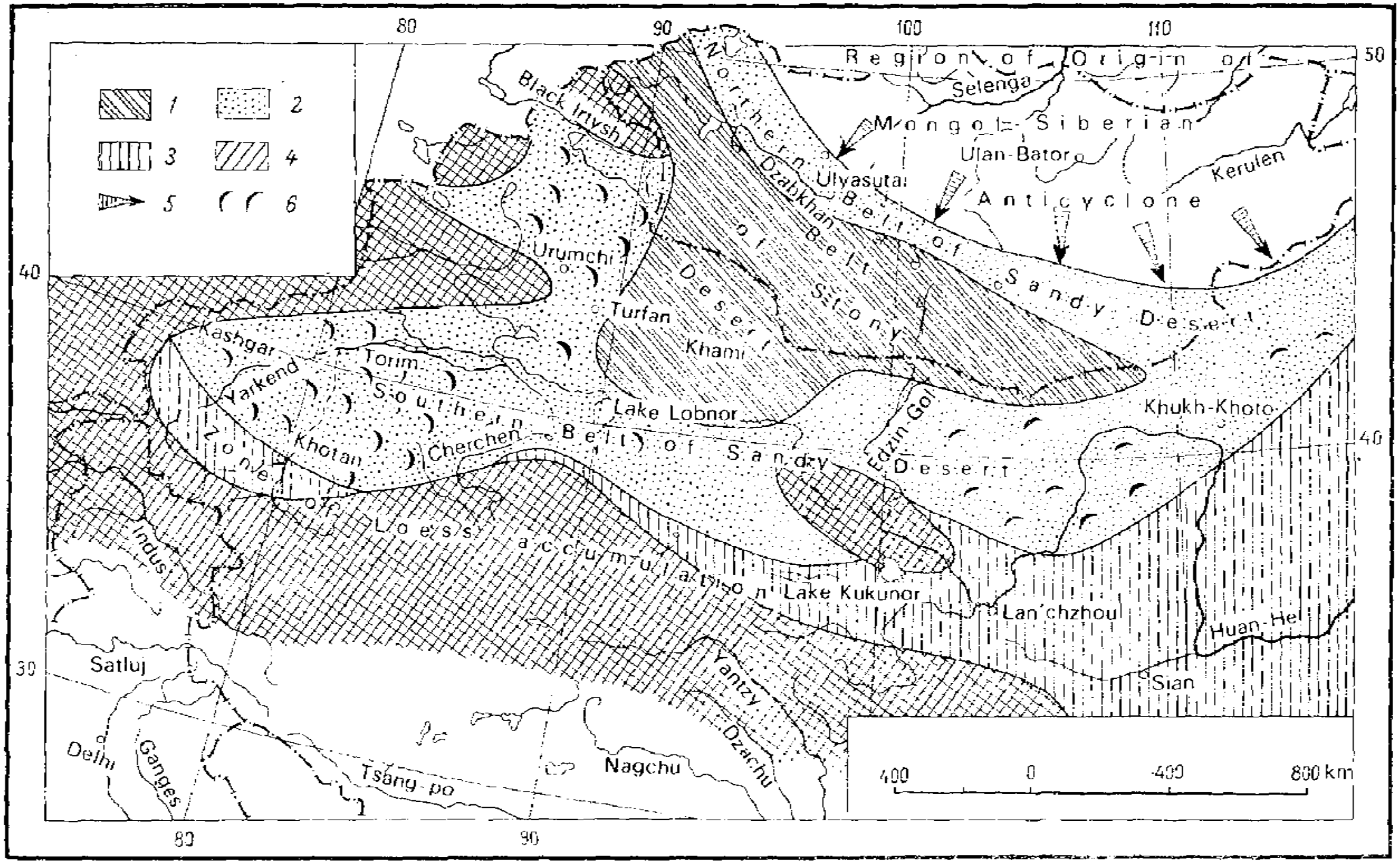


Fig. 59. Central Asia (Sinitsyn, 1959a, map 8).

1—Rocky desert, hammada; *2*—aeolian sands; *3*—loess; *4*—mountain massifs; *5*—wind direction; *6*—position of sandhills.

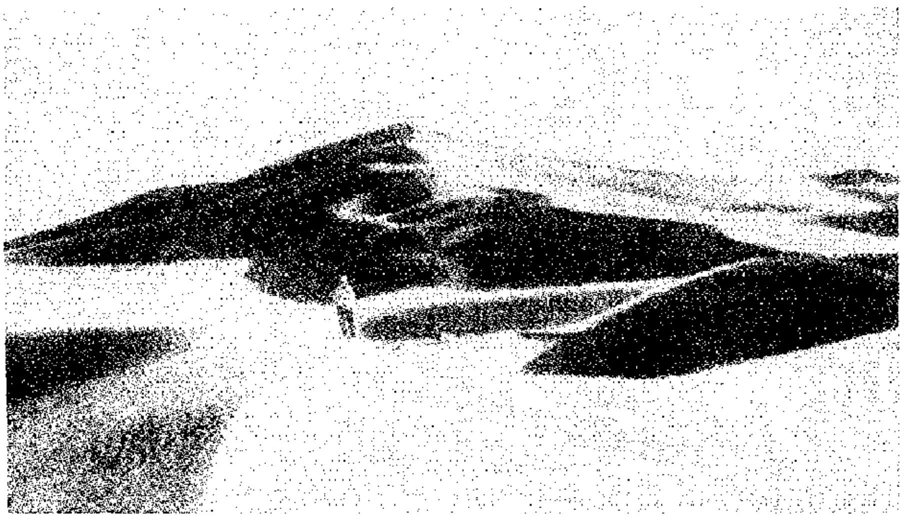


Fig. 60. Pyramid sandhill, Alashan (Petrov, 1966, Fig. 96).

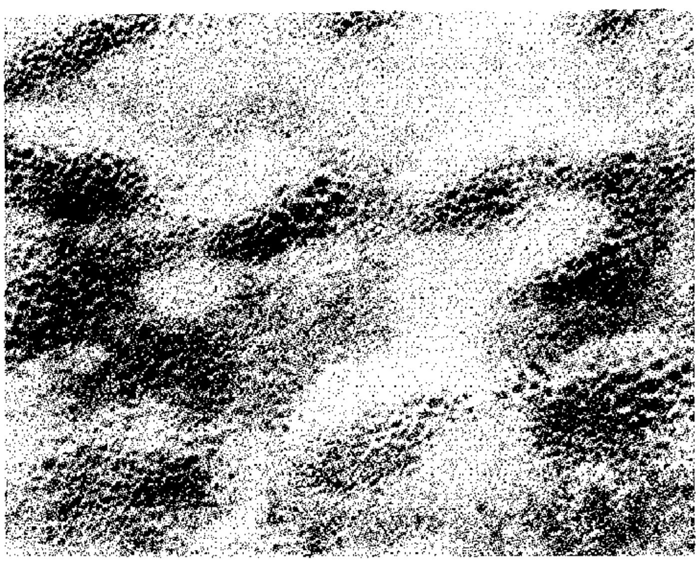


Fig. 61. Pyramid sandhills and knots, Takla-Makan (Fedorovich, 1961, Fig. 4).

to the number of mountain peaks.

All the sandhills are situated in the regions of the Mongol-Siberian anticyclone during the winter and autumn. These display clear, less windy weather. The wind is northerly and northeasterly.

In spring and summer the anticyclone dissipates, frontal activity is intensified and some of the cyclones cause cold waves in their rear. The wind intensifies considerably, and sometimes is stormy, accompanied by dust storms and downpour. In the north the wind is northeasterly or north-

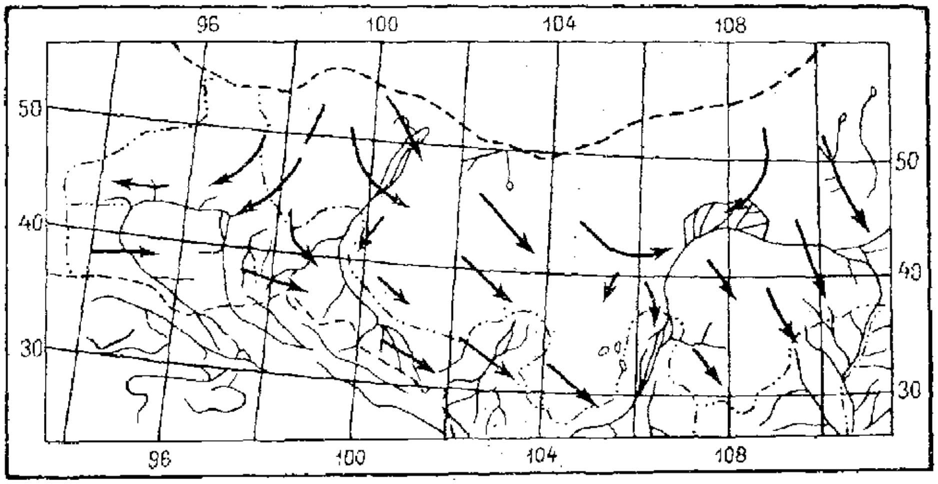


Fig. 62. Schematic diagram showing directions of gusty winds in Central Asia (Petrov, 1966, Fig. 92).

westerly and in the southwesterly or northwesterly. This can be observed distinctly in Suburgan, not far from Yumyn (Fig. 63). Its western (left) side is much more eroded than the eastern (right) side.

M.P. Petrov describes the stormy rain vividly: "From the west a dark sinister cloud appeared. It grew fast and covered the sun. Darkness fell everywhere. In quick succession, first a squally wind blew, then the rain started. It came as a continuous wall, striking noisily with pebbles and stones. Our surroundings of pebble-rocky desert were instantly transformed. Falling with force on the hot stone, the drops of rain changed into dust drops which evaporated instantaneously. The clouds swirled over the desert. Immediately the film of dust covering the mountains and valleys disappeared. Everywhere, in thick or narrow channels, muddy water started flowing, down to the edge of the dry channel where we stood. Soon it was carrying rapid, dirty currents: turbulent water in which the stones rattled together. The rain came down over it in torrents.

"The rain stopped suddenly within quarter of an hour. The cloud disappeared and the sun reappeared. After the rain a rainbow appeared over the horizon. The sunlight was reflected from the wet rocks, which sparkled with the water drops. All this lasted only a short time.

"The channels disappeared, the pool of water quickly percolated into the loose soil. The current in the main channel disappeared. From everywhere clouds of steam rose. The hot sun dried the rocky outcrops and the pebble beds in no time and they started heating up again. The desert returned to its original form" (Petrov, 1966, p. 243). The rapidity, violence and short duration of all the phenomena is pictured clearly and beautifully.

The northwesterly wind dominates completely at Alashan. It determines the northeastern alignment of the sand ridges and transports dust particles

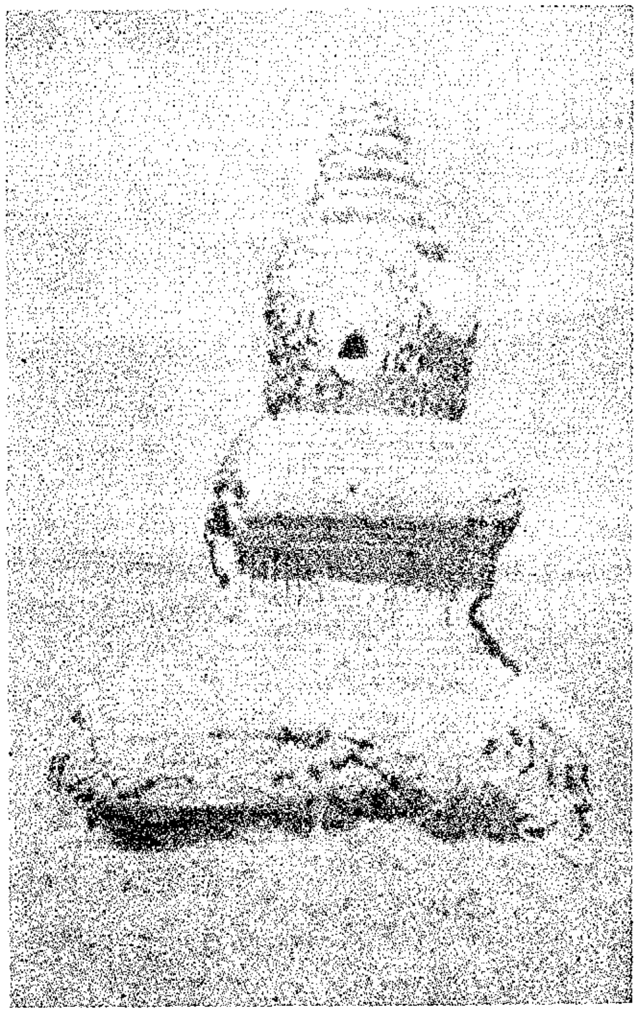


Fig. 63. Suburgan in Yumӱn. Western (left) side is more eroded than eastern (right) side (Petrov, 1966, Fig. 103).

(loess) far to the west, at Ordos. Only in the southeastern region does the northwesterly wind change to southeasterly. Due to this an enormous mobile mass of sand forms unique pyramids. Such pyramids are not found in Central Asia. This shows the prevalence of the northwesterly winds. They develop in the deserts of Takla-Makan.

The northwestern part of Ordos has a desert like that of Alashan. The direction of the wind here is mainly northwesterly; the wind, stronger in summer, becomes a dust storm. Sand massifs develop at places. Some dry steppes are seen to the east of Ordos, especially in the southeastern area. The wind regime is a contest of northwesterly and southeasterly winds, as can be seen in the hodographs given in the monograph by M.P. Petrov (1966, p. 60). All the northwesterly storms are displayed here. All the dust particles are transported to the loess plateau situated southeast of Ordos.

The hodograph (Fig. 64) shows that in the northwest (meteorological station Otok), throughout the period in question (months I–XII), the particles in the air (dust) move rapidly to the southeast; this ceases in March (III). In summer and autumn (VII–VIII, IX) the dust remains almost static. In the northeast (meteorological station Jasag) the movement of particles is to the southeast, but quite slow; delay occurs in March (III); summer (VI, VII, VIII), and winter (XI, XII). The hodograph is capricious at the southeastern end (meteorological station Yulin). During January–May the particles move southeast. They turn in the opposite direction and during June–August they move northwest, returning to their initial location. During September–December they again move southeast, but a relatively small distance.

The hodograph should not be seen as an absolute state. It changes every year, but gives a clear and distinct picture of the direction of the wind and of the stability of these directions. Unfortunately, such hodographs are seldom found in meteorological literature. Not to speak of international literature, it is not even found in the Central Asian monographs. If hodographs for Termez and Kushki were available one could have answered Romanov's question: Is dust being removed even now from the region of our deserts or does it move the same distance to the north and to the south?

Hodographs of wind at Alashan (Petrov, 1966, Fig. 93) show that the general movement of the particles over a year, to the southeast, attains considerable speed. Sometimes (in February and in summer) it breaks to the northeast. Data to prepare a hodograph for Beishan were not available. There, quite likely, it has its original, usual complex character.

There is a section "Deserts and dust storms" (p. 207–209) among the series of additional data on the storms of China. It is mainly based on study of the form of relief of the aeolian sands and distribution of aeolian deposits. They depend on the transportation strength of the wind.

As in the case of Central Asia, very little is given in the literature regarding the transportation activity of the wind in China. For Central Asia we have detailed descriptions of individual winds, e.g. the "Afghan wind", "ibye", etc. The dust storms have been studied in great detail. For the loess province of China such descriptions are possibly absent.

Therefore from the information contained in this book, we can give an idea of the strength and activity of wind in China. It forms an enormous mass of aeolian sand. The region of maximum accumulation of loess (loess province) in the world and of aeolian clay, chiefly of the red variety, also comprises special areas. The distribution of these complex aeolian deposits is discussed in detail in the work of I.P. Gerasimov (1959) and in the outstanding monograph *Loess-Red Clay Formation and Loess Relief* by A.S. Kes (1964). The massive aeolian sand and its composition in Ordos, Alashan and Beishan have been described by M.P. Petrov (1961, 1966).

Numerous Chinese workers have dealt with various problems related

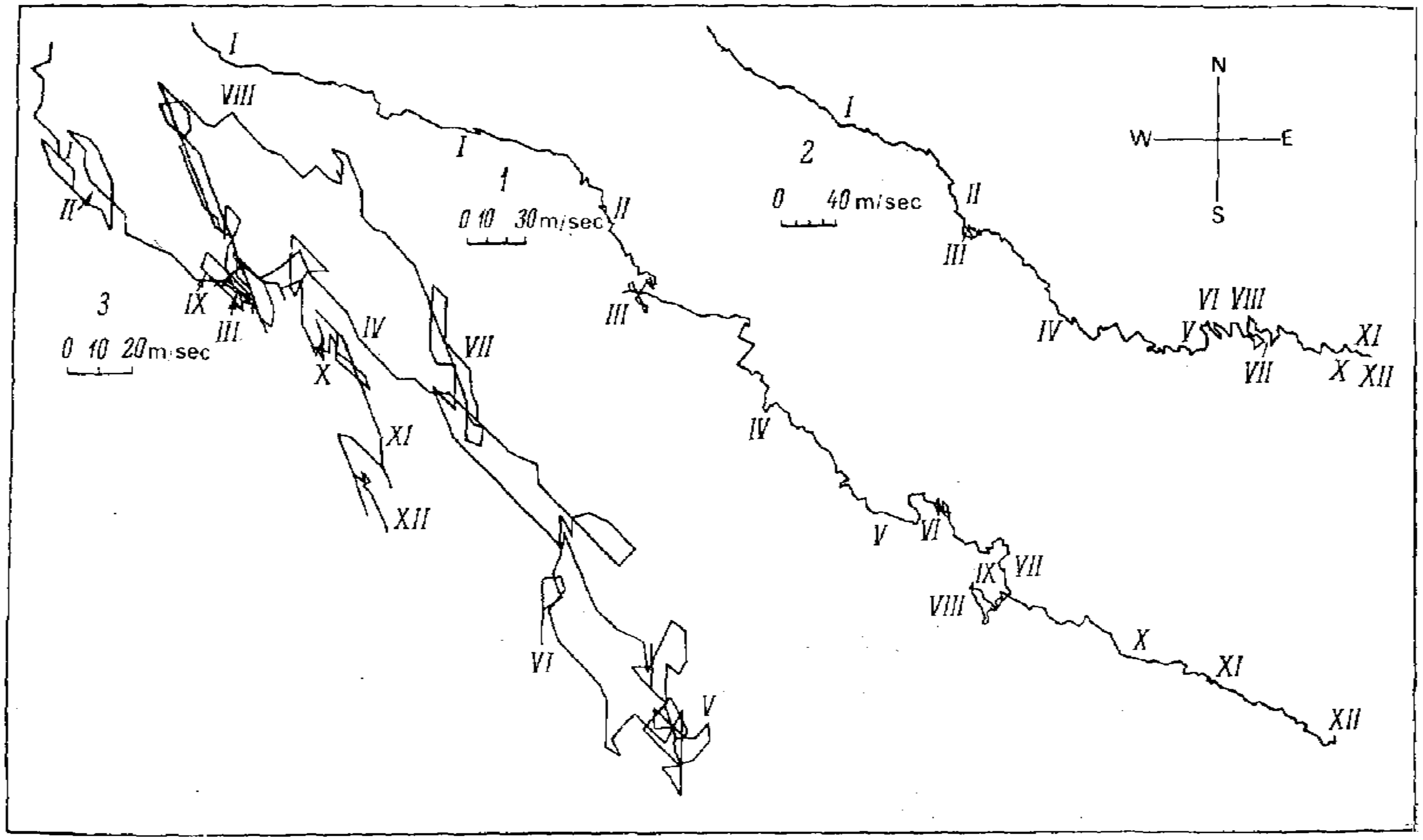


Fig. 64. Hodographs of wind at meteorological station Ordos (Petrov, 1966, Fig. 29).
1—Otok, 1956; *2*—Jasag, 1956; *3*—Yulin, 1954; I–XII—months.

mainly to the loess and sand. Most of it is written in the Chinese language and is therefore difficult to use. Among a few works written in the Russian language the work of Chan-Tsun-Khi on the genesis of loess may be cited (1959). Bibliographies in Chinese as well as Russian are given in the review papers of A.S. Kes (1964) and M.P. Petrov (1966).

North African Storms

In the Sahara dust storms occur quite widely and constitute important phenomena. They have therefore received special names. In the eastern Sahara and Egypt the dust storm is known as "khamsin"; in the north Sahara as "shekhali"; in the Priatlantic regions as "prifi"; in the central Sahara as "harmatan". The wind blowing from the Sahara and Arabia to Italy and the north coast of Africa is known as the "sirocco".

The dust storms of the Sahara are identical with the dust storms of Asia except for two differences. The most important difference is the extremely wide distribution of the dust that they transport. To the west and to the north the dust propagates over several thousand kilometers. Due to this, concentration of dust does not take place and the thick loess characteristic of Asia is altogether absent here. To the west the main mass of dust settles at the bottom of the Atlantic Ocean, forming marine aeolian deposits which have drawn considerable attention (described on pp. 521–531).

This explains the differing vertical distribution of dust. In Asia the dust is rarely lifted above 3 km, usually to a height of 1.5–2.0 km or less. Therefore 5–6 km high mountain peaks form an obstacle and the dust settles on the slopes.

Over the Sahara, due to the special configuration of the wind flow, the dust is lifted to a height of 6–7 km. Therefore even such peaks as the Atlas and Alps do not impede its movement.

The second difference is in the coloration of dust. In Asia the dust is yellow, straw gray or loess-colored. Therefore the dust storms are akin to the group of yellow storms. In the Sahara red dust is predominant and so the storms belong to the category of red storms. This feature was noted 120 years ago by Ehrenburg (1849). Examining the dust under the microscope, he established that the grains of quartz contain a thin halo of iron oxide, giving them a red or reddish color. Often the red color is so bright that rain with this dust looks like blood. Such "blood" rain causes terror in the superstitious mind. The red dust is described hereinafter (see pp. 160, 502–509).

A more important difference is the abundance of tornadoes accompanying dust storms in the Sahara and their almost total absence in Asia. Quite probably this is related to the different types of cloud cover, cloud being abundant with the dust storms of the Sahara and very much less in evidence over the deserts of Asia. This is due to the fact that the Sahara is bounded by the sea on either side and the deserts of Asia are far from the sea.

The majority of dust storms are caused by fronts where masses of warm and cold air meet. In winter fronts are more frequent to the north of the Sahara, but they are observed deep in the interior too. R. Kapo-Rei (1958) in his monograph gives three synoptic maps of winter sandstorms. One of the storms (December 16, 1948) occurred in the south of Sahara in the form of a relatively narrow belt of intense wind moving from east to west (Fig. 65). Another storm, of March 21, 1942, originated in the northwest, but exhibited a similar narrow belt moving southwest to the Atlantic Ocean (Fig. 66). In summer, on the contrary, the north of the Sahara is stable while in the south a number of strong sandstorms accompanied by numerous large vortices occur. Almost all the sandstorms move to the ocean, carrying with them masses of red dust. They are known as "Irifi" in the central zone and "Harmatan" in the south zone. The normal duration of an "Irifi" is a few hours. They cease at night and revive in the daytime. Data on the quantity of dust transported by them are not available.

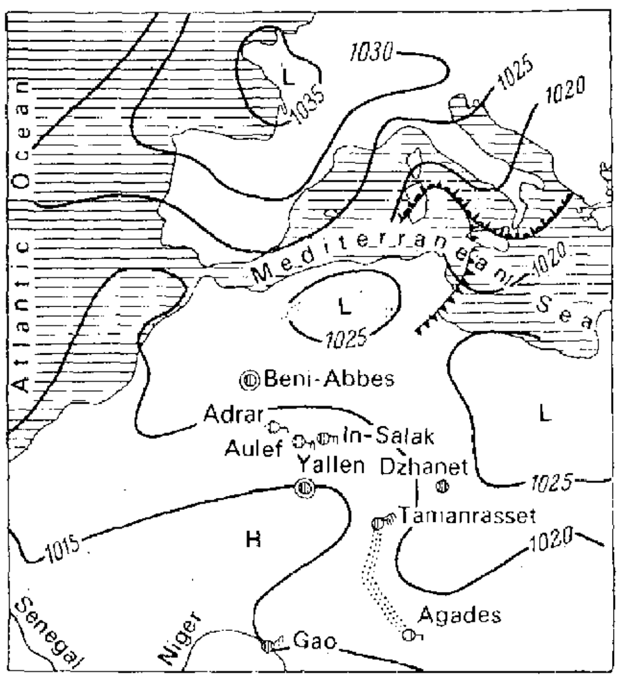


Fig. 65. "Sand" storm (shown with dots) between Tamanrasset and Agades of December 16, 1948 (Kapo-Rei, 1958, Fig. 7). *L*—anticyclones; *H*—depressions.

The transition of a wind blowing west over the northern Sahara to a hurricane can be clearly seen in the colored photograph of the west coast of Africa and the adjoining Atlantic Ocean taken by an American astronaut during the flight of a space vehicle in 1965 (Lowman, 1966). It shows the

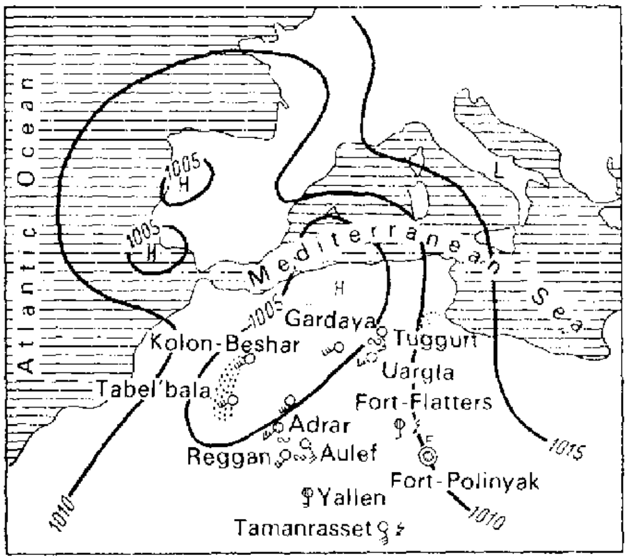


Fig. 66. Strong "sand" storm of March 21, 1942 (shown with dots) (Kapo-Rei, 1958, Fig. 8). *L*—anticyclones; *H*—depressions.

hurricane at the initial stage of growth without the "eye of the storm". The spiral cloud mass of rose color, possibly caused by the red dust, is of interest.

Still more interesting is the bright red storm, making the entire surface brick red. The red color of the soil that makes the surface red can very well be visualized.

The photograph covers Morocco and Ifin and includes the western part of the Ante-Atlas to the south of Agadir and to the north of the Canary Islands.

The red coloration, though not so bright, can be seen in other photographs taken by the automatic camera of a satellite in 1961 (Weaver, 1962). These photographs cover a still bigger area of the Sahara and the red coloration of the surface is maintained everywhere.

Winds of the Sahara: The winds of the western Sahara have been studied and described in great detail by Dubieff (1952, 1959). Their flow patterns are different in winter and summer (Fig. 67).

The wind is more typical and variable in winter, at first blowing from the north and then from the east. It attains considerable strength and steadiness. Along the north coast a "westerly" wind prevails and along the west coast the wind is known as "Aliyez". Almost all the dust is transported to the Atlantic Ocean by the harmatan.

In summer the westerly wind is absent, the "Aliyez" continues to blow but its direction has a southerly component. To the east of the Mediterranean Sea the "Yetezii" wind blows first toward the south and then toward the west. In location and direction the summer "Yetezii" over Africa is close

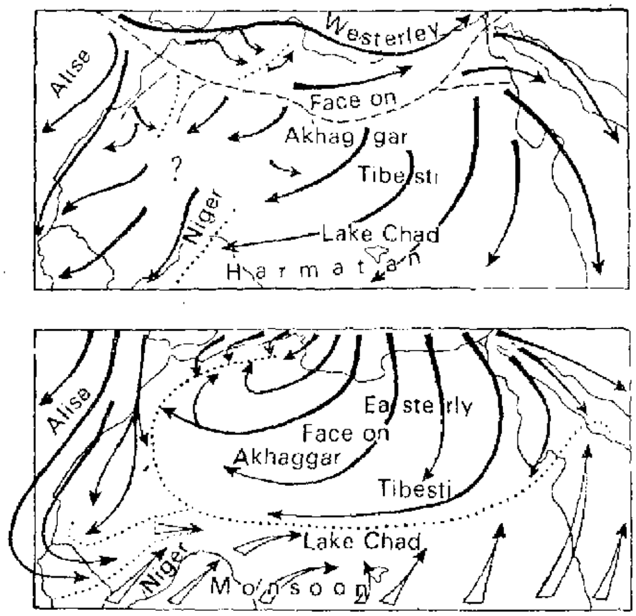


Fig. 67. Winds of western Sahara. *Top*—January; *bottom*—June. January Harmatan changes to June monsoon (Dubieff, 1952, Fig. 3).

to the winter "Harmatan". The yetezii limits the humid, cold monsoon from the south.

Dubieff believes that the harmatan and the monsoon are not interconnected. Other workers, however, think that the southern part of the Yetezii with an easterly direction is the summer harmatan. They believe that in the southern Sahara the humid, cold monsoon is at the bottom and the summer harmatan blows over it in the opposite direction.

Dubieff's diagram takes into account only the wind over the surface. At higher levels, above 2–3 km, the wind often has the opposite direction. In the central part of the Sahara a northerly wind blows both in winter and in summer. It causes development of a cold front and the dust wall lies ahead of the front (Fig. 68). This flux of dust at a height of around 2–3 km adopts the opposite, southerly, character and passes over the Mediterranean Sea to Europe. This explains the red dust storms moving from the Sahara to Europe, described by Ehrenburg and Helman.

Such an explanation is offered by Bochet (1948). The dust storms develop ahead of the cold front among the high mountains, such as the Atlas range. The southerly wind sucks up the dust and carries it first to the shore of the Mediterranean Sea in Oran, where the dust falls to earth in the form of silty red rain. Farther on the reddish clouds cross the Mediterranean Sea at a speed of 50–60 kmph. In southern Europe there is again rain with red dust.

At Oran the red cloud is observed at a height of 1,500–2,000 m. At such an altitude on the slopes of the Alps, the snow is colored red due to the dust

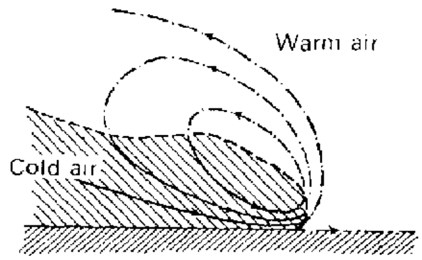


Fig. 68. Cold air meeting warm air creates an upward moving stream, lifting dust (Koschnieder, from Fett, 1958, Fig. 52).

from the Sahara. This is the limit of the height of movement of warm air from the Sahara, transporting the cloud with red dust. It should be noted that the cloud with red dust does not occur only at an altitude of 1,500–2,000 m. Often it crosses the Alps, i.e. occurs at a height of 5,000–6,000 m, as has already been mentioned.

Warm hot air transporting the mass of red dust from North Africa is often found in the Canary Islands. Here it has been given the special name "Levanto". Often it attains the strength of a hurricane, e.g. on September 20, 1919. The cause of the occurrence of the Levanto is not very clear. Earlier it was associated with the Sirocco, but this does not seem to be correct. It is probable that it belongs to the group of winds that transport dust from North Africa to southern Europe.

The dust storm and silt rain occurring over the north-western Sahara are described in the collaborative work of Petitjean (Combier, Gaubert and Petitjean, 1937). Eleven strong dust storms accompanied by silt rain occurred from 1926 through 1934. Among them four did not even enter Algeria or Morocco, five ended with silt rain over southern France or Spain, and two penetrated the Alps and Yugoslavia, forming "yellow snow" over the Alps. Petitjean describes the wind and the meteorological conditions in detail but says nothing about the dust.

There is one article on the composition of soil in this collaborative monograph (Combier, Gaubert and Petitjean, 1937, p. 50–68). The facts mentioned here are well known. Attention is drawn to the indications (p. 59 of the above reference) that in 1872 dust containing fossils of protozoa from the upper chalk blew in from the surface of the Egyptian Sahara. In the "productive" oil-bearing stratum of Pliocene age of the Apsheron subcontinent the protozoa (foraminifera) of the upper chalk age are quite often found. It is quite likely that their transportation for tens and even hundreds of kilometers is associated with the activity of dust storms and not with the water flow, as is usually thought. This possibility is interesting since it suggests that the lower Pliocene of the Apsheron subcontinent had a semi-desert, i.e. bare surface similar to that of today.

In the third paper Combier (Combier, Gaubert and Petitjean, 1937, p.

40–49) describes dust storms in Syria and Mesopotamia, in the valley of the Euphrates, and provides a number of interesting photographs. The storms in these photographs can easily be compared with Central Asian storms. The data on the height and structure of the dust walls of the initial storm, as seen from aerial observations, are quite interesting. The wall is not very high, not more than 1,500–2,000 m.

Harmatan: The harmatan is a typical development along the southern edge of the Sahara. It is very stormy, often with hurricane winds of easterly direction. Passing over the dry marshy land in the uplands of Nigeria, it lifts a large quantity of light whitish sand having a high content of freshwater diatoms. This dust settles along the shore of the Gulf of Guinea, to the south of the region of origin of the red dust wind. Summelhack (1932), Danekelmann (1899, 1913) and Gruner (1899) have given examples of very strong harmatans.

The dust transported by the harmatan has been studied by Seafried (1913) and Leinz (1937). The marine deposition with the mixture of this dust (Leinz, 1937) is described hereinafter in the section "Aeolian-Marine deposition". Both these authors record an unusually large quantity of freshwater diatoms and the usual mixture of charcoal from forest and marsh fires

An interesting suggestion is posed by Dubieff (1952), who believes that the red dust is also transported to the Black Sea by the harmatan. This opinion has been expressed by no previous worker. They assumed that the red dust and gray diatomic dust are transported to different parts of the Atlantic Ocean by different systems of wind and that the harmatan transports only gray, whitish dust. If Dubieff's idea is correct it means that a single system of winds can transport dust of different compositions.

The differences in dust storms are not dependent on the strength and direction of the wind but on the dust they lift. This fact has been correctly noted by M.M. Zhukov (1964).

Haboob: The dust storms in the southeastern part of Sahara, in Sudan, are as many and as frequent as in Central Asia. There are similar short-duration storms, lifting dust to a small height, as well as strong storms lasting two or three days, lifting walls of dust to a great altitude and stopping all traffic. A short review on the subject is given by Freeman (1952). Freeman's work, like Romanov's, is meant for aviators.

The strong summer dust storms are known as "haboob". They originate due to the movement of masses of cold air. Along the cold front a turbulent flux of warm air rushes upward from the surface, carrying an enormous mass of dust. The sharply defined wall of dust characteristic of the haboob is formed and moves along with the cold front. Often, the wall of dust is a majestic, frightening sight (Fig. 69). Going up to 1,500–2,000 m, it joins with the dark, thick clouds carried by the storm and is often lifted still higher.

The color of the dust depends on the color of the sand of the region over which the Haboob passes. In Khartoum it is red but at other places it is yellow

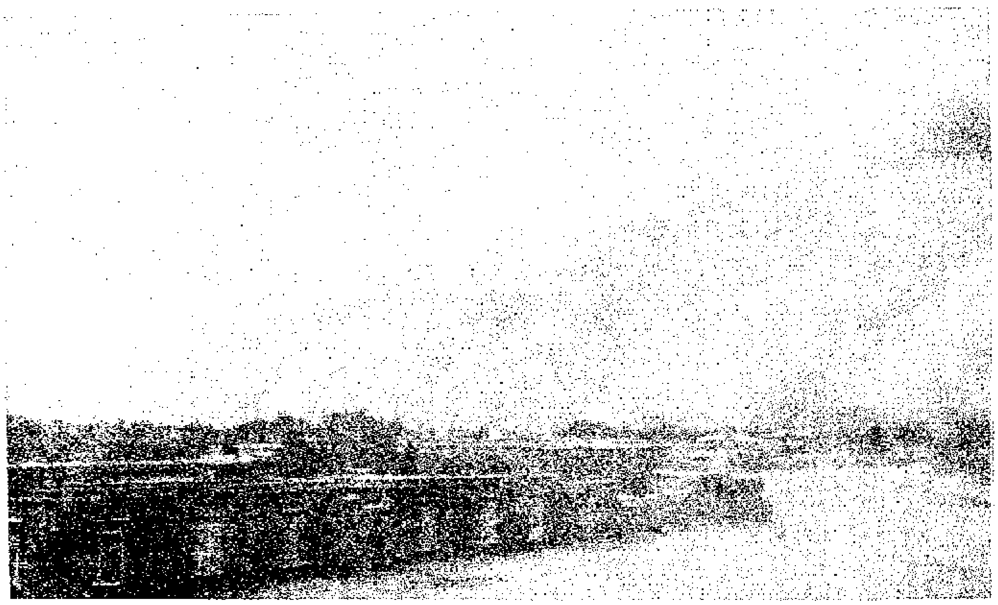


Fig. 69. Typical Haboob over Khartoum, Sudan. Dust cloud is moving to left with cold front (see Fig. 68).

or even black. This once again underlines the difficulty of isolating red dust storms from yellow.

Analysis of dust taken from a height of 15 m showed that it consisted of particles of quartz, organic matter (humus, remains of insects and plants) and clay particles. The color of the dust is determined by their ratio. The size of the particles is 10–70 microns, usual for dust storms (Schempff, 1943).

Schempff (1943) showed that the haboob is invariably associated with a gigantic thundercloud. This indication agrees with the observations by Farquharson (1937), who has described in detail the synoptic situation that gives rise to the Haboob. According to his observations the approaching dust wall always precedes the vortex formations (Fig. 70). It resembles a big dust vortex in form and size, but is associated with thunderclouds. In this it resembles a tornado and is sometimes referred to as such. It differs from the tornado in its less dense, undefined outline and greater width. It is a different type of formation, intermediate between dust vortex and tornado.

The Haboob appears in the form of gray columnar vortices contiguous to each other. A continuous homogeneous wall of dust occurs in between the individual columns. Its width is of the order of 20–30 km.

Often the quantity of dust is enormous. In two months an obstacle creates a ridge of sand and dust 4–4.5 m in height. The frequency of Haboobs is also quite large. In eight years (1916–1923), at Khartoum, 196 cases were recorded, primarily in the rainy season, when thunderclouds are quite common. The duration of the Haboob varies from half an hour to a few hours, three hours on an average. The direction during the rainy period is

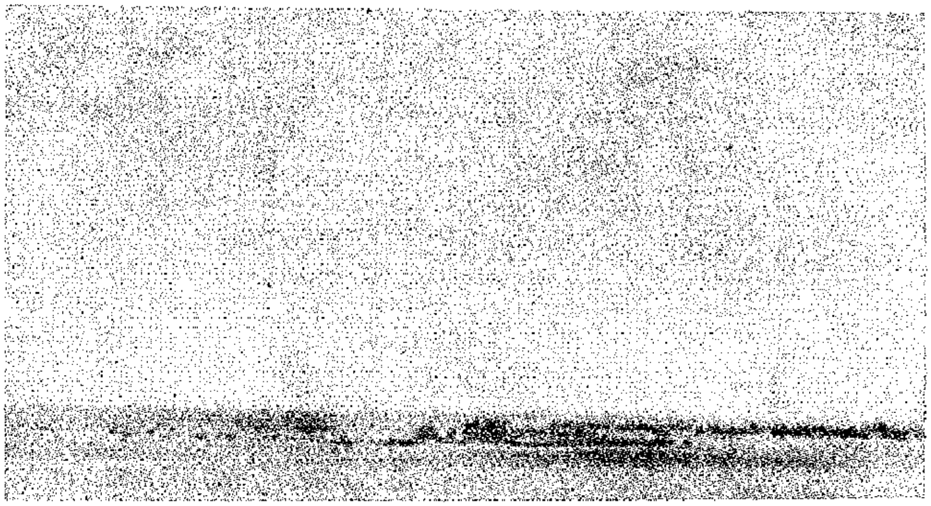


Fig. 70. Vertical dust storm preceding Haboob, Sudan (Farquharson, 1937, p. 30).

from south to east and it transports red and yellow dust. In the dry season the Haboob blows from the north or northwest, carrying black dust. The area of development is large, from the Red Sea to the region 800 km west of the Nile. To the north it is observed in Aswan, but here it is rare; in all there were about 10 over a period of 18 years.

The Haboob is close to the Simoom and dust storms of Central Asia and is often associated with tornado-type vortex formations (Fig. 58).

Khamsin[1]: This is a dry, hot, dusty desert wind in the Egypt and Sinai deserts and over the Red Sea. The main direction is northerly and northwesterly. Often it attains great strength, culminating in a dust storm.

The khamsin rages red in the desert.
The languishing passion rushes in the air.
The sand uses its wing
And burns with fiery breathing.

. . . .

The khamsin became happy, remembering the past,
And then the desert moves
And rushes to the sky. In the yellow sky
The sun fades.

Here the Khamsin is vividly described by Lesya Ukrainka (Prokh, 1961, p. 132).

A less poetic but more factual description of the Khamsin is given by Oliver (1945, p. 28, 35–40). Usually a light wind starts after sunrise. With the intensification of sunshine an opal haze forms in the air. Around 11

[1]This word means "fifty". It is believed that these winds blow for 50 days after the vernal equinox.

o'clock it attains the strength of a storm or even hurricane. The entire atmosphere is filled with yellow, hot, dry dust. Visibility drops to 200–100 or even 50 m and finally to zero. All activity comes to a standstill. Lights are switched on in the houses. After three or four hours the strength of the wind falls and visibility improves. In the evening the wind sharply changes direction and may stop altogether. In very rare cases the khamsin continues all night and the following day. The speed of the wind becomes 70–80 kmph. (Fig. 71).

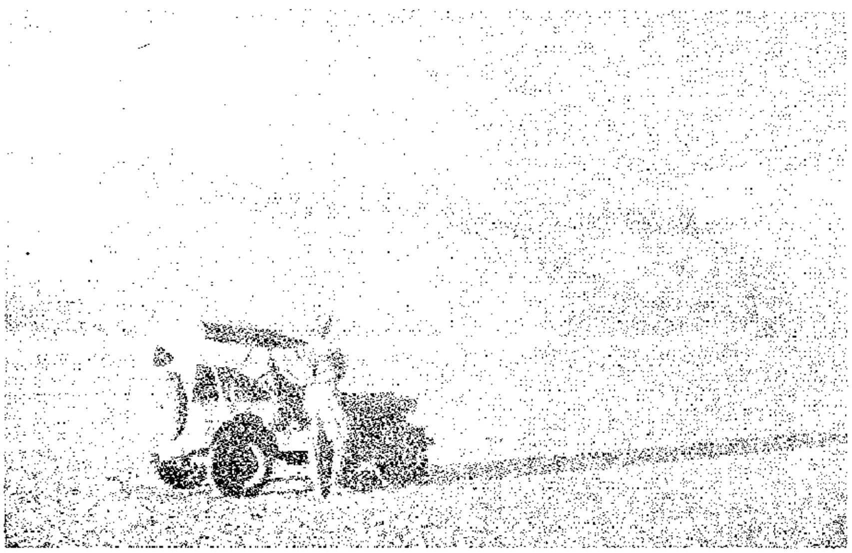


Fig. 71. Khamsin. Egypt, shore of Mediterranean Sea (Lane, 1966).

The size of the dust grains varies from 7 to 1 micron. The particles more than 80 micron in size are sand which is not lifted above 1–2 m even by strong storms.

The calculation of the quantity of dust is quite rough. The quantity of dust may go up to 0.5 ton per acre (4,047 m^2) per hour at the time of the strongest dust storm. Usually the dust is less, 0.2–0.1 ton per acre per hour.

Plant cover was destroyed during the war and the frequency of dust storms sharply increased: from eight storms it increased to 40 or 50 (in 1941–42). After the end of the war the plant cover quickly revived and by 1944–45 the number of storms had fallen to 11.

The dust storm observed in 1902 at the Suez canal was associated with the khamsin (Prager, 1903). The high dust wall moved in from the west. It consisted of warm dust and was accompanied by a loud noise. The dust was so compact that the eyes could not be opened. The strength of the wind reached 7–8 units. The storm continued for three hours and went as fast as it came. The water surface of the canal became gray-red due to the dust. The red dust covered the decks of ships.

A similar dust storm passed over the eastern Mediterranean Sea in 1913.

It continued for two hours. The air was so full of dust that darkness fell all around. The storm moved in quickly and as quickly left.

The khamsin often blows from a northerly direction, carrying a mass of red and yellow dust to the sea. Oliver (1945) describes how in 1943 the English warships in the Mediterranean Sea operating at a distance of hundreds of kilometers from Africa were covered with layers of dust transported by the khamsin.

There is no doubt that the khamsin lifts masses of dust in the Sahara and carries them to the Mediterranean Sea. It is not clear, however, whether the name "khamsin" can be given to the high wind that envelops this dust and carries it to a height of 3–4 km or more to southern and central Europe and even to the Ural. Often the name "intercontinental storm" is suggested for such a wind. This name is appropriate except for the fact that it does not reflect the synoptic features of this peculiar air flow.

One of the latest major intercontinental dust storms is briefly described by A.D. Zamorsky (1964). It started in North Africa on March 20–22, 1962, and moved over Syria, southern Greece and Turkey. On March 23 it reached the Caucasus, where it rose to a height of 4 km. Here it bifurcated: one branch turned northeast, to the North Caspian, and the other to the north, to Penz—a distance of 5,000 km from Tunisia.

The frontal vertical movement, described above in detail, lifted an enormous quantity of dust into the air. The dust was engulfed by currents aloft and was transported thousands of kilometers to the northeast. It settled on the surface in the form of colored rain and snowfall. Such rose-yellow snowfall occurred over Penz. In the mountainous Caucasus the rain and snow had a dark red coloration. The quantity of dust in the rain in the Caucasus was 0.3% of the total amount of rain. According to A.D. Zamorsky (1964), part of the dust came from the Sahara (red dust) and the rest from the Livinsk desert (yellow dust). This needs further verification. The dust lifted in the Sahara rose up to a great altitude and it is unlikely that it can be associated with the cold front that raised dust in the Livinsk desert. The dust lifted in the Sahara can be red and yellow, as has been repeatedly recorded.

The khamsin, like the "Afghan wind", often is associated with the intense manifestation of atmospheric electricity, arising out of the friction in the dry dust particles. Siemens' observations are first-hand and interesting. Along with other engineers the well-known electrical engineer carried out a study for the installation of telegraph lines in Egypt. In Cairo they decided to climb the Heopsov pyramid (Siemens, 1860). Early in the morning of April 11, when they left the city, the guide was apprehensive when he saw light gray-red clouds over the northwestern horizon. At 9 in the morning they were at the base of the pyramid and after 20 minutes they were pulled "like bales of cotton" to the top of the pyramid by three Arabs for each engineer.

At the top a bitter cold wind, becoming stronger and stronger, was blowing. The red spot on the horizon changed into colorless smoke, engulfing Cairo and its surroundings. Siemens observed that small vortices lifted dust into the air and an impenetrable yellow cover hid everything. The dust was lifted higher and higher. At last, with a rustling sound, it reached the top. The Arabs hid themselves behind the stones or jumped up and down and shouted "khamsin, khamsin". Lifting up their hands they stretched the index fingers and immediately heard the unique soft sound reminiscent of the sound of flowing water. Siemens also lifted his finger and felt fine pricks due to electrical charges.

Siemens then lifted his wine flask fitted with a stopper and tin top. Again he heard the murmur and a small spark jumped from the metal label of the flask to his hand. He lifted the flask still higher, holding it with the stopper. There was a big spark and he got a severe shock. It became clear to him that the flask had become a Leyden's jar. He and his associates started carrying out various experiments with their flasks.

The wind attained hurricane speed, transporting an enormous amount of dust. The Arab guides, lying on the stones, watched the Germans with horror. Finally they decided the Germans were practicing witchcraft and asked them to go back down. The engineers refused and continued their observations. The Arabs then started dragging them down. The chief guide grabbed Siemens and started dragging him. Siemens touched the flask to his nose. There was a strong spark 10 mm long and the Arab fell down as if he had been struck by lightning. With a loud cry he sprang to his feet and with a few bounds disappeared. The other Arabs followed his example. The engineers were left alone and the khamsin did not stop for two hours. The storm passed over, the Arabs appeared and the descent from the pyramid was smooth.

In this vivid description, apart from the electrical phenomena observed by the engineers, attention is drawn to the mention of a cold, strong wind preceding the khamsin and to the absence of any moving dust wall. The vortex lifted the dust at places in the manner Oliver described at a later date (see page 156).

Red storm of 1901: This storm has been described in detail by two German meteorologists, Hellman and Meinardus (1901). It started on March 9 in the north-central Sahara and from the night of March 9–10 it passed over the entire coast of Tunisia and western Tripolitania in the form of an exceptionally strong sirocco. The air, full of red dust, was opaque. The sun was not visible and darkness fell. There was panic among the people as they waited in the darkness. During daytime the phenomenon reached its maximum intensity and everything was covered with layers of dry soil of dark yellow, yellow-red or rose color.

The main cloud system moved over Tunisia, crossed the Mediterranean Sea and reached Sicily. Here a strong storm lasted the whole day. The air was filled with red dust and in the evening "red" rain fell, causing panic among the superstitious Sicilians.

In the evening a dust storm with the speed of a hurricane reached northern Italy and in the night moved over the eastern Alps, covering the snow and ice with a dense layer of red dust. At some places "red" rain fell, but with less intensity. On the morning of March 11 the storm crossed the Alps and headed straight north.

At midday it reached the north of Germany, weakening rapidly, and passed over Denmark, the Baltic Sea and Russia. Here dust of yellow color precipitated on March 12, in Kostrom and Perm provinces, at a distance of approximately 4,000 km from the Sahara.

The area covered by the storm is shown in Fig. 72. It has a relatively long, narrow shape. Its length is about 2,800 km, its width 500 km in the south and 700 km in the north in the Baltic Sea. The area of dustfall is about 800,000 km^2, to which 450,000 km^2—the surface area of the Mediterranean Sea—should be added.

Detailed calculations carried out by Hellmann and Meinardus (1901, p. 30–31) showed that in this area "such a fantastic amount of dust fell that it

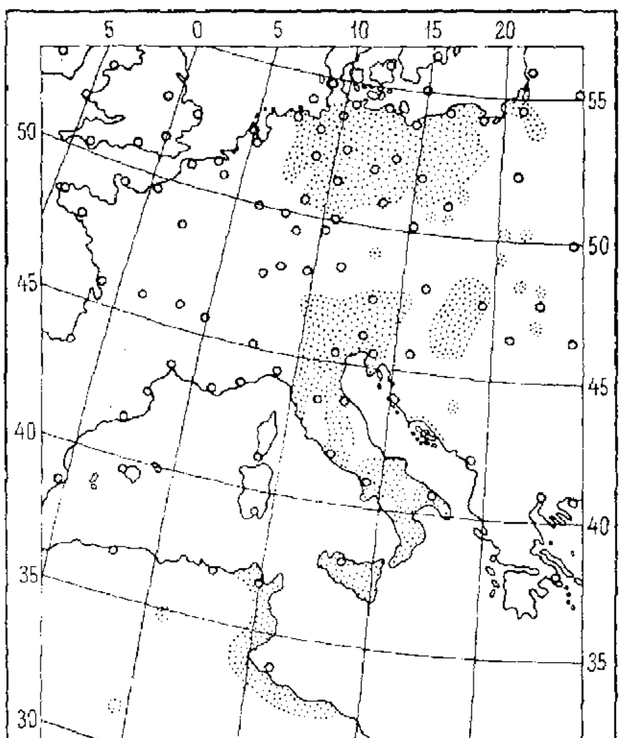


Fig. 72. Area of propagation of red dust storm of March 9–12, 1901 (shown with dots) (Meinardus, from Fett, 1958).

was difficult to believe". It was: to the north of the Alps, more than 300,000 tons without taking into account the dust that fell in Russia; in Austria, south of the Alps, 160,000 tons of dust; in northern and central Italy, 430,000 tons, in southern Italy and Sicily 880,000 tons. The total quantity of dust falling in Europe was not less than 1,800,000 tons.

The quantity of dust was greater to the south. Over the Mediterranean Sea not less than 3,000,000 tons of dust settled; on the surface of Tunis and Tripolitania not less than 500,000 tons. This makes 5,500,000 tons in all. In spite of this enormous figure, it was many times less in quantity than the dust (25 km^3) transported to Ukraine in 1960, in a dust storm that has been studied in depth.

The calculations made by various workers, given in the work of Hellmann and Meinardus, showed that over a 1 km^2 area 7 to 11 g of dust settled in the south and about 1 g in the north.

In the geological context this quantity is not very high, but if red dust storms recur frequently, the quantity becomes quite substantial. For the study of recent deposits it should certainly be taken into account. The red dust has one indication which helps to distinguish it—the thin film of iron oxide, embedded in the angular grains of quartz from 1 to a few tens of microns in size. The aeolian dust can easily be distinguished even from the marine deposits in the west of Africa (Sahara) by this indication.

The speed of the dust storm of 1901 fluctuated from 50 to 70 kmph, i.e. 15–20 m/sec. Only in the south did it attain a speed of 30 m/sec or more.

The composition of the dust has been studied by many specialists in different cities but they only confirmed the findings of Ehrenburg (1849). Places with numerous freshwater and marine diatoms (Melosira) as well as siliceous sponge needles were found but the studies were never as detailed as Ehrenburg's.

A similar storm of less strength which caused "silt" rain (Schlammregen) to fall in Vienna on May 25, 1935, is described in a paper by Schmidt (1936). The paper is short and contains very little new material. But it gives the interesting information that the dust storm started in the northern Sahara on May 22. It reached the shores of the Mediterranean on May 23, penetrated the Tyrrhenian Sea on May 24 and passed over the foothills of the Alps, obscuring the sun with gray clouds. On May 25, Vienna and its environs had rain. The drops contained dust, making yellow and green spots on objects. They were mainly particles of quartz and clay material.

In the above case the dust storm was classified as a yellow storm on the basis of the color of the dust, although it was similar to the usual red storm, moving from the Sahara to Europe, tens and hundreds of times. This shows that a distinction between red and yellow storms is not always possible and it seems that it would have been better to classify them in one group: yellow-red storms.

The observation on the darkening of the sun in the foothills of the Alps is interesting. It supports the repeatedly expressed opinion that the main mass of dust is transported by air at a height of 2–5 km above the surface of the earth and, when it falls, often reveals the character of the locality of origin. Transportation of dust stops when the wind transporting it at an altitude weakens or changes.

Measurement of the size of the dust grains of 1901 showed that the greater the distance from the Sahara, the smaller the size of the grains. In Italy it was 11–13 microns, in northern Germany, at the limit of its spread, 4–9 microns.

The meteorological conditions of the dust storm of 1901 are discussed in the papers of Valentin (1902) and Koppen (1903). In successive synoptic maps, Koppen showed the movement of the cyclone with which the dust storm was associated. The track of the cyclone and its speed governed the track and speed of the storm, but on all three days the storm was located in the eastern sector of the cyclone. Deposition of dust did not occur at all in the western sector of the cyclone. On March 9 and 10 dust was not present in the central sector, but on March 11 the dust penetrated into the center of the cyclone. On all three days the main mass of the dust was precipitated to the east of the cyclone.

The dust was transported to a great altitude: over the Alps the storm was not halted nor was its speed reduced. It only deviated slightly to the east. The quantity of red dust on the southern slope of the Alps was more than that on the northern slope.

A similar dust storm occurred in February, 1903. It also started in the Sahara and reached England in three days but its track was somewhat different, being more westerly. The dust was primarily yellow, often with a red tinge.

The cyclone with which the storm of 1903 was associated originated in the northern part of the Sahara. At this time a big anticyclone was located over the Mediterranean Sea and southern Europe. Another anticyclone lay over the central part of the Atlantic Ocean. The immature cyclone moved between these two anticyclones, first to the west and then to the north. On February 21 it merged with another cyclone to the west of Europe and the combined system moved north.

The dust storm associated with the cyclone stayed on its eastern flank. On February 19 dust settled over the Canary Islands, on February 19–20 over the Azores, on February 21 and 22 over the region between the Azores and England. During this period, the storm moved over southern England, northern France, Belgium and Holland. On the 22nd and 23rd the dust settled over the eastern parts of Germany, Austria and Switzerland. The storm was over on February 24 and the dust also ceased (Fig. 73).

In Portugal, Spain, southern France and Italy dust did not fall. But dust was found on ships near Gibraltar. In the map prepared by the Meteorological Department of England and shown in the work of Herrmann, darkening

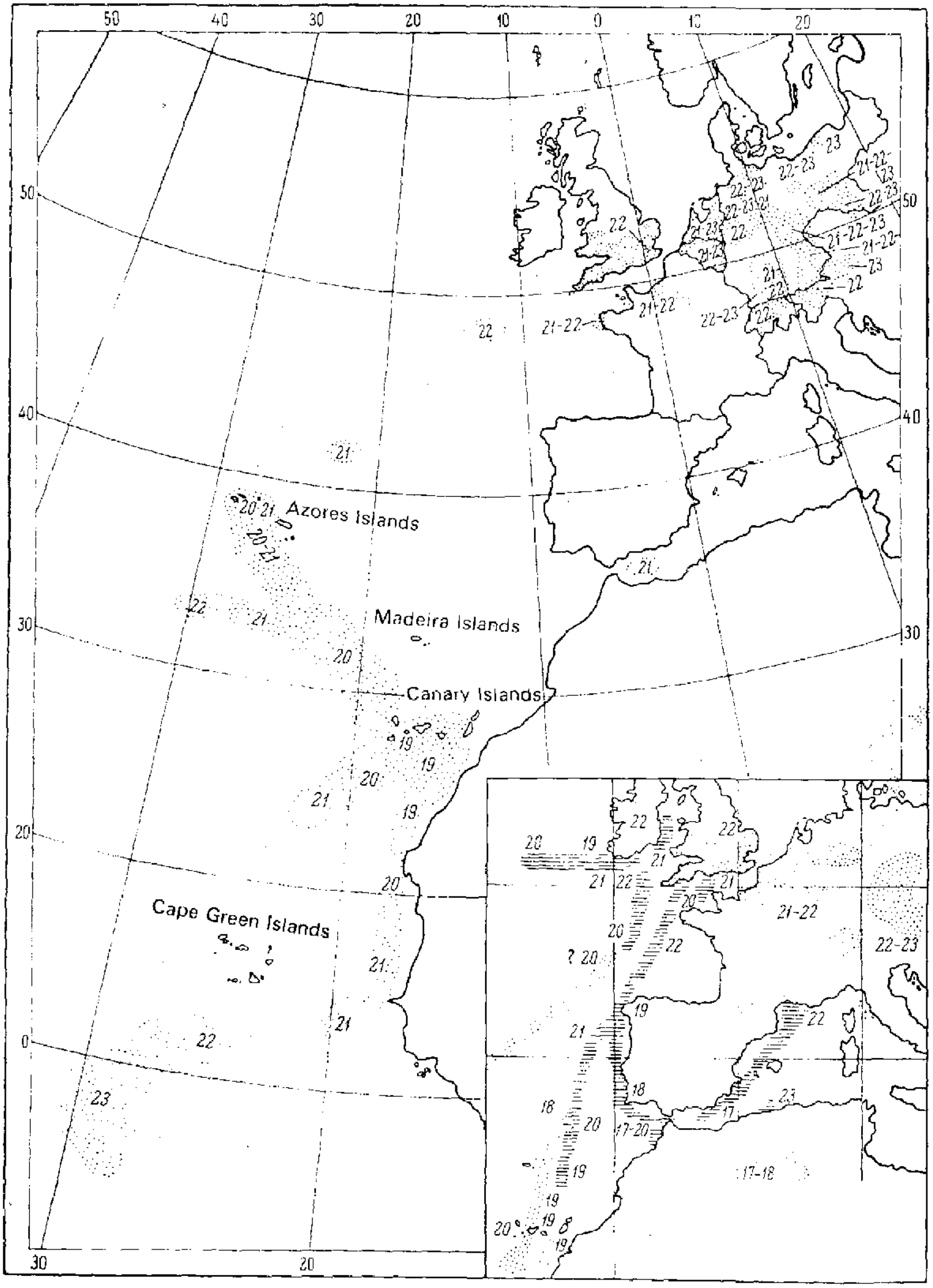


Fig. 73. Spread of red dust storm of February 19–23, 1903 (Herrmann, 1903, Taf. 20). *Dots*—dust; *dashes*—haze; *figures*—date of fall of dust.

of the sun is shown all along the coast of southern France, Spain and Portugal. Possibly the dust storm passed over the western part of the Mediterranean Sea, Spain and southern France but at a great height. It caused darkness but it was not accompanied by the fall of dust.

The cloud associated with the dust storm in Yel'zas is interesting in the account of the storm. It resembled a gigantic packet tied with rope. This cloud gave rain with yellow dust (Fig. 74).

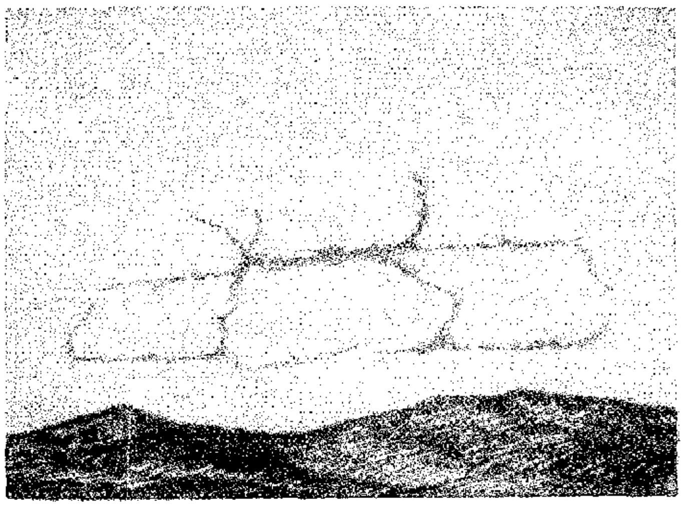


Fig. 74. Extraordinary cloud accompanying dust storm of 1903 in Yel'zas (Krebs, 1903, p. 463).

Herrmann (1903) conducted numerous observations on the color and composition of dust. The color of the dust was inconsistent. It was yellow, gray, chocolate, at places rusty, reddish, red and often white.

Numerous analyses showed that the size of the grains of dust was generally of the order of 15–20 microns or less. Grains of the size of 100 and even 200 microns were also encountered. The grains were of quartz covered with a trace of iron; many were of yellow clay particles. They always displayed siliceous and clayey matter and a thin film of iron oxide in fair quantities. At places the organic and carbonate content increased abruptly.

The dust storm was accompanied by strong winds and rain. Hence at many places its constituents were to a great extent mixed with local material added by the rain and the wind. Numerous remains of plants and microorganisms, ash and gray and white dust of local origin were found in the material (Fruh, 1903).

The organic components of the dust have not been studied in detail. From time to time the presence of diatoms, spores and pollens has been recorded. The comprehensive observations of Ehrenburg (1849) remain the most complete.

The observations of Hellmann, Meinardus and Herrmann are already 60 years old. After them there is not a single complete description of a western European dust storm. The work of the four German scientists, however, is sufficient to define the characteristics of this important phenomenon.

In the scorching, bare regions of the Sahara intense atmospheric perturbations, almost always of the vortex type, occur. They lift an enormous amount of dust. Frequently this dust originates from recent river depositions of alluvium, occurring during rainy periods.

This dust rises to different altitudes and is transported by two types of air circulation. The first, the near-surface circulation of the harmatan type, comes from the west and transports dust to the Atlantic Ocean at a height of 1–2 km. The second circulation is high, at 2–6 km, comes from the north and transports dust to Europe via the Mediterranean Sea. The dust is rich in diatomites, foraminifera and other microorganisms.

The periodic recurrence of dust storms causes successive layers in marine sedimentation, as has been recorded by Wegmann (1948).

Asia Minor and Arabian Storms

The red and yellow dust storms are widely distributed and attain tremendous strength in the desert and semi-desert plains of Asia Minor (Near East)—Turkey, Syria, Jordan, Palestine, Iraq and Arabia.

Near the shores of the Mediterranean Sea they are related to the wind bearing the name "Sirocco"; within the continent, "Simoom"; in the Gulf of Persia "Shemal"; and on the south coast of Arabia "Belat".

Sirocco: The Sirocco is derived from the Arabic "shark" (east). It is a hot, strong wind over the shore of the Mediterranean Sea, often attaining the strength of a storm and even hurricane proportions. On the north coast of Africa and on the eastern shores of the Mediterranean Sea it is dry, hot and dust-laden. Crossing the Mediterranean Sea,,the sirocco becomes humid and is often associated with low cloud. From its characteristics over the coast of Italy it has been given a special name. Here and in Palestine the sirocco has the characteristics of the foehn wind at places.

There is no doubt that the "Sirocco" on the coasts of Africa and Asia is the same wind that is known as Khamsin, Haboob and Simoom within the continents. Therefore the name "sirocco" here has an indefinite connotation. It is typical of the winds of the south coast of Europe.

The Sirocco is a European name for different winds blowing in from the Sahara and Asian deserts onto the shores of the Mediterranean Sea. Its origin is associated with the formation of a region of high pressure over the deserts and a depression over the Mediterranean Sea (Wittschell, 1930).

Simoom: The Simoom is the hot, dry wind of the deserts and semideserts of Asia Minor and Arabia. Often it reaches great strength and exhibits a squally nature.

The gusts lift an enormous quantity of scorching dust into the air. The sky

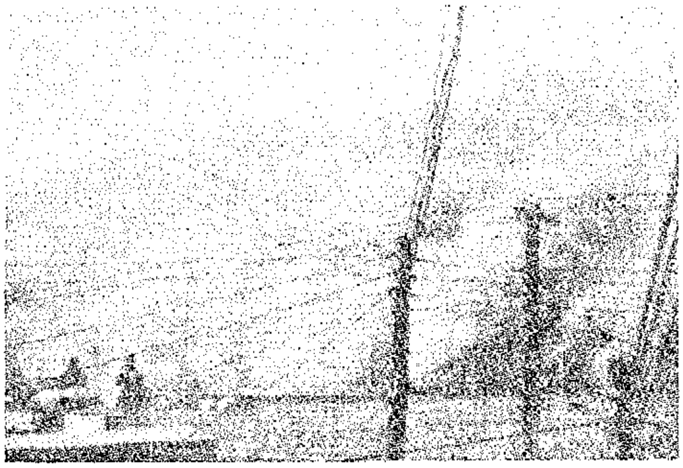


Fig. 75. Dust storm moving toward Spur, Texas, on April 14, 1935. Circular vortex can be clearly seen. It merged with cloud (*Monthly Weather Review*, vol. 63, 1935).

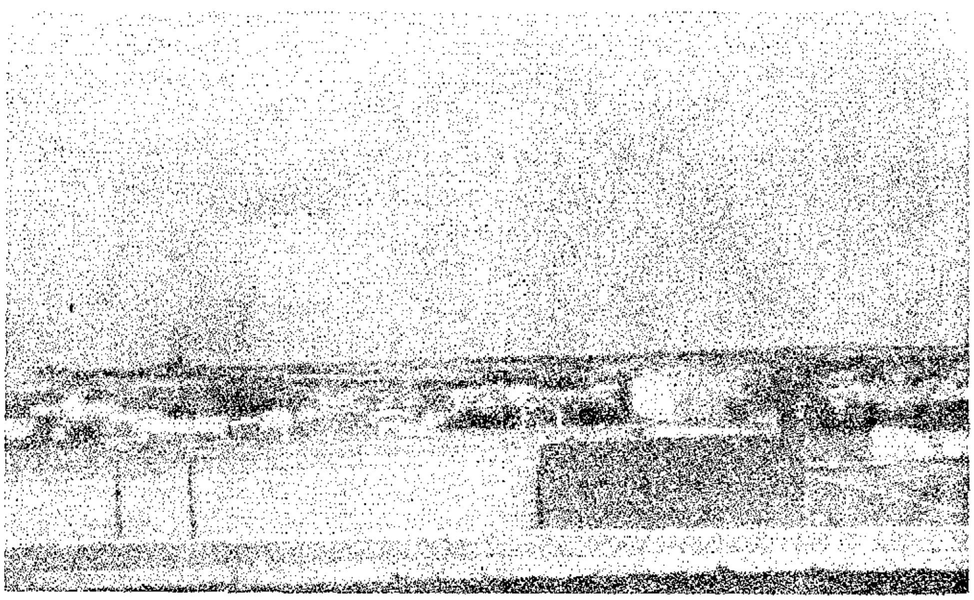


Fig. 76. Dust storm in Texas. Similar to haboob (Riley, 1935, Fig. 1).

are numerous and of various types. They are generally small, short-lived phenomena of small vertical extent. But from time to time there are severe hurricanes with a duration of several days, causing great losses on cultivated land and transporting dust to a height of 4.5–6 km over thousands of kilometers. The height of the dust cloud of an average storm is 1,200–1,800 m (Martin, 1936, 1939).

In March, 1936, a violent hurricane-strength storm affected the entire area of the southwestern plain. The cloud of dust rose to a height of 5–6 km and, steered by the northerly flow, was carried to the Atlantic Ocean. Visibility fell drastically, at times to zero. The sand transported from the land damaged the paint and windshields of cars. The static electricity was so strong that the ignition of cars would not function and sparks jumped from the metal parts (Choun, 1936).

During the dust storm of January 18, 1933, the static electricity was quite high in the state of Wyoming and local engineers said that a small motor could be operated by it. The speed of the wind was 80–100 kmph. Small stone chips moved with the sand just above the ground. Sheep struck by the stones ran amuck. At places soil was removed to a depth of 25–30 cm and the cover was ripped off gravel roads (Disterdick, 1933).

There are many such descriptions and all of them are similar to the descriptions of our dust storms.

The strong dust storm of April 21–24, 1931, in the states of Oregon and Washington is of interest. It continued for four days with breaks at night. An enormous quantity of dust was transported, not only on land but also to the Pacific Ocean (Cameron, 1931).

WHITE DUST STORMS

White dust storms are relatively rare. They feature either white or gray-colored dust, depending on the quantity of grains of salts like gypsum, etc. that they carry. They are formed by vortex storms over large areas with salt surfaces. Along with dust the vortex lifts grains of different types of salt. The high wind transports them thousands of kilometers. The white dust storm is described hereinafter.

2
Other Vortex Storms

DUSTLESS STORMS

It has been mentioned above that two conditions are necessary for dust storms: dust and storm. Often the dust is absent and the storm remains. A very strong wind blows at a speed of the order of 15–20 m/sec and the air remains clean due to the absence of dust. The loss and destruction due to such storms are relatively small and often go unreported.

In March, 1960, in the desert near the Caspian Sea, a strong storm occurred. It crossed the Caspian Sea and moved west along the Caucasus Mountains. All along its path the soil and sand were either wet or frozen. There was no dust and the storm passed without any special effect. But from the beginning of Stavropol'sky plateau dry, loose soil started and an enormous amount of dust was lifted into the air. The storm strengthened rapidly. The air collected more and more dust and the dustless storm of the east was transformed into the terrible dark dust storm of 1960 in the west.

Such dustless storms are not rare, but they go unrecorded. Our deserts often have large areas of rocky surface and clayey, pebbly surfaces which are firm and solid. Dust is absent from such surfaces. A strong wind blowing over them is a typical example of a dustless storm. When it approaches sandy massifs, gradually dust is lifted into the air and sand is transported. The typical dust storm or, as it is often wrongly called, sandstorm starts.

For geographers the dustless storm is of no interest. For geomorphologists the remarkable form of erosion due to it is of interest.

SNOWSTORMS

In winter, cyclonic storms often turn into snowstorms. They are known as "purga", "buran" or "metel". They are identical with normal cyclonic storms in all their features.

A historic snowstorm struck New York in March, 1888. The total amount of snowfall in three days was 52 cm, of which in one day, i.e. on March 12, 42 cm of snow fell. Life in the city was disrupted. Many people were frozen in this enormous, densely populated city (*Weatherwise*, v. 14, No. 2, 1961, p. 70). The snow accompanied a storm with a speed of 75 kmph.

Peculiar snowstorms with strong stormy wind, hail, showers and often tornadoes accompanying the wet snow and ice have been recorded in Illinois State on three occasions: in March 1923, March 1932 and February 1960 (Changnon, 1964).

During the terrible snowstorm of November 1950, 60 to 75 cm of snow fell in one day (Bristor, 1951).

The northeastern part of the USA, known as "New England", is the region of development of snowstorms. The catastrophic storm of the winter of 1914–15 has drawn the attention of many workers: it was the chief example in a review by a well-known meteorologist (Brooks, 1917). The main cause of these storms, often changing into hurricanes, is a deep cyclone located over southern New England. They contain large quantities of moisture and the snowfall is of considerable depth. The snowfall is more than 1 m over one or two days and drifts are of the order of 10–12 m. People have to dig a tunnel through the snow to leave their houses. Fences disappear under the snow and communications are disrupted. Tens and even hundreds of vessels sink at sea. Dozens, even hundreds of people freeze in snowdrifts. The loss is of the order of millions of dollars.

There was an exceptionally strong snowstorm from March 3 through 11, 1960, over the eastern part of the USA. The depth of the snow cover was more than 1 m. Traffic was disrupted and tens of thousands of vehicles were stuck in the snow. In many cities schools were closed and in the State of Kentucky an emergency was declared. The loss was millions of dollars and 237 people were frozen to death.

On December 31, 1962, another snowstorm hit the eastern States. The temperature fell to −15°C. A huge amount of snow fell in Maine State. The depth of the snow was 6 m in the city of Bangor. Life in the city was paralyzed and an emergency was declared. Dozens of people froze to death.

In March, 1966, a vicious snowstorm ("blizzard") hit the central States. Dozens of people were killed and there was enormous material loss.

From March 1 through 5 an unusually strong snowstorm raged over the northern States. It attained its maximum strength in North Dakota, where 50 cm and at places 75 cm of snow fell in one day. The wind attained speeds of 130 kmph, gusting to 160 kmph. At places it continued for three or four days. The temperature fell below zero.

The hurricane wind caused heavy drifts of snow. Dry snow crystals filled the air to such an extent that it became dark as night and visibility was extremely poor. On March 3, for 11 hours visibility was negligible. Next day, for 19 hours, it was not more than 200 m. This was a first in the weather records of North Dakota.

The snowstorm was so terrible that in many cases people froze to death a few meters from their homes. In all, 18 people died. The small number of deaths was due to the fact that a warning was given in time.

It will be interesting to compare these data with the data on the famous winter storm of January 12, 1888, which lasted for only 12 hours. In this storm at least 112 people died and a whole herd of cattle was frozen. Even on March 15, 1941, when a hurricane wind struck North Dakota for 7 hours at a speed of 110 kmph, 90 people including 40 traveling in cars died.

The snowstorm of 1966, however, caused large-scale death of animals. In three states 74,500 cattle, 54,000 sheep and 2,500 pigs died. On one farm 7,000 turkeys were frozen. The total loss in dead animals was around 12 million dollars.

The gusty wind not only shifted the snow cover but at places transported the upper layer of soil too. The soil mixed with snow formed enormous wet piles. At other places, on the contrary, the snow blew in such amounts that snow drifts 10–12 m high were formed. Some farmhouses, situated in lowlands, were covered to the roof. Only the tops of telegraph poles peeped out of the snow (Fig. 77).

Fig. 77. Telegraph pole protruding from snow, USA, 1966 (Stommel, 1966).

All traffic movement stopped. Hundreds of automobiles were buried in snow. Schools and plants were closed. Hearing the howling of the wind, frightened farmers did not leave their houses.

Even the trains did not run. On one stretch of track the storm buried a freight train. The engine and the first car were completely covered (Fig. 78). The snow was so dense that it had to be removed with a bulldozer.

At other points three long-distance trains were buried. Five hundred

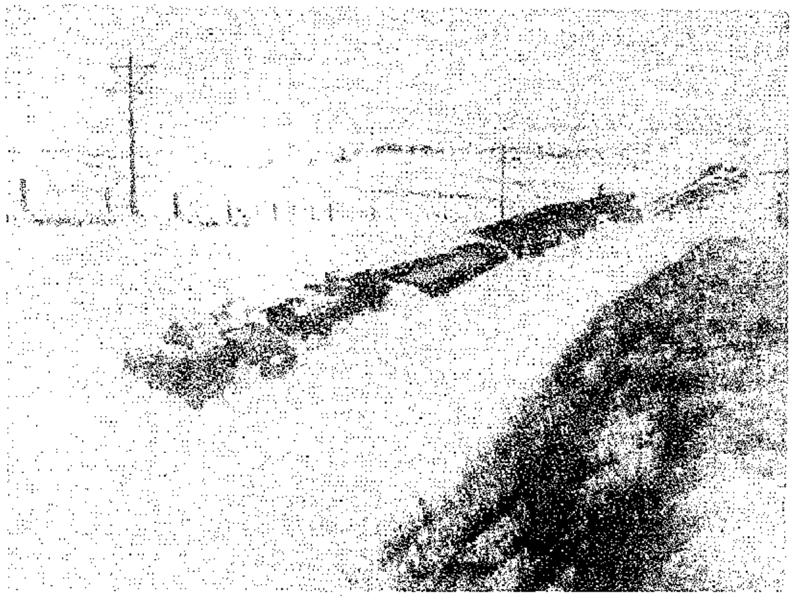


Fig. 78. Engine and freight train buried in snow, USA, 1966 (Stommel, 1966).

passengers sat in the cold compartments for several hours. Here the snow was as solid as stone.

An unbelievable mass of snow covered an enormous area. When the snow started melting at the end of March and April a flood of unusual size occurred. The plains were covered with water in which only the trees showed the riverbed channel. Fig. 79 shows the flooding of a small city. This snowstorm has been described by Stommel (1966).

Another storm, centered farther south, enveloped a number of states three weeks later. It attained abnormal strength and killed 27 people.

Exceptionally violent storms occur over the vast plains of the European part of the USSR. Here for several days all traffic, including that on the railroads, stops in cities and villages. Dozens of people die and heavy loss of property occurs. But the death and loss are many times less than those in the USA, where such a phenomenon is often catastrophic.

In April 1893, an exceptionally strong snowstorm passed over southern Russia. It raged from the Black Sea and Astrakhan to the far north, removing rooftops at many places. In Kamyshin the snowstorm transported sand and fine gravel, which stung the faces of people.

Still stronger storms strike the boundless spaces of the Siberian steppe, now virgin lands. They not only carry away all the snow from the fields but make holes in the top layer of soil.

The geological activity of the snowstorm is less than that of the dust storm. The snow is softer than sand and dust and protects the soil from being blown away. Moreover, in the winter the soil freezes and cannot be blown away easily.

the downpour continued for another 10 minutes" (Tiron, 1964, p. 200–201). The downpour caused the most destruction and death. The torrent was so strong and sudden that 20 people died in the basements of houses as they could not come out. There was 93.4 mm of rain in half an hour—four times more than that at the time of a tropical cyclone.

In August, 1893, Samar province had a few squall storms of unusual strength. The rain and hail lasted only 15 minutes near the village Ivanov, but they caused havoc. The storm raged over the village of Polibin, in all for 20 minutes, but the air was saturated with dust lifted from the plowed fields. Wheat stacks were blown away and the sheaves scattered all over. At Kame, near Elabugi, the duration of the storm was 10–13 minutes, but a ship in the river was driven onshore and plunged into the bank. The crew used the mooring ropes to land.

On August 13, 1894, in Voronezh province a squall lifted a cart and tossed it over the granary onto a straw stack. A four-meter plank was lifted from the ground and landed on an iron roof.

The storm of 1894 in upper Bavaria had a width of 2.5 km and length of 22.5 km. Here 400 houses were destroyed. One man died and several people were injured.

On June 18, 1900, a storm passed over Moscow. The village of Bykov had hailstones weighing 400 g. The village experienced total darkness for a period of 10–13 minutes due to thunderclouds. Moscow and its suburbs suffered tremendous loss and some people died.

Among the famous squalls, the briefest was over San Franscisco on November 21, 1910 (McAdie, 1910). It became totally quiet. Thunder started and became louder and louder. The blast of the wind shook brick buildings but they withstood the onslaught. After half a minute, the noise dropped and soon everything became quiet. The duration of the squall at different localities varied from half a minute to two minutes. The speed of the wind reached 100 kmph. The destruction was relatively minor. This instant squall with its sudden appearance and disappearance caused amazement. It seemed the city had experienced one enormous, long, narrow wind wave.

In all these cases, the storm was sudden and short-lived and covered a narrow belt. In this respect they were close to tornadoes. They were similarly associated with frightening thunderclouds and wind of unusually high speed, going up to 80 m/sec (at Ekaterinburg, now Sverdlovsk, on May 15, 1900). It was similarly associated with big thunderclouds. But the patterns of wind were radically different.

We will discuss some cases that occupy an intermediate position between squalls and tornadoes. These examples are from the book by Z.M. Tiron (1964).

On July 14, 1892, a storm struck the neighbourhood of Ekaterinburg but lasted only 20 minutes. It was responsible for considerable loss of forest timber. A swath of felled trees 50 km wide extended 200 km in a northeastern direction. It numbered around 600,000 trees. From the position of the fallen trees it could be seen that the vortex of the storm passed over the forest.

On May 23, 1957, a strong squall with a speed of 20–30 and even 40 m/sec passed over the foothills of north Ural, near Cherdyni. The storm over the Bondyuzhsky forest left behind a fallen tree zone 5–6 km long and 300–400 m wide. The wind strength was unusual. A two-hundred-year-old cedar was twisted like a rope at a height of 2 m, uprooted and thrown a distance of 8 m. This phenomenon was called a squall, but it could appropriately be referred to as a tornado (Yastrebov, 1958).

The suburbs of Moscow were struck by a squall storm on May 28, 1937 (Kolobkov, 1937). It started at 1300 hours in Zvenigorod, 30 km from Moscow, approached Moscow via Lyuberts and Ramensk and over Kolomn had already developed into the usual type of storm. All along the 120–140 km path it had a constant speed of 35 m/sec. The storm was associated with thunderclouds, hail, etc. There was continuous lightning but thunder could not be heard due to the roar of the wind. The temperature dropped by 12°. The wall of continuous rain hid everything.

The storm continued for only 10 minutes at any point of observation but caused considerable damage. Big trees were uprooted. Rooftops were blown away, fences were damaged and windowpanes were broken. There was no rotation of the wind.

The storm of September 1, 1934, in the western part of Gdan (Poland) had a similar character. One particular part of the forest 20–30 m wide with the trees standing approximately in line at some distance from each other, suffered worst. A detailed study of the damage, especially of the uprooted trees, showed that the storm had a vortex of small diameter and cyclonic rotation in it.

In August, 1947, the Mshinsk region of Leningrad district had thunderclouds of exceptionally high density accompanied by a hurricane wind and heavy downpour. The hurricane at that time was accompanied by low clouds of dark brown color. From the base of the cloud hung a twisted trunk about 30–50 m long but not reaching the ground. The rotating trunk (funnel) broke tree trunks 60 cm in diameter. The broken and uprooted trees formed a continuous belt 80–120 m in width and a few kilometers in length. A large number of trees were struck by lightning. To the windward side of Lake Vyal'e, at a distance of 100 m from the lower level of the water, there was blockage of silt raised from the bottom by the wind (depth 20–30 cm).

The hurricane wind continued for 40 minutes, during which the rain did not cease. After crossing the lake the funnel broke into individual vortices. These continued to move in different directions and occasionally touched the surface of the earth. Afterward the forest was left with a number of zones 80 m in width where the trees had fallen, while the rest of the forest remained intact. It was in these areas that a large number of trees were struck by lightning.

These three storms are extremely interesting in their similarity to tornadoes. The vortex over Gnadsk and the downpour are characteristics of tornadoes.

The great differences from tornadoes are the large diameters and ill-defined outlines.

Three European storms and the gigantic tornadoes of the USA are examples of individual phenomena intermediate between squall storms and tornadoes.

This underlined the necessity of studying the tornado that occurred in the USA in 1954. The squall storms with narrow tracks were not different from the low, wide, gigantic tornadoes of the type that occur in the three states (Brooks, 1965).

Earlier, on June 9–10, 1922, such a squall storm (cloudburst) was recorded in Wisconsin (Stewart, 1922). The destruction and the track recalled a tornado but no tornado funnel was observed. The characteristics of a tornado were not observed in the storm. It resembled a thunderstorm accompanied by a very strong, gusty wind. In one minute 100–150 flashes of lightning occurred. Some places were hit by unusual hail.

Arch Squall

An arch squall is a squall storm of great hurricane strength. It is stretched and bent in the form of an enormous arch, extending to tens and hundreds of kilometers (arcus). Often such an arch has a threatening, gloomy shape (Fig. 81). It is popularly known as a "rotor cloud". The vortex formation, rotating around a linear axis, is stretched along the cloud in the way a rotor turns inside an electrical machine. A photograph of such a cloud, called a "Sierra wave", is given in Fig. 87. Elsewhere the cloud is called a "Chinook arch".

Arch storm cloud originating over the Bay of Bengal are common in eastern Bengal. Here they form on the outer edge of an enormous thunderstorm cloud of great height, with the typical "anvil" at the top (Fig. 82). They are accompanied by a fluctuating but destructive wind of very great strength. Occasionally there are showers with hail of exceptional size. During one storm the hail killed several hundred head of cattle.

The size of arch clouds varies widely. Generally they are a few kilometers long. Often, at the center of the cloud, vortex circulations of violent strength form. They are 200–300 m in diameter and are similar to tornadoes.

The arch (rotor) cloud is secondary circulation, usually associated with an enormous cumulonimbus cloud. The rotor develops on its lower edge, forming a sharply defined border. It is rarely encountered but has been described repeatedly. In the Gulf of Guinea the arch cloud gives rise to a

Fig. 81. Arch-shaped linear, squally thundercloud. Photograph of "linear storm" by D. Kerry (Boswell, 1939).

Fig. 82. Typical cumulonimbus: thunderstorm-raincloud, with anvil. Big city below it (Knight, 1964, p. 75).

"tornado"—a squall storm having no similarity with the American tornado.

In Indonesia the "sumatra" attains enormous speed and is related to an arch cloud 300–400 km in length.

The name "arch cloud" was first used in Europe, where this phenomenon was accompanied by strong squall winds. It attains its maximum size over the tropical waters of Asia (Schuck, 1877).

Thunderstorm Squall

The thunder squall is a sharp, strong gusty wind below the base of a thunderstorm cloud. Dust, dry leaves and small debris are lifted. It precedes every thunderstorm. Its strength is not great. However, it can vary from insignificant strength and a duration of tens of seconds to such high values that it ranks as a "squall".

The conditions of formation are given in the book by Davis (1899, Fig. 100). It is noteworthy that thunderstorm squalls and gusts are associated with rotor clouds, culminating mainly in thunderstorms. It is quite possible that the size of the cloud determines the strength of the wind accompanying it (Fig. 83). Davis refers to rotor clouds as squally. Webster (1924) has described it.

A violent thunderstorm, ahead of the squall cloud, moved over Germany on August 9, 1881. Between 9 in the morning and 9 in the evening it moved from the Rhine to the Oder. Lightning was infrequent but the rain was quite heavy. There was hail at places and a violent squall blew below the cloud. Its duration was 5–10 minutes, but it caused large-scale destruction during this short period (Davis, 1899, p. 252).

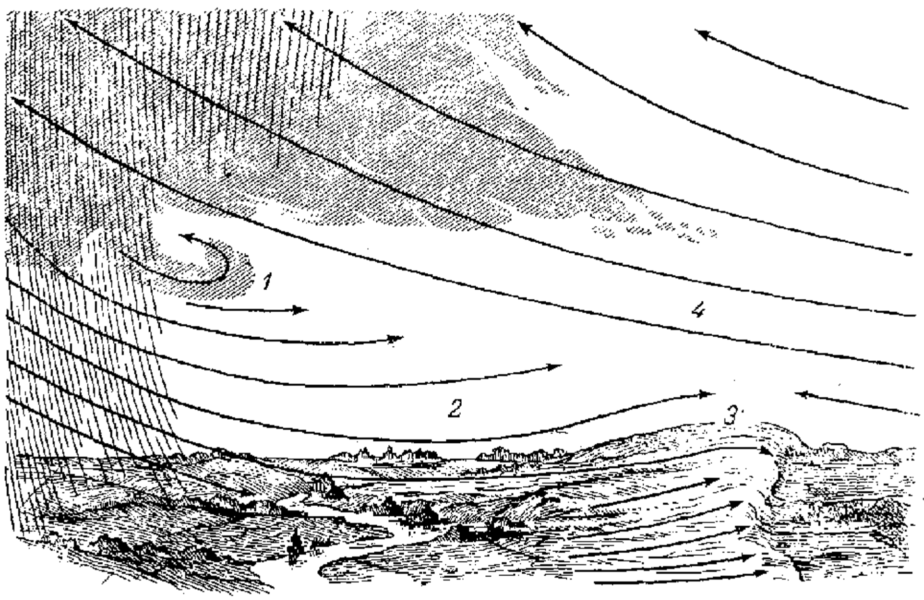


Fig. 83. Section of base of thunderstorm cloud. Flux of warm air is ascending. Tubular vortex squall clouds occur below. Thunderstorm squall originates here, lifting clouds of dust from earth (Davis, 1889, Fig. 100).
1—Squall cloud; *2*—thunderstorm squall; *3*—dust cloud; *4*—lifting of warm air.

An interesting description of the squall storm "tornado" has been given by an officer of a ship that was cruising in the Gulf of Guinea. "The sharp boundary of the black arch clouds could be seen as the storm approached. It was not continuous and generally came from the shore. The squall originating under the arch was unusually strong, accompanied by thunder, lightning and heavy downpour. I clearly remember not less than six such squalls, one of the most frightening sights I ever saw" (Scott, 1885, p. 384).

This "tornado" is undoubtedly a member of the arch squall family. Schuck (1877) has given a series of examples of such squalls.

The well-known meteorologist Humphreys (1929) believes that the squall cloud takes the form of a horizontal cylinder situated in the lower one-third of the thunderstorm cloud. It is of very small size but fully developed, clearly defined and located in the lower edge of the front part of the thunderstorm cloud.

3
Atmospheric Phenomena

AUTO ELECTRICITY

The term auto electricity, or auto electrification of dust, has been used by Blacktin (1934, p. 34) for the peculiar phenomenon associated with hot, dry dust storms. It enhances the electrical field in the air due to the increased charge on the sand grains caused by friction with each other and with other objects. In particular the electrical charge of metal bodies or good conductors is enhanced. The observations by K.A. Karetnikov and my own during the "Afghan wind" at Termez (p. 137–138) have been described earlier.

The phenomena observed during the dust storms in the desert regions of the USA are no less striking (Flora, 1913; Disterdick, 1933; Choun, 1936). During a strong dust storm in Kansas in 1913 electric sparks 5–10 cm long occurred between telegraphic wires and metal objects. In Egypt, during the khamsin abandoned cars resting on their tires and so insulated from the ground had such an accumulation of electricity that an electric spark 25 cm in length occurred when the hand was brought near. The sparks were repeated and the subject received severe shocks. An increase in electric charge has also been observed during snowstorms. It is possible that the lightning associated with volcanic activity is due to the mass of volacanic dust thrown into the air at great speed. Blacktin (1934, p. 64) writes that everywhere, wherever dust and sand move, electric charges originate. He says it is possible that lightning in many cases is due to the electrification of dust. This phenomenon has drawn a lot of attention and a number of researchers, quoted in the monographs by Blacktin (1934) and Fett (1958), have worked on it.

A number of interesting and peculiar electrical phenomena associated with dust storms have been described by Flora (1912, 1913). A herd of cattle was returning home in the evening. A dust storm started and suddenly small fireballs appeared on the tips of the cows' horns. The phenomenon was unusual and fascinating.

The sparks from metal bodies during the khamsin on the top of the Kheopsov pyramid are no less surprising. It has been described by Siemens (1860) and repeated briefly in a paper by Rossmann (1948). Rossmann cites similar observations by Humboldt in the desert of Peru on dust vortices with electric charges.

Among Russian meteorological works there is no monograph on auto electricity. The problem is briefly dealt with in books written before the Revolution by Klossovsky and Voeikov and in the small but interesting papers by N.A. Gezekhus (1903, 1911) and D.I. Kulagin (1950).

"Electrification of dust, as experiments show, is simply a special case of electrification due to the contact or friction between two pieces of the same body, the surfaces of which are irregular" (Gezekhus, 1903). This was written in 1903. At that time he alone noted that the dust is negatively charged and the earth positively. The phenomenon is similar in the case of friction of snow and dense snow or frozen surface.

In the same paper, he refers to the description by two observers of a volcanic eruption: "We felt strong electric shocks all the time... The atmosphere everywhere was full of electric charges... We were blinded by the rain of ash" (Gezekhus, 1903). The electricity was associated with the friction between the ash particles and the volcanic eruption.

In his paper of 1911 N.A. Gezekhus adds that during a violent snowstorm auto electricity reached such a high order that the snowflakes were often illuminated with blue flashes.

Such blue radiance is seen in the dark due to the friction between two pieces of quartz.

Siemens' observations at the top of the Kheopsov pyramid were confirmed by Shova on the Eiffel Tower during a strong wind carrying an enormous quantity of dust.

Based on these observations, he concludes that auto electricity originates not only on the surface of the earth but also at different heights.

Airplanes flying at an altitude of 2–3 km or less encounter dust storms and auto electricity. The order of this auto electricity varies widely. It is proportional to the quantity of dust and its speed of transport.

During one strong dust storm the rate of electrification of cars was so great that the starter ceased to function. When touched, all the metal parts gave off fairly big sparks like the samovar at Tejen during the "Afghan wind" or the thermos flask at the top of the Kheopsov pyramid during the khamsin.

Sand and fine particles move toward the funnel of a tornado at great speed, sometimes at ultrasonic speed. It has been noticed occasionally that the funnel exhibits high auto electricity at places.

ATMOSPHERIC ELECTRICITY AND CYCLONES

The vortex circulation of air with great force, tropical and extratropical hurricanes, cyclonic storms and tornadoes, are quite frequently, but not always, associated with atmospheric electricity.

Often atmospheric electricity is revealed by the manifestation of linear and complex lightning. Occasionally it becomes unusually strong and takes the form of a brilliant discharge of great frequency. Peculiar forms of lightning are seen. The lightning sometimes becomes so frequent that it appears as if the cloud is filled with it. It gives almost continuous luminescence.

Possibly an important role is played in raising the voltage and the discharge by the horizontal vortex movements. Such movements are special characteristics of the lower part of the thundercloud.

There is no doubt that part of the atmospheric electricity originating in the clouds due to the intensive horizontal movement of vortices is associated with the friction of the various particles embedded in the vortices.

The static electricity formed in dust- and sandstorms due to the friction between the dust particles and sand particles is proof of this. Examples have been given of storms in which the static electricity attained high voltages.

At the same time, it should be noted that thunderstorms are absent in the polar regions. This agrees with the sharply reduced horizontal motion of vortical circulation. In the polar regions tornadoes and tropical cyclones are absent and even extratropical cyclones are comparatively rare. Almost all the hurricanes and storms of the Antarctic have a flux structure.

There is no doubt that there is a gradual reduction of thunderstorms from the equator to the poles. There is also no doubt as to the process of weakening of tornadoes and tropical hurricanes of maximum development in the form of horizontal vortex movements going from the equator to the poles. A relationship between these two processes certainly obtains. The law governing this relationship, however, is still not very clear.

There is no doubt that tornadoes and thunderstorms are associated with the same type of thunderstorm cloud. The absence of tornadoes in the polar regions is due to the absence of thunderstorm clouds. The cause of the latter is planetary, but it is not yet very clear how it operates.

It is, however, clear that the horizontal movement of vortices causes friction of different particles in the air. This friction creates atmospheric electricity, but the magnitude of this process is not clear.

Not every thunderstorm cloud has horizontal movement of vortices, but every vortex is turbulent. The significance of this turbulence in the formation of atmospheric electricity may be quite substantial.

Vonnegut (1960) advanced the theory of the formation of tornadoes by atmospheric electricity. There is no doubt that a relationship obtains between these two, but to postulate atmospheric electricity as the cause of tornadoes appears dubious. It is possible that it is not the electricity that causes the tornado but, on the contrary, the tornado is responsible for the development of atmospheric electricity.

THUNDERSTORMS

The thunderstorm is a complex meteorological phenomenon. It is composed of 1) electrical phenomena, lightning and thunder; 2) a thunderstorm cloud; 3) downpour and hail; 4) squally wind.

In Huschke's meteorological dictionary the definition of a thunderstorm is as follows: "Local storm, always associated with cumulonimbus cloud and always associated with lightning and thunder, usually with strong gusty wind, heavy rain and often hail. It is generally intermittent, rarely more than two hours" (Huschke, 1959). The works of Kramer (1950a) and I.S. Stekol'nikov (1954) give the bibliography on thunderstorms.

Lightning and Thunder: In spite of its grandeur, lightning goes unrecorded in geological chronicles. The only thing imprinted by it is fulgurites, courses in the sands formed by flying grains of sand. They originate where the lightning strikes the sand.

Lightning strikes not only sand. It strikes a variety of rocks. Undoubtedly the floating particles are triggered by it and metamorphosis occurs. This phenomenon is not yet understood. It is undoubtedly present in the sedimentations of different ages but remains unrecognized by lithologists and petrographers.

Thunderstorm cloud is a very important atmospheric phenomenon with considerable geological significance. Vortex motions originate in thunderclouds, often of very large magnitude, e.g. the central zone of tropical hurricanes and the base of tornadoes. Such vortex formations are quite stable and continue for a number of days, up to 10–15 days and more. The vortices are capable of keeping aloft a large amount of dust and often even coarse materials and of transporting them a distance of hundreds on even thousands of kilometers. The thunderstorm cloud is an important factor in the transportation of dust. Such clouds can carry an enormous amount of water, weighing millions and even billions of tons. All our means of transportation look like toys when compared to thunderstorm clouds.

The stages of growth of a big thunderstorm cloud are shown by Davis (1899, Figs. 94–97). At first a small cumulus cloud with a horizontal base forms just above the surface. The cloud moves slowly and grows rapidly. Its leading part takes on a characteristic form and rises to a great height. The cloud then descends. Moving on (Fig. 84, C, D, E), the clouds develop an anvil at the top, but still with an irregular, uneven and cumuliform top. The cloud hangs over the earth. In the last stage, when fully grown, the cloud (D, E) shows the typical form of an anvil with an almost flat top, and the thunderstorm and downpour start. On July 2, 1887, over New York (Fig. 84)

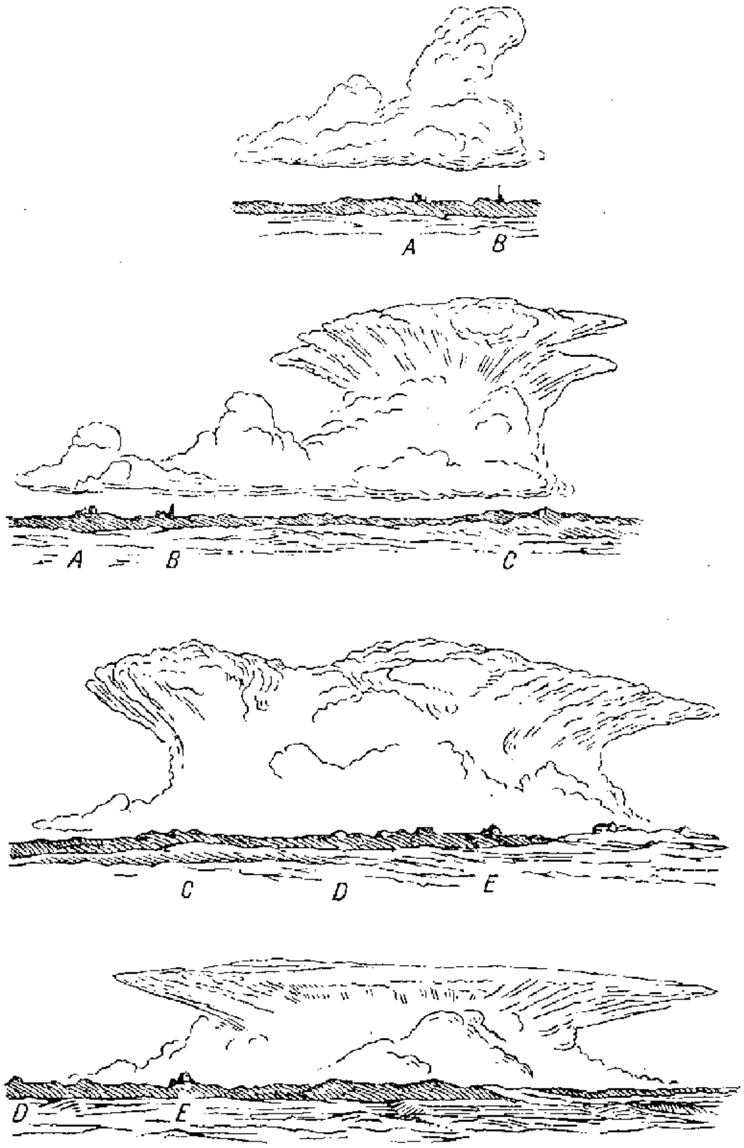


Fig. 84. Growth stages of thundercloud. Last stage is anvil; rain and thunderstorm begin (Davis, 1899, Figs. 94–97).

the first three stages occurred between 1100 and 1140 hours, the last stage at 1245 hours.

The usual thunderstorm cloud is of the cumulonimbus (Cb) type. The typical, fully formed cumulonimbus cloud in the form of block is shown in Fig. 82 from the top. It exhibits vigorous movement inside and is accompanied by thunderstorms and often tornadoes (Fletcher, 1962).

The dimensions of a thunderstorm cloud vary. Its width varies from a few kilometers to a few hundred kilometers, its height from 3 to 15 km and more. The main cloud is black, dense, greenish or bluish, the base almost horizontal and below 2 km, often coming down to ground level and now and then covering the surface.

With the formation of the "anvil" the small vortex cloud, rotor or squall, descends. It rotates intensively around a horizontal axis like the rotor of an electric motor. Often it is known as a "collar storm". It grows into very strong gusty wind-squalls, rushing down with the approach of the thunderstorm cloud.

Now and then, below the base of the vortex cloud, the funnel cloud of a tornado is formed.

Downpour and hail falling at the time of a thunderstorm often attain enormous magnitude. They give rise to numerous wide channels which fill the rivers and canals, causing floods and often catastrophe.

Squally wind, accompanying thunderclouds, is not continuous but attains the speed of storms and hurricanes. It is one of the characteristics of thunderstorms and therefore a thunderstorm is often referred to as a local storm.

The squally wind strengthens when the edge of the thunderstorm cloud moves. The wind comes down to ground level and lifts dust, etc. to the cloud (Fig. 83). From the cloud the rain falls. The squall creates the peculiar vortex rotor cloud, the squall cloud (Davis, 1899). Such has been described by Brooks (1919). He states that the squally thunderstorm wind often attains destructive strength.

In 1924 airplanes started flying in squall clouds. This had to be discontinued since the planes started disintegrating. Even for modern planes, which are infinitely stronger, flights in thunderstorms are dangerous.

In 1944 the flight in a special plane showed that the wind attains a speed of 320 kmph in the thunderclouds (Gillmer and Nietsch, 1944).

The interesting paper by B.E. Peskov (1963) describes the features of the structure of cumulonimbus clouds and the conditions of flight in them. The speed of movement of the wind system is also considered.

The vortex structure of the clouds is described in the paper by L.S. Minin (1964) from the data of weather satellites. He believes that the majority of the vortices are associated with cyclones. According to the type of clouds they are more common in stratocumulus (60%). But less so in cumulus and other clouds (15%).

Whether we call this atmospheric phenomenon a thunderstorm or a storm, the essential facts do not change. The enormous cumulonimbus cloud, moving in a particular direction, accompanied by lightning, downpour, hail and strong wind, often attains the speed of a storm or even hurricane (Byers, 1944, 1951; Byers and Braham, 1949, Farkhauser, 1965).

"On August 25, 1890, the thunderstorm front was seen at 1500 hours over Perugia province (Central Italy); it reached Trieste and Polo between 1700 and 1800 hours, Grats (Tirol) at 2000 hours, Vienna and southern Moravia at 2200 hours and then dissipated over Carpathia. The speed of progression was very high: at first 100 kmph, and from 1830 to 1915 hours around 170 kmph. The thunderstorm was very intense and was accompanied by a very strong wind, causing extensive loss" (Kolobkov, 1951, p. 239–240). It should be added that the speed of 170 kmph was attained when the thunderstorm crossed the Alps. Evidently the thunderstorm cloud was so high that the Alps did not pose a barrier. We have also recorded the crossing of the Alps by hurricanes and transportation of red dust from Africa to the Tirol and Vienna. The crossing of the Alps by a thunderstorm cloud is similar. N.V. Kolobkov refers to the phenomenon as a thunderstorm (Fig. 85) but it could be correctly referred to as a cyclonic storm too. Very high cumulonimbus cloud, traversing a wide path at great speed, accompanied by storms and possibly by hurricane winds, thunderstorm and downpour, are all characteristics of a cyclonic storm. It is interesting that N.V. Kolobkov determined the track of the frontal thunderstorm from the isochrones of storms. The thunderstorm and storm, obviously, can be thought of as one entity.

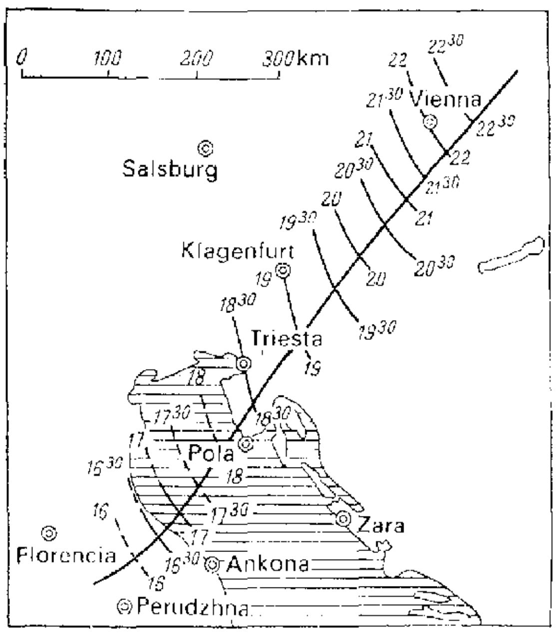


Fig. 85. Track of frontal thunderstorm from isochrones of storms of August 25, 1890 (Kolobkov, 1951, p. 239).

4
Torrential Storms

In all the hurricanes and storms discussed so far the special feature has been vortex and spiral motion. At the same time, the vortex body of the hurricane shows progressive movement, often with long duration and great speed.

There is another category of hurricanes and storms in which the vortex body is absent. In this case, only the current of air moves. The rational name for it is "torrential hurricane or storm".

TORRENTIAL STORMS

Torrential hurricanes and storms, moving down the slopes from the top to the bottom of hills and widely prevalent, have been studied in detail. The movement of a stream of air traveling along the bottom horizontally and ascending even to the top up the slopes has not been studied in detail, though such cases are no less common. It should be called "streaming hurricane or storm".

Torrential storms are formed by a stream of air flowing from the top or crest of a hill down to the valley or the seashore. Many such wind streams occur under different local names.

Antarctic storm: This strong, cold storm is encountered in Antarctica. From the mountainous interior the wind flows toward the coast at great speed. Here it is superimposed on hurricane storms, giving rise to storms and hurricanes of unusual frequency and strength. At Cape Denison storms have been recorded on 340 days in a year, for 30 days of which they were associated with hurricanes. The average speed on May 15, 1912, was 40.2 m/sec; for the whole of May, 27 m/sec and for one individual gust 90 m/sec. The Soviet observatory Mirnyi, in September, 1957, recorded 22 days with storms and five days with hurricanes with speeds up to 50 m/sec. The Mirnyi observatory records 247 stormy days in a year. At other points the winds are

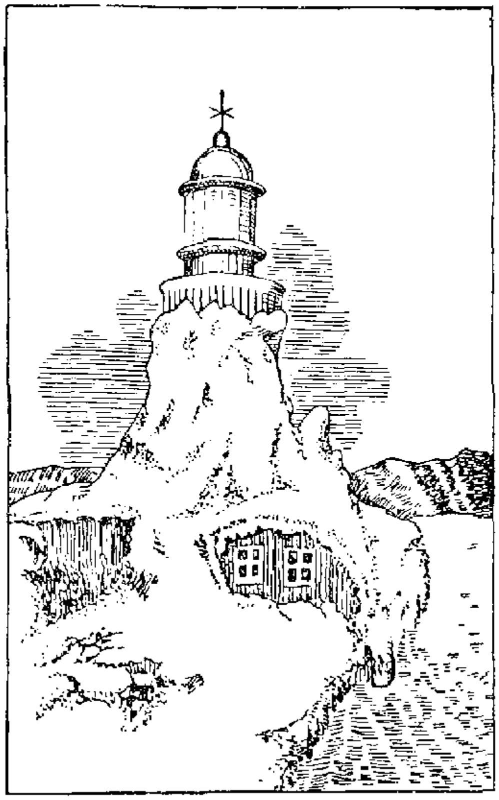


Fig. 86. Lighthouse in Novorossiisk covered by ice due to bora (Kolobkov, 1957b, p. 246).

then, all along the coast this transportation gives rise to a remarkable belt of aeolian-marine deposition. Here the continental fauna is mixed up with continental organisms. On the coast, on the contrary, the continental fauna is mixed up with significant quantities of marine microorganisms. They are carried inland along with the sea water spray torn off by hurricanes and storms. Thus a belt a few kilometers wide is created showing pure and mixed organic worlds.

Balkhash bora: The strong, dry, cold northeasterly wind (northeast of Counrad) flows from the crest of the Chengiz Mountains to the shores of Lake Balkhash. It is typical of the region of Counrad. The main role in the development of the flow is taken by anticyclones, located north and northeast of the crest of the Chengiz.

Balkhash bora has been described in detail by B.P. Alisov (1935), who believes that the Counrad northeasterly wind is of gravitational type, analogous to the Novorossiisk bora or Novaya Zemlaya bora.

Generally the bora blows in the winter when it attains enormous, often hurricane strength and persists for several days. In the spring and autumn it weakens but it is weakest in the summer. In the winter the bora lifts masses of snow, giving rise to fierce snowstorms. In the spring and summer it gives rise to dust storms of considerable strength. The 'dust' is transported and falls to the bottom of Lake Balkhash, giving rise to clayey layers between the salt and dolomitic layers.

Often the bora makes the flight of aircraft hazardous.

The Counrad region is a big industrial center. It is only for this reason that attention was drawn to the Balkhash bora. There is no doubt that an analogous cold, dry gravitational flow of wind exists at the base of other mountains of the central Caucasus, but it has not yet been studied. The development of the bora depends on the anticyclone of northeast Kazakhstan, known as the "axis of Voeikov".

Sarma: This is a cold, gusty, strong wind, attaining a hurricane speed of 40 m/sec. Emerging from the narrow mountain valley of the River Sarma into the arena of Lake Baikal, the wind breaks off the waves and splashes the water on the Ol'khon Islands. The shore rocks are covered with thick ice as in Novorossiisk.

The Sarma has been described in detail by G. Yakhontov (1906). At the mouth of the valley, on the surface of the small delta, the wind is almost always blowing at a speed of up to 10 m/sec, often 17 m/sec and at the time of strong storms 40 m/sec or more. A hurricane raged continuously from October 27 through 30 in 1901. The crests of waves were torn off to form white clouds and blown over the water at Ol'khon. A convoy of boats putting out was blown away and one barge with 300 passengers capsized. The lakeside ridge over which the Sarma flows has a height of 1,300 m.

A strong air flow emerges from the deep, narrow valleys of other rivers, blowing onto Lake Baikal. Such winds are known by the names of the rivers flowing in the valleys: "kharakhaika", "bugul'deika", "barguzin" (Prokh, 1961, p. 140). The song below was composed for the last-mentioned:

The glorious sea of sacred Baikal
The glorious ship
The waves hurry up,
Wonderful, not far to float.

Mistral: The 'Mistral' blows in the valley of the Rhone in southern France, the 'tramontane' in western Italy, north Corsica and Catalonia, the 'biz' in western Switzerland. It is a cold, dry wind, often attaining the strength of a storm. It resembles the foehn but the latter's special feature is not always found. When the foehn character is not pronounced or is absent it becomes a torrential storm. Generally its strength is less than storm strength (Benevent, 1930).

The speed of the mistral in individual cases goes up to 40 m/sec and is equal to the speed of a hurricane. It topples rail cars. In the city of Arles it carried rail materials a distance of 40 km (Rue, 1940, p. 28). In Geneva the biz attains a speed of 70–100 kmph.

Where the cold flow of wind and storm has longer travel, the warm wind

Astapovich showed that the maximum size of the grain was 50–70 microns; one oval particle was 50 × 110 microns. It was mostly quartz, other minerals being less than 5%. Particles of 10–15 microns were also present and the first drops had particles of the size of 3–5 microns. Grains of sizes less than 1.5 microns were not present in the first drops. One drop, with a volume of 7.7 mm^3, had 185,000 grains above 1.5 microns in size. It may be added that these sizes completely conform to the dimensions of diatoms. Unfortunately, I.S. Astapovich did not study the organic residues present in the dust, although undoubtedly they were present. It should, however, be noted that such detailed observations on storms and study of grains as those carried out by I.S. Astapovich are rarely found either in our country or abroad. Only a small number of papers are available on the subject.

Snowstorms of the Alps: Mountainous regions are particularly favorable areas for the formation of torrential storms, often attaining the speed of a hurricane. A number of cases have been described above. These are different, widely distributed but primarily pertaining to the warm, summer period of the year.

The strength and distribution of snowstorms in the winter is not less, rather it is likely to be more.

Alps: This is not a big mountain range. It is situated almost in Central Europe. Numerous villages and cities are scattered in its middle region. Through a number of passes, the traffic continues throughout the year. The winter snowstorms in the Alps have been experienced by the inhabitants and travelers and described in detail.

Snowstorm: This is one of the savage phenomena of nature in the Alps. One who has not experienced it cannot imagine its unusual strength and harshness. It can be correctly compared with the simoom of the deserts. The terrible gusty wind lifts enormous clouds of dry snow. It is so dense that the darkness of night takes over and visibility deteriorates. The unfortunate travelers trapped by the snowstorm can see nothing and either get lost or are held up and frozen. The snowstorm lasts for hours and often for days. Enormous snow clouds mixed with dust, sand and often with fine chips of stone sweep down the valley with terrific strength, blocking roads, damaging houses, tearing off roofs, destroying lighter structures. In the mountains stones are placed on the roofs at the time of a storm so that they are not blown away.

In one instance so many people were killed that the monk community of Holy Bernard (Saint Bernard) constructed a small monastery specially for the salvation of dead travelers. They use a special breed of dog, not afraid of any type of storm, to search for frozen people. This breed of dog is named Saint Bernard.

The enormous mass of dust, sand and stone chips transported by the storms along with the snow is of interest. Unfortunately no data are available on the composition and quantity of transported material. Moreover, it gets mixed up with river deposits.

Aeolian formations—aeolian sands, aeolian clay—are a possibility. We simply do not take note of them in the varieties of mountain-valley depositions.

Santa Ana: This is the name of the torrential wind of Southern California. It comes from the desert, crosses the mountains and flows to the Pacific Ocean through the river valleys at great speed. The speed of the wind reaches 140–150 kmph. It tears off house tops and inflicts other damage. It works havoc with horticulture.

The Santa Ana wind is always dry and hot. Attaining a great speed, it lifts a mass of dust which fills the torrents of air and makes it visible from a distance. An observer standing on a ridge wrote that standing in the clear, quiet atmosphere he saw from a distance how the torrent of air, filled with dust, flowed down the valley like a river. The boundary of the flow was so distinct that it looked just like any river (Sergius, Ellis and Ogden, 1962).

Chinook: This is a typical torrential wind, blowing from the Rocky Mountains to the east, the prairies. It is observed in western Alberta, Canada over a stretch of 400 to 1,000 km; on the prairies, the path is up to 230 km wide. The dry, warm wind attains a speed of 30–50 kmph, and gusts up to 65–80 kmph. It is often accompanied by clouds of dust of huge size, blowing over the surface, quite close to the ground. It is similar to the foehn of the Alps.

"In the infinite, snow-covered plains, the weak, frozen, hungry cattle moved but the grass was covered with hard frost. All of a sudden from the west, from the mountains, the first gusty, warm, humid wind blew. All the cattle turned their heads to the wind. The wind grew stronger, warmer and soon became a powerful, roaring air flow. The snow melted and by the evening it had disappeared, leaving a brown exposed surface and channels of water everywhere. The Chinook saved everybody" (Col, 1896).

The Chinook is associated with the characteristic cloud known as the "Chinook arch". It is an amazingly straight, sharp border of high cumulus cloud with an average height of 3,000–4,000 m, having a length of 800–1,000 km. It forcefully lifts warm sea air over the Rocky Mountains. The thickness of the cloud is 1,500 m and more. The wind accompanying the clouds attains a height of 10,000 m (Thomas, 1963).

An analogous phenomenon, known as "Sierra wave" is observed in California, along the eastern slope of the Sierra (Fig. 87). A strong westerly wind blows down the eastern slope of the Sierra into the valley, sharply lifting the edge of the peculiar roll clouds. At this speed and volume it raises clouds of dust and debris. It can be seen clearly in the diagram (Sierra wave, 1965).

It is very important to note that this mass of dust is lifted only at the edge of the clouds. This can happen if the cloud is due to circulation produced by ascending currents. From an aircraft such a flow has been observed at a

Fig. 87. "Sierra wave". Strong air flow is descending from Sierra ridge (right) to valley. At boundary of thunderstorm cloud (left) it gives rise to gigantic waves. At boundary of cloud arched rotor squall cloud is formed (*Weather,* No: 5. 1965, p. 162).

height of 3,000–10,000 m with the engine switched off. The flow of air and ascending current were observed at the edge of the "Chinook arch".

The "Chinook arch" type clouds have been grouped under "arcus", often known as "roll clouds", in the meteorological dictionary by Huschke (1959). This dense, horizontal, tubular cloud with more or less broken edges is located below the front of the main cloud. The large size gives the dark, hanging, archlike appearance (Fig. 81). This cloud is associated with cumulonimbus, rarely with cumulus clouds (Andrus, 1929).

In Europe, similar formations are known as rotor clouds. The rotor cloud is a cloud of the central layer, encountered on the slopes of large mountain ridge barriers, e.g. in Sierra Nevada, near the city of Bishop in California. The air in the rotor cloud rotates about an axis parallel to the ridge (Huschke, 1959).

The formation over the city of Bishop is known as the "Bishop wave". It includes a rotor cloud and a series of lens-shaped clouds, parallel to the crest of the ridge.

The "Chinook arch", "Bishop wave" and other such formations, e.g. the

Moazagotl in Sudetakh, are similar to foehn clouds. The foehn clouds appear over the Alps during foehn storms.

Over the Rocky Mountain ridges and over the ridges of South America strong torrential winds blow, carrying an enormous quantity of dust.

The Wasatch wind, flowing from the Wasatch ridge in Utah State, is an example. Its speed reaches 80–100 kmph. It lifts and transports a large quantity of dust (Williams, 1952).

An interesting example of a torrential wind was observed in California (Asher, 1923). Its speed reached 130 kmph and in individual cases still more. Pebbles carried by the wind pierced the windowpanes of houses, making round holes like bullets from a machine gun. The paper has a photograph of a window with such a hole. The wind flows from Sierra to a distance of about 150 km. It carries not only an enormous amount of dust but also sand, small pebbles and debris. The metal is removed entirely from roads and the soil is removed completely from fields. The paint of a colored object is removed as if scraped with a file. Quite probably this wind is similar to the Chinook.

An interesting horizontal rotor cloud was observed in North Carolina (USA) in the winter of 1895. Over a small mountain ridge a big, heavy black cumulus cloud was hanging. At its base, at the edge the formation, a long rotor cloud started. Separating from the parent cloud, rotating around a horizontal axis, it quickly descended along the wide valley (Proctor, 1896).

JET STORMS

Nord (Khazri): This is a strong northerly wind, generally attaining the speed of a hurricane (up to 40 m/sec) and lasting for one or two days, often three or four days, continuously. The Nord blows along the Caspian coast and over the Apsheron subcontinent. Therefore it is quite significant as an agent for the transportation of marine microorganisms to the continent. The Nord is a jet storm of considerable speed and strength, strengthening over the Caucasus Mountains. Generally the Nord lifts a considerable amount of dust. A storm in Azerbaijan has been described by A.A. Madat-Zade (1965) and the Nord by S.D. Koshinsky (1959).

Ulan and Santash: This is a stormy wind bursting into the valley of the Issyk-Kulya in the west via Buam gorge (Ulan) and in the east via the Santash pass (Santash). A very strong wind blowing along the northern foothills of Tyan-Shan emerges in the long narrow gorge of the rivers Chu and Tyup with great force. Rising from the gorge, it penetrates the valley of the Issyk-Kulya with increased speed, giving it the typical landscape of high mountainous desert. The Ulan carries sand and fine gravel, creating bare surfaces covered with debris. The storm with sand polishes granite blocks. According to B.N. Ovachinikov (1939) the meeting of the Ulan and the Santash over Issyk-Kulya is the main reason for tornadoes over this lake.

It is quite likely that most dust storms over Kazakhstan and especially over Central Asia are typical jet storms. As has been mentioned earlier, they are quite numerous. It should not be forgotten that they are often associated with a vortex movement, which complicates the general picture.

Ibe: This jet wind, attaining the strength of a storm or even hurricane, worked havoc with the famous Jungar Gate. The Jungar Gate is a big valley, the natural corridor of which is 200 km long and 10–20 km wide, situated between two mountain chains. It joins the depression of Yebinor Lake (243 m above msl) and the Balkhash-Alakul depression (height 35 m) with the watershed at an altitude of 450 m. At the bottom of the Jungar Gate is a desert of debris, plain and flat. All the sand and dust particles are carried away by the Ibe, which even shifts the debris (1–3 cm).

The Ibe is weak on the shores of Lake Yebinor but is accentuated at the entrance through the gate and halfway along attains terrific strength. After breaking out from the valley of Alakul and gradually weakening it reaches Balkhash. In summer the Ibe lifts thick clouds of dust, often changing to a hurricane, carrying clouds of sand and fine debris. In winter it is a terrible blizzard, often killing men and animals and now and then destroying entire caravans.

The synoptic condition favorable for the development of the Ibe has been described by M.D. Ponomarev (1936). Its thickness does not exceed 1.0–1.5 km. Its speed is often more than 20 m/sec.

Ursat'ev wind: This is completely analogous to the Ibe but blows on a smaller scale. It blows in the pass joining the Fergan valley to the Kyzylkum (Fig. 88). It occurs 70 times in a year. The Ursat'ev wind occurs mostly in January. In winter its speed attains the speed of a hurricane (40 m/sec). The frequency of wind with a speed of 20 m/sec is 22%. The vertical thickness of the air flow is generally around 300 m, but often reaches 1.0–1.5 km (Prokh, 1961, p. 124–127).

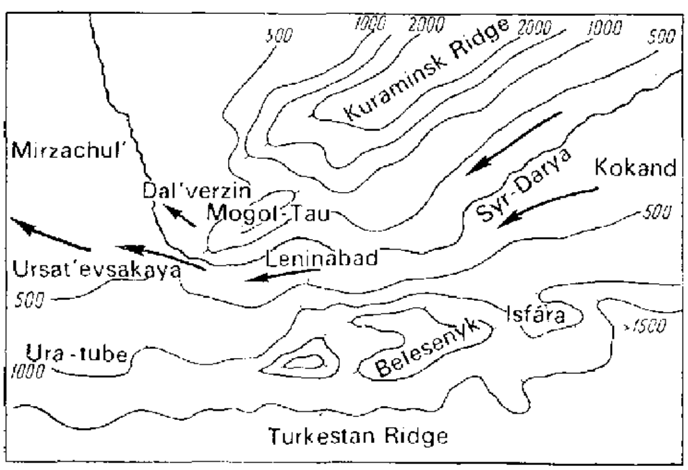


Fig. 88. Region of formation of Ursat'ev wind (Prokh, 1961, Fig. 56).

Kaus: Jet storms occur over many regions of the world, over continents as well as over oceans. One occurring over the sea is an example of the Kaus or Kuas. This is a south-easterly wind, attaining the strength of a storm, blowing over the Persian Gulf. It generally occurs between December and April. It is accompanied by clouds, rain and squally weather.

Gibraltar wind: The jet wind, often of considerable strength, blowing over the Gulf of Gibraltar, but confined to the area between the mountains.

Tekhuantepe: This is a strong squally wind. Starting in the north, in the Gulf of Mexico, it blows in between the hills of Mexico and Guatemala. In the process it sharply strengthens and strikes the Gulf of Tekhuantepe. Over the sea it can be traced to a distance of 150 km.

Like the Ursat'ev and Gibraltar winds, the Tekhuantepe is often classified in the group of mountain pass winds.

Breeze: This is a periodic, daily coastal wind. In the evening it blows from the sea to the land and in the morning from the land to the sea. The evening breeze is stronger than the morning one. The breeze is active over tens of kilometers from the coast. It is caused by the unequal heating of the water and the land. The thickness of the air flow is a few hundred meters, but on the coast of California it goes up to 2,500 m. The speed of the breeze is not very much, usually 15–30 kmph, but often it attains storm speed. In Valparaiso (South America) the wind carries pebbles. The breeze is very widely encountered and blows not only on the seacoast but also over the shores of big lakes and even over the banks of large, wide rivers, especially downstream. In the USSR it occurs on the coasts of the White, Black, Azov and Caspian seas, on the Ladoga, Oneshask, Sevan, Saisan and Issyk-Kul lakes, and downstream of the Volga, starting from Saratov (Khromov and Mamontov, 1963, p. 70).

The breeze is a current of considerable width and relatively small length. Due to the high frequency, it has an important role in the transportation inland of sand and dust particles from the zone of breakers. Coastal dunes are formed due to the activity of the breeze.

The breeze carries many marine microorganisms deep inland, giving false indications regarding the position of the coastline. This, once more, emphasizes the point that the position of the coastline should not be determined on the basis of microorganisms, as is unfortunately done by our micropaleontologists.

GEOGRAPHICAL AND GEOLOGICAL SIGNIFICANCE OF TORRENTIAL STORMS

The area of distribution of each storm is relatively small, although the number is large. Over many mountain ridges, each valley and each ravine has its own channel wind, often of considerable strength. The winds and storms blow in each mountain pass.

Wherever there is sand and dust the channel storm turns into a dust storm. It transports sand and even small road metal. All these move from the mountain valleys with the gigantic flow and are deposited at the base of the mountains. The dust is widely distributed and deposited as fine clay layers. The sand forms the aeolian massif sands at the base of mountains. The road metal accumulates in the form of small lenses in the sand and clayey layers. The quantity of debris carried by the storms is quite high. It is generally believed that all the deposits at the base of the mountains are of aquatic origin. In many cases this is not correct, especially for arid, desert regions. Here massive aeolian deposits are not rare, e.g. the massive gypsum sands of Alamogordo (Fig. 229). The dust and the clay particles in river valleys are absorbed by river deposits, but in the plain watersheds and isolated valleys large parts of the clayey formations are of aeolian origin.

Hot and cold, dry and humid flow storms often cause significant changes of temperature and are accompanied by hail and downpour. They give rise to floods, landslides, avalanches, etc. The plant cover undergoes changes and is considerably damaged.

It can be said that flow storms substantially affect the geography of mountain slopes and foothills and cause important changes in the depositions. All these phenomena occur in a relatively narrow zone but this zone is large in extent and widely distributed. The flow storms, as a factor of rainy deposition, deserve serious attention.

5
Transportation Strength of Storm

GENERAL CHARACTERISTICS

The transportation strength of a wind determines its speed and the magnitude of the transported material. Exact measurements are relatively few. N.A. Sokolov (1884), studying coastal dunes, gave the following data:

Speed of wind m/sec	Size of mobile particle, mm
4.5– 6.7	0.25
6.7– 8.4	0.50
9.8–11.4	1.00
11.4–13.0	1.50

These figures were obtained by measurements conducted at a distance of a few centimeters from the dune surfaces. Direct measurements in the higher levels of the atmosphere are absent.

The hurricane of March, 1918 (see p. 167), starting in the deserts of the western States (New Mexico, Arizona) carried an enormous amount of dust to the State of Wisconsin and adjoining states, a distance of around 3,000 km. The size of the grains varied from 0.005 to 1 mm: 85% of the grains had sizes of 0.005 to 0.025, and 56% from 0.01 to 0.025 mm. The total amount of dust deposited in the States was not less than 1 million tons, probably considerably more (Winchell, 1920).

According to Udden (1894), the average grain size of the dust transported by the storms in the United States fluctuates in the range 0.016–0.25 mm. Particles of this size are transported a distance of 1,500–2,000 km. Particles of smaller size are transported still greater distances and there are particles that can be transported any distance. The dust cloud thrown up in the air during the volcanic eruption of Krakatau (1883) circled the earth three times.

The average size of the grains of ordinary central Asian and Chinese loess fluctuates between 0.025 and 0.05 mm. These figures are quite close to the size of the particles of North American dust. If the distance of transportation is 1,500–2,000 km for the latter, then for the Asian loess it must be of the same order, not less than several hundred kilometers.

Thus a very important conclusion can be drawn: particles of sizes up to 0.025–0.05 mm are transported by hurricane to a distance from a few hundred to 1,500–3,000 km.

Many microorganisms found in skeletal form are not more than 0.025–0.05 mm in size. They are transported along with inorganic particles to a similar distance. Several diatoms and foraminiferas are associated with such microorganisms.

According to V. Twenhofel (1936) relics of plants and diatoms in small quantities were found in the residue of the dust storm of 1918. He writes: "The material of the dust downpour contained shells of diatoms. It was small in quantity, but such microscopic organisms may be expected in all the depositions whose composition is enriched by the wind. The material transported inland from the seacoast often contains shells of marine organisms" (Twenhofel, 1926, p. 55).

He gives the examples: the coastal sands of the Bermuda Islands and dunes on the coast of Ireland are mixed with the shells of foraminifera (miliolin and trunkatulin) and aolitic limestone. To these examples may be added the dunes in Eupatorii, dunes in Batumi, the shale and salty sand content in the upper layers and the dunes on the coast of the Baltic Sea in which small, light shells and their debris are mixed with the sand (Mushketov, 1906, p. 105–107). All these are common and thousands of examples can be added to them.

In the fossilized condition all similar sands will undoubtedly be carried to shallow marine deposits. As such it is a typical continental coastal-marine deposit. Similar mistakes are numerous in the geological literature. Geologists do not realize that they are committing mistakes.

Generally a coastal wind with a speed of not more than 12–13 m/sec transports materials 1.5–2.0 mm in diameter a distance of several tens or even hundreds of meters. It is in this way that dunes are formed.

The transportation strength of hurricanes and strong storms with speeds of 30–40 m/sec is many times greater. They transport particles a greater distance and the particles are bigger than 1.5–2.0 mm.

The conditions during a hurricane do not encourage correct, protracted measurements of small objects and particles. Actually such measurements are not available. The descriptions include the blowing away of ships, transportation of damaged rooftops to tens of meters, destruction of houses, damaged fences, uprooting of thousands of trees, cattle and people, lifting and transportation of heavy tiles tens and hundreds of meters and many other phenomena. Data on how and to what distance the particles and the debris of 2.0 mm to 3.00–5.00 cm size are transported are absent. This question can be answered only from the results of the transportation.

The most striking examples for size and thickness of depositions and the area of transportation are desert sands or, as they are usually called, sandy deserts. These are boundless plains, hundreds of kilometers long, almost continuously covered by sand with irregular, rough, hilly surfaces and a plain, dense alluvial base. Almost every year dust storms pass over the valley bed. Once in 10 years they attain great strength and transport an enormous amount of sand and dust. It seems that the sandy desert must always encroach forward, in the direction of the wind. This, however, does not happen and from the topographic maps it can be said that the deserts change very little. The aeolian sands are related to the alluvial plains in which they are found, and are formed due to the wind blowing over these plains. As the alluvial plain changes with the slopes of the foothills, uneven sands and sandhills change the loess cover and the loamy loess.

Another feature of aeolian sand is its high homogeneity in composition and grain size and the relatively small size of the grains. The average size of the grain is 0.05–0.5 mm, rarely 1–2 mm. Debris of more than 2 mm size is very rare. It accumulates in the form of lenses, formed at the base of sandhills. It also accumulates in any depression where the wind weakens considerably and as a result a considerable mass of sand of the usual size remains.

The size of aeolian sands, as furnished in the exceptionally detailed and accurate work of Bagnold (1941), fluctuates in a narrow range. Generally it is 0.3 to 0.15 mm and in the finest sand it falls to 0.08 mm. This figure is related to the particles that are the components of the added sands. However, there will always be bigger and smaller particles in the general mass.

The aeolian sands, their movement and the struggle with them are described in the monograph by M.P. Petrov (1950). Generally mobile sands consist of small particles of the size 0.25–0.05 mm. The more fine-grained aeolian sand is, the more homogeneous it becomes. Even in fine-grained sand the quantity of dust does not exceed 1.5–2%. Total transportation of dust particles never occurs. This explains the continuous replenishment of the particles of less than 0.05 mm by grating and destruction of larger grains.

The constant presence of dust in the aeolian sands is the reason that storms occurring over sand massifs always become dust storms.

The transportation of bigger grains and debris other than grains of sand also always occurs, but in a limited quantity. Generally such grains and debris accumulate at the base between the ridges of sand, but the quantity is very small.

According to A.V. Sidorenko (1948), in the south Karakoram the gray sands mixed with pebbles are generally associated with the accumulation of gravel. This consists of paleozoic rocks which formd in the lake of Amu-Darya. Generally it moves very slowly but it is not altogether impossible that during a strong storm the pebbles and gravel are picked up by the wind and lifted in the air, like sand, to a small height.

Analyzing the above figures, we see that dust particles not more than 0.05 mm in size are transported by hurricanes and storms to a distance of thousands of kilometers and distributed over a large area. The sands of 0.05–0.5 mm size are similarly transported in a large quantity to a distance of hundreds of kilometers and distributed over a large area, but less than that of the dust. Sands of 0.5–2.0 mm size are also transported hundreds of kilometers but the quantity is one-tenth as much.

Shells of 0.05–2.0 mm size belong to the following groups: diatoms, foraminifera, sponge, etc.

The presence of young aeolian sands in the northern part of Kyzylkum and at places crowded with freshwater peletsipods and gastropods living in Syr-Darya is of interest.

The aeolian sand massifs in the USSR are numerous and some of them are enormous in size. Their description is given in the monograph by M.P. Petrov (1950, p. 60–97). The sands of Karakoram are spread over an area of about 35 million hectares. In Kazakhstan the sand massifs cover an area of around 40 million hectares and in Uzbekistan and Karakalpaki 11 million hectares.

In the deserts of Central Asia and the Sahara the aeolian sands are distributed over still larger areas. Enormous massifs of sand are found in the deserts of North America, the Arabian peninsula, India, Iran and Iraq.

On the other side of the equator, all the deserts of South America, South Africa and Australia have enormous areas covered with aeolian sands.

The total area on earth covered by aeolian sand is of staggering size. This is a good indication of the incredible transportation potential of hurricanes and storms.

The regions of growth of aeolian sands coincide with the regions of maximum incidence of hurricanes and storms.

For a complete picture of the transportation strength of the wind it should be added that not only sands but clays and dusts are also transported in large quantities. The area of growth of loess and aeolian loam is quite enormous. Its total mass is approximately equal to the total mass of sand. In small quantities gravels and big debris are also transported.

If the aggregate of transported terrestrial material is taken into account, then the incredible strength and activity of the wind, especially that of hurricanes and storms, becomes clear.

TRANSPORTATION OF DUST

Transportation of dust is an important and complicated problem and requires special attention. All dust storms have a limited area of distribution and relatively small height, not more than 2–3 km. This can be distinctly seen in the photographs of the haboob (Fig. 69). It has already been mentioned that the transportation of sand and small debris, in spite of the strong wind, takes place on the surface of the earth, usually in spurts. The transportation of sand ceases as soon as the storm weakens. The clearly defined boundary of distribution of aeolian sands shows a similar well-defined boundary of distribution of sandstorms.

The range of transportation of dust is quite wide, but it is not more than a few hundred kilometers beyond the aeolian sands. The transportation of dust to thousands of kilometers by dust storm is relatively rare. Still, it does happen. This process depends on the wind blowing in the altitude band 2–3 to 8–12 km.

Dust from the southern part of the Sahara is transported to the Atlantic Ocean by trade winds and is known as "trade wind dust". The dust storm lifts the dust to the level of the trade wind zone and it is the main transportation agent.

It is difficult to indicate specifically the level of the wind that transports dust from the north Sahara, via the Mediterranean Sea, to Europe. One thing, however, is clear: that it is at an altitude where even the Alps do not form a barrier. The Alps only weaken the wind, blowing at a height of 3–5 km, causing the fall of red dust on the ice and snow of the peaks. The wind, blowing above 5–6 km, transports dust 1,000 kilometers beyond the Alps, to central and northern Europe. Often, though not always, these winds attain the speed of hurricanes and are accompanied by dense thunderstorm clouds.

The transportation of volcanic dust by wind at a great height, when ejected to that height by a volcanic eruption, is well known. The dust thrown out by the Krakatau volcano was transported by a system of winds that was unconnected with any dust storm.

One system of winds that can transport dust many thousand kilometers is the Atlantic Antilles hurricanes. Picking up the dust of the Sahara carried by the trade winds, it is transported to Central and North America and Antilles Islands. The dust of the deserts and plain regions of the United States is transported far to the east, to the shores of the Atlantic Ocean. It is quite possible that some hurricanes reaching southern England and southern Europe bring dust from the American deserts.

The dust invariably carries microorganisms, especially spores, pollens and diatoms. The size of the quartz grains constituting the main mass of the dust is not increased.

DESERTS AND DUST STORMS

Rainfall is insignificant over the deserts and often altogether absent for several years. Therefore the transportation of the products of erosion and primarily sand and dust is carried out by air, not water. The dust storms and hurricanes are of special significance. The normal wind, vertical vortices (dust vortex) and tornadoes take second place.

In the deserts, due to intense heating and cooling weathering is quite fast and numerous products of weathering are formed. A large number of geographers and geologists believe that the solid basement rocks, primarily the granites and sandstones, form the main products of weathering. Actually, the situation is the same at various places, but detailed research over the last few years has yielded a totally unexpected picture. It appears that the additional mass of sand and dust is formed due to erosion of loose younger deposits, primarily river and alluvial deposits. A unique interconnection was obtained: the aeolian sands and loess of the deserts come from the river and the riverine deposits where often there was no trace of a valley. The plains in which these rivers flow are the bottoms of the seas of the recent past.

The history of all the deserts of the world has the same life-cycle: at first the bottom of the sea, then gigantic alluvial plains covered by numerous rivers, and lastly boundless sand deserts.

It is interesting to note one more important fact. The beds of the rivers that formed the larger part of the present-day deserts were wide and a few thousands of kilometers long like the Amu-Darya and Syr-Darya. Their sources and upper courses were situated in young mountainous regions covered by the icecaps.

An enormous glacier, several tens of kilometers long, slowly moves down, deepening its bed and forming small glacier channels in the subsurface rocks. The madly rushing water current is so turbid that the water has the color of coffee with milk. The color of the rivers is the same all along, till they cross the desert with powerful currents to form enormous lakes, the basic cause of erosion.

All across the deserts the river deposits are full of glacial mud. This mud forms the main mass for aeolian loess and red loam.

The transportation potential of the wind, especially of storms and hurricanes, in the deserts attains extraordinarily large magnitude and manifests over a large area.

The deserts always occupy depressions in the relief of the earth's surface. The well-known geologist Grabau, an authority on the Asian and American deserts, said that the depressions covered by the deserts were formed by the winds. This concept has to be substantiated (Grabau writes a few lines only) but it is correct in essence. Grabau writes: "Some of the biggest depressions in the earth's surface occupied by deserts are due to the deflation activities of the wind" (Grabau, 1932, p. 58).

The deserts of the world can be divided into two groups: open, and closed deserts.

The open deserts are open on all sides, either to the sea or to the steppe. They are not surrounded by hills. The closed deserts, on the other hand, are surrounded on all sides by hills 3–5 km or more in height.

River deposits constitute a major part of the desert. Their erosion gives rise to an enormous amount of sand and clayey material and, in particular cases, a considerable amount of pebbles accumulates. The open deserts contain an enormous amount of sand only and pebbles are rare. The entire silt and clayey materials are carried away by dust storms, far beyond the limits of the desert. The distance of transportation is many hundreds and even thousands of kilometers. Distances of 2,000 km have been recorded several times (Wittschell, 1930). The large quantities of dust are transported to the ocean and thus the aeolian marine depositions are formed. The dust particles are spread over large areas. Due to this, dust does not accumulate, rather it is mixed with other deposits.

The particular deposition is formed and a special name is given to it—"aeolian-continental", analogous to aeolian-marine, aeolian lake and aeolian-effusive deposits. However, geologists do not divide these even in the anthropogene, where such divisions are quite simple.

All these bring about the characteristic feature of the open deserts—absence of a layer of loess at the periphery.

The Sahara

A typical example of an open desert is the Sahara (see Fig. 236). Only in the northwest is it bounded by peaks of small heights and the dust storms pass across and travel to southern Europe quite freely. In the northeast the dust storms freely travel to southern Europe across the Mediterranean Sea and often to central Europe across the Alps. In the southwest, the Sahara opens directly to the Atlantic Ocean. The dust storms give rise to the famous sea of darkness (see page 527), whose bottom is covered with peculiar aeolian-marine deposits. The gusty Harmatan rages over the entire southern Sahara and the dust is not retained there. Lastly, in the east—in the realm of the Haboob—the dust soars upward and is transported thousands of kilometers.

The dust is not retained within the Sahara. An enormous area of the desert is occupied by rocks and debris. The Libyan Sahara is characterized by pebble cover. Here the storms are so strong and frequent that they not only carry all the dust away but all the sand as well.

In north Tripoli and south Tunis, the spurs of the Atlas Mountains are continuously covered with layers of fine-grained red sand, up to 5–40 m in thickness. The sands are pure quartz (90%) and contain particles of grain size 0.1–0.5 mm. The area is not layered; it consists of lowlands, slopes and hills up to a height of 700 m.

Wittschell (1928), writing about this peculiar formation, treats it as aeolian deposits retained at high elevations. He shows the wide distribution of red aeolian sands. According to him, "terra rossa" in a number of cases is the aeolian type and even the Red Sea got its name from the red aeolian sands deposited frequently on its surface. In another paper (Wittschell, 1930) he states that an important role is taken by the dust of the Sahara in the formation of the loess of the western Sahara.

The significance of transportation of red dust from the Sahara is enormous. A large amount of work is available on the subject, starting with the well-known monograph by Ehrenburg, the work of Charles Darwin, the detailed monograph by Meinardus and Hel'man and many others. Part of it is reproduced in the aeolian-marine deposit chapter (p. 521–526). The bibliography can be supplemented by the work of Mill (Mill, 1902; Mill and Lempfert, 1904). In the latter, the more detailed work, he writes that in 1903, in southern England during a storm accompanied by a large yellow cloud so much red and yellow dust fell that a thick layer was formed on the windowpanes and the rooms became dark. The dust was clayey and the grain size was less than 0.01 mm. Now and then diatoms were found in the quartz material.

The Alps act as a barrier to dust storms. Although many storms surmount the Alps, in the upper parts of the mountain valleys, especially on the snow, a fair amount of red dust from the Sahara is deposited. A detailed description of this is given by Ehrenburg (see p. 502–507). One of the latest cases is described by Glawion (1937): the dust settled in the valley of Aroz.

The absence of any loess belt around the Sahara was recorded by so well-known a specialist on Quaternary deposits as Penk. He showed that a similar condition is observed in the Kalahari and North American deserts. In the latter case, he suggested that the dust, transported to a distance of hundreds of kilometers, formed the loess in the Mississippi Lake. The Sahara, Kalahari and American deserts are all cases of open deserts (Cloos, 1911).

Closed deserts are surrounded by loess belts, which form in the immediate vicinity of the deserts. The deserts of Central Asia belong to this category.

Deserts of the Soviet Central Asia

The Karakoram, Kyzylkum and other deserts, of small size, form one geographic unit. The basic cause of erosion is the Aral Sea, Balkhash and Alakul'. In the depressions the air circulates, the wind flow encounters no barrier. The important factor affecting the wind is the large anticyclone located over Siberia. It gives rise to a north-easterly flow, determining the main direction of the dust storm. This flow tears off the soil cover over a large area of the virgin land, turning the arable land into a sandy tract.

Blowing over the alluvial plains of Kyzylkum and Karakoram, the hurricanes and storms easily erode the loose fine-grained river and lake deposits. The enormous mass of sand is not transported far, but deposited in the center of the plain, in the region of maximum wind strength. In the foothills in the south the wind weakens. The sand does not penetrate here: only dust reaches them.

In the south, southeast, and southwest, the Central Asian deserts are closed by mountain ranges linked with one another. First come the foothills with a height of 1–2 km, then the snow-capped peaks 3–5 km in height and still farther on the giant glacial peaks 6–7 km in height.

The height of the dust storms is not generally more than 1.5–2 km and therefore the main mass of the dust settles on the slopes of the foothills. Here loess is widely distributed and attains its maximum thickness. On the high mountain ranges the dust penetrates in small quantities and settles on the lower slopes in the form of loess and red loam. On the great mountain massifs the aeolian deposits are either absent or are of local origin, e.g. in Pamir. Pamir is a unique high mountainous desert with its own local winds and aeolian deposits.

The Soviet Central Asian desert has one open region through which the storms carry a large amount of dust. This is the eastern part of the north Caspian, between the Krasnovod peninsula and the mouth of the Ural. Here the prevalent winds of southeasterly and easterly direction often steer the storms and even hurricanes. These storms, passing over the old river beds of the Amu-Darya and Uzboya, lift enormous amounts of dust and carry it to the Russian Platform. In the Volgograd region, at the watershed between the Khopr and Medvedits, the loess deposit of a thickness of 10 m consists of dust transported from Central Asia. It shows the presence of large quantities of hornblende. The transportation of dust from the Soviet Central Asia to the northwest has been studied by many workers.

Storms from the easterly direction are rather rare. They move over the salt marsh of the Aral Sea, lifting salt particles. A remarkable white salt dust storm develops (p. 169, 484). The salty dust is transported and settles over the Russian Platform.

The northeasterly wind plays an important part in the distribution of aeolian material in the deserts of Central Asia. It gives rise to a cell of the Asian anticyclone, located over the central part of Kazakhstan.

In the deserts where the average annual speed of the wind is more than 6–7 m/sec nothing is deposited and the surface is exposed with debris. Massive aeolian sands are formed where the speed of the wind is around 3 m/sec. On the periphery of the desert, over the foothills, the speed falls to 1.5–2.5 m/sec and the loess is deposited.

Deserts of Central Asia

The deserts of Central Asia, closed on all sides, form a unique region. Though far and inaccessible, it has drawn the attention of explorers, starting with the legendary Marco Polo. The great explorers V.A. Obruchev (1892–

1894), N.M. Przheval'sk (1871–1887), P.K. Kozlov (1899–1901), Swen Gedin (1894–1897) and G.N. Potanin (1884–1886) are well known. Among recent explorers, the work of Teilhard de Chardin (1923–1937) ranks first.

Next comes the work of the Chinese-Soviet expedition covering a large area. V.M. Sinitsyn, N.A. Belyaevskii, Ye.M. Murzaev and B.A. Fedorovich participated in the expedition. Their data are used in this brief account.

In the third category come the works of various Chinese geographers and geologists. Unfortunately, this material is almost inaccessible to European workers.

Among the consolidated works, the paper by V.M. Sinitsyn, "The Mongol-Siberian anticyclone and the regional zonality of the aeolian deposits of Central Asia" (1959b), his monograph *Central Asia* (1959a) and the monograph by M.P. Petrov (1966) are important.

In these papers the concept that the most important factor in the formation of dust storms is the Mongol-Siberian winter anticyclone is postulated. This anticyclone, as already mentioned, determines the direction of the wind over the deserts of Soviet Central Asia. Under the influence of this anticyclone a mass of dense, dry, cold air accumulates and gathers enormous speed in the surrounding desert over which the air is warm and light.

The cold, heavy air along a continuous front moves into the warm, light air of the desert, lifting it up. The warm air carries dust, forming the characteristic continuous dark wall of dust and, below that, of sand—the typical dust storm. At the end of the spring and in the summer, the Mongol-Siberian anticyclone dissipates and the dust storms weaken, but at the end of winter and at the beginning of spring, they are frequent and extraordinarily strong. They constitute the chief factor in the transportation of dust, sand and at places pebbles.

The air currents flowing from the anticyclones can easily surmount ranges of 1.5–2.0 km in height but ranges of 5–6 km in height constitute permanent obstacles. The dust storms, striking the plains, weaken considerably in the foothills and cease altogether at higher elevations. This causes a zonality in the distribution of aeolian deposits. All the pebbles and sand move only in the plains; the loess-forming dust settles on the lower part of the slopes, and at still higher levels only red loam dust settles.

This zonality in the strength of the wind often becomes complicated, because a strong storm is not only forced up the slopes, decreasing gradually, but is channeled along the slope, almost without loss of speed. Carrying the sand, it forms sand massifs, distributed along the slopes and in the foothills.

The zonal distribution of aeolian deposits can be seen clearly in the schematic diagram (Fig. 59) prepared by V.M. Sinitsyn (1959a). Along the periphery of the anticyclone the storm is relatively weak and carries only sand; the sands form a small massif. The direction of the ridges and sandhills in these massifs is always perpendicular to the direction of the wind.

In the middle of the desert where the wind is quite warm and light the storm attains its maximum strength. The speed of the wind is so great that not only dust but also sand is transported. The surface of the desert becomes rocky and the desert is like the Sahara.

Still farther from the anticyclone we get the main belt of sand massifs, attaining a large width. Individual ridges and knolls of sand have heights up to 100–200 m and at places up to 300 m (Belyaevskii, 1947).

The dust particles, the material for the formation of loess, are deposited right from the start of the foothills. A fairly large area is occupied by loess in the northwestern part of Central Asia, in the region of Kashgar-Khotan. Then a small portion is situated in Cherchen. At Tsaidam the loess is relatively less in quantity, but starting from Lanchzhon and Ordos the loess covers an enormous area, forming the well-known loess plateau of China. This region of loess growth has been described in detail by A.S. Kes' (1959, 1962, 1964).

The clay particles that settled on the slopes over the dust are shown combined together in the schematic map by V.M. Sinitsyn, but in a more detailed map, prepared by A.S. Kes' (1964), they are shown separately. The zonality of the arrangement can be distinctly seen in the distribution of red loam.

V.M. Sinitsyn (1959a) has shown that the high peaks of Kun'lun, Nau'shan and others not only stop the dust storms but also deflect them to the southeast. This explains the relatively small size of the area covered by loess in the west, and the enormous size of the plateau covered by loess in the southeast.

The storms are mainly, but not entirely, connected with the Mongol-Siberian anticyclone. An especially complex interrelationship obtains in the northwestern part of Central Asia, in the deserts of Takla-Makan, situated between Kun'lun and Tyan-Shan. This is described in the important work of B.A. Fedorovich (1961), illustrated with interesting maps.

In addition to the wind of northeasterly direction, a wind of northwesterly direction also occurs here. Often dust storms develop and sand accumulates. Due to their interaction, sandy relief is formed. Initially davans (davan means "pass") are formed. This sandhill is tens of kilometers long and 100 m or more in height (Fig. 89). The maximum size is attained in the sand massifs of Taukum (Kumdag), adjoining the deserts of Takla-Makan in the southeast. Here the davans are of unusually great height (480 m) with a length of 60–70 km and the distance between the ridges is around 3 km (Fedorovich, 1961, p. 45). They are the highest such formations on earth.

Another peculiar form of sandy relief is the isolated circular hill (Fig. 61) or pyramid. The pyramids near Lake Bagrashkul', according to the observa-

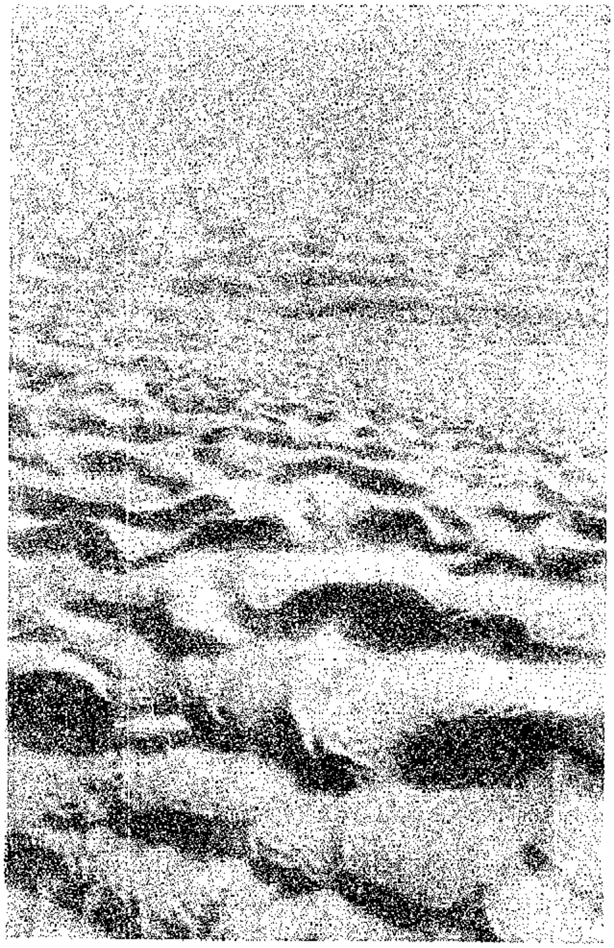


Fig. 89. Davans, sandy ridges in deserts of Taukum. Height exceeds 100 m (Fedorovich, 1961, Fig. 5).

tion data, have heights of 120–190 m. According to N.A. Belyaevsky (1947), sand pyramids under the Mazartag cliff attain a height of 300 m and form a unique feature.

As such, the desert of Takla-Makan is quite remarkable. Swen Gedin referred to it as the "desert of deserts".

The Gobi desert stretches to the southeast of Takla-Makan to the peaks of Kunlun. It has been referred to by V.M. Sinitsyn as "the great Gobi". In it many individual, isolated desert regions are situated. These have been described in the book *Central Asia* by V.M. Sinitsyn (1959a). We will confine ourselves to its southeastern part—Alashan and Ordos. The main loess plateau of China borders on the west. This interesting part has been described by V.M. Sinitsyn (1959a) and later by A.S. Kes' (1964) and M.P. Petrov (1966). In their work we get a comprehensive picture of the characteristics of aeolian deposition, developed fully in this region, and a short account of the climatic conditions, particularly of the winds.

The main transportation of dust and erosion of sand is carried out by the storms of a northwesterly direction. They form dust walls and dust clouds and carry masses of fine sand from the surface. "Throughout the Alashan desert a peculiar orientation of the sandhills is observed; their slopes are directed to the west and northwest" (Sinitsyn, 1954, p. 121).

This feature of the wind determines the zonal distribution of aeolian deposits, described in detail by A.S. Kes' (1964). In the northwest, in the Alashan desert and on the borders of Ordos, the growth of sand massifs takes place.

The zone of coarse loess occurs in Ordos, replacing the typical loess of the loess plateau. The fine-grained red loam still develops on the borders of the loess.

The action of hurricanes in the Ordos and Alashan areas is the same as in Central Asia.

Another peculiar phenomenon, especially in Alashan, may be mentioned. This is Tsaidam—the subsidence of sand massifs. These are of different sizes, often stretched along the ancient channels of the left tributaries of the Huangho, which is now dry. The center of the channels still has one or several shallow water lakes or salt marshes. Due to the shallow level of potable ground water, the Tsaidam is covered with vegetation of saline-marsh type meadow. It forms an oasis in the desert. All the stock-breeding centers, and often even the ancient monasteries, are situated in these oases.

M.P. Petrov (1966) considers Tsaidam to be the residual riverbed of a branch of the Huangho. Now this bed is almost continuously covered by aeolian sands. Among these only the Tsaidams remained.

The Tsaidams are important indications to show that not very long ago the wide Alashan covered numerous riverbeds, constantly changing course and covering large areas. Therefore the river deposits, alluvials, etc. played an important part in making the plains of Alashan.

The aeolian sand massifs and loess of Ordos are mainly the products of erosion by storms of the upper anthropogen alluvial of the wide plains of Central Asia. The relationship is the same as that in Central Asia.

The rule is the same, whether it is the great desert of the Sahara, the still more boundless desert of Central Asia or the more modest but enormous desert of Central Asia.

Its bed, the boundless plain, is an alluvial plain, formed not long ago by dried-up rivers, whose beds continuously shifted across the plain. An inconceivable mass of loose sand, dust, clay and rarely pebbly materials is formed.

The drying up of the rivers accompanied the erosion of the deposits. It started in the upper anthropogene and halogene formations and continued up to the present time.

Along with the erosion dust storms and hurricanes carried the products of destruction. The pebbles and sands were not transported far and generally they remained within the plains. The case with dust and clay particles was different. In the open deserts they were transported a great distance. In the closed deserts they were deposited on the slopes of the mountains or on top of the plateau. The classical example is the loess province of China.

Loess Province of China

The origin of the Chinese loess and the subloess red loam has been described in the work of I.P. Gerasimov (1959b) and in the monograph by A.S. Kes' (1964). They combine the loess and loam in one loess-red clay formation and believe that the "aeolian-soil origin of the formation is supported by the geomorphological features and tectonic structures of the loess province and its place of occurrence (Fig. 90—D.N.). The province is situated in the region of reduced speed of the transportation of dust by the dry wind blowing from the Central Asian anticyclone and passing over the desert where denudation and depletion prevail" (Kes', 1964, p. 561).

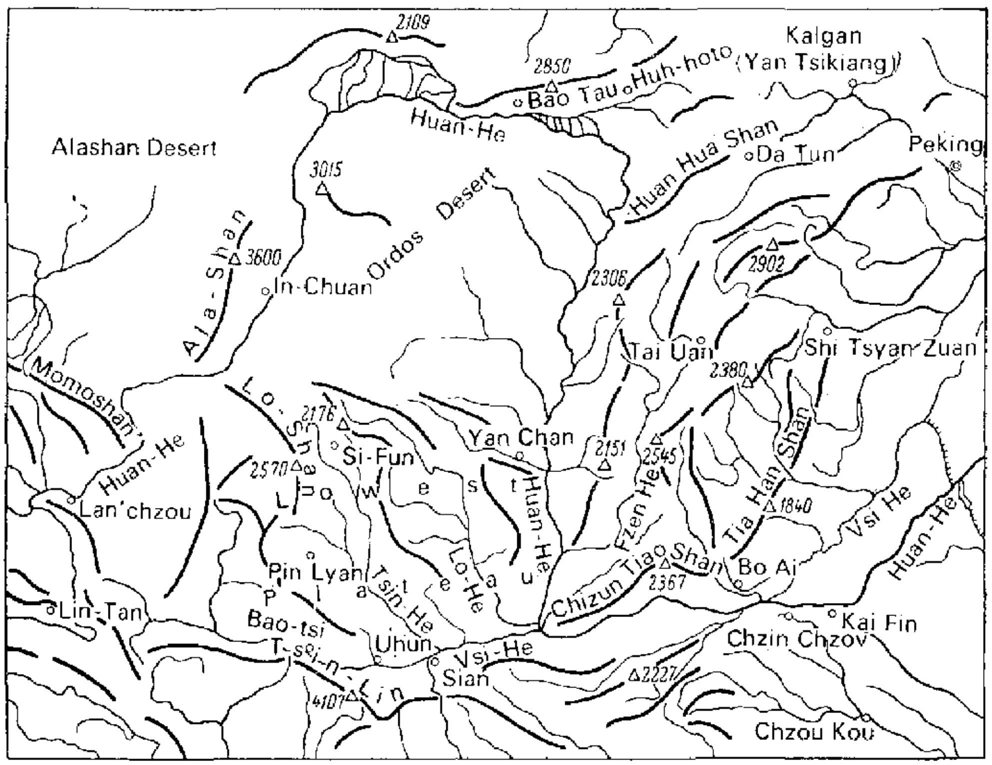


Fig. 90. Geographical position of loess plateau of China (Gerasimov, 1959b, p. 206).

On the Ordos plateau and in the loess province of China the zonal disposition of the aeolian deposits can be distinctly seen. The zone of sand is in the northwest, bordering the desert of Alashan, and the alluvial depression to the north of Ordos—the region of denudation. After the zone of sand comes the loess zone, occupying an enormous area of around 300,000 km^2. Its orientation is over the hills and plateau. Still higher, in the mountains, individual zones of clayey loess and red loam-fine-grained aeolian deposits are found.

The accumulation of dust in the loess province is caused by a sharp decrease in the wind speed. The main mass of dust (Sinitsyn, 1959b) is carried by the northwesterly wind in winter, often attaining the strength of a dust storm. The areas of the provinces are situated on the border of the Central Asian anticyclone. The speed of the wind decreases and a large part of the dust settles, especially during the rains (spring and autumn). Only the finer, clayey particles are transported higher, to the hilltops.

The total area covered by loess increases to 315,000 km^2. The thickness of the loess changes widely, but on an average it can be taken as 200 m. In the Quaternary period (600,000 years) the annual growth of dust comes to 0.3 mm (Kes', 1964, p. 499).

In the maps of the distribution of sand loess prepared by Obruchev (1948), V.M. Sinitsyn (1959a) and Fedorovich (1960) the zonal distribution with respect to the regions of depletion according to the wind systems can be distinctly seen.

A typical expression of the same process can be seen on the northern slope of Kun'lun', especially in the region of Khotan (Murzaev, 1961). Here the dust storms are well-developed, blowing from the north, from the deserts of Takla-Makan. Their number averages 174 per year. The aeolian sand massif is situated on the border of the desert. The zone of loess is at higher levels, on the slopes, and the loamy zone is situated at still higher levels.

The interrelationship of these zones is described in detail by A.S. Kes' (1964). He shows that all the areas of aeolian sand, loess and red clay are parts of the same unit, inseparably linked and gradually transforming from one to the other. In a number of regions the area of growth of loess is directly contiguous to the aeolian sand massifs (Fig. 59). However, here as well as in Central Asia the gradual transition of aeolian sand to sandy loess does not occur. The aeolian sand and loess are sharply demarcated.

The loess province of China shows all the granulometric differences of loess, starting from highly sandy to highly clayey.

The clays and loams are developed in the hills, occurring in individual zones, isolated from the regions of continuous growth of loess.

Possibly in such cases it should be looked for in the mountains of Tajikistan, at greater elevations than the region of the growth of loess. This assumption supports the observations mentioned above on the penetration of dust storms to the upper part of the mountain valleys and even beyond the watershed.

The observations by M.A. Glazov (1952) on the accumulation of dust on the glaciers of Terskei-Alatau are quite interesting. He shows that during haze, the number of settled particles doubles.

Lastly, even among the loess a zonal distribution is distinctly reflected. A.S. Kes' (1964, p. 569) shows that the largest grain loess sand stretches laterally along Ordos. Its zones shift the sandy and loamy loess zones and fine-grained, fine clay loess settles along the foothills of Tsinlin. The loess is rather fine-grained at the higher levels and on the leeward slopes of the mountains.

"The loess is formed in a warm, dry climate, close to that of the steppe. The red clay is associated with the hot, seasonally humid climate, like that of the savanna, which has a snowless winter and a long dry period alternating with brief, abundant seasonal rain" (Kes', 1964, p. 572).

The speed of the accumulation of loess is considerable. Specific observations on this aspect for the Central Asian region are absent. The accumulation of loess in the 2000-year old Chinese graves is around 2 m.

The rate of accumulation of the aeolian loess can be found from the numerous inclusions of crop residue in the loess found in the deep interior of China. The loess often contains the well-retained residue of bonfires.

TRANSPORTATION OF MICROBES AND VIRUSES

The great transportation potential of storms is so obvious and their tracks so long that for a long time it has been assumed that storms transport large amounts of microbes and viruses. It has been assumed that storms and hurricanes are the cause of large-scale epidemics, particularly the epidemic plague in Europe in the 16th century. The terrible epidemic of influenza (Spanish) of the 20th century, affecting millions of people, was also blamed on storms carrying viruses.

The problem is not clearly understood. It is not clear under what conditions the wind carries bacteria and viruses. There is no doubt that bacteria and viruses are carried by human beings and animals but it is not clear how they are transferred to the air. Theoretically such transfer is possible, although the magnitude of transfer is not known.

It is quite likely that storms carry dust and microorganisms living in lakes in larger quantities than the bacteria and viruses found in animals.

In any case, the problem is interesting and deserves attention. Malaria and other diseases are carried by insects. Their transportation to a great distance is quite possible, although it has never been recorded.

WEIGHT OF TRANSPORTED MATERIALS

We love the panorama of the rain clouds, slowly moving in the sky. The dark thunderstorm clouds with flashes of lightning frighten us. It never occurred to any one that these light air formations exhibit exceptionally large transportation potential.

The caravan moves across the desert. A dark cloud is seen on the horizon. It grows rapidly and comes closer and closer and the enormous yellow wall moves in on the caravan with a roar. The terrible sandstorm strikes. Everyone lies on the ground, every kind of shelter is attempted but in vain. The hot sand strikes everything and penetrates everywhere. There is no escape from it. The storm passes after everyone has waited anxiously for some hours. The yellow cloud can already be seen moving away.

Sandstorms carry many things. Many workers have made observations on them but no one has asked the question: What is the weight of the dust storm, what is the volume of sand and dust transported? No data on this aspect are available. Only one thing is clear: the cloud of a height, width and length of several kilometers, and maybe even hundreds of kilometers, totally saturated with dust, must have incredible weight and the volume must be tens of cubic kilometers.

More or less complete and exact data are available in respect of the dark blacksoil storm. These storms cause great loss to agriculture. The winter crop suffered great loss during the spring storm of 1960. The old grasses were exposed due to erosion. In Krasnodar region 50,000 hectares of this crop was affected. The loss was considerable in the fertile zone: 50 to 100% of the young seedlings were destroyed. This is the case in Krasnodar region only and the storm covered the Caucasus and the whole of south Ukraine.

M.M. Zhukov (1964) did considerable work in 1960 regarding depletion. He collected the data from organizations like the hydrometeorology and agricultural inspection departments of 166 meteorological stations, and maps of March and April storms were prepared. From these maps it was calculated that the area affected by storms with a speed of not less than 15 m/sec, was around 1 million km^2. In this area the movement of air was irregular and with vortex circulation. Therefore depletion of the soil took place in specific areas. This can be clearly seen in the map of the dust storm for April 26–27, 1928 (Fig. 51), prepared by A.V. Voznesensky (1930). The size of the depletion fluctuated from 0 to 12 cm and at places was even 30 cm.

For calculation purposes M.M. Zhukov (1964) reduced the area of action of the storm by half, to 500,000 km^2, and took the minimum depletion as 1 cm. Then the calculated volume of transported material was 5 km^3. He then took the average depletion as 5 cm and the volume was 25 km^3. A.V. Voznesensky (1930) made similar calculations for the storm of April 26–27, 1928. According to him the area of action came to 1,068,000 km^2. He did not average the amount of depletion but considered the actual figure. It was 19 km^3. This figure was close to the figure obtained by M.M. Zhukov (25 km^3). The enormity of the magnitude can be appreciated if we realize that 25 km^3 is equivalent to a solid mountain ridge 25 km in length, 2 km in width and 1 km in height. This ridge is lifted into the air and carried by one dust storm.

The weight of the storm comes to around 50 billion tons without taking into account the water that comes out of the cloud as rain. 50 billion tons—that is 5 million big freight cars or 100 years of operations on the railroad between Leningrad and Moscow.

The weight of the heavy rains associated with the hurricane clouds is interesting. Jamaica had 241 cm rain in four days. The weight of this rain, considering that the area of Jamaica is 10,780 km^2, was around 27 billion tons. This is the weight after excluding the weight of the rain that fell over the sea around Jamaica. To transport it by rail 2,705,780 trains would be required, i.e., 67.6 years of work for the railroad. This calculation is no doubt approximate but it shows clearly the enormous weight of a good downpour (Fassig, 1916).

For purposes of comparison we will consider the weight of the rain accompanying the hurricane in the middle of August, 1940 (Hoyt and Langlein, 1955), which occurred over the eastern States of America. On an average 10'' of rain occurred over an area of 35,000 sq. miles. Its weight was 22.4 billion tons; the number of trains required to carry it would be 2,240,000 and the time of transportation 55.1 years. The figure is close to the downpour in Jamaica and is striking in its magnitude.

Even heavy rains under normal conditions are striking in amount. On June 19, 1951, a thunderstorm released 42 mm of rain in 4–5 hours in the Leningrad region. More than 10 mm of rain was recorded over an area of 200,000 km^2. This area had 300 million tons of rain (Shishkin, 1964, p. 39).

On September 17–18, 1880, northern India had 25 cm of rain over 10,000 sq. miles. The weight was equal to 7.25 billion tons (Davis, 1899, p. 292).

The hurricane of average strength that struck Puerto Rico on August 8, 1899, was accompanied by a downpour which gave 25 cm of rain on the island. The weight of this downpour was 2,602 million tons (Fassig, 1916).

Light storms are unusually diverse in character but how great is the transportation potential? Storms are less powerful and formidable than hurricanes but the frequency is much higher. The destructive and depositional action of storms possibly exceeds that of hurricanes. Their effect in the past is almost unknown to us.

PART III

TORNADOES AND VERTICAL VORTICES

1
Definition and the General Rules

A tornado is a very rapidly rotating air funnel hanging from a cumulonimbus cloud. It is observed as a "funnel-shaped cloud" or "tuba".

The fully developed tornado reaches the surface, moves along it and causes large-scale destruction (Fig. 91). Often tornadoes do not develop fully and are suspended from the cloud in the form of a funnel, of big or small size (Fig. 92).

The tornado is the smallest in size and greatest in speed of rotation among all the formations with vortex motion in the atmosphere.

Tornadoes have been studied more or less in detail and volumes of literature are available on them. Data on 250 tornadoes of Europe have been given by Wegener (1917); a concise but important report has been provided by Brooks (1951); a big monograph, mainly on the tornadoes of the USA, has been written by Flora (1953). Short reviews have been given in many handbooks of meteorology even in the Russian language (Khromov, 1964; Khromov and Mamontova, 1963). Short articles have been written by Z.M. Tiron (1964) and N.V. Kolobkov (1957b). The literature in the Russian language is not large but still 10 works can be counted.

Most research on tornadoes has considered them independently, i.e. independent of thunderstorm clouds. Only in recent years have a few workers paid attention to the close relationship between tornadoes and vortex formations in the clouds.

The main phenomenon is the vortex formation in the clouds. The tornado is a secondary formation, originating in the cloud and hanging down to the earth's surface in the form of a funnel.

The vortex cloud giving rise to the tornado is a powerful transporting agent and has considerable geological significance. Many objects drawn into the top of the tornado fall in the vortex inside the tornado cloud. These are transported, due to the movement of the cloud, tens and often hundreds of

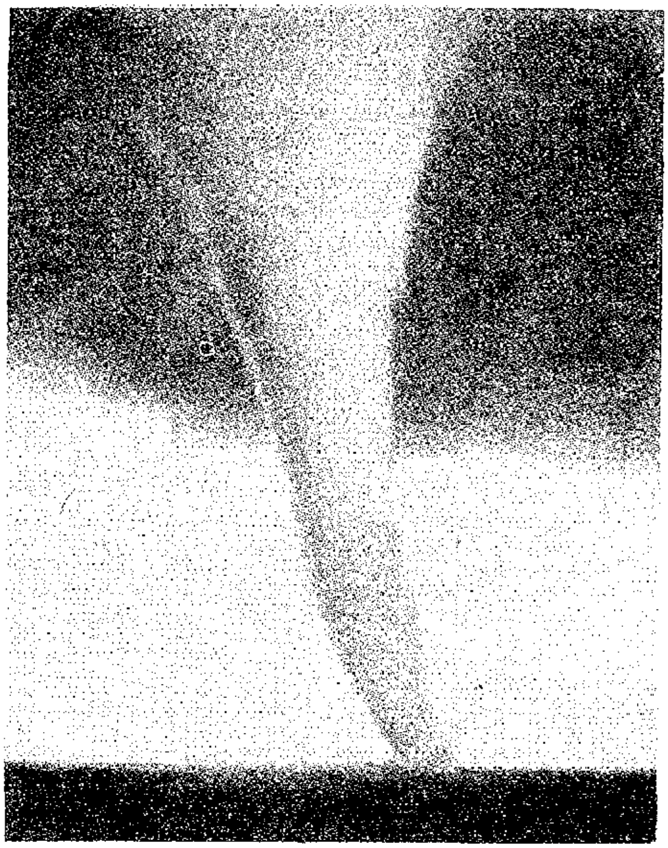


Fig. 91. Typical funnel-shaped tornado, Kansas, June 2, 1920. Destruction was total where it touched ground (Flora, 1953).

kilometers. They fall to earth, not from the tornado but from the cloud along with the rain, generally in the wake of the tornado after it dissipates.

There are various theories on the formation of tornadoes but one of them is widely accepted and answers most of the questions.

In 1951, Blecker and Delver (1951) postulated the thermal theory, according to which tornadoes and vertical vortices are formed due to a rise of temperature at the center of the circulation. This theory is correct as far as vertical vortices are concerned, but does not explain the most important question—the association of tornadoes with tornado clouds.

Koschmieder (1951) concurrently put forward the thermo-dynamic theory, in which the thermal phenomenon is related to dynamics—the movement of the air mass. It, too, ignores the relationship between tornadoes and tornado clouds.

S.P. Khromov (Khromov and Mamontova, 1963) believes that tornadoes are associated mainly with the development of strong unstable layers in the atmosphere in the warm air mass. The close proximity of the front may trigger the process of tornado formation. Unfortunately, nothing has been

Fig. 92. Funnel has not reached surface: USA tornado of September 3, 1961 (Hexter, 1962, Fig. 5).

said regarding the relationship with the parent cloud.

The first major step toward the formulation of a theory of formation of tornadoes was taken by the great scientist Wegener (1917). He was on the right lines regarding the horizontal movement of the parent cloud but illustrated it with inappropriate material. The parent clouds move, but not in the fashion suggested by Wegener. The tornadoes give rise to vortex circulation, not in the form of a vertical cylinder but as horizontal spiral vortices, of the vortex hurricane type.

The leading American meteorologist Brooks (1949) first put forward the theory of the vortex. He showed that the tornado is partly the initial parent cloud showing spiral vortex motion, similar to that in the cyclone. Therefore he named it "tornado-cyclone". As a tornado is also a cyclone the name "tornado-cyclone" did not gain wide acceptance. The part of the cloud giving rise to the tornado is simply known as the parent cloud. The latter name will be used hereinafter. Its equivalent name is "tornado cloud".

Fujita (1958, 1960a, 1960b, 1965) studied a large number of tornadoes in great detail and showed the correctness of Brooks' theory. From a detailed study he further developed this theory and gave the short and exact definition: "The parent cloud is a small tropical hurricane". The cloud displays an "eye of the storm", has a spiral structure and gives a radar echo in the hook form.

The relationship of the tornado with the parent cloud has been underlined by Dinwiddie (1959a, 1959b, 1961), Flawin (1952), Reber (1954), Samuel, Pierce and McGuire (1955), Beebe (1959a, 1959b), etc. in their papers. This relationship is widely accepted nowadays.

The parent cloud has been studied in fairly great detail. Its deep, to be exact, three-tiered structure has been shown in the works of Wobus (1940) and Hoecker (1960).

The association between the formation of a tornado and a cyclone deserves attention from synoptic considerations also. This was shown by S.P. Khromov (1939) for the Moscow tornado of 1904 on the basis of the synoptic situation. The same relationship with a cyclone for the tornado of 1884 in the USA described by Finley (1884) was shown by S.S. Gaigerov (1939a). He established the relationship between the tornado and the warm front.

2
Tornado Clouds

GENERAL CHARACTERISTICS

Every tornado originates in a tornado cloud. The number of tornadoes that form every year is considerable. In the USA alone the number is 600 and often goes up to 850 per year. It is formed in many parts of the world. If only the major ones are taken into account the annual count comes to thousands. The number of tornado clouds is equally large. Their structure and size are relatively less known.

The form and structure of the tornado cloud are like those of a typical thunderstorm, cumulonimbus cloud. A diagram of a cumulonimbus cloud is given in Fig. 84.

The tornado cloud is almost always accompanied by a thunderstorm, hail and heavy downpour of unusual strength and size.

Very many descriptions of the mother cloud during the formation of tornadoes have been given by Finley (1881). They have been done by nonspecialists and therefore are elementary and approximate, but the principal processes—the convergence of air currents from various directions and the formation of spiral rotation of a horizontal vortex at that point—have been clearly brought out.

Tornado clouds originate under different synoptic conditions, mostly along the line of the fronts of two air currents—warm and cold.

FORMS AND DIMENSIONS

The forms and dimensions, as has already been mentioned, have not been studied in detail. Numerous observers have described in the most general terms: "an enormous thunderstorm cloud", "a dark, heavy cloud, hanging over the earth", "a thunderstorm cloud of greenish color underneath", etc.

The dark, greenish, grayish or yellow-gray coloration of the underneath of the cloud is referred to quite often. It is quite likely that this coloration is related to the large quantities of water and often dust.

Quite often the thunderstorm cloud in the form of a single mass moves in when the sky is clear. Frequently it breaks up into small separate fast-moving clouds at the edges. It is very rarely that the sky will be covered with clouds and the tornado cloud will move into them. Its average size is small: length 5–10 km, rarely up to 15 km and height 4–5 km, often up to 10–15 km. In large tornadoes the width of the cloud is 30–40 km and the length 50 km.

The flat, dense, almost horizontal base is quite typical. It is sharply defined with distinct protuberances of funnels or pipes from it (Fig. 93).

The distance between the main cloud and the ground is small, of the order of a few hundred meters and sometimes more. Often the cloud comes down to the surface (see Fig. 99). Now and then it moves along the surface. Then the funnel is not formed and the mother cloud is transformed into a hurricane vortex wind, causing enormous destruction.

The transportation strength of the cloud is enormous and it is described in detail on page 419.

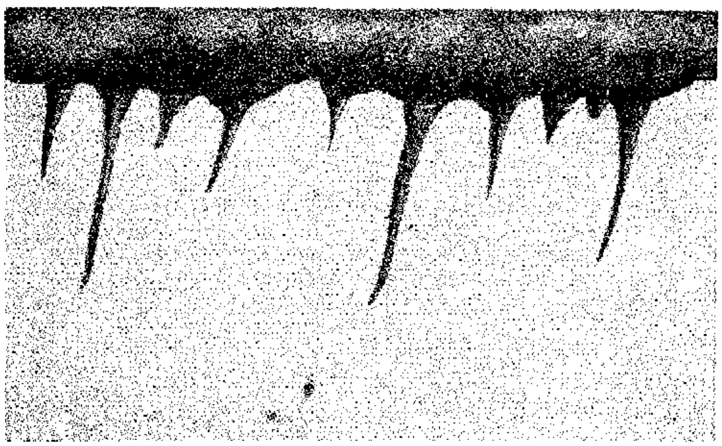


Fig. 93. Initial formation of funnels (Finley, 1881, diagram 2).

INTERNAL STRUCTURE

Tornado clouds, like any other thunderstorm cumulonimbus cloud, show two main features: high turbulence and heterogeneity. Simple visual observations showed that certain individual parts of the thunderstorm tornado cloud display special features, generally with vortex motion. Such parts are known as the "collar storm", "arc cloud", "squall cloud", etc. These are described below.

The most important fact is that many of them show vortex circulation. These are actually the carrier, generator tornadoes and therefore known as mother clouds.

HORIZONTAL VORTEX CLOUDS

The horizontal vortex clouds are broken and move at a small height, from a few hundred to 2000–3000 meters, above ground. The fish and other animals which they carry drop from the clouds in nonfrozen, live condition.

The vortex clouds have been known for a long time and have been referred to in the literature by different names, especially as tubular clouds.

As early as 1917 Wegener put forward the theory that the tornado cloud is a rotating vortex thunderstorm and is a squally formation. Individual parts of it, bending toward the earth, form the tornado. This theory had both supporters and opponents in Europe.

In 1937 a tornado struck Magdeburg. It was 850 m in length and 8 m in diameter. It was embedded in clouds 1,000 m in height. Koschmieder (1937b), describing the tornado, considers that there is no doubt that it is horizontal. This idea is supported by Patterson (1938) after a detailed study of the observations of Koschmieder. He believes that in spite of a band of 10–30°, the tornado can be considered to be horizontal.

Letzmann (1938) doubts the existence of the Magdeburg-type horizontal tornado and similar formations. If he had all the data available today his doubts would have been dispelled.

The direct observations on the horizontal part of the tornado in the suburbs of Moscow on September 2, 1945, carried out from an airplane, are quite interesting (Kolobkov, 1957b). The pilot flew past the tornado at a height of 300 m and miraculously escaped. Figure 94 gives a sketch of the tornado drawn afterward.

The horizontal parts of these tornadoes are typical rotor clouds of small size, vortex formations rotating around the axis, elongated parallel to the surface. There is no doubt about the existence of such clouds. They are especially well-developed in squall storms.

The horizontal, rotor part of the tornado was observed on October 14, 1928, over Issyk-Kul. The tornado appeared at 11 o'clock at the time of strong rain and hail. It was lowered from the left side of the thunderstorm cloud. An enormous column of water moved from the lake for 20 minutes and covered a distance of 12–15 km. Twice it disappeared for a short time but again reappeared. While disappearing, the tornado gradually became dim in the center. The lower part came down to the ground and the upper part entered the cloud. Reappearing, it emerged from the cloud. Near the tornado, other tornadoes of smaller size appeared twice and then quickly disappeared. The most interesting fact is that at the upper end of the tornado, at the junction with the cloud, water accumulated in the smooth horizontal pipe, which was one-and-one-half times longer than the tornado itself. This colossal tube, totally saturated with water, was distinctly outlined against a background of dark cloud. The tornado fluctuated continuously but the vertical position was maintained. The water tube was bent in the

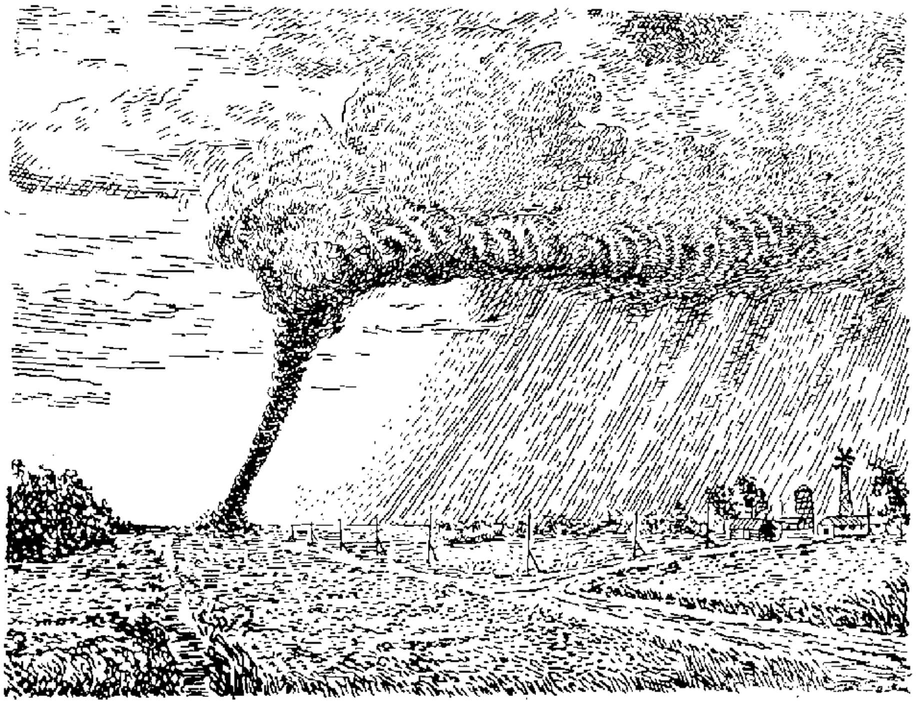


Fig. 94. Tornado near Moscow, 1945. Horizontal, tubular rotating part. View from airplane (Kolobkov, 1957b, Fig. 89).

cloud like a big snake (Fig. 95). When the tornado disappeared a storm boiling like a pot remained in its place. Only the water was reduced.

Though tornadoes have been observed thousands of times and studied in great detail, their horizontal parts, often covered by black cloud, have rarely been observed. Hence they have been studied less and not even given a name. N.V. Kolobkov (1957b) believes that it has the form of a bent tube, an "enormous coiled snake". Full information is not available. The horizontal part originates earlier than the tornado. It originates in a thunderstorm cloud which does not exhibit a tubular form. Generally the cloud has a circular form. Therefore it can be said that the horizontal part has a circular form, to be precise—it is an enormous circular ring. Observed from the side of the wall the ring will look like a bent pipe.

A. Mikhailov's postulation (1888) of several rotating circular vortices in the lower part of the tornado cloud has been overlooked. According to him they rotate at different speeds and therefore at the meeting point a new vortex of the eddy type is formed. This vortex drops down in the form of the funnel of the tornado.

This theory is supported by the observations of eyewitnesses reported in the works of Finley (1881, 1884) and other American workers. They saw isolated rotating cloud masses move inside the large thunderstorm cloud. The funnel originated at the meeting point of these individual cloud elements. Others observed the formation of tornadoes at the meeting point of

Fig. 95. Tornado over Lake Issyk-Kul, October 14, 1928. Horizontal serpentine part entering cloud (Kolobkov, 1951, Fig. 85).

independent, relatively small clouds, within which quick movement was noticed.

In water an eddy originates at the meeting place of currents of different strengths and directions. The occurrence of such a phenomenon in the air is quite natural.

The comparison of the tornado to an eddy has been repeatedly drawn. A. Mikhailov used this concept to explain the formation of tornadoes for the first time as early as 1888. For the first time he put forward the idea of the existence of a horizontal, circular vortex in the tornado cloud.

Wegener in his own work cites a number of examples of the horizontal part of the tornado. The drawings and photographs of the horizontal tubular formations remind one of the drawing by N.V. Kolobkov (1957b). These are schematic and do not give the nature of the vortex formation in the cloud itself.

Wegener (1917) contributed the idea that "the vortex part of the tornado is bent, continues horizontally in the cloud and is similar to the vortex movement in air". In many tornadoes the horizontal parts are 10 times longer than the vertical part. In some other tornadoes the horizontal part is absent, is replaced by small vortices, which are oriented horizontally and parallel to each other (Wegener, 1917, p. 297).

The main property, according to Wegener, is that the tornado is only the horizontal vortex movement corresponding to the lower part of the thunderstorm (tornado) cloud as a whole. Study of these vortex motions may explain the origin of tornadoes. One can only agree with this idea.

The drawing (Fig. 96) of a tornado over the waters of Central America, given by Wegener (1917) is no less interesting. The columnar type of large rotating body connected the main thunderstorm cloud to the tornado cloud, situated below. This body with the rotating cloud column has also been photographed by Fujita from an airplane (Fig. 97).

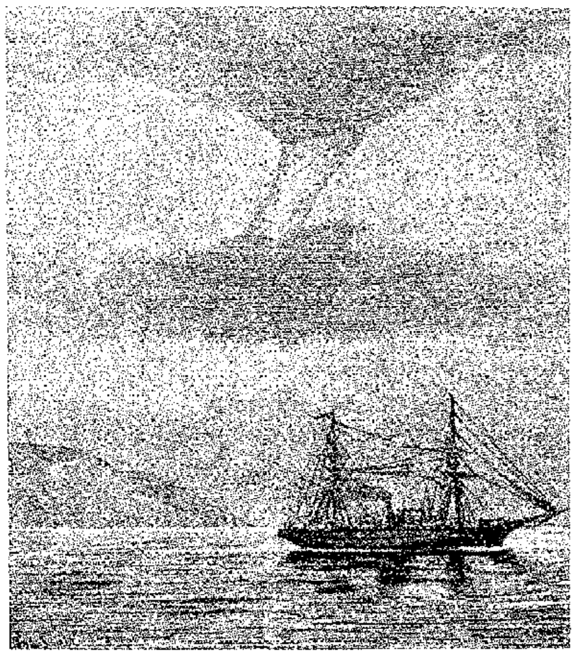


Fig. 96. Rotating column connecting two clouds (Wegener, 1917, Fig. 26).

American meteorologists, without giving special attention to the work of European scientists, later reached the same conclusion that the parent cloud of the tornado exhibits a rotating vortex structure and that the vortex motion in the cloud is the main cause of the tornado forming.

This idea was first put forward by Brooks (1949). He called the tornado cloud a "tornado-cyclone". The name "cyclone" already defines the existence of vortex rotation, the type of rotation of the tropical cyclone-hurricane. He showed that the main difference from the hurricane is the small size of the tornado-cyclone, of the order of 15–20 km. Tracking of tornado-cyclones gives important indications on the possibility of a tornado forming.

This idea is actively supported in the many papers by Fujita (1960a, 1960b, 1965). Further, in the description of the Fergo tornado, which occurred on June 20, 1957, he shows that five tornadoes with rotating clouds were formed, possibly with the "eye of the storm" in the center. In his interesting work, accompanied by a bibliography, he gives a number of

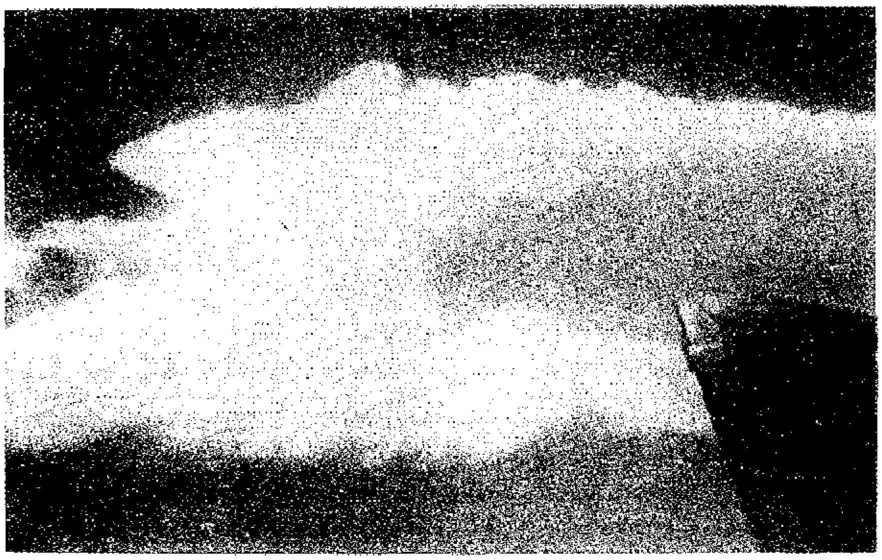


Fig. 97. Fergo tornado, 1957. Rotating cloud column 10 km in height. Photo from airplane (Fujita, 1965, Fig. 2).

unique photographs. The most interesting is the photograph (Fig. 97) he took from an airplane, from a height of 6,000 m and at a distance of 15 km from the rotating cloud column. The spiral formation in the lower cloud and the rotating column rising more than 10,000 m from it can be distinctly seen. Two other photographs depict the Fergo tornado cloud of 1957. One of them (Fig. 98) is the rotating cloud 8 km in diameter which literally came down to the surface, causing enormous destruction. In the other (Fig. 99) it had lifted above the surface, forming a massive, low tornado of diffused outline, with similar large destructive force.

In all three photographs the rotating structure resulting in the tornado can be clearly seen. It forms only part of the entire cumulonimbus cloud.

It is formed horizontally, to be exact quite sharply defined, in its lower part but rises inside to a great height, often more than 12,000 m.

A more detailed description of the Fergo tornado, 1957, is given by Fujita (1960b). The description is accompanied by numerous photographs and diagrams. The rotating mother cloud is observed in all the five tornadoes originating consecutively. They are all related, attached to the same thunderstorm cloud, moving from west to east.

The parent cloud of the Fergo tornado has been described in great detail (Fujita, 1960b, 1960, p. 37–44). The description and the accompanying 27 photographs not only show its occurrence beyond doubt but make it possible to reconstruct its structure like that of the Dallas tornado of 1957 (Hoecker, 1960).

The main thunderstorm cloud is generally arranged as a collar cloud (Fig. 100). Hoecker (1960) refers to it as the upper step. Its width is 3–4 km,

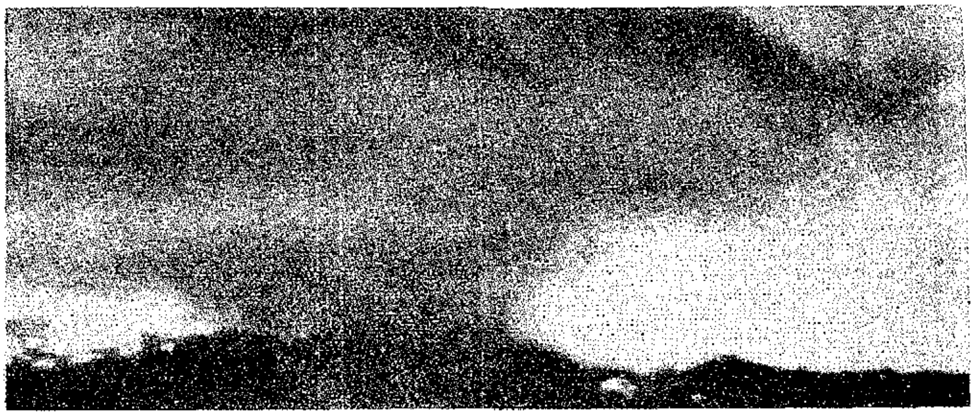


Fig. 98. Rotation of tornado-cyclone, coming down to surface (Fujita, 1965, Fig. 7).

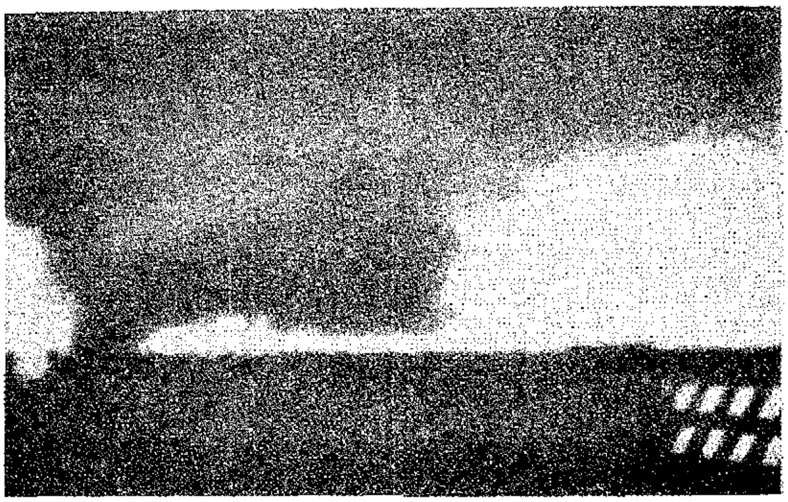


Fig. 99. Rotation of tornado-cyclone, coming down to surface. It is connected to lower, broad tornado (Fujita, 1965, Fig. 17).

thickness about 300 m; the top surface is situated at a height of 1,500 m. The wall cloud lies below the funnel cloud, from the surface of which the tornado hangs. The width of the wall cloud is 1.5–2 km and thickness 300–450 m, with the base at a height of 500–600 m. From the wall cloud a tail cloud, long and narrow, of the same height but of different length protrudes. The wall cloud is referred to as the lower step by Hoecker (Fig. 100). The wall cloud of a waterspout in the Tuaps region has been described by N.I. Popov (1955).

Attention is drawn to the earlier work of Fujita (1958) which throws light on the group of tornadoes in Illinois on April 9, 1953. The tornado-cyclone attained a diameter of 45 km and showed a well-developed "eye of the storm". This cloud was essentially a small hurricane.

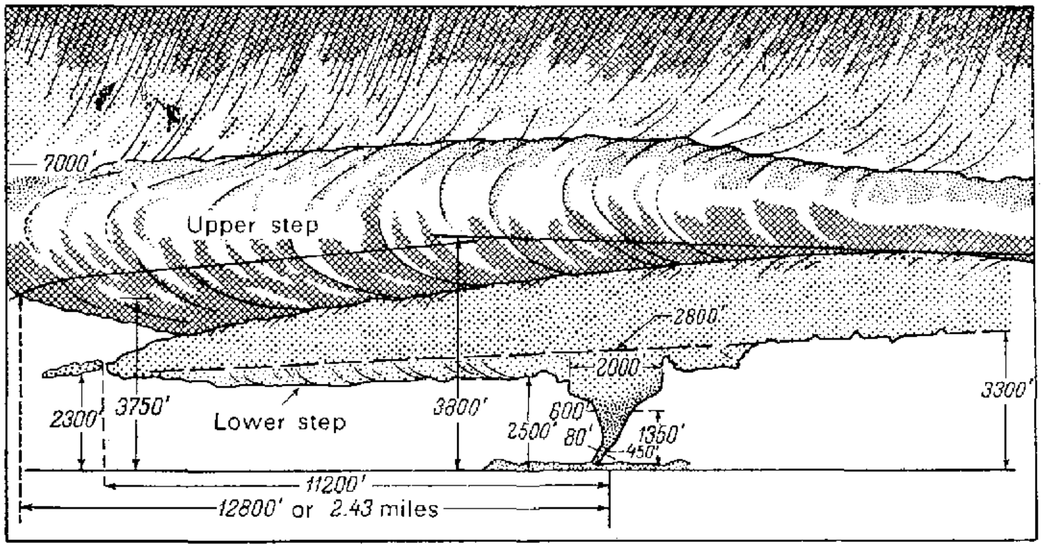


Fig. 100. Structure of tornado cloud, Dallas, 1957. Two steps, upper and lower. Third step is rotating cloud which becomes funnel of tornado. All dimensions are in feet (1 ft = 0.3 m) (Hoecker, 1960, Fig. 7).

Fujita (1965) obtained a radar photo of the tornado-cyclone of April 22, 1958, in Texas. It shows the "eye of the storm" rising to a height of more than 12,000 m, with a dense central part and undefined periphery. The diameter of the tornado-cyclone was around 150 km approaching the diameter of a hurricane.

Fujita notes that on the radar screen the tornado-cyclone can be seen as a peculiar echo resembling a hook (hook echo). At first this echo exhibited the spiral structure so characteristic of cyclones. The "hook echo" is characteristic of hurricanes at the beginning of their growth.

Dinwiddie (1959a, 1959b, 1961) observed the spiral vortex formations in the tornado-clouds at the same time as Fujita. He worked on the sandy spit to the north of Cape Hatteras, and his observations showed that the tornado moved over the sea and over the low, sandy islands. It could be clearly seen at all stages of development (Fig. 101). At first a small cumulus cloud was isolated from the large cloud-roll (1); then it started rotating (2); the rotation led to the growth of a complete ring in the main cloud (3); the funnel of the tornado emerged from this ring, the central part of which was not yet visible, (4). The funnel was completely formed and touched the surface, forming a cascade of dust. The tornado, at this stage, caused large-scale destruction, (5), and then moved off along with the tornado cloud (6). The vortex movement in the cloud could be distinctly seen.

At the end of its growth the other tornado was snapped off from the earth and was stretched in the cloud in the form of a long, coiled, horizontal pipe (Fig. 102). In such a situation it was very similar to the horizontal part of the tornado observed by the pilots in 1945 near Moscow (Fig. 94).

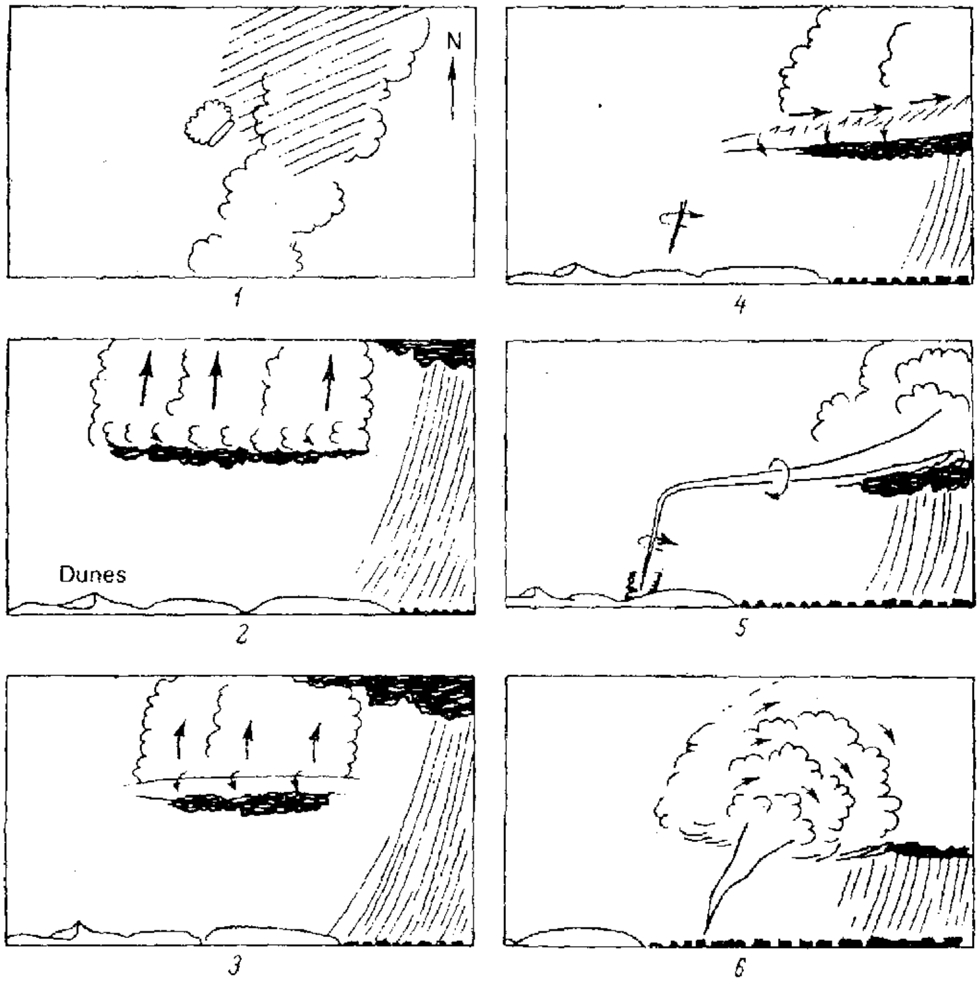


Fig. 101. Various stages of formation of tornado of 1959, Cape Hatteras, USA (Dinwiddie, 1959b, Fig. 2–7).

1—Large cumulonimbus cloud: in front of it, on left, small cloud rotates; *2*—cloud increases, grows upward; *below*—dunes; *right*—rain and rainclouds; *3*—rotation of tornado cloud is enhanced; *4*—funnel of tornado is separated from main tornado cloud to one side; central part is still without water and invisible; *5*—funnel is filled and connected to earth; large horizontal part; *6*—tornado takes usual shape.

Due to lateral illumination by the setting sun it could be seen that the white rotating cloud was sharply divided into three funnels moving away from it. One of them reached the earth. This peculiar cloud was observed in the State of Nebraska (Fig. 103) (Some photographs..., 1937).

The separation of the circular rotation of the cloud, from which the funnel of the tornado descends, is clearly seen in the tornado clouds (Fig. 92) that occurred over Chesapeake Bay on September 3, 1961 (Hexter, 1962).

Similar formation can be seen in the many photographs of tornadoes and have been repeatedly recorded in the descriptions, e.g. the tornado of 1929 in Arkansas (Cole, 1929). In the tornado of May 24, 1958, in the State of

Minnesota, the funnel over which the horizontal vortex formed was photographed. It formed bright clouds, sharply separated from the main dark thunderstorm cloud (Beebe, 1959a, 1959b).

The separate vortex formation between the funnel of the tornado and the main cloud can be clearly seen in the photographs of the tornado of April 2, 1958, in Dallas (Harrison, 1957).

In the USSR, the rotation of the tornado-cyclone was observed in the tornado of June 12, 1927, in Belorussia (Voznyachuk, 1954b).

In the USA one of the first descriptions of the rotation of a tornado-cyclone was given by Oliver (1931) for the tornado of June 12, 1930, in Goteburg (Nebraska). An enormous thunderstorm cloud moved to the side, a distance of not less than 7.5 km. Below it two rapidly rotating secondary clouds were seen. The upper cloud was rather bright and gray and the lower one black, menacing, often dipping below the lifting cascade of dust. The lower cloud developed numerous funnels, hanging in the air and dipping right down to the ground. One of them is shown in Fig. 122. The entire system of the thunderstorm cloud slowly moved to the northeast. Oliver's observations agree with Hoecker's (1960) and Fujita's (1960a) on the step structure of the thunder-cyclone.

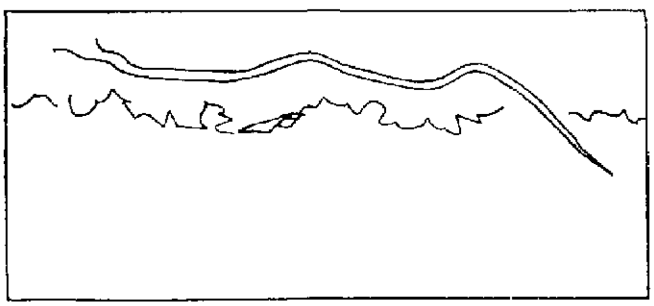


Fig. 102. Final stage of growth of tornado over Cape Hatteras, 1959. Funnel has snapped off from ground to be drawn into cloud and adopt horizontal position (Dinwiddie, 1959, Fig. 15).

Indirect indications of the presence of vortex motion in tornadoes and thunderclouds have been repeatedly noticed by pilots whose planes have flown through such clouds. The bumpiness tosses the plane violently (Peskov, 1963; Jorjio, Petrosyants and Romanov, 1963).

Another indirect but significant indication of a vortex ring (vortex wheel) in the lower part of a tornado-cyclone is the transportation potential of the latter.

The tornado is nothing but a pump, sucking and lifting into the cloud various small objects; twigs of trees, straw, sheets of paper, fish, jellyfish, silver coins, frogs, etc. Trapped in the vortex ring, these objects are retained in it and carried tens of kilometers. Far eastern jellyfish and English crabs

Fig. 103. Tornado with horizontal part (white). Nebraska, 1937 (*Quarterly Journal of the Meteorological Society,* vol. 63, 1937, Fig. 5).

have traveled more than 50 km and sheets of paper more than 120 km in the cloud. Fish, frogs and coins have dropped from the cloud with the rain, long after the disappearance of the tornado. If the rotating vortex ring were absent all these objects would have been trapped by the tornado. Only such a vortex ring could have retained them in the air for a relatively long time (tens and even many tens of minutes).

The transportation potential of the tornado and tornado-cyclone is described in detail hereinafter (pp. 419–420).

It is quite likely that the tornado-cyclone and such formations described by Fujita, are similar to Koschmieder's "collar cyclone" (1940a, p. 47). This dense low cloud of fibrous structure is quite sharply separated from the main cumulonimbus cloud (Fig. 104). Generally it is situated in the frontal edge of the thunderstorm cloud. Its lower part is lifted inside this cloud and transformed into an actual raincloud.

In Denver (USA) not only the tornado but also the cloud above it was photographed. The cloud was a small cumulus, sharply defined with dark, even base, at a height of 1,500 m above the ground surface. The height of the

Fig. 104. "Collar-storm". Rotating tornado-cyclone in main cumulonimbus cloud. Reblingen, Germany (Koschmieder, 1940, Abb. 48).

cloud was 2–3 km. The horizontal vortex (the projection) was seen over the tornado. The tornado occurred on May 21, 1952 (Flawing, 1952).

Interesting observations of a tornado and a tornado-cyclone were made from an airplane on July 15, 1961, in Kansas (Bates, 1963).

The drawings of other rotating tornado-cyclones separated from the main thunderstorm cloud are no less interesting. At the base of the tornado-cyclone groups of funnels of different forms and sizes continuously appeared and disappeared and some of them reached the surface (Reber, 1954).

On July 9, 1953, a tornado-cyclone with tornadoes hanging from it was observed in Massachusetts. In one case the cloud started dipping and at last touched the ground. This situation has been photographed. The synoptic situation and the photograph of the radar echo are interesting (Samuel, Pierce and McGuire, 1955).

The group of tornadoes that occurred in June, 1955, in Scottsbluff (Nebraska) has been described in detail. Rotation of the cloud 7 km in diameter was clearly observed. Many funnels and tornadoes descended from its base. The main tornado was located at the center of the tornado-cyclone. The rotation of the latter was observed by many people. The cloud stretched for 45 km and gave rise to tornadoes at the beginning (Beebe, 1959b).

Photographs of the tornado of September 5, 1938, over Dubrovnik on the shore of the Adriatic Sea were published in 1940 (Koschmieder, 1940a). In these the collar cloud, identical to that of the Fergo tornado of 1957 from which the columnar tornado was lowered, can be clearly seen. The collar cloud is situated below the main thunderstorm cloud, distinctly separated from it. The tornado column protrudes from the end.

Simultaneous formation of two closely placed tornado clouds was observed on May 4, 1922, in Austin, Texas (Morris, 1922). The irregular, intensely turbulent motion in the main cloud changed the regular rotating movement in one plane. After this the funnel lowered, quickly approaching the surface. The clouds moved parallel to each other at a distance of 5 km. Each formed a tornado, causing large-scale destruction.

The step structure of the tornado-cyclone was observed in the USA in 1940. The three stages resembled elliptical disks lying one above the other, the thickness of each disk being 900–1,000 m. The upper disk was of bigger size, 30 × 40 km; it formed an anvil, showing vortex movement in a clockwise direction. The lower disk resembled the collar storm and rotated in the reverse direction. The tornado was separated from it.

A rare and unusual phenomenon was associated with this cloud. At the end of the track the tornado snapped from the cloud and moved ahead. Literally within a minute a new cloud developed over the separated tornado, rising to a height of around 10,000 m. Intense lightning could be seen in the new cloud for several hours (Wobus, 1940). Though the development of cloud over vertical vortices has been observed repeatedly, this case is unique in such a condition and with such intensity.

On July 21, 1965, a tornado-cyclone occurred over southern England. The thunderstorm cloud came from the southwest. The lower stage consisted of ragged fragments, resembling smoke. While passing over observers (Radford, 1966), it showed rotational motion in the horizontal plane. After a few seconds the wall ("collar") of strong turbulent cloud was observed. The funnel of the tornado, filled with ragged clouds, came down from it. The fragments of cloud were so numerous that two students, observing the tornado from the experimental botanical garden, mistook them at first for a flock of birds. The birds turned out to be the ragged fragments of cloud. The tornado caused great damage to the botanical garden (Gilbert and Walker, 1966).

On October 14, 1960, a tornado passed over Malta (Kirk and Dean, 1963). As such there was nothing special about it except that the observations of the tornado cloud deserve attention. Observations from a plane showed that the height of the main thunderstorm tornado cloud was 12,000 m, and the height of the tornado-cyclone 3,000 m. The observations clearly showed that as soon as the tornado reached the surface, it dissipated and moved in a galloping fashion. The funnel of the tornado was linked not to the main cloud but to a tornado-cyclone of quite small size, situated below the main cloud. Rotational motion was observed before the formation of each funnel in the tornado cloud. The authors note that the topography had no relationship whatever with the formation of the funnel: it lowered due to the processes inside the tornado cloud (internal turbulence).

The sharply defined, step tornado-cyclone can be clearly seen in the photograph of the tornado of August 20, 1911, over Antler in North Dakota. This tornado differs from others in its large diameter and size (Fig. 105).

The sharply-defined tornado cloud with flat perpendicular sides (the

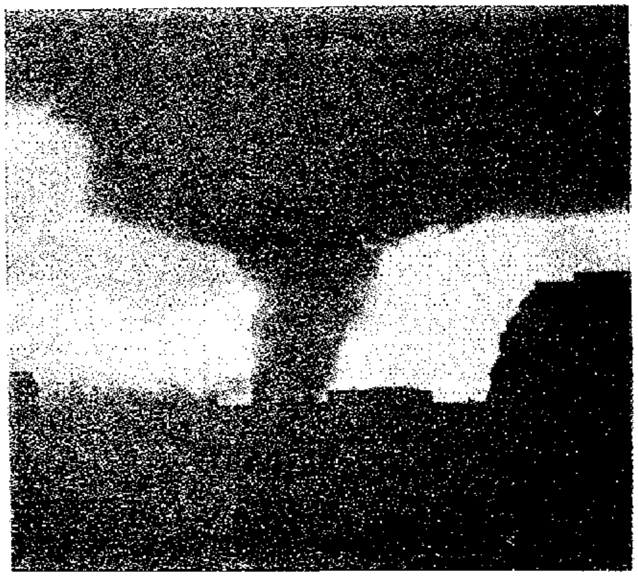


Fig. 105. Low, wide, ill-defined tornado. Angular tornado-cyclone. North Dakota, August 20, 1911 (Simpson, 1917, Fig. 2).

typical stage) was observed in one of the Kansas tornadoes (Fig. 106). Its outline is interesting. The width is small. The main funnel occupies almost one-third of the cloud.

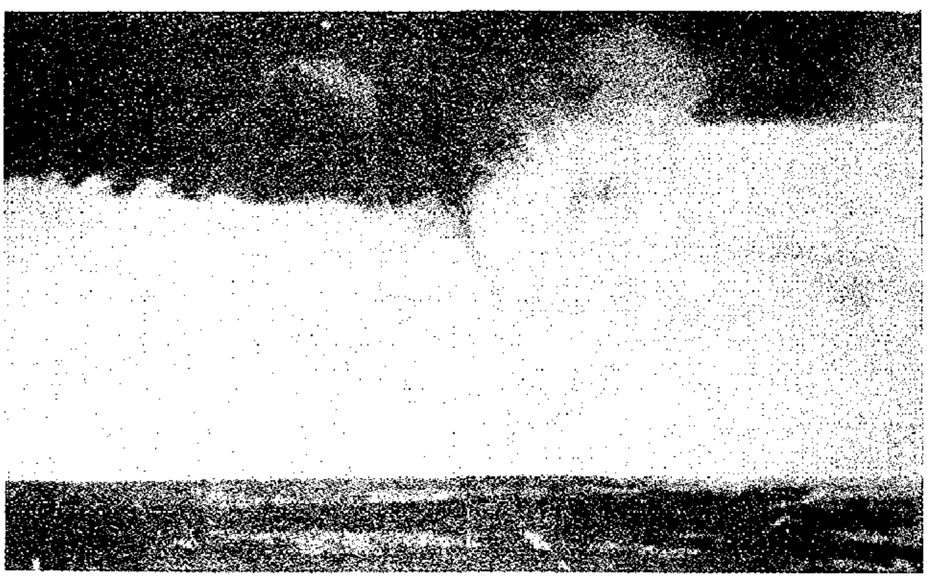


Fig. 106. Typical columnar tornado, Kansas. Angular tornado cloud over funnel (Knight, 1964, p. 145).

The multilayered structure of the tornado cloud was the reason for division into a special group of layered cumulus cloud.

TOWER VORTEX CLOUDS

In addition to the rotating and circular lower vortex formations, ascending high vortex motion occurs and this can be most appropriately referred to as a tower vortex formation. It is shown in Figs. 96 and 97.

Tower vortex formations grow to a considerable height, in the region of subzero temperatures. They give rise to hail, often associated with tornadoes. The large size of the hail shows that it can be retained by the high speed of the vortex motion.

TYPES OF VORTEX FORMATIONS

Vortex formations are typical features of the tornado cloud but these formations are quite numerous. It is quite likely that other types of formation also occur in addition to the three mentioned above.

The occurrence of tornadoes is relatively rare in the Soviet Union. Therefore observations on tornado-cyclones are few. The interesting and important observations by N.V. Kolobkov (1957a, 1957b) on the horizontal, rotational part of the tornadoes near Moscow and Issyk-Kul are of significance. The problem of horizontal, spiral or circular vortex formations, however, remains open. The little-studied tower vortex, accompanied by a tornado, differs in the unusually large size of the hail.

Vortex formations of the rotor cloud type occur in thunderstorm clouds, although they cannot be distinguished.

In his interesting and authoritative work, N.Z. Pinus (1960) considers, in detail, the problem of turbulence in the free atmosphere, which causes bumpiness in airplane flights.

From the study of horizontal vortex motion the following conclusions can be drawn: "The thickness of the disturbed layers of atmosphere does not exceed 300–600 m; it generally decreases with any increase in the intensity of the turbulence. The horizontal extent of the turbulent zone generally does not exceed 60–80 km. The distribution of the turbulent zone has a patchy character.

"The turbulent zones are not continuous but form an aggregate of irregular alternation of calm and disturbed zones.

"Turbulence is quite often observed in clouds, causing bumpiness to airplanes, especially in cumulus clouds" (Pinus, 1960, p. 49).

The horizontal vortex is observed in a number of cases. The figures furnished by N.Z. Pinus (1960) give an idea of the size and distribution of horizontal vortices. Its size is relatively small. The thickness (height) of the vortex is 300–600 m or less. The extent—up to 60–80 km—is generally beyond the usual size of cumulus clouds, but considerably less than the vortex circulation of hurricanes.

In conclusion, it should be noted, as can be seen from the numerous descriptions, that there is no established general classification of clouds giving rise to tornadoes. Possibly it would have been correct to call all cumulonimbus clouds "tornado cloud" and to restrict the name "parent cloud" to those parts of the tornado cloud that undoubtedly give rise to tornadoes.

Tornado clouds, like any thunderstorm cumulonimbus cloud, are quite diverse in form, size and internal structure.

The parent cloud can be divided into three types. The first has either a straight or a curved horizontal axis of rotation of the vortex. The straight form is referred to here as a tubular (in the USA, as a rotor) cloud. The curved form is referred to as an arch cloud.

The second type displays a horizontal axis of rotation, but closed. The circular form resembles the funnel. In the USA it has not yet been given any name. German scientists refer to it as a "funnel storm" (Boenkragen). Correspondingly it can be referred to as a "collar cloud".

The third type has vertical axis of rotation. It can be referred to as a "tower cloud". The tower cloud is often part of the tornado cloud as a whole, as though it pierces it (Fig. 107). Often the tornado cloud, like that of a hurricane, shows vertical rotation of the funnel.

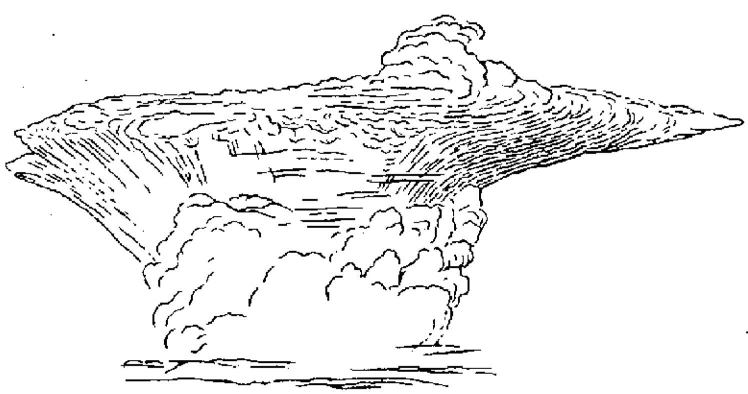


Fig. 107. Tower cloud breaking through anvil. Formation of rising current of hot air. Formation of hail is associated with such clouds (Davis, 1899, Fig. 102).

When the parent cloud is not separated from the tornado, which is not a rare case in reality, the tornado cloud as a whole is known as the parent cloud.

3
Structure of Tornado

The tornado consists of three parts: 1) horizontal vortex in the parent cloud; 2) funnel; 3) auxiliary vortex, giving cascade and envelope.

The horizontal vortex has been discussed earlier in the section on tornado clouds.

FUNNEL

The funnel is the main component of the tornado. It has a spiral vortex consisting of very rapidly rotating air.

Generally water and dust are entrained in the air. Due to this, the funnel can be seen clearly in the cloud. It is known as a "funnel-forming cloud" or "tuba".

Sometimes such entrainment is absent and in such cases the funnel can hardly be seen. Invisible tornadoes are described hereinafter (p. 315).

The structure of the funnel is similar to that of a hurricane and consists of an internal cavity and wall. It may be said that the funnel of the tornado is a small-scale hurricane.

Internal Cavity

The internal cavity in hurricanes varies from a few kilometers to tens of kilometers, but in tornadoes, it is a thousand times less, i.e. from a few meters to a few hundred meters.

The main features are quite similar. It is a space more or less sharply defined by the walls. It is quite clear, without cloud. Often peculiar small lightning flashes jump from wall to wall. The motion of the air in it is sharply reduced and the direction is mainly downward.

The most important feature—sharp reduction of pressure—is identical. Reduced pressure is responsible for the remarkable phenomenon: hollow objects, especially houses, that come in contact with the funnel of the tornado crack. Suck cracks cause large-scale destruction (see p. 384). The internal cavity of the hurricane has been observed from the decks of hundreds of boats, which have been trapped in it without being lost. It has been studied in detail during flights through it by special planes. Generally, whatever falls within the internal cavity of a tornado is destroyed and people are killed. On very rare occasions it has been observed when it passed over an observer. The observations were very interesting and the sight was certainly remarkable.

A group of students were on a picnic on the outskirts of Lincoln City (Nebraska). Suddenly a fiercely rotating tornado appeared over their heads. Looking up they saw an enormous empty cylinder, as dark as night, illuminated by the glitter of lightning. The noise was that of the buzzing of millions of bees.

A more vivid description of the internal cavity of a tornado is given by a Kansas farmer (Justice, 1930). Standing at the entrance of his shelter, he observed the approaching plane of the tornado. Near the shelter, the end of the funnel of the tornado was above the ground and passed over the farmer: "The big shaggy end of the funnel was hanging right over my head. Everything was static all around. A crackling, and hissing sound came from the end of the funnel. I looked up, and to my surprise saw the heart of the tornado. The cavity had a diameter of 30–60 m and rose to a height of 1 km. The walls of the cavity were formed of rotating clouds and illuminated by the glitter of lightning jumping from one wall to the other in zigzag fashion. The cavity was totally empty and only cloud formations moved up and down. The tornado moved slowly and I had time to see clearly inside and outside" (Flora, 1953, p. 11).

A third observation, on May 26, 1963, near Oklahoma, was made by two operators of the radar station. The inside of the funnel was smooth, continuous and circular in transverse section. At the same time, the inside walls were not well-defined and the visible signs of empty space inside the funnel were not present. The entire region inside the internal shell was filled with flaky clouds resembling scraps. These flakes moved and changed turbulently against a background of regular rotation of the funnel. Lightning or luminiscence were not seen. There was no roar and the only sound was that of the whistle of the storm.

All these three descriptions support the existence of the cavity inside the tornado. An interesting photograph of this cavity was taken from below during the passage of a tornado (Fig. 108). The spiral cavities in the walls can be clearly seen.

A vivid description of a tornado and its internal cavity is available for the tornado of 1951 in Texas (Hall, 1951). The tornado, passing over the observer, had its edge only 6 m above the ground. The width of the internal cavity was around 130 m (150 yards), the thickness of the wall 3 m. No cracks

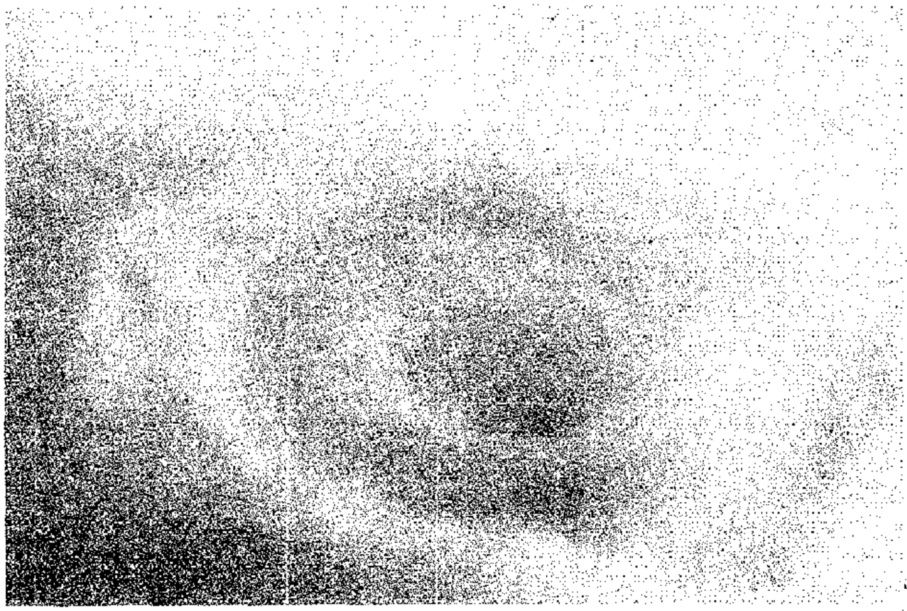


Fig. 108. Internal cavity of tornado (photographed from below). Walls of cavity are visible (Hoecker, 1964, Fig. 1).

were visible in it. A bright blue transparent cloud was situated at the center of the cavity. There was no vacuum in the cavity and therefore one could breathe freely during its passage. The walls rotated extremely fast and their rotation could be seen right up to the top. It had obviously developed in the cloud.

Soon after the tornado was over the observer, its funnel dipped to the surface, passed over a neighbor's house and carried it away. The house disintegrated in the air.

During the Fergo tornado of 1957 a woman, looking up, saw above her a black cloud sack, hanging down from a large thunderstorm cloud. There was a hole in the sack and it contained large quantities of objects resembling branches of trees. These objects rotated quite fast inside the sack. She did not notice anything special on the surface.

The internal cavity of the tornado, as has been shown by numerous observations and measurements, displays a sharp fall of pressure (Fig. 109). Therefore, when it passes over a closed house with closed windows, as was the case on June 7, 1947, in Pennsylvania, the house literally explodes and all the walls collapse outward (Fig. 110). Kerosene was sucked up from lamps and splashed about the room (see page 249).

The movement of air inside the cavity is directed vertically downward and often attains great speed. It is quite likely that it causes the formation of the cascade and facilitates the movement of the tornado.

In the walls of the tornado, on the contrary, the movement of air is directed upward in spiral form and often attains unusual speeds of up to

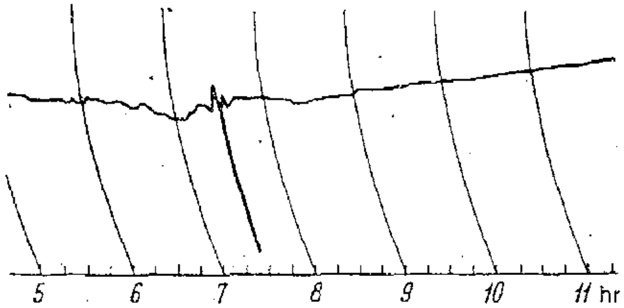


Fig. 109. Sharp drop of pressure (to 951.8 mb) with passage of tornado, Topika, June 8, 1966.

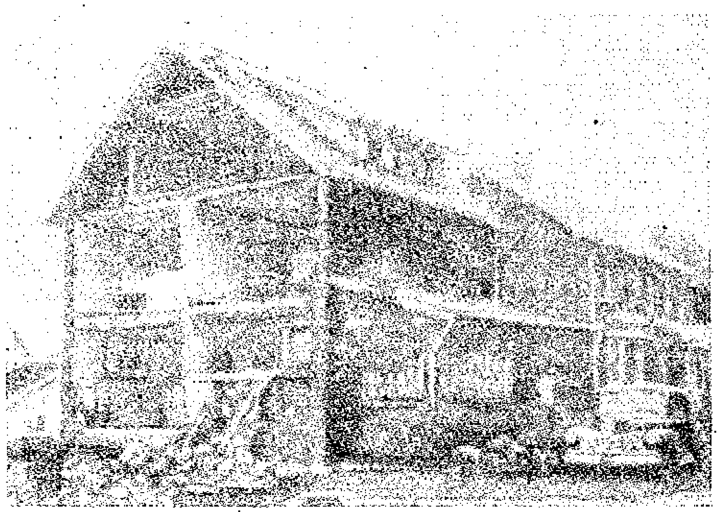


Fig. 110. Tornado of June 7, 1947, Sharon, Pennsylvania. Walls of house burst outward in explosion when internal cavity of tornado passed over (Flora, 1953).

100–200 m/sec and more. Dust, debris and other objects, people and animals are lifted, not in the cavity which is usually empty, but into the walls of the tornado. As in hurricanes, the walls of tornadoes are the most active part. Objects are sucked into the walls, and into the funnel.

The internal cavity of the tornado is entirely analogous to the "eye of the storm" of hurricanes, which underlines the resemblance in structure.

Wall of the Funnel

The wall of the tornado is its active, destructive and typical part. Its structure shows wide variation. It can be divided into two main types, with transitional forms in between. The first type exhibits dense, smooth, sharply defined walls (Fig. 91). In the second type the wall is diffused and ill-defined (Fig. 126).

In spite of the difference in the boundary of the external form of these two types, there is no fundamental internal difference between them. A particular tornado at the beginning of growth may have smooth walls but the wall can then become diffused and massive, and at the end become smooth and narrow. This was observed in the well-known Mettun tornado of May 26, 1917. For the major part of the 500 km long track it displayed the normal smooth funnel but the funnel was absent over a distance of 15 km. The black, whirling clouds were spread over the ground surface.

The other enormous and better-known tornado, Three States of March 18, 1925, on the contrary exhibited a smooth funnel only at the beginning of its track: during the remaining hundreds of kilometers it had the form of a dark, whirling cloud, dipping to the surface.

It is quite likely that the walls of the funnel become diffused when the speed of rotation drops below a particular range.

The thickness of the wall has not yet been measured. The width of the funnel is well known because of repeated and accurate measurements but the width of the internal cavity has been determined only hypothetically. Therefore the width of the wall mentioned is only provisional.

Direct measurements inside the cavity of smooth tornadoes, described earlier, show that the cavity is quite wide and the width of the wall is a few meters.

The inner cavity was never observed in blurred tornadoes. Judging from the relationship existing in hurricanes, which blurred tornadoes resemble, the width of the inner cavity is considerably less than the width of the wall. The latter fluctuates from a few tens of meters to a few hundreds of meters.

These figures are typical of fully-developed tornadoes and can be taken as the maximum values. The minimum values are observed in very long, thin tornadoes before their dissipation. In them the width of the funnel does not go beyond 1–3 m and the width of the wall is tens of meters, if not less.

As such, the thickness of the wall changes not only in different tornadoes but in the same tornado at different stages of growth and even in its different parts.

The wall of the funnel consists of rotating, moving air, i.e. wind. This wind has a spiral motion and the walls of the funnel show the vortex. Such vortices are relatively rare and practically invisible. Such invisible tornadoes are described below (p. 315).

Almost always the air is mixed with water and the funnel becomes a cloud, which is known as a "funnel cloud".

When the funnel originates over the sea and passes over it, it contains only air, water and organisms present in the water. When the tornado passes over land it sucks up dust, rubbish and small debris, often in such a quantity that it becomes a "dirt cloud".

The mixture of air and dust significantly enhances the density of the wall of the funnel and its destructive strength.

The tornado that crossed a river on May 30, 1897, in Kansas exposed its bottom all along its path. The funnel, after sucking water and silt from the bottom of the river, changed into a mass of air, water and dirt, rotating at inconceivable speed. Its destructive strength grew enormously and when it passed over the house of farmer Kron the spectacle was astonishing (see pages 369–371).

Sharp Boundaries

The sharply-defined, almost smooth, dense wall of the funnel is one of the important, unique properties of the tornado. Possibly there is no other atmospheric circulation with such a sharp boundary. Perhaps only in lightning is the speed greater.

In his monograph Flora (1953, p. 79) writes: "The demarcation between the strong wind in the tornado core and the quiet air in its periphery is so sharp that a large number of striking phenomena are caused."

A most surprising incident was that of a fowl which had its feathers plucked. Tornadoes are quite frequent in the central plains of North America. There are numerous farms in this region. Every farm has poultry. Many hundreds of chickens are destroyed by tornadoes. The picture of destruction differs widely. Often, nothing remains of the poultry and the debris of the poultry and fragments of the fowls can be found strewn across the plain far from the farms. Sometimes, the walls and roofs of the fowl house disappear and the chickens are left in place either dead or alive. Often the chickens are merely injured. On one farm a large number of chickens were killed. About 30 birds were found dead without their feathers. On another farm the cocks were crowing wildly. They were hungry. Chickens dead or with feathers plucked have often been found.

The exact process of plucking of the feathers is not clear. There may be two explanations. When the chickens are trapped in the wall of the funnel, the vortex sucks them up the way it sucks up water from the well or kerosene from the lamp. The other explanation is more complex. The fowls are trapped by the air column and when the air column touches the internal cavity of the funnel, the feathers are plucked and tossed aside. Which of these two explanations is correct is not known, but one thing is clear; that chickens lose their feathers when they are trapped in the funnel of a tornado.

Now we come to the most astonishing case. After the passage of a tornado one chicken on a farm was found with feathers on only half of its body. This was possible if one-half of its body was inside the funnel and the other half outside it. The boundary of the funnel and calm air were not more than a few centimeters apart. The wall of the funnel was quite smooth.

In Kansas, a tornado on October 9, 1913, passed over a small farm. It uprooted one large apple tree 30 cm in diameter and broke it into pieces. There was a beehive with bees one meter away from the apple tree and it remained intact (Hayes, 1913).

A farmer had gone out with his cart drawn by two horses, on a cart track.

The day was sultry and hot and there were thunderstorms. The track was rough. The horses trotted and the farmer started dozing. He woke up to terrifying thunder. There was darkness all around. A severe vortex came overhead. After half a minute the vortex moved away and everything became clear, quiet and sunny. The cart and the farmer remained intact, but the shaft of the cart and the two horses had disappeared. They had been carried away by the tornado.

In the State of Nebraska, on a farm, the milkmaid was sitting in the dairy milking her cow. All of a sudden the cowshed and the cow were lifted and carried away into the air. The milkmaid was left sitting on a chair with a bucketful of milk. The distance between the cow and the girl milking the cow was very small, not more than a few centimeters. Still, the cow was carried away and the girl remained where she was with the bucketful of milk.

In the state of Oklahoma a two-storied, four-room house was carried away by a tornado with the farmer's family alive inside. The house was broken to pieces and the entire family was killed. The house had a three-step verandah with a light railing in front. The steps and the verandah remained where they were. An old Ford car was parked not far from the steps and a burning kerosene lamp was standing on a table under a tree. The tornado wrenched the two rear wheels off the car but the body remained intact. The kerosene lamp continued to burn as if there was no vortex anywhere around (Finley, 1881).

In all these cases, the distance between the vortex in the wall of the funnel and the calm air in the center was of the order of a few tens of centimeters, and it was still less in the case of the cow and the half-plucked fowl.

The cause of these unusual phenomena is not clear. The sharp boundary of the vortex gives it the unusual speed. It is quite likely, as already mentioned, that it may have ultrasonic speed.

The Rotational Speed of the Funnel

The rotational speed of the funnel, to be precise the wind speed in its walls, is the most important feature of the tornado, determining its main properties.

This speed differs widely and changes quickly, even in the same funnel, but the most important feature is that frequently it is extremely high, often exceeding the speed of sound in air—1,200 kmph or 332 m/sec. This is the cause of a number of peculiar phenomena and events. The higher the speed, the greater the force. It becomes still greater if water and dirt (dust with water) are mixed with the air. Any instrument recording the speed of a wind of such force is smashed and disappears without trace. Therefore direct measurements of the wind speed in tornadoes are not available. However, engineers and specialists on the strength of materials, calculate these speeds fairly accurately from the bend and breakage of the materials.

The tornado of April 2, 1957, over Dallas, shown in Figs. 147–149, derailed several heavy freight cars while crossing the track. From their weight and form, the specialists found that the speed of the wind was 210–225 kmph and gust velocity up to 350 kmph. Slightly ahead, the destruction was enormous and even permanent signal structures were uprooted. The speed was of the order of 480 kmph.

These figures have been derived from calculations, but a number of observers give a figure of 600–1,000 kmph. An American meteorologist, after studying hundreds of tornadoes in detail, gave the figure of 1,300 kmph as early as 1884. This figure exceeds the speed of sound, which is 1,200 kmph. His determination of the speed was based on a number of striking, almost unbelievable, facts.

One is often reminded of a large egg pierced by a dry bean in such a way that the eggshell around the hole remains intact as when a revolver bullet is fired. In other tornadoes, small pebbles penetrated window panes, not damaging the glass around the hole, once again reminding a revolver bullet.

A still more surprising event occurred during the well-known tornadoes, Three States in 1925. A one-inch-thick plank was planted vertically in the ground not far from a house under repair. With the passage of the tornado, it was pierced by similar plank with a sharp end which was picked up and thrown parallel to the ground (Fig. 111). The fact that one thick plank penetrated the other is itself surprising. But what is more surprising is that the plank which was pierced in the middle was not uprooted. The surprise of the observers, clearly seen in the photograph, is understandable. The board must have moved at the same speed as the pebbles that pierced the glass and the bean that pierced the shell of the egg without damaging it. All this is evidence of the ultrasonic speed of the wind.

An incident with another plank was no less striking. After the passage of the tornado the wall of a frame house was pierced through by an old plank, one end of which was charred. Piercing of the walls of wooden houses and other structures has been repeatedly observed in different tornadoes and there is nothing special about it. What is special in this case is that the wall was pierced by a sharp, charred board and the charcoal, relatively friable, remained intact, almost without damage. The plank must have moved at such a speed that it penetrated the wall of the house like a needle (Fig. 112). This occurred in Kansas in June, 1928.

On March 14, 1933, a tornado of unusual strength crossed Nashville, Tennessee. It caused large-scale destruction, killed 15 people and exhibited high wind speed. A straw penetrated a piece of fairly thick cardboard. A wooden plank 2 cm thick pierced the trunk of a small tree. The big steel towers carrying high-tension wires were bent to the ground (Williamson, 1933).

During the tornado of 1919 in Minnesota, the fine stem of a plant penetrated a thick plank. Leaves of clover were carried at such speed that

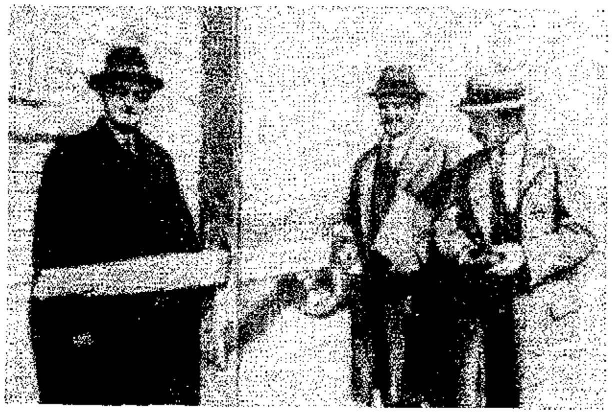


Fig. 111. Vertical plank pierced by another plank (Changnon and Semonin, 1966, Fig. 3).

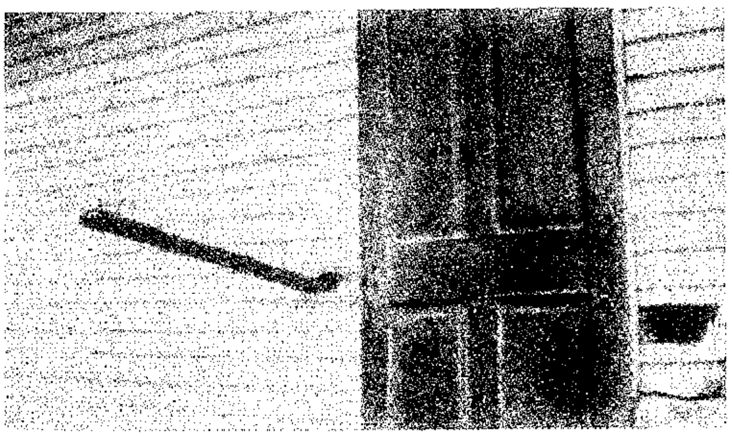


Fig. 112. Wooden wall of the house pierced by plank flying almost horizontally, Kansas, June 1928 (Flora, 1953).

they were pressed into solid plaster and remained fixed in that position (Tornado at Fergus Falls, 1919).

It is difficult to believe that straw can penetrate a tree but it is certainly a fact, observed and photographed repeatedly (Fig. 113).

In Fig. 111 it can be seen how one plank pierced another. A small chip moved at such speed that it not only penetrated the bark but also the core of a small tree (Fig. 114).

The most striking phenomenon was observed during the tornado of 1896 in Saint Louis: a pine stick penetrated an iron sheet 1 cm thick (Lane, 1966, p. 38).

In other tornadoes stems of plants and leaves have been pressed deep into treetrunks, telegraph posts and wooden plank fencing.

At Rostov (Yaraslavsk region) in the USSR, during the tornado of August 23, 1953, in house No. 37 on February street, tree branches were

Fig. 113. Stalks and stems piercing chips, bark and other wooden objects (Lane, 1966, p. 19).

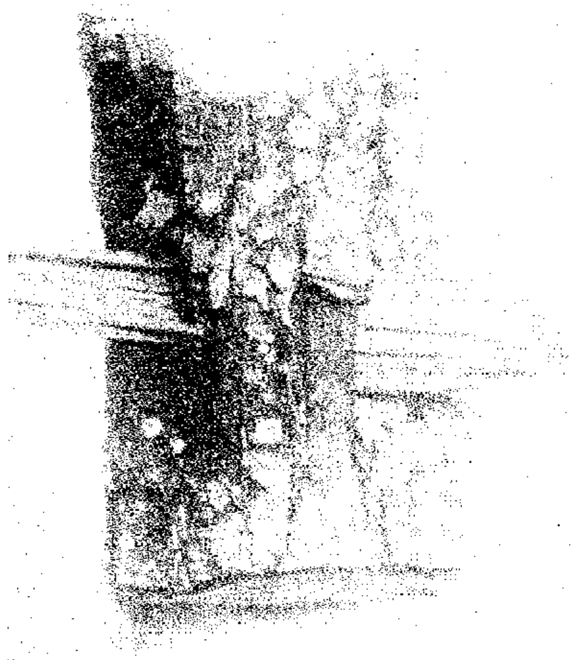


Fig. 114. Treetrunk pierced by chip (Lane, 1966, p. 18).

dropped in the well but the bucket and the wooden tub in front of the well remained intact. In one house on Spartakov street a pillowcase was stripped and carried away, but the pillow remained untouched. On the same street a small piece of pig iron of considerable weight (it could not be lifted by a man) dropped in front of Mr Soglasnova's house and it is not known where it came from. The frame of a five-ton truck, weighing about a ton, was lying in a ditch not far from the railway track. It was lifted into the air and thrown a distance of 10-12 meters on the other side.

But the most surprising incident occurred on this same February street (Fig. 202), in house No. 28. The alarm clock on a chest of drawers was carried away by the wind through three doors, the kitchen and a corridor and up to the garret. After the trip the alarm clock remained intact and "keeps time to this day without any repairs" (Chizhikov, 1956, p. 80).

In the tornado of April 25, 1859, in Belorussia, a plank pierced a pig. Another tornado carried a beehive with the bees to a distance of 500 m and a woman was lifted and transported through the air to a distance of 100 m (Voznyachuk, 1954b).

When the tornado passes through a thickly populated area the destruction is great and the air is filled with debris. This is carried at great speed and there is much destruction and loss of life. In the tornado of March 23, 1917, in New Albany the debris killed a family of five. The father was beheaded and badly disfigured. In another place, a painter painting a house was beheaded by a flying plank. A flying crossbeam from a fence pierced another man and he died after a few days. Pieces of glass carried through the air seriously injured a woman and deprived her of her eyesight. In another house, totally destroyed, the debris killed the mother and two children on the spot. Two little girls playing in the yard were sucked up into the vortex and carried away.

Often debris is transported at such speed that walls are pierced as by a shot, killing people and animals. A well-known case is that of the woman whose leg was pierced by a plank. The most tragic case was that of the farmer whose head was cut off by a piece of metal as if by the axe of a butcher.

In the United States tornadoes are so frequent and aweinspiring that they have found a place in folklore. In one book on the folklore of the central States some stories are told that are like fairy tales about tornadoes. In Kansas, a tornado of unusual strength darkened the entire region, a house was carried away and only an iron pot was left in its place. The owner was happy and took it in his hand and found that the pot had been unscrewed from the outside. In Missouri, during a tornado, roosters were carried into the air at great speed and uncannily fell into a pitcher. The pitcher had a narrow neck and only one head protruded crowing with despair.

During the lunch hour a farmer was eating the traditional apple pie. All of a sudden he heard an unbelievable din and roar. Darkness fell all around. The house with all furniture and the farmer were blown into the air and broken into pieces. When the farmer regained consciousness he found that he was sitting on the branch of a tree holding the apple pie in his hand.

Different types of debris were being carried about. He was frightened, caught hold of a plank flying through the air and covered his head. After he calmed down, he ate the pie and by the time he had finished it the tornado had weakened and there was sunshine. The farmer got down from the tree and went back to his house. But instead of the house he found a flat, smooth surface.

In folklore, as is always the case, fantasy is inseparably linked with reality.

Accurate measurements of the speed of rotation are rare and different results are available. Observations and cine-camera shots of debris rotating in the walls of a tornado gave figures of 306 and 382 kmph (Measurement... 1959). Brooks (1951), in his review of tornadoes, gives a speed varying from 180 kmph to 540 kmph and even up to 720 kmph. In a later work (Abdullah, 1955) the calculated speed is equal to the speed of sound (331.4 m/sec) or even more.

The ascent and transportation of heavy objects show that the speed of rotation in the funnel is very fast and changes considerably. The lower part of the funnel rotates considerably faster than the upper part. It easily lifts big, heavy objects, even men and animals, but the height they are lifted is never more than a few tens of meters. The rotation of the upper part is slow and the bigger objects are thrown out of the funnel and fall to the ground. Objects not heavier than a few kilograms are lifted into the cloud.

In the case of the incident described on page 250, when the cow was lifted into the air, it rose to a height of not more than 10–15 m, but did not stay there for long. However, the gusty wind that lifted it was fluctuating. It gradually weakened and the cow came down to earth.

Numerous examples of gusts associated with the transport of heavy objects are given below in the section on the transference of air and air stream.

It is quite likely that ultrasonic speed is attained in such gusts. The main mass of the funnel rotates slowly. But even in this case, the speed of rotation is quite high, of the order of a few hundred kilometers per hour. Due to this speed of the air filled with dirt and water tremendous destructive strength is attained. The walls of many tornadoes become dense and almost smooth.

The distribution of speed in diffused tornadoes is the same as in hurricanes. In the center, near the inner zone, the speed is enormous, reaching ultrasonic speed. It is due to this that tornadoes are often extraordinarily destructive, e.g. the tornado Three States or Mattoon.

An interesting situation arises when the parent cloud descends to the surface, the funnel is altogether absent and the cloud slowly moves hugging the ground. The destruction, in such cases, is not less, rather more. This shows, as may be expected, that the rotating circulation with enormous speed is not the property of the funnel alone but also of the part of the parent cloud with which the funnel is linked.

4
Forms of Tornadoes

DENSE TORNADOES

Tornadoes have unusually diverse forms which change quickly even in the same tornado. Their typical feature is the sharply-defined, stable, dense base, differentiating the tornado from all other atmospheric formations. Another feature is the quite long tube of small diameter. A third feature is the more or less vertical position of the tube.

Tornadoes can be divided in two groups, based on their length and width:

1. snake or whip type;
2. funnel, trunk or column type.

The snake type tornado is relatively rare. Except for the long coiled body, resembling a snake or whip, it differs to the maximum extent from the other type in the horizontal position and sharp bend (Fig. 115). The monograph by Flora (1953) gives a number of photographs.

A very long, thin tornado was observed in 1937, in Nebraska (Some photographs . . ., 1937). The lower part of the tornado was semitransparent, almost invisible, but it had formed below the wide cascade of dust. The hemispherical dark cloud from which the tornado protruded, rotating quite fast, is of interest (Fig. 116).

Study of the development of a number of tornadoes showed that the snake, whip and rope-like shapes formed at the end of the life-cycle of these tornadoes. They break off and then the tornadoes disappear.

This has been studied in detail and photographed for the tornadoes of April 2, 1957, in Dallas (Beebe, 1960a), Fergo, 1957 (Fujita, 1960b) and Scottsbluff, 1955 (Hoecker, 1959). They are described below (pp. 262–267).

These shapes have been observed in water tornadoes.

Rope-shaped tornadoes have a certain horizontal portion, going into the

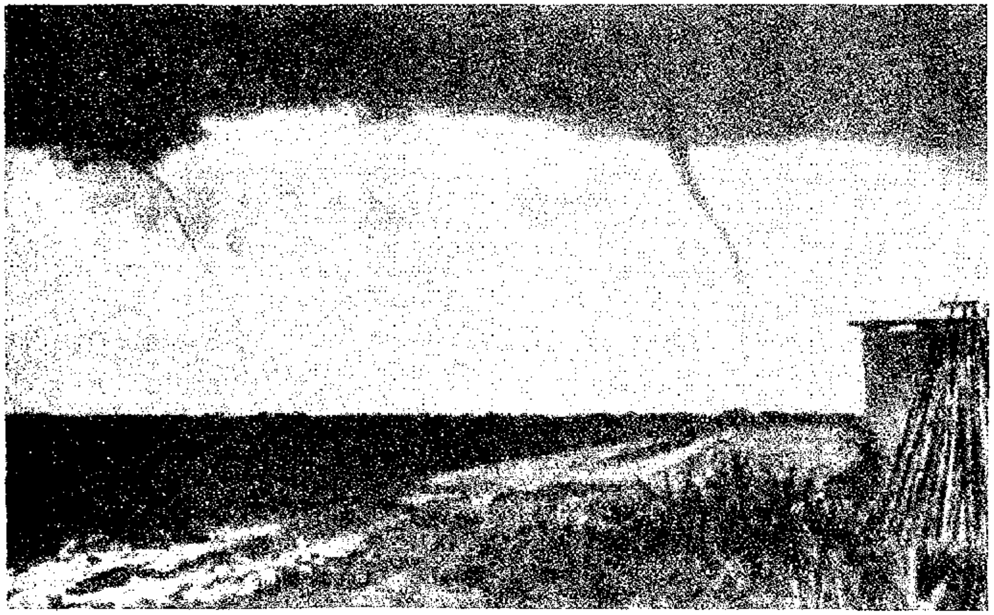


Fig. 115. Two water tornadoes off coast of Florida, Miami, 1958. Tornado on left is whip type and diffused; that on right, fully developed. Steplike tornado cloud can be seen in tornado on left (Dunn and Miller, 1960, Fig. 3).

cloud, as in the tornado of 1959, near Cape Hatteras, USA (Fig. 102).

The tornado over Peshawar, Pakistan, on April 5, 1933, became precisely defined at the last stage of growth, became snake-like, then whip-like and lastly thread-like. It was very long, sharply bent and broke off in the middle and dissipated.

Column- and funnel-type tornadoes are common, of varied appearance, but typical. They are generally known as "funnel" tornadoes. Such a funnel is gently bent, narrowing toward the ground, widening toward the cloud end and merging with the cloud. An example is shown in Fig. 117. It occurred over Kansas on May 31, 1949. The length of the path was 18 km and there was no particular destruction. A similar tornado occurred in northern Pakistan, over Peshawar (Fig. 118), without causing destruction (Fig. 118). Its entire lifespan, lasting for half an hour, was photographed. The photographs (Veryard, 1935) show clearly the initial stage, formation of a cascade of dust and dirt and trasformation into a peculiar color.

A typical columnar tornado was observed over Leningrad on August 15, 1925. This phenomenon was extremely rare for the Leningrad region. If a small funnel is observed in the lower part of the thick thunderstorm cloud, then as a rule the embryonic tornado does not develop further.

The tornado of 1925 displayed an entire panorama. Around 4 o'clock in the day the sky was covered with cloud and the sound of distant thunder in the eastern part of the city could be heard. At 2 minutes past 4 o'clock in the center of the city, a funnel dipped from the thundercloud in the east-

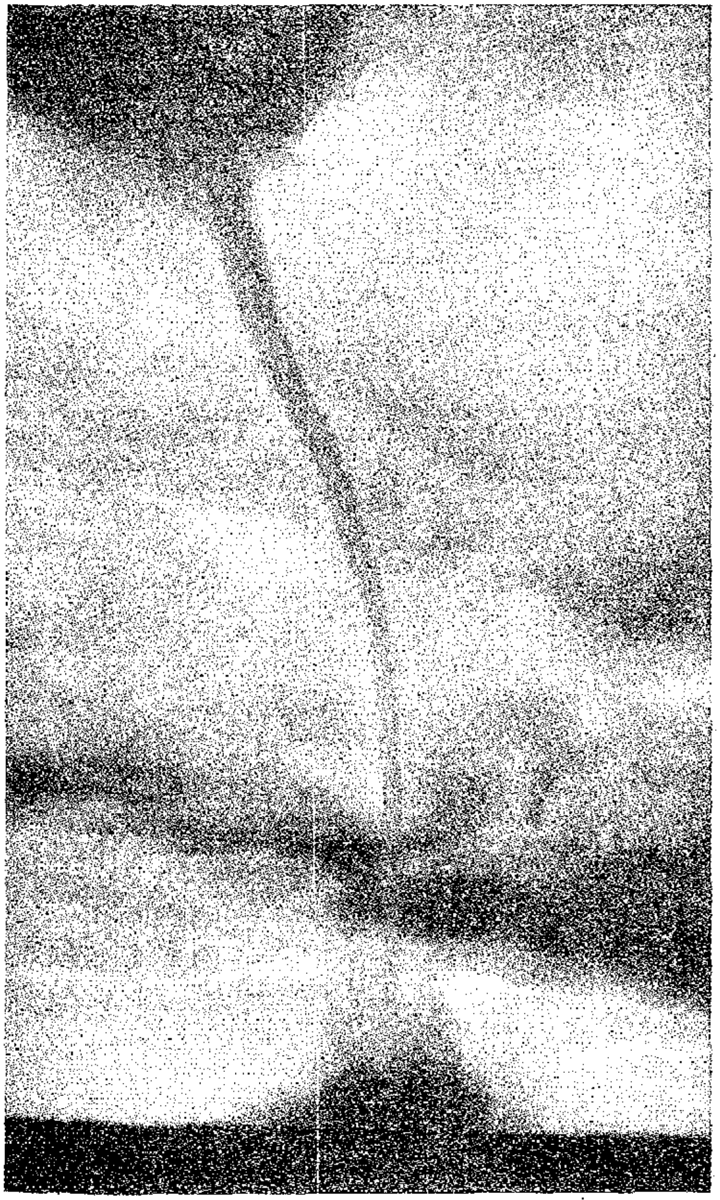


Fig. 116. Tornado with high, narrow funnel and large cascade, Nebraska, 1937 (*Quarterly Journal of the Meteorological Society*, vol. 63, 1937, Fig. 19).

southeastern sky. It resembled the bent trunk of an elephant. After 1 to 2 minutes the tornado came to resemble a sand glass: the thinnest part was in the middle.

The tornado lasted a few minutes. The lower part rapidly disappeared and at 5 minutes past 4 o'clock the upper part changed into small ringlets and disappeared into the cloud.

The lower part of the tornado could not be observed as it was obscured

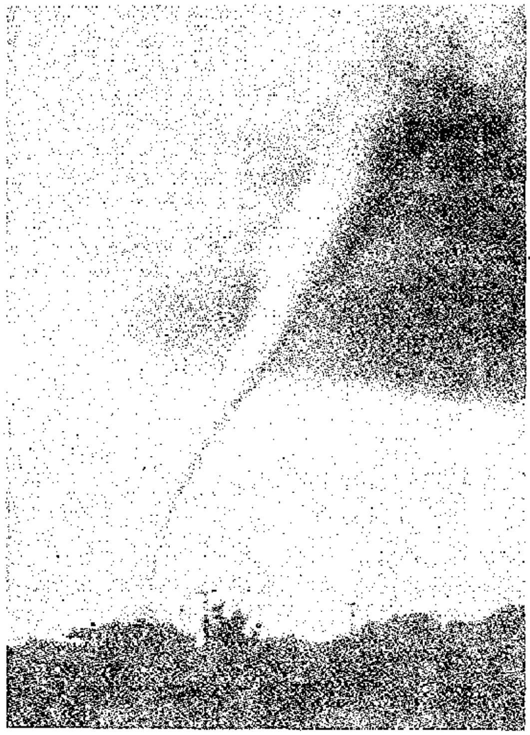


Fig. 117. Columnar tornado widening at top and entering cloud, Kansas, May 31, 1949 (Flora, 1953).

by houses. In the absence of any destruction it appears that it did not reach the ground.

It is interesting that in spite of the sharp definition the tornado not only had no vortex on the ground but the wind did not strengthen much. It was observed under completely calm conditions.[1]

In the USA, as elsewhere, small tornadoes show a long, narrow form, a sharply-defined funnel widening into the parent cloud and narrowing down toward the surface where it is accompanied by a cascade of dust. The funnel is generally of bright cloud and can be seen clearly from a distance. This gives people enough time to take shelter in special tornado cellars. The scene is depicted in the picture by the American artist D. Kerry (Fig. 119). The wife of the farmer, holding her child, is entering the cellar. The farmer is hurrying the children, who are holding the cat, etc. At a distance the funnel of the tornado can be seen approaching the farm. If the tornado really passes over the farm none of the structures shown in the picture will survive but the farmer and his family will be safe in the cellar.

Figure 120 shows how a columnar, slightly bent, tornado of small height just grazed the ground, lifting an enormous cascade of dust. The tornado

[1]Reported by L.A. Whitelsom.

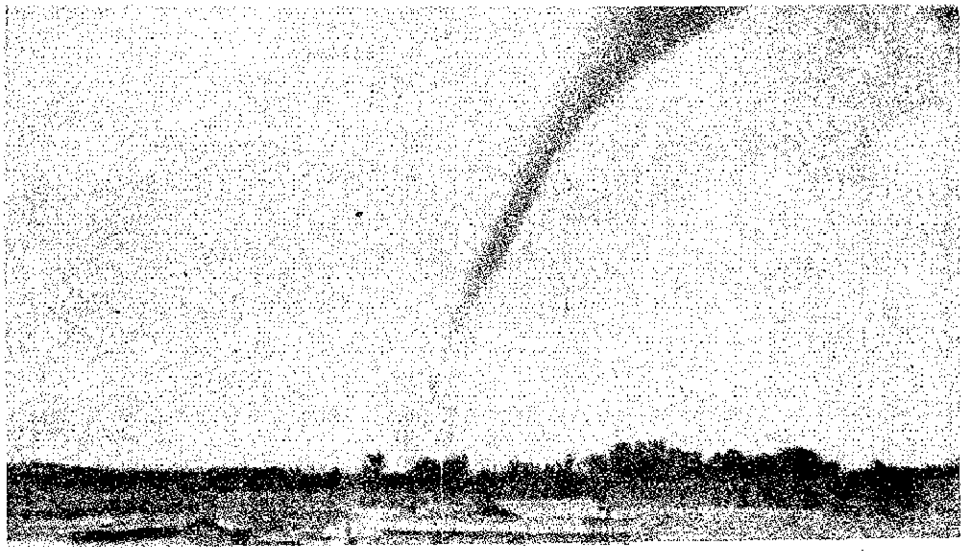


Fig. 118. Tornado in Peshawar, Pakistan, April 4, 1933. High, narrow cascade cover (Flora, 1953).

Fig. 119. Picture by D. Kerry: "Tornado over Kansas" (Boswell, 1939).

cloud base is sharply defined. The clear sky all around and the two funnels at the embryonic stage (August 28, 1884 in South Dakota) are of interest. The tornado struck the plain, bypassing the city without inflicting any loss.

Another columnar, almost straight tornado (June 2, 1923, Wyoming State) is interesting in that it widens at the base and not in the cloud, as is generally the case. It was accompanied by a cascade of dust. The entire sky was covered by clouds (Fig. 121). This tornado occurred over the semidesert plain without causing any loss.

A typical funnel-forming high tornado is shown in Fig. 91. It moved slowly, fully illuminated and could be seen from a distance of 40 km, giving people sufficient time to take refuge in their shelters. The destruction was total wherever the end of the funnel touched the ground (June 2, 1929, Kansas). The black tornado cloud, sharply defined at the base, is a typical feature.

Fig. 120. Columnar tornado of small height, South Dakota, August 28, 1884. Enormous cascade with two embryonic funnels (Flora, 1953)

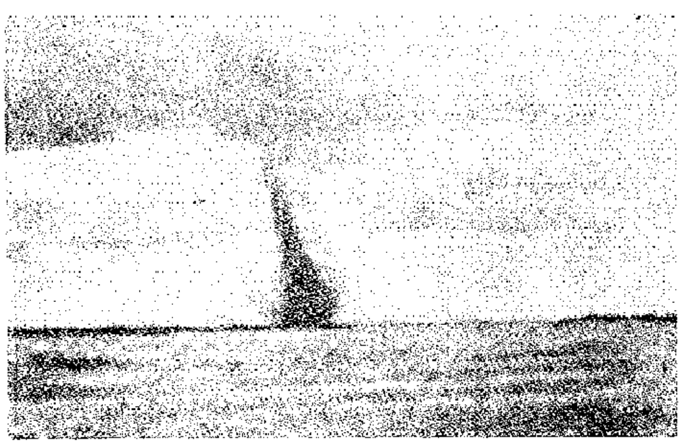


Fig. 121. Columnar tornado widening below, possibly due to cascade, Wyoming, June 2, 1923 (Flora, 1953).

An enormous funnel-shaped tornado struck the city of Wichita Falls, on April 3, 1964 (Stankewitz, Johnson and Dobry, 1964). The enormous "cascade" lifted from the ground where the funnel touched the surface is of interest. The height of the cascade was a few hundred meters and almost equal to the length of the funnel.

The columnar tornado, due to its enormous size, causes large-scale destruction. The tornado over Wichita Falls destroyed 225 houses but thanks to the timely warning the death toll was only seven.

A most striking, tall, trunk-shaped tornado (Fig. 122) occurred over Gothenberg, Nebraska, on June 24, 1930 (Oliver, 1931).

Funnel-shaped and columnar-shaped tornadoes are common and widely distributed. Their sizes and shapes differ widely. Even the same tornado continuously changes its form. In the case of the Scottsbluff tornado of 1955 such changes have been traced by Hoecker (1959) in detail, with numerous still and movie photographs.

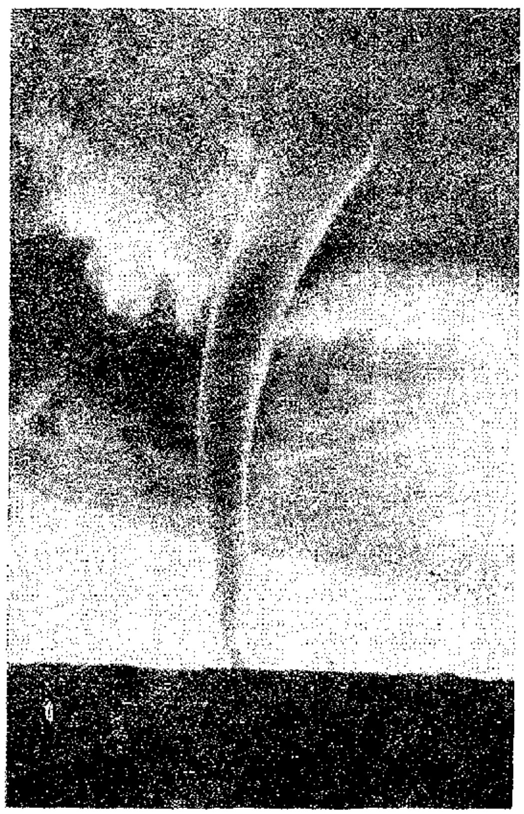


Fig. 122. Typical trunk-shaped thick funnel, still not touching ground; cascade is absent. Nebraska, June 24, 1930 (Oliver, 1931, Fig. 6).

The changes in the tall tornado are shown in 30 successive drawings (Fig. 123). They are for each minute while the tornado traveled five kilometers. The dimensions are given in feet (1 ft = 0.3 m). The outline of the funnel is shown by smooth lines and the outline of the cascade by wavy lines. The shaded portion is the elevated, concealed funnel. The figures between the drawings are the time elapsed, in minutes. The figures: *1, 2*—wide funnel seen in the air, between the hills; *3–5*—the funnel reaches the ground forming high cascade; *6, 7*—the funnel contracts, the cascade reaches enormous height, 800 m; *8*—the funnel standing almost straight, with small cascade; *9, 10*—the funnel again moves, bends; the cascade is enlarged; *11*—the funnel breaks off from the ground; no cascade is present; *12, 13*—a funnel of enormous height, 1,400–1,500 m, narrow, curved; cascade is of average size; *14, 15*—parent cloud is lower, funnel is low and curved; *16, 17*—the funnel is high, almost straight, narrow; *18–20*—the funnel is low, with wide top, narrow bottom; *21–23*—the funnel again breaks off from the ground; *24–26*—an enormous, massive funnel again reaches the earth, but the cascade is small; *27, 28*—the funnel is high, columnar, sloping and thick; *29, 30*—in the last stage, funnel breaks off from the ground and finally withdraws into the cloud. The drawings by Hoecker are extremely clear and interesting.

The second Scottsbluff tornado originated not far from the place where the first one disappeared and appeared as if it was a continuation of the first. The length of its path was 14 km, which was covered in 45 minutes. The symbols in the diagrams are the same, except that the shape of the parent cloud has been shown generally.

The shape of the second tornado is more unvarying but shows special features (Fig. 124); *31–36*—the funnel is low, wide, similar, small cascade; *37–39*—the funnel is lifted into the cloud, its place is occupied by a high columnar cascade of blurred shape; *40*—the funnel and the cascade meet in the air; the size of the parent cloud is about 4 km; *41–43*—a peculiar, stable funnel of enormous columnar form hangs from the front side of the parent cloud. On account of this a horizontal vortex of enormous strength develops. It gives rise to a cascade of unusual width, almost 6 km; *44, 45*—the funnel becomes sharp and bent; *46, 47*—the funnel is narrow and low; *48, 49*—the funnel is very fine, arched, disappearing into the cloud, dipping almost to the ground. This is the end of the tornado. The sharp, continuous change of its form is striking.

DIFFUSE TORNADOES

The most remarkably destructive, low, wide tornadoes are ill-defined and diffuse. Due to the last feature they are known as cloud masses. Often they have a frightening dark color.

Such a tornado of the same width and height, about 800–1,000 m, occurred over Oklahoma on April 11, 1927 (Fig. 125). It was associated with a low, black sharp-edged cloud hanging over the ground. This tornado passed over the desert plain, bypassing the cities.

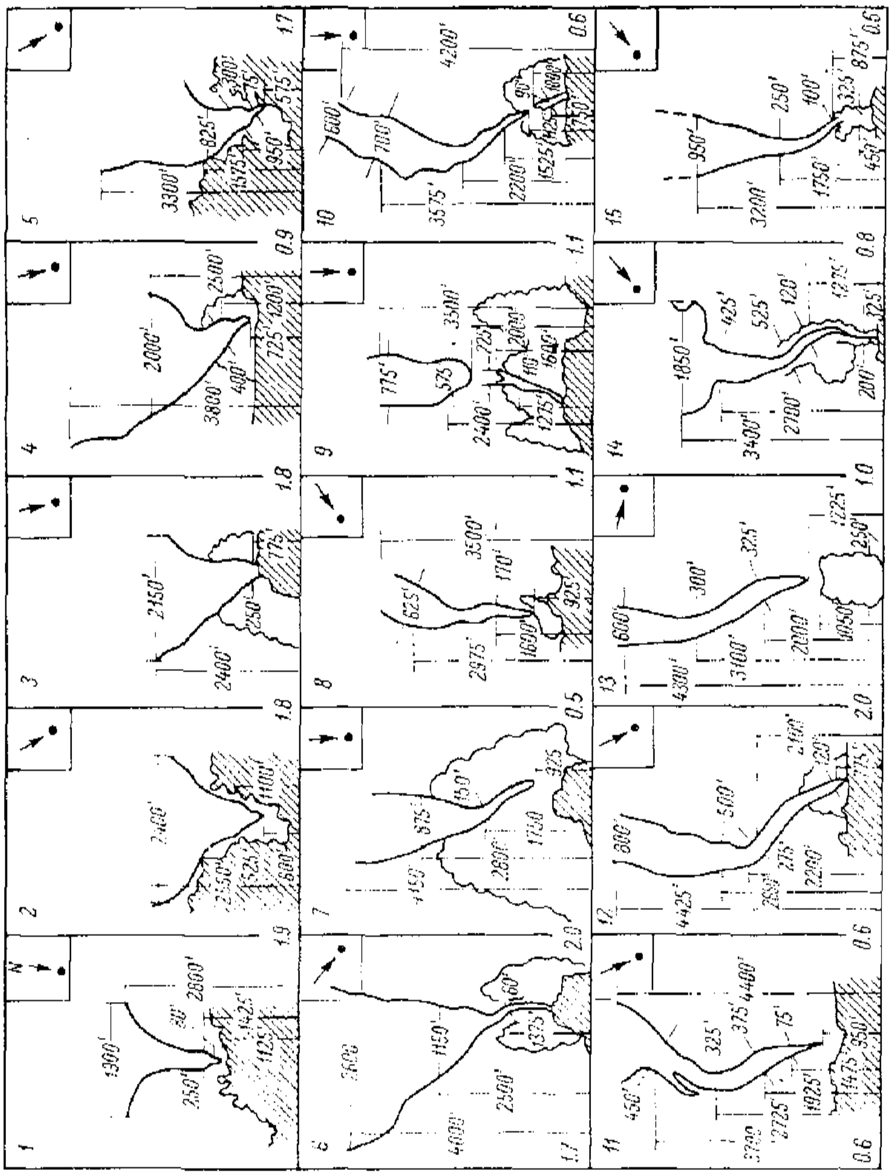
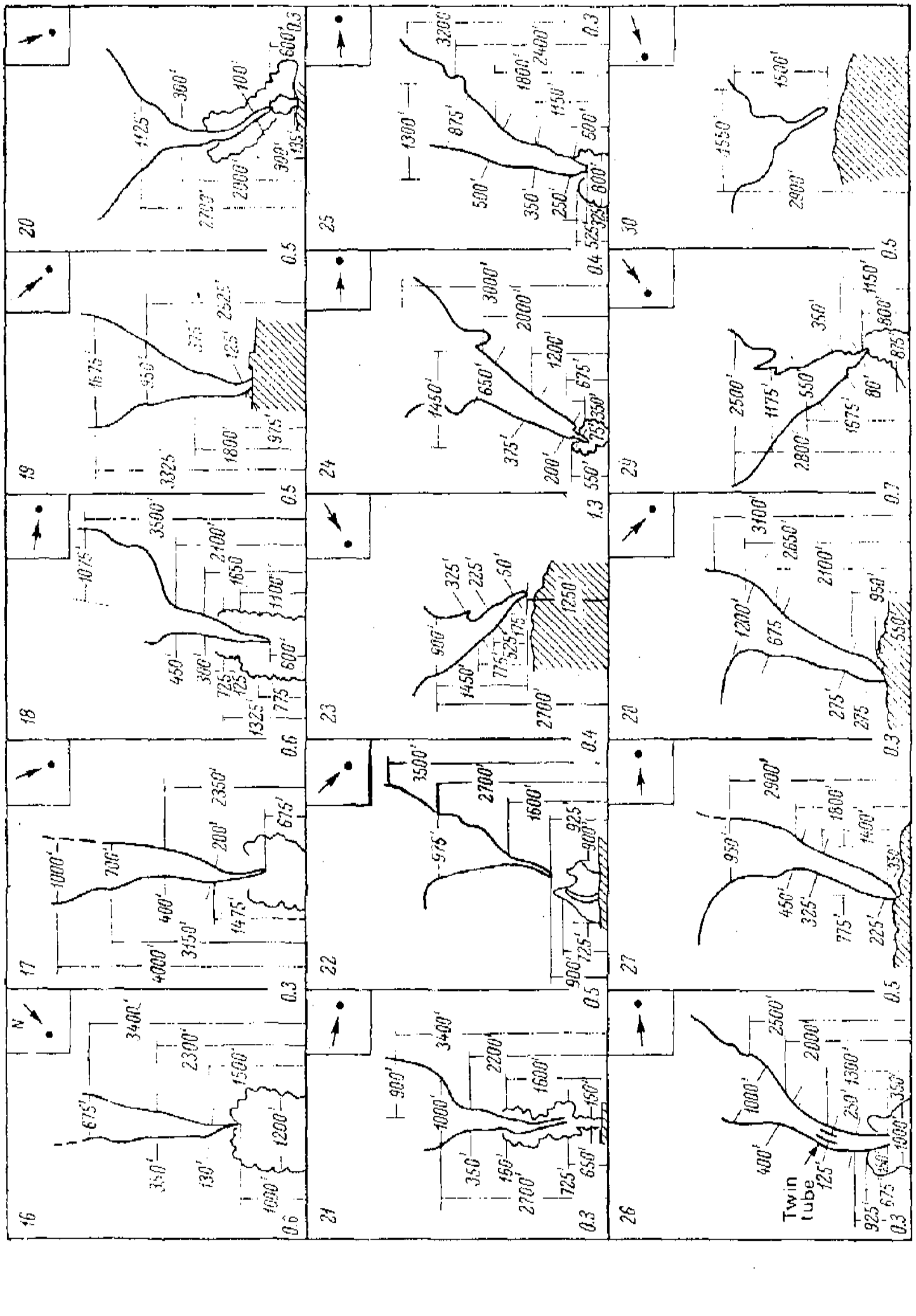


Fig. 123. Successive drawings of Scottsbluff tornado of June 27, 1955, Nebraska. Dimensions in feet (Hoecker, 1959, Fig. 2, 1–30).

Figures left bottom—interval between drawings (in minutes); *arrow in right corner*—direction from which drawing was made.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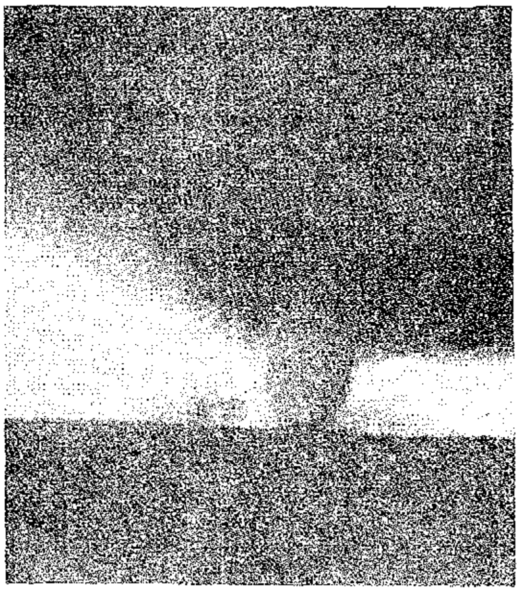

Fig. 125. Thick, low, barrel-shaped tornado, Oklahoma, April 11, 1927. Width of funnel: about 1 km (Flora, 1953).

A low tornado whose width is more than its height is shown in Fig. 126. The peculiar diffused outline resembles squall storms of similar size. The photograph was taken during the passage of the tornado on March 15, 1938, over Bellville (Illinois City), where it damaged 18 blocks, killed 10 people and caused a loss of 500,000 dollars. Its height was 150–250 m.

The tornado of 19 May, 1960, which occurred not far from the city of Topeka, Kansas, belonged to this group (Garret and Rockney, 1962). Numerous photographs and radar images clearly illustrated its entire track. It both contracted and expanded, during the period, giving rise to an unusually wide track. This is one of the distinctive features of this group of tornadoes. The outline all along was not sharp but diffuse (Fig. 127). Eyewitnesses described it as a "black rotating mass", and the similar tornado of 1960 near the city of Tulsa as a "gigantic white cloud, like a barrel standing on the ground" (Beebe, 1961, p. 17). The destruction was enormous.

It should be noted that the well-known tornado Three States was observed on March 18, 1925. It was more destructive in respect of loss of life and loss of property (see p. 351). The tornado started from the State of Missouri, followed a straight, continuous path via the State of Illinois and ended over the State of Indiana.

The distinctive feature of this tornado, comparable to a vortex storm, was the absence of a sharply-defined outline. Crossing the city of Princeton in Indiana it had the form of a dark mass like the leafy branch of a tree. Another eyewitness described it as "cloud" rolling toward him and appear-

Fig. 126. Low tornado with width greater than height. Diffused outline. Bellville, Illinois, March 15, 1938 (Flora, 1953).

ing as a whirling, raging mass. There was no lift or jump, so common in tornadoes, and the strength of the storm throughout was steady. If it had occurred over Europe it would have been referred to as a storm.

Fig. 127. Low, wide, diffused tornado, Topeka, Kansas, May 19, 1960. Large-scale destruction (Garret and Rockney, 1962, Fig. C).

This case was described after 40 years (Changnon and Semonin, 1966), after a detailed study of the wide range of literature available. The length of the track was 350 km, the maximum width fluctuated from 800 to 1,600 m, the speed from 115 to 96 kmph. The duration was 3.5 hours. The distinctive features were: almost straight-line movement from the northeast and the absence of any jump: throughout its path the tornado did not lift from the surface. It was due to this that enormous destruction took place over an area of 164 sq. miles. Fig. 128 shows what remained of a large coalmine pithead and the surrounding village—a shapeless heap of debris.

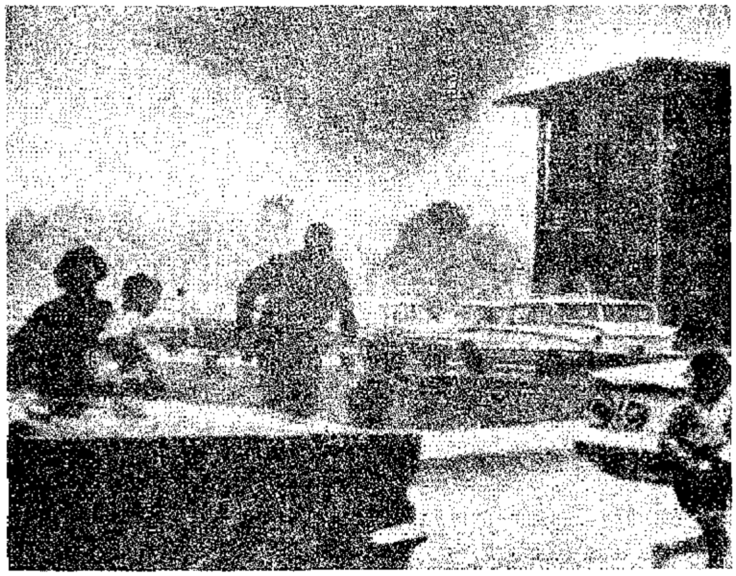

Fig. 130. Tornado of 1966, Topeka, Kansas. Tornado is approaching. Family just arrived by car runs for shelter. Funnel is low, wide and diffuse (Galway, 1966).

that had come to the hotel ran for the special basement shelter. The photographer was on the second floor of the hotel. In the second photograph (Fig. 131) the enormous, diffused funnel of irregular conical form has been snapped. In the third photograph (Fig. 132) the funnel is very near and only part of it has been caught in the photograph. Much small debris of damaged buildings pours out from it onto the surface (right half of photograph). The photographer was too scared to take any more photographs and ran to the shelter. After a few minutes there was no sign of the roof from which the photographs were taken. It was leveled by the tornado (Galway, 1966).

Attention is drawn to the form and diffuse outline of the funnel in the photographs of the Topeka tornado of 1966. The tornado was enormous and caused large-scale destruction in the city. It not only destroyed one- and two-storied buildings (often nothing remained of them) but also a sector of the university. The length of the zone of destruction was 12 km. The loss of property was enormous, more than 100 million dollars, but the loss of life was only 17. Due to the timely warning everyone had taken shelter in basements.

Diffuse tornadoes with the height more than the width are quite rare. In this respect they are similar to the usual smooth tornadoes but the sturcture of the walls of the funnel is quite different. This can be clearly seen in the photograph of the tornado of August 20, 1911, in the city of Antler, North Dakota (Fig. 105). The photograph was taken from a distance of 2.5 km and not only the tornado but also its rotating parent cloud can be seen. It is separate from the main thunderstorm cloud and has the form of a step with angular edge. This angular, straight-line outline of the cloud is quite rare. It could have been formed only by steady, fast rotation (Simpson, 1917).

This tornado was photographed from a close distance, about 1.5 km (Fig. 133). Its form was frightening: a black, raging cloud creeping to the surface, destroying everything in its path.

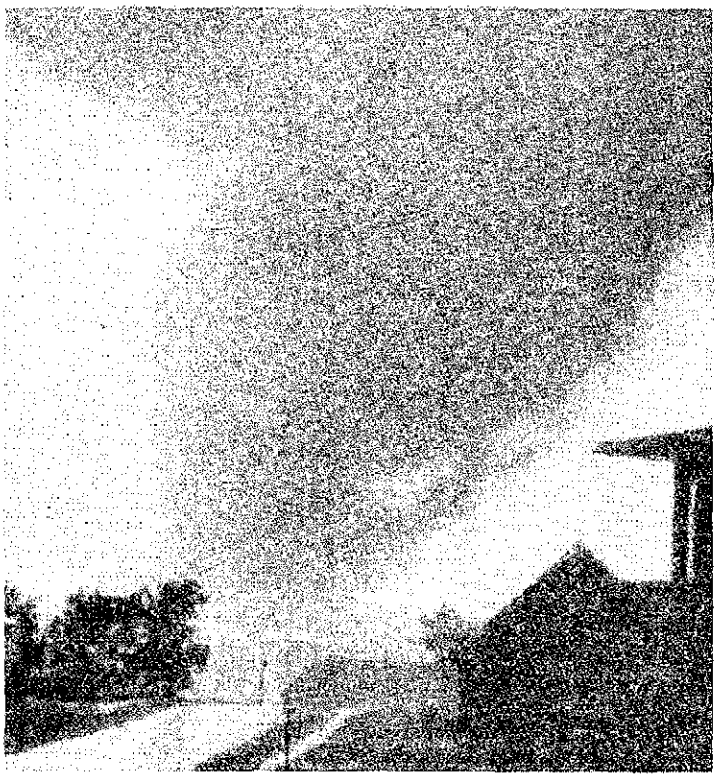

Fig. 131. Tornado of 1966, Topeka, Kansas. Tornado is approaching. Typical irregular form resembles cloud with diffuse outline (Galway, 1966).

Another tornado, a transitional type between the smooth and the diffuse tornado, occurred over Oklahoma on April 11, 1927. It was similar to the diffuse tornado, showed similar width and length, but the outline of the funnel was sharp, like that of smooth tornadoes; a low, wide cascade could be seen at its base.

The inhabitants of the central States are used to tornadoes, but once (April 11, 1965) even they were amazed: two diffuse tornadoes were connected with the parent cloud, like two horns of the devil (Fig. 134). Actually after a few minutes these two horns were united in the air over Dallas, Indiana, reducing it to ruins and killing dozens of people (Palm Sundays . . ., 1965).

In another diagram (Fig. 135) the sketch of a tornado with two horns which occurred over Kansas (Irwing) in May, 1879, is given.

away the walls and trees and many people were killed by the debris flying through the air. An enormous balloon broke its cable and flew up into the air like a feather (it can be seen in the right top corner of Fig. 136). It was found later in Hungary. From a large number of indications it was established that the exhibition was destroyed by a diffuse vortex of large size. Its funnel resembled a dark rolling cloud (Zurcher and Margolle, 1883).

The diffuse tornado differs considerably from the smooth one mainly in its diffuse cloud boundary, in its form (low and wide) and the correspondingly wider track and belt of destruction. It is quite likely that they do not form cascades. They display less speed of rotation and longer duration. Quite a number of properties are shared with squally storms.

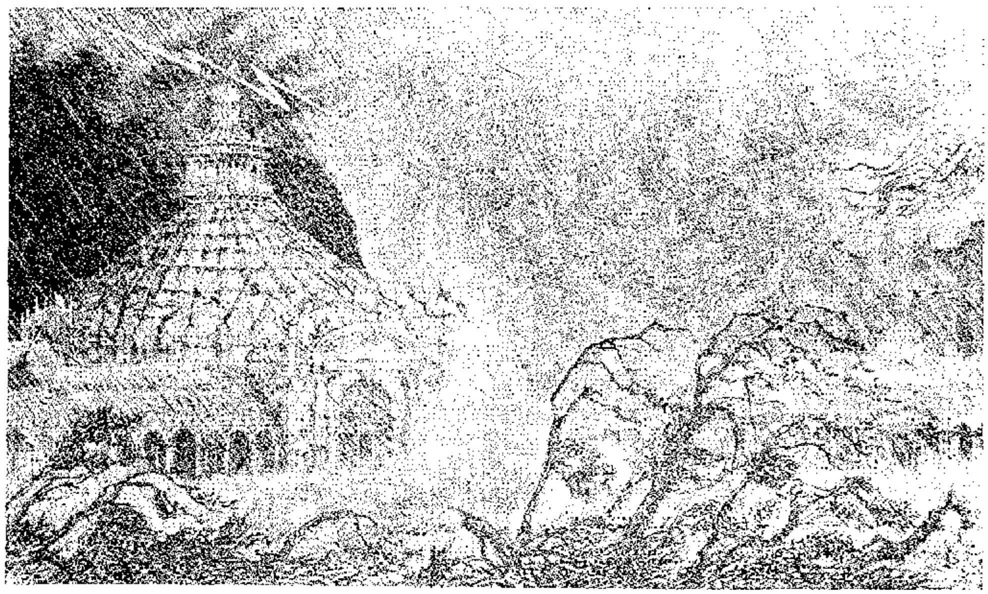

Fig. 136. Tornado at 1873 exhibition in Vienna Destruction is considerable; funnel is not distinct; similar to squally storm (Zurcher and Margolle, 1883, Fig. 16).

At the same time, the history of a number of tornadoes shows that the same tornado at the beginning and end of its development may display a smooth funnel, but in between during its maximum strength, it becomes diffuse. It is quite probable that the enormous diffused outline with low, wide form is associated with the proximity of the parent cloud to the ground. Such a case has been observed, when a tornado emerged from the parent cloud as it dipped to the surface.

Earlier it was assumed that the tornado is an isolated phenomenon, entirely independent of the parent cloud. It has been shown that the smooth tornado, diffuse tornado and the parent cloud are different components of one single vortex circulation. These three formations differ sharply from one another but they are inseparably interconnected. The establishment of this relationship is considered an important achievement of present-day meteorology. In a subsequent section smooth and diffused tornadoes and parent clouds are treated simultaneously.

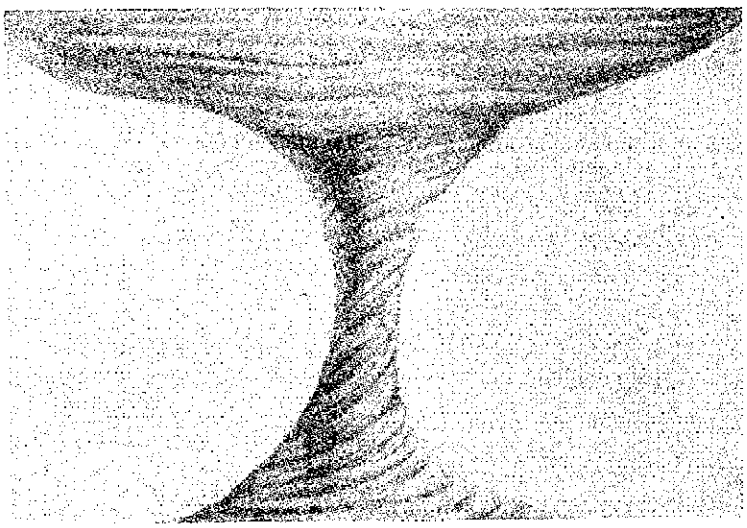

Fig. 137. Tornado, having form of sand clock, Missouri, 1879. Formed at junction of funnel and cascade of dust (Finley, 1881, Fig. 4).

Finally we will describe a few examples of the phenomena, occupying an intermediate position between the tornado and squall storm. These are taken from the interesting book *Hurricanes* (1964) by Z.M. Tiron.

On May 23, 1957, in northern Ural, near Cherdyani, a strong, short-lived squall occurred. The speed of the wind was 20–30 m/sec and at times 40 m/sec. The storm left a 5–6 km long, 300–400 m wide swath of damaged forest. The strength of the wind was unusual. A 200-year-old cedar tree was twisted like a rope, uprooted and thrown to a distance of 8 m. This phenomenon has been referred to as a squall storm, but on the basis of the strength of the wind, twist and small width of the track, it is more akin to a diffused tornado.

The same can be said of the storm that occurred over the western part of Gdan'sky (Poland) on September 5, 1934. The damaged forest had individual belts 20–50 m wide which followed one another almost in a straight line. From the study of the position of the fallen trees it was found that the storm showed a spasmodic vortex with cyclonic rotation.

The storm that occurred over the Mshinsky station in Leningrad region in August, 1947, closely resembled a tornado (see page 177).

These examples show that tornadoes, vortex storms and hurricanes are essentially phenomena of the same type. They differ only in the dimension and form of the vortex formation.

A large number of "old" tornadoes that occurred a hundred years ago have been described by F.A. Batalin (1854). In 1835, a tornado of dense, black columnar form occurred over France. Another tornado over France had the form of an enormous dark sphere. It dipped at one moment and lifted the next. In Bonn a tornado had a rare form: it was a cone with the base oriented toward the ground and the narrow top directed toward the cloud. In Ireland a tornado had a long tail, released from the cloud. At one moment it was straight and the next it was folded. Its color changed from black to white-gray.

Of 234* tornadoes, 209 had funnel shape; nine conical in shape; seven resembled an inverted funnel; four, an inverted cone; four, a sand clock; one a basket; one a snake; one, a balloon; one a dense rolling mass (Finley, 1884, p. 24).

Often the cascade of dust incorporates part of the funnel. This explains the appearance of such forms as an inverted funnel, inverted cone and sand glass. If this is taken into account, then the form of the tornado will always be funnel-shaped, either elongated or shortened.

The junction of the funnel and the cascade was observed in the tornado of May 30, 1879, in Missouri (Finley, 1881, p. 16). The black cloud moved with rain and hail. A small funnel protruded from the cloud. Dipping to the surface, a cone of dust with fine debris was lifted up. Soon this cone fused with the funnel, forming the tornado, widening both at the top and at the bottom (Fig. 137). The formation of the tornado was accompanied by terrifying thunder.

Similar phenomena have been observed repeatedly when the cascade of dust met the lowered funnel half way. This explains why the lower part of the funnel, forming the cascade, was initially invisible and became visible only when it was filled with dust (Fig. 158). The cascade gives the impression that the tornado is wider below (Fig. 121).

* According to split-up details the number of tornadoes should be 237 and not 234—General Editor.

5
Groups of Tornadoes

GENERAL REVIEW

If the cumulonimbus tornado cloud has small size, a few kilometers laterally, then it forms one tornado, rarely two to three tornadoes. An enormous cloud of 30–50 km and more laterally is often the progenitor of a group of tornadoes of considerable size.

On April 11, 1965, an unusual outbreak of tornado formation occurred over the central States of the USA. In total, 47 tornadoes occurred, caused large-scale destruction (Fig. 207, described in detail on pp. 394–397) and killed 257 people. In loss of life it took second place after the well-known tornado Three States in 1925. Among the 47 tornadoes, the two-horned tornado with the two connected funnels (Fig. 134) and a gigantic diffused tornado were exceptional.

The well-known tornado Three States of March 18, 1925, is considered as a unique formation. The enormous size of the tornado cloud, 30 × 50 km in area, its duration and the existence of several funnels support the assumption as to existence of a group of funnels, originating one after the other and existing simultaneously.

The same can be said of the less famous Mattoon tornado of 1917.

The Scottsbluff group of tornadoes of June 27, 1955, had 13 funnels reaching down to the ground and a considerable number of rudimentary funnels hanging in the air. They were connected with one thunderstorm cloud.

The Irwing group of tornadoes of May 30, 1879, described in detail by Finley (1881) (see pp. 352–376), had not less than 10 tornadoes. It caused large-scale destruction and killed 42 people. The exact size of the tornado cloud is not known but it was large, as indicated by the position of the tracks of individual tornadoes, about 30 km laterally. The track of one tornado is shown in Fig. 187.

The most thoroughly studied tornado is the Fergo group of June 20, 1957, consisting of five tornadoes (Fujita, 1960b). Fujita established that all of them originated from the same rotating parent cloud. The center of the track of this cloud is clearly shown in Fig. 150. Its length was around 130 km. The length of the track of each individual tornado was not more than 20 km. The width of the parent cloud was about 15–20 km. The entire group is described on pages 292–295.

Analysis of tornadoes shows, as already mentioned, that the main feature is the cumulonimbus thunderstorm cloud and that the tornado is a secondary phenomenon due to the former.

The main phenomenon is the origin of the spiral vortex like an eddy inside the cloud. It has been found from available measurements that its diameter is not more than a few kilometers. The parent vortex is situated at the lower part of the cumulonimbus cloud, not above the 3 km level. This shows that the transported organisms do not freeze but remain alive.

The parent vortex gets separated and isolated from the main cloud in the form of a peculiar step, described earlier (pp. 242–244).

It should be remembered that the parent vortex gives rise not only to tornadoes and funnels dipping downward, but also to other funnels, rising upward, often piercing the anvil. The formation of unusually strong hail, often accompanying the thunderstorm cloud, is related to these lower vortexes.

Thus we find that "group tornadoes" are complex atmospheric phenomena. From them a relatively small number of funnels dip to the surface, dozens of rudimentary funnels are suspended in the air and scores and often hundreds of parent vortices form underneath the thunderstorm cloud. Last of all, scores of tower cloud vortices give rise to hail. The tornado is only a small part of the total phenomenon.

AUXILIARY VORTICES

In the formation of a tornado the main role is taken by the parent cloud and the funnel but the auxiliary vortex is always well-developed. Generally it originates at the base of the funnel, never rises very high, but often rotates around the funnel and reaches the cloud. It is only rarely that the auxiliary vortex is lowered from the cloud, enveloping the top part of the funnel.

Very little has been learned about the auxiliary vortex. There is rare mention of its existence. Undoubtedly this phenomenon deserves more attention than it has received.

The auxiliary vortex gives rise to the part of the tornado known as the "cascade" and "envelope".

Cascade

When the funnel approaches the surface, either a cloud or a column of dust or a sprinkle of water is always found at its base. It contains only water in the case of water tornadoes. This water is first lifted and then dropped, forming the cascade. Such formations over land consist of dust and debris and are therefore known as a "sheaf" or "bush". Nowadays they are commonly known as "cascade", even when they consist only of dust.

Cascades are numerous and of various types. They are formed quite frequently. There is no special classification for them. They may be divided into two extreme groups: sharp and high (Fig. 138) and wide and low (Fig. 139). The unusual varieties of cascade in the same tornado can be clearly seen in the drawings by Hoecker (1959) for the Scottsbluff tornado of 1955 (Figs. 123, 124).

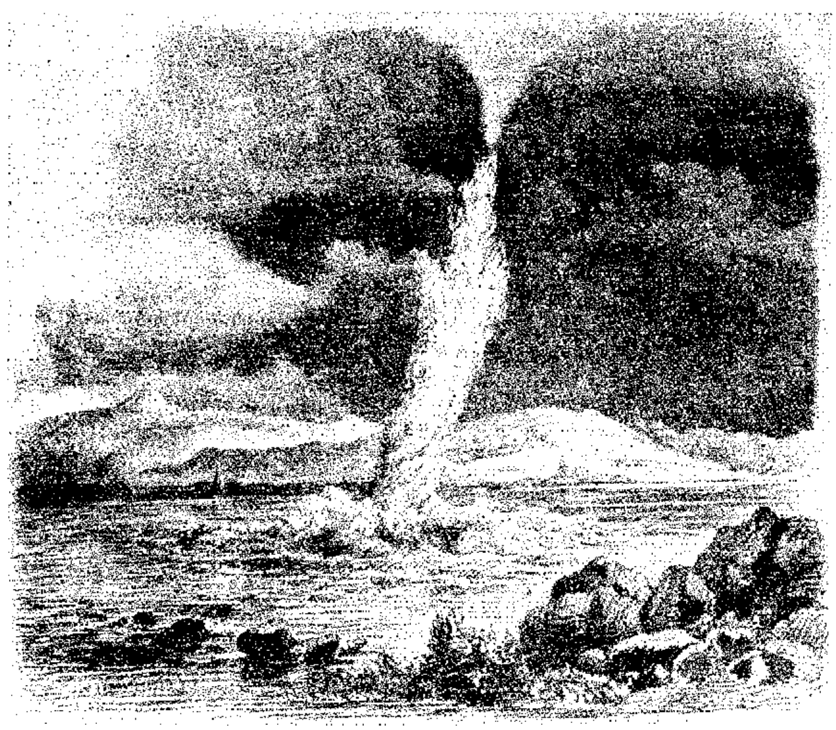

Fig. 138. Waterspout on River Rhine. Small funnel and enormous columnar cascade (Wegener, 1917, Fig. 82).

The cascade of tornadoes over land as well as waterspouts are described in great detail by Wegener in his monograph (1917, p. 244–262). Wegener believed that cascades furnish important information on the circulation of air at the point of contact between the tornado and the surface. According to him a circular vortex is formed around the base, giving rise to cascades of water or cloud or dust. He gives several examples of cascades of different forms and dimensions. A drawing of the cascade occurring at the point of contact of the tornado with the river is given in Fig. 138. The figure clearly shows the circular formation of relatively small height giving rise to vortex motion at the base of the tornado. The water sucked up by the tornado forms quite a high column, consisting of several concentric layers. Its height is 12–15 m.

An interesting relationship between the tornado and the cascade was observed on June 24, 1930, in Gotheburgs, Nebraska (Oliver, 1931). The tornado itself was unusual: low and wide, almost black. It hung from a semicircular pile of clouds, quite low over the ground and rotating quite fast. The upper part of the tornado was almost twice as wide as the lower part, forming a good envelope. Such "envelopes" are repeatedly formed in tornadoes. The lower edge of the envelope coincides with the upper edge of the cascade of dust of unusual width and height. The cascade appears as the continuation of the envelope, connected to it, distinctly separated from the tornado (Fig. 140).

Cascades were well-developed in the tornadoes of Dallas and Fergo, 1957. They have been studied in great detail (Beebe, 1960a; Fujita, 1960b). One observer in Dallas recorded that the dust and debris in the cascade were lifted exactly in the same way as by the thrust of water when watering is done with a garden hose. "The upward thrust was very strong." It resembled the straws and plant tops piercing the soil, as observed at the time of the Rostov tornado of 1953.

It is not only the pressure of the air at the top that forms the cascade but also the horizontal vortex surrounding the bottom of the funnel. Otherwise it is difficult to explain the cascades where the width considerably exceeds the height, and also exceeds by many times the width of the funnel of the tornado.

In the well-known Scottsbluff tornado of 1955 one cascade had a width of 1,092 m, and a height of 260 m. The width of the funnel was only 70 m. In another case the width of the cascade was enormous (1,700 m), while the width of the funnel was only 220 m (Van Tassel, 1955). Drawings of these tornadoes have been supplied by Hoecker (Fig. 124).

An entirely different type of cascade in a waterspout was observed over the River Yangtze, not far from Shanghai (Fig. 141). The waterspout rose to an enormous height, about two-thirds of the height of the funnel, i.e. several hundred meters. The cascade narrowed down at the base, widened at the top and the water fell back into the river. The funnel was long, narrow and columnar. This cascade cannot be explained by one thrust of the funnel to the water. It was very big and high. Here, undoubtedly, an additional vortex, lifting the splash of water, was present. The photograph of the waterspout was taken in 1933 from an American warship at the entrance to Shanghai, from a distance of 100–200 m. The bank of the river can be seen in the distance.

Fig. 139. Waterspout, Tampa Bay, Florida, June 25, 1964. Columnar vertical funnel. Wide, low cascade (*Weatherwise,* vol. 17, No. 4, 1964, p. 166).

Fig. 140. Tornado of June 24, 1930. Enormous cascade forms envelope of very low funnel (Oliver, 1931, Fig. 7).

In 1840, a frigate was sailing in the Mediterranean Sea off the mountainous coast of Algeria.

A thunderstorm cloud moved in, the dark, dense cloud hanging low over the water. It was hot and sultry. Suddenly, in the smooth base of the cloud some movement started, changing it into three spiral, fast-moving formations. From the centers of these three spirals dense, dark funnels descended. After a few minutes the funnels suddenly lengthened as if to hit the sea. Small cascades of water were lifted into the air. This moment is recorded in Fig. 142. Two tornadoes occurred near the frigate but the third taveled right

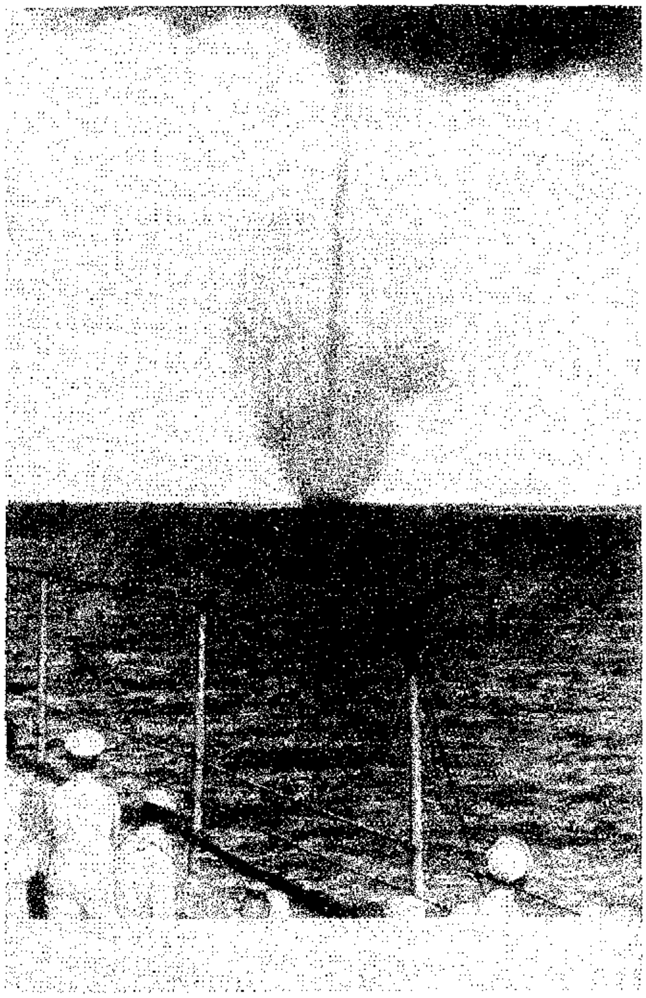

Fig. 141. Waterspout with big cascade, Shanghai (Capital ..., 1931, p. viii).

across her. The crew waited with horror for a collision but all went well. The strong gusty wind tore off the ship's bow and carried away everything from the deck. The deck was swept by a waterfall and after some seconds everything passed over. The cascade of the tornado actually appeared as a waterfall.

A rather large-sized cascade accompanied the tornado of May 4, 1961, in Oklahoma, at the time of its full development. The tornado passed over the dry desert. The dust and fine debris in abundance caused the large-sized cascades of the same width and height.

The peculiar and mysterious invisible cascade at the initial stage of the tornado is interesting when the lower part of the funnel is still not filled with dust and water and is invisible.

In 1896 a farmer was working in his field in the plains of Kansas. The air

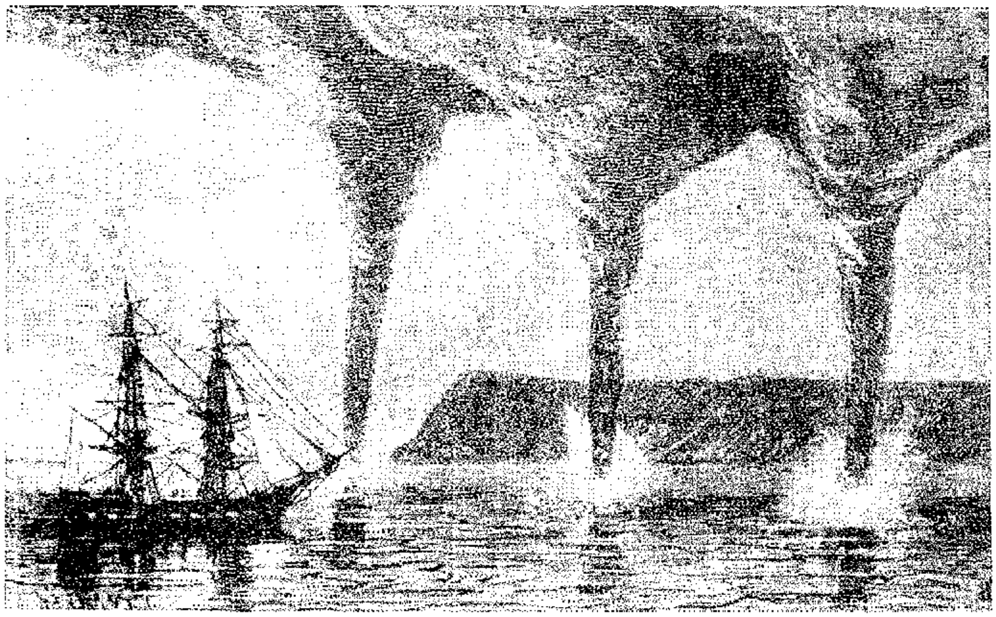

Fig. 142. Waterspouts with well-developed cascades and parent clouds, Mediterranean Sea, off coast of Algeria (Zurcher and Margolle, 1883, Fig. 13).

was still and it was very hot. A low, dark thunderstorm cloud was seen nearby. The farmer stopped, wiped the sweat from his face and looked at the sky. Suddenly he was terrified to see between the base of the cloud and the ground, some terrifying monster appear. The black, dense, round, whirling mass, an "elephant-like block" slowly moved toward the ground. It was 3 m, in length as well as in width. Like a performing elephant, it jumped up and down in the air and then again moved to the ground. It continuously rotated, the top was smoky and the smoke rose up. After a while it struck the houses and structures which came in its path and everything was reduced to debris. The farmer said later: "I stood at a distance of half a mile and watched the whole thing" (Henry, 1896).

The monster continued the to-and-fro movement even after destroying the farm. The "smoke" increased sharply, rose into the cloud, became dense and after a few minutes changed to become the enormous trunk of the tornado. "The elephant-like block" was not different from the invisible cascade, except that the funnel was not filled with dust. The destruction of the farm provided the necessary dust and debris. The funnel was formed and the cascade was connected to the cloud.

On November 14, 1878, the sailing boat *Beautiful Stewart* was slowly drifting on the mirror-like surface of the Gulf of Mexico. The day was calm and clear. The entire crew went to the deck and enjoyed the wonderful weather. Around noon the wind started blowing in gusts, like deep breathing. The sky was suddenly covered with low, black, menacing clouds.

They were discussing these phenomena when all of a sudden small, unusual waves appeared on the sea. At a distance the waves intensified, became bigger and vortex rotation started. The sea swelled, rose high enough to meet the low cloud, amalgamated with it and struck the boat. In an instant the two masts of the hoisted sails were snapped and carried away by the waves. In place of the boat a wreck floated aimlessly in the waves. In the evening the captain noted in his logbook: "The squall prevailed for half of the day. Until two minutes from the catastrophe, there was no sign of the threat. The entire mast was destroyed. The boat is helpless." The raging sea, its spiral rotation, the sea surface lifting the boat up and down—all these were due to the invisible cascade of the tornado (Ferrel, 1890).

It is difficult to photograph an invisible tornado but the Dallas tornado of 1957 was photographed by dozens of photographers from different sides and points and one of them took a rare photograph (Fig. 148). In the photograph the overhanging cloud, the single-storied frame house below it at the city limits, small trees on the horizon, and jets of black dust thrown up in the air, dark at the bottom and widening at the top, can be clearly seen. There is practically nothing in between. Slowly the trunk-like, almost invisible funnel of the tornado appears. After a few minutes the funnel descended over open fields and it was fully grown. The cascade attained large size.

For more than 200 years waterspouts and tornadoes on land have been observed and described in different countries by different observers. Even today they remain a puzzle. How do they form, why do they form, what force forms them and moves them?—all these questions are unanswered.

Envelope

The envelope of the tornado, or the double wall, is a peculiar, rare phenomenon and occurs more frequently in waterspouts (Zurcher and Margolle, 1883). This means that in addition to the main funnel, with sharply-defined walls, another, external, wall is formed which is less sharply-defined and often diffused. It is not far from the main funnel, forming like an envelope or sheath. Its origin is not known.

Some series of successive photographs show that the splash is lifted up to the parent cloud. Possibly the envelope of the tornado is formed in such a way. There is no other method of formation of cascade.

The envelope of the tornado exhibits intense rotation and has a part in the destruction wrought by the main funnel.

In land tornadoes of the less transparent variety envelopes are rarely noticed (Fig. 118). They are observed more frequently in waterspouts which are more translucent. The envelope was well-developed in the case of a waterspout over the Mediterranean Sea around Nice in 1780. The envelope almost reached the parent cloud, where it could be seen clearly that the main funnel merged with it (Fig. 143). An enormous envelope was seen in the waterspout over the Gulf of Tampa, Florida, in 1964 (Fig. 144) (Lane, 1966).

It has already been mentioned that the formation of different cascades has been studied very little. This is more so in the case of the envelope.

One thing, however, is clear: in addition to the funnel there are additional vortices associated with it. One type has considerable width, up to 1.5 km and more, but is very low. The other type, on the other hand, is very high but narrow and clings closely to the funnel. The form of the cascade and the envelope determines the form of the vortex and its formation.

Beads

Bead formations are rarer than envelopes but may be close to it in the process of formation. In the long, fine, curved, whip-like funnel circular, rather big bulges are formed. They give the funnel as a whole the form of a string of beads (Fig. 168).

The waterspout shown in Fig. 168 is described by Hurd (1950). In it four well-defined circular bulges can be seen. Two of them in the lower part, connected to the bulge, resemble the envelope. The two others in the upper part of the funnel are separate. The significance of these bulges is not yet clear. First of all, they are related to the small, narrow, additional vortices originating in front of the vanishing funnels.

6
Life-cycle of Tornadoes

Like many other long-lasting phenomena, the tornado shows three stages of development: initial, middle and final or young, mature and the old.

The essential aspect is the life-cycle, which is generally short. It determines the length of the track and the propagation of the tornado.

The speed of movement, dimensions, volume and such peculiar indications as weight are all different.

STAGES OF DEVELOPMENT

The initial stage of formation of the tornado was observed in the State of Nebraska in 1937. In the left of Fig. 145 it can be seen how part of the low, almost flat surface of the tornado cloud hangs down. Still more interesting is the right photograph. The hanging part of the cloud has already formed into a very sharply-defined column, hanging in the air, right over the surface. The cascade is absent. The most important factors are the circular, well-defined parent cloud and the sharp boundaries of the columns. They show that the cloud and especially the column experience extremely fast rotational motion. This is quite common for the tornado, but not for the parent cloud (Fig. 145).

A peculiar phenomenon was observed in England on July 14, 1962. At first the cloud was linked with the dark gray column (Fig. 146a). After a few minutes a spiral of three to four turns was formed (Fig. 146b). The spiral became thin and almost broke off (Fig. 146c), but then bulged sharply from the surface (Fig. 146d, e) and again changed almost to the dark column (Phillipson, 1963).

Among all the tornadoes that have occurred in America, the most thoroughly studied is the one of April 2, 1957, over Dallas. There are many hundreds of photographs available, about 600 m of cinefilm and a special

Fig. 143. Waterspout of 1780 in Nice. Funnel entering into envelope, almost reaching cloud (Zurcher and Margollé, 1883, Fig. 10).

Fig. 144. Waterspout of June 25, 1964, over Tampa Bay, Florida. Size of cascade and funnel is enormous (Lane, 1966, pl. 26).

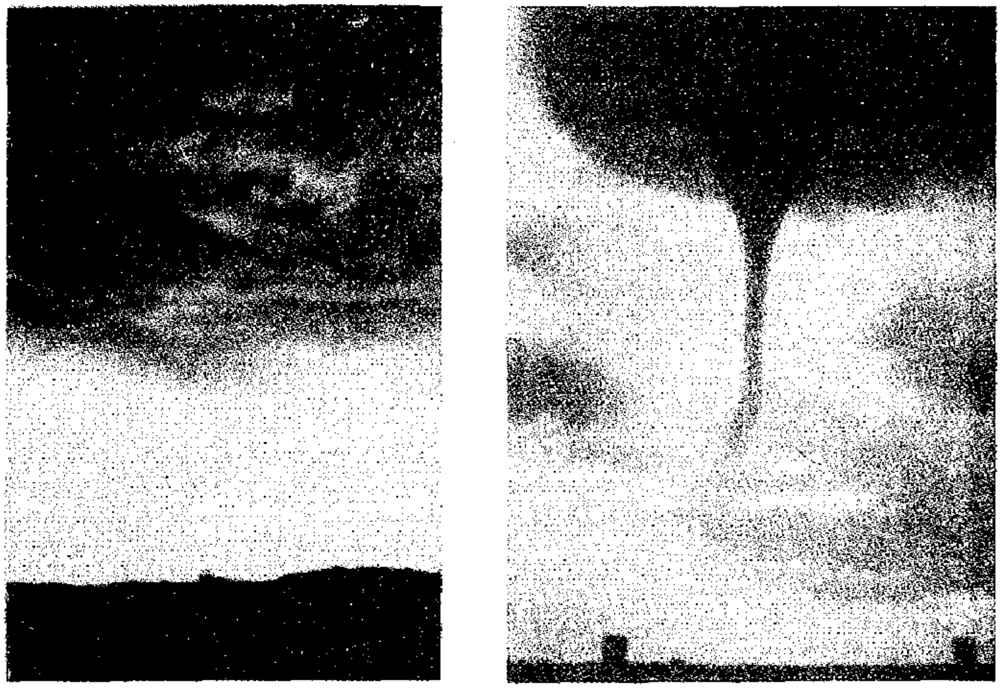

Fig. 145. Initial stage of development of tornado of 1937, Nebraska.
Left—projection at base of parent cloud. *Right*—funnel has reached halfway down to surface.
Circular parent cloud is small (*Quarterly Journal of Meteorological Society*, vol. 63, 1937, Fig. 20; for fully-grown stage see Fig. 116).

monograph containing a collection of papers (Hoecker and Beebe, 1960). Hoecker's paper (1960) throwing light on the tornado cloud has been discussed above. The paper by Beebe (1960a) considers the history of the tornado.

An enormous thunderstorm cloud started moving toward the southern limits of the city at 1630 hours on April 2, 1957. An intense horizontal vortex motion was observed in the projection of its lower part. At 1635 hours one triangular, wide funnel was isolated from this projection, not far from the surface (Fig. 147). After 2 minutes it lengthened and dissolved in the air, but below it, in the air, appeared the cascade of dust and the debris of a damaged roof. At this stage the column of the tornado was transparent and invisible, as has been observed in many tornadoes at the beginning of development.

The invisible column moved north but its end touched the surface here and there in galloping fashion, causing destruction in the city. During this period the width of its track was small, 9–15 m only. Gradually the strength of the tornado increased, the jumps became fewer, the funnel of the tornado was filled with dust and debris and became more visible (Fig. 148); the width of the track increased and the destruction worsened. It not only tore off roofs but uprooted houses.

In Fig. 148 we can see the great height the debris reached and how light

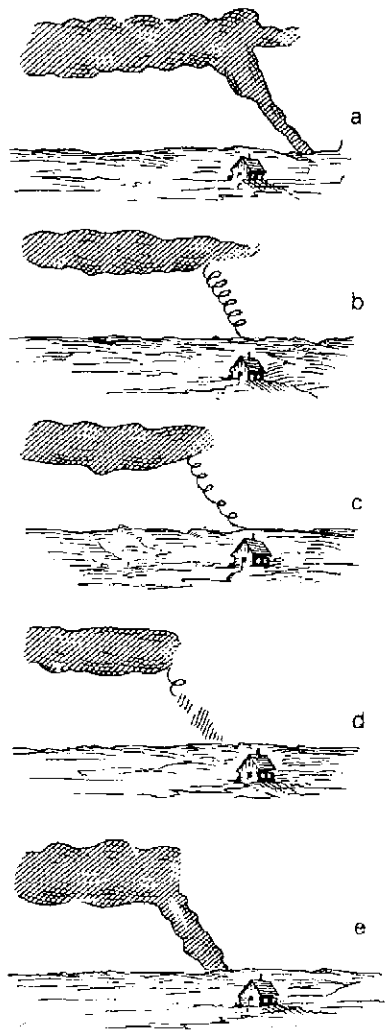

Fig. 146. Small tornado of July 14, 1962, England. Schematic diagram showing change of funnel and tornado cloud (*Weather*, vol. 18, No. 1, 1963).

the house destroyed by the tornado appeared. The funnel was visible and almost filled with dust. The length of this part of the track was 15 km.

At 1645 hours the tornado attained its maximum development. The galloping ceased, the belt of destruction became continuous and attained its maximum width, 30–60 m. The loss of life and destruction were maximum. The funnel of the tornado was full; the cascade reached enormous size (Fig. 149). The total destruction of houses, as if they have exploded, and their rising into the air, are linked with this stage of development (Fig. 148). The length of this part of the track was 5 km.

The speed of the air in the tornado attained unusual magnitude. The tornado derailed quite a number of freight cars while crossing the railroad (see p. 250).

The maximum growth stage continued for 8 minutes and at 1652 hours the tornado weakened. Its track contracted and galloping started. The funnel brightened up, became narrow and took on a whip-like form; at 1658 hours the tornado ended. The last stage continued for altogether 6 minutes. The length of this part of the track was 3.5 km.

The total length of the track of the Dallas tornado was around 25 km; its life span was 23 minutes.

The Fergo group of tornadoes of 1957 have been studied in great detail (Fujita, 1960b). The first tornado, Whiteland (Fig. 150), over the entire length of its 15 km track remained not fully developed: it had a rope-like form with a diameter of not more than 30 m.

The second tornado, Kasselton, was already well-developed but the lower funnel occasionally lifted off the ground. The width and height of the funnel were 120 and 270 m respectively. At the end of its short track the cloud lifted and the funnel took on a rope-like form.

The third tornado, Fergo, started with the rotation of the parent cloud, which moved over the city, settling below the main thunderstorm cloud. The parent cloud was situated right over the ground and the wide funnel hung from it. Soon it reached the surface, starting intense destruction. The cloud was throughout very low and the funnel constantly changed its outline. Assuming the columnar form or widening and losing its sharp outline, it resembled a black cloud lying over the ground (Fig. 151). From some of the numerous photographs taken by Fujita it can be seen that often the entire surface of the cloud moved over the ground, causing continuous destruction.

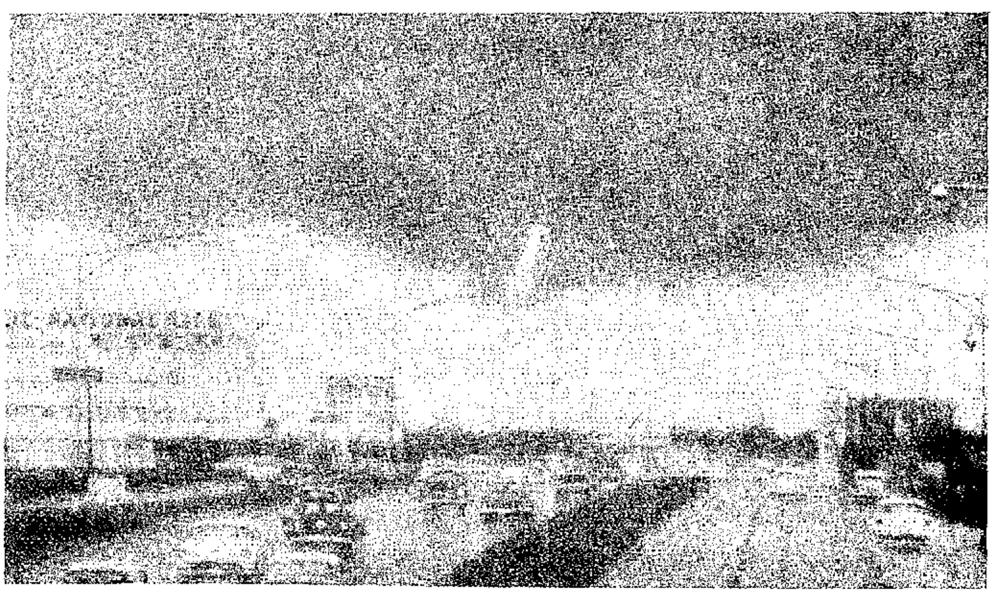

Fig. 147. Initial stage of tornado of April 2, 1957, Dallas (shown by arrow) (Beebe, 1960a, Fig. 3).

The cloud lifted up and a relatively narrow, well-defined funnel formed. Thirty minutes after the start of the tornado it became rope-like, lengthened and took on a curved shape. Half an hour later it again struck the surface, causing destruction. Then and only then did it withdraw into the cloud. The total length of the track was 12 km.

Fig. 148. Tornado of April 2, 1957, Dallas. Funnel is almost invisible, still not filled with dust. House was destroyed at point where it touched ground (Beebe, 1960a, Fig. 7).

The fourth tornado, Glindon, traveled a length of 16 km. At first it displayed a relatively narrow, high funnel; then the cloud lowered and the funnel became big and very wide. For the latter half of the track it again exhibited a long, fine, rope-like funnel.

The fifth tornado, Del, started as a narrow, high funnel, became low and wide at a distance but soon took on the form of a long, curved, black

Fig. 149. Tornado of April 2, 1957. Dallas. Fully developed. Enormous cascade reached halfway up funnel. Fragments of structures are sprinkled from it (Beebe, 1960a, Fig. 19).

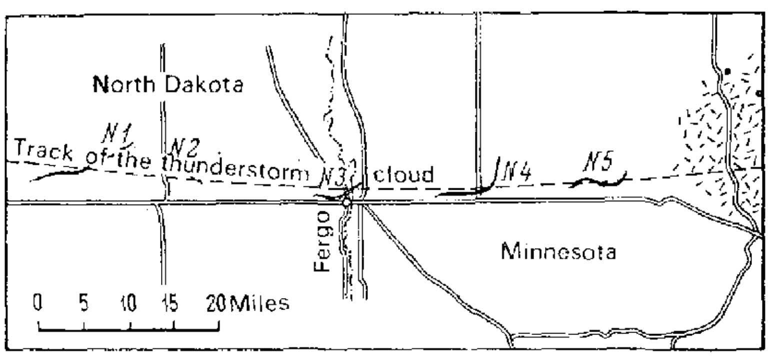

Fig. 150. Track of Fergo group of tornadoes, North Dakota and Minnesota, June 20, 1957. To right of diagram: region where debris fell. Scale is in miles (Fujita, 1960b, Fig. 7).

intestine. Finally the funnel adopted gray, long, rope-like form. The total length of the track was 10 km.

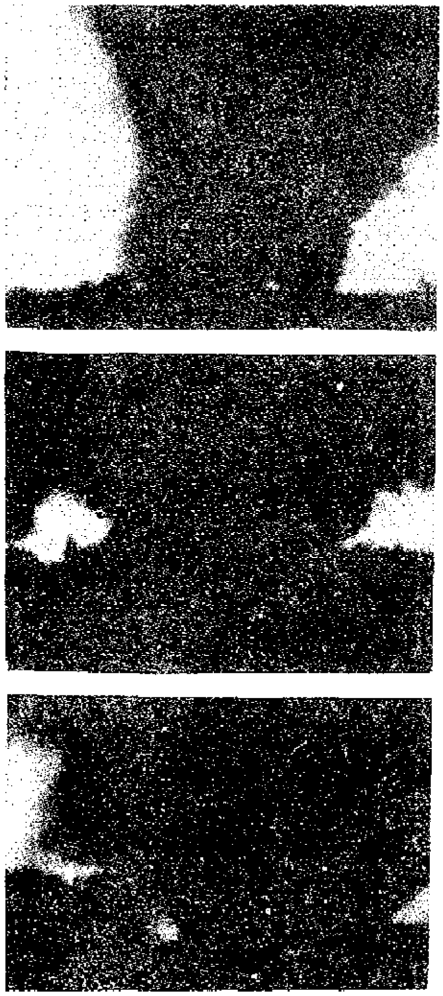

Fig. 151. Three successive photographs showing Fergo group of tornadoes lying over ground with their cloud (Fujita, 1960b, Fig. 20).

The group of Fergo tornadoes covered a total distance of 100 km. The maximum width of the track was 210 m.

The Fergo group of tornadoes is the most thoroughly studied system of horizontal parent vortex clouds.

The third group of tornadoes—Scottsbluff, of June 27, 1955—has also been thoroughly studied for the system of the parent cloud (Beebe, 1959b). It spawned 13 tornadoes. A model of the development of the tornadó has been drawn (Fig. 152) and described by Hoecker (1959).

RATE OF MOVEMENT AND LIFE-SPAN

The rate of movement and life-span of tornadoes are quite different and fluctuate over a wide range.

The speed of movement depends on the speed of the cloud that spawns the tornado. It varies like all clouds of this type. Often the clouds move very slowly, remaining almost stationary, but at times they move with great speed. In his article Brooks (1951) gives a range from 0 to 240 kmph, the average speed being 50–60 kmph, i.e. the speed of passenger trains. According to an eyewitness account, the Rostov tornado of 1953 passed over the city (2.8 km) in 4.5 minutes, i.e. at a speed of 33–43 kmph, but the meteorological station recorded the period as 2 minutes 3 seconds, i.e. a speed of 82 kmph. The speed of the tornado of October 14, 1928, in Issyk-Kul, was 40–50 kmph.

These figures show that the average speed of tornadoes in the USSR and in the USA is more or less the same, 40–60 kmph.

The duration of a tornado depends on the track and the absence of barriers along the way. In the USA the duration fluctuates from a few minutes to 7 hours. A seven-hour tornado traveled a length of 450 km.

On the Russian platform the track of tornadoes is considerably less and the duration is a little more than an hour. Generally it is of the order of tens of minutes and often only a few minutes.

In this property the tornado is similar to squalls and dust storms. Tornadoes differ sharply from the hurricanes and storms which last several days.

Often the tornado is accompanied by a hurricane cloud, but invariably only for a short period and short distance.

Obviously the vortex ring or body in the cloud that gives rise to the tornado has a short life span.

DIMENSIONS AND TRACKS

The dimensions of tornadoes are small as compared to those of hurricanes and storms. Prof. S.P. Khromov (1964) refers to them as "small-scale vortices". However, a gradual transition takes place between storms and tornadoes and a few squall storms hardly differ from tornadoes in size.

Snake-like and rope-like tornadoes display the minimum width, of the order of a few meters, and the maximum length. Trunk-shaped, funnel-like and columnar tornadoes are wide and short. The average width, from calculations for 2,000 tornadoes in the USA, comes to around 350–400 m. The height reaches a few hundred meters and often 1,500 m. Very rarely low, barrel-like tornadoes exhibit similar width and height, also of the order of a few hundred meters. In individual cases the tornado cloud descends right to the ground. The horizontal vortex causes large-scale destruction.

The length of the track is also short. In the United States the maximum length of a track, correctly measured, was 293 miles. Here 270 people were killed, but Root (1926) mentions that five other tracks were more than 500 km long. In Kansas and Oklahoma, where tornadoes are quite frequent, the

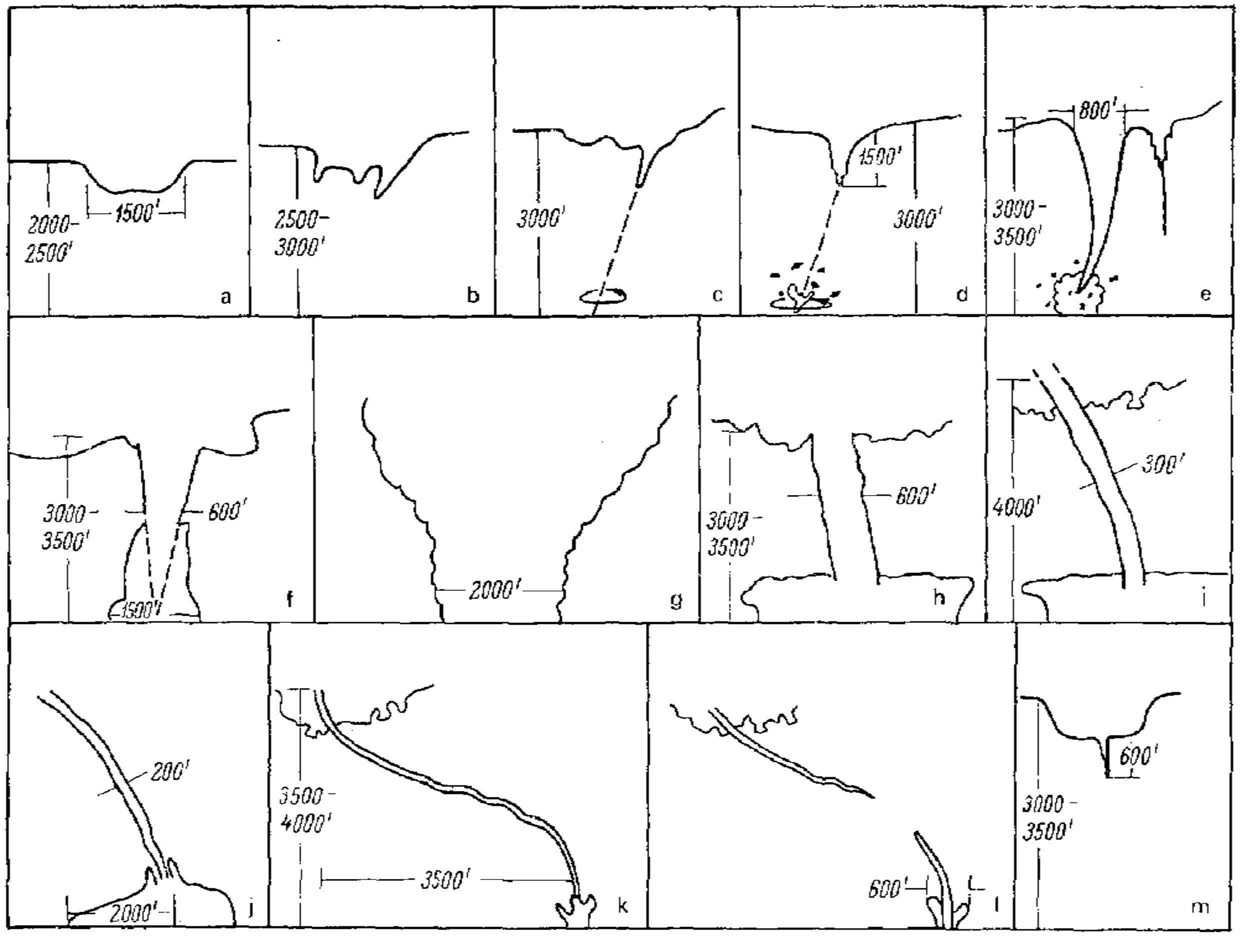

Fig. 152. Model of development of tornado prepared on basis of Scottsbluff (1955) and other tornadoes (Hoecker, 1959, Fig. 5).

a—first visible protuberance stage; *b*—it takes funnel-shaped form; *c, d*—still invisible column has reached ground and formed cascade; *e*—entire column is visible but cascade is small; *f*—column is big and wide; cascade is enormous, reaching half height of column; *g*—unusual cascade, reaches cloud and conceals column; *h*—cascade slumps but is very wide; column can be clearly seen; *i*—same as *h*, but cloud lifts; column lengthens and bends; *j*—funnel is narrow with big cascade; *k, l, m*—funnel is rope-shaped, breaks in middle and disappears into cloud; cascade is small.

larger distances are of the order of 150–200 km (Asp, 1950). Calculations showed that the average length of 1,000 tornadoes is of the order of 20 km. A figure of 50–100 km is not unusual. In all cases the transportation of micro- and often macrofaunas tens of kilometers is a usual phenomenon. Transportation to a distance of 200–300 km and even 500 km is also possible and this is a significant figure.

Hills, forests and lakes do not serve as barriers to tornadoes. After emerging from the hills tornadoes often reach unusual force. Passing over forests, tornadoes damage and uproot hundred-year-old trees, leaving behind long, narrow swaths of destruction. Tornadoes move freely from sea to land, almost without change. In 1924 a tornado traversed Lake Erie for a distance of 40 km and then destroyed the city of Lorain on the shore (see page 323).

The effect of tornadoes on a small water mass is of interest. A number of cases have been described where the tornado sucked up an entire well, to a depth of about 10 meters. Small lakes and marshy patches may dry up totally. The water with all the fauna and flora is swallowed by the tornado cloud and transported tens of kilometers or more by the horizontal vortex. When the tornado crosses a small river, for a short while, the bed is completely exposed.

A peculiar feature of tornadoes is their "bounce". They are lifted up into the air after covering a certain distance over the surface, and the destruction ceases. Then they are lowered again and the destruction resumes. They are alternately lifted and lowered and the process is repeated several times. When the "bounce" occurs over a forest there are spots of damage at intervals, alternating with undamaged zones.

The tornado of May 10, 1920, in Estonia (Letzmann, 1922) and its "bounce" have been described in great detail. It started at Odenpah, south of Tartu, and traveled a distance of 35 km. The width of the track fluctuated, reaching 750–800 m from as little as 20–40 m. The average width was around 400 m. The tornado was accompanied by a hanging thunderstorm cloud with stormy wind. There was severe hail at places. The tornado occurred over hilly terrain, mostly covered with forest. It was clearly visible from forest paths. The damaged zones marked the points where the air funnel touched the ground and was again lifted into the air. The entire track is described in detail by Letzmann. The case of a girl being lifted into the air by a tornado and carried several tens of meters (58 m) is really interesting.

The Rostov tornado of 1953 covered a distance of 9–10 km. At the base its width fluctuated from 35 to 75 m but the width of the belt of destruction was 300–500 m. The tornado of 1904 over Moscow had a 40 km track and was 100–700 m in width. The tornado of 1928 over Issyk-Kul covered a distance of 12–15 km.

I.V. Chizhikov (1956) suggested the following classification for the vortex motion of air:

1. dust vortex;
2. small tornado of short duration;
3. small tornado of greater duration;
4. tornado or the hurricane vortex.

The dust vortex corresponds to the vortex with dust described below.

Small tornadoes of short duration have a track of not more than a kilometer, but show considerable destructive strength. They are relatively rare.

Small tornadoes of greater duration cover a few kilometers. They are quite close to the next group.

Tornado: the hurricane vortex covers a few tens of kilometers.

This scheme represents the gradation of the tracks of tornadoes over the Russian platform.

An example of the track of a tornado that was studied in detail and photographed from the air is given in the work of Prosser (1964). One destructive tornado, occurring on May 5, 1964, blew away all the structures in its track. The total length of the track was 110 km, of which 25 km was in the air. One photograph of 3 km of the track is shown in Fig. 153. The trajectory of the tornado can be clearly seen throughout as a narrow, bright, almost straight belt. On the left of the photograph the tornado cut across a farmstead (small rectangle). It was razed to the ground. To an observer following the entire track it looked like a gigantic vacuum cleaner had sucked up plant cover, loose soil and other mobile objects from the surface. The track of the tornado was sharply restricted and light, empty wooden crates lying at a distance of 30 m to one side remained undisturbed.

The track of the Moscow tornado of September 2, 1945, is shown in Fig. 154. Its length was 12–15 km.

The 120 km track of the tornado of May 20, 1957, which passed through Kansas and Missouri States differed only in its continuity. Its width changed from 300–600 to 900–1,200 m; considerable size, however, was not observed. The speed was 60–70 kmph (Flowers, 1957).

The track of the Peshawar tornado of 1933 has been studied in great detail (Veryard, 1935). Its length was 6.5 km. For the first two kilometers it passed over a flat, dense, rocky plain. Here it encountered irregular furrows of about 30 m width and 0.3–0.5 m depth. Entering a cultivated area it caused large-scale destruction, though there was no loss of life. It passed over a peasant and tore her clothes. Two cowsheds were slightly lifted and thrown to one side. Small trees were uprooted, leaves fell and the trunks were smeared with dirt.

The tracks of the two tornadoes in England are of interest. The first tornado of October 27, 1913, differed by its exceptionally long track: 290 km. For 5 hours it moved at a speed of 50–60 kmph. The route was clearly marked, wide and discontinuous. The tornado was remarkable, though not

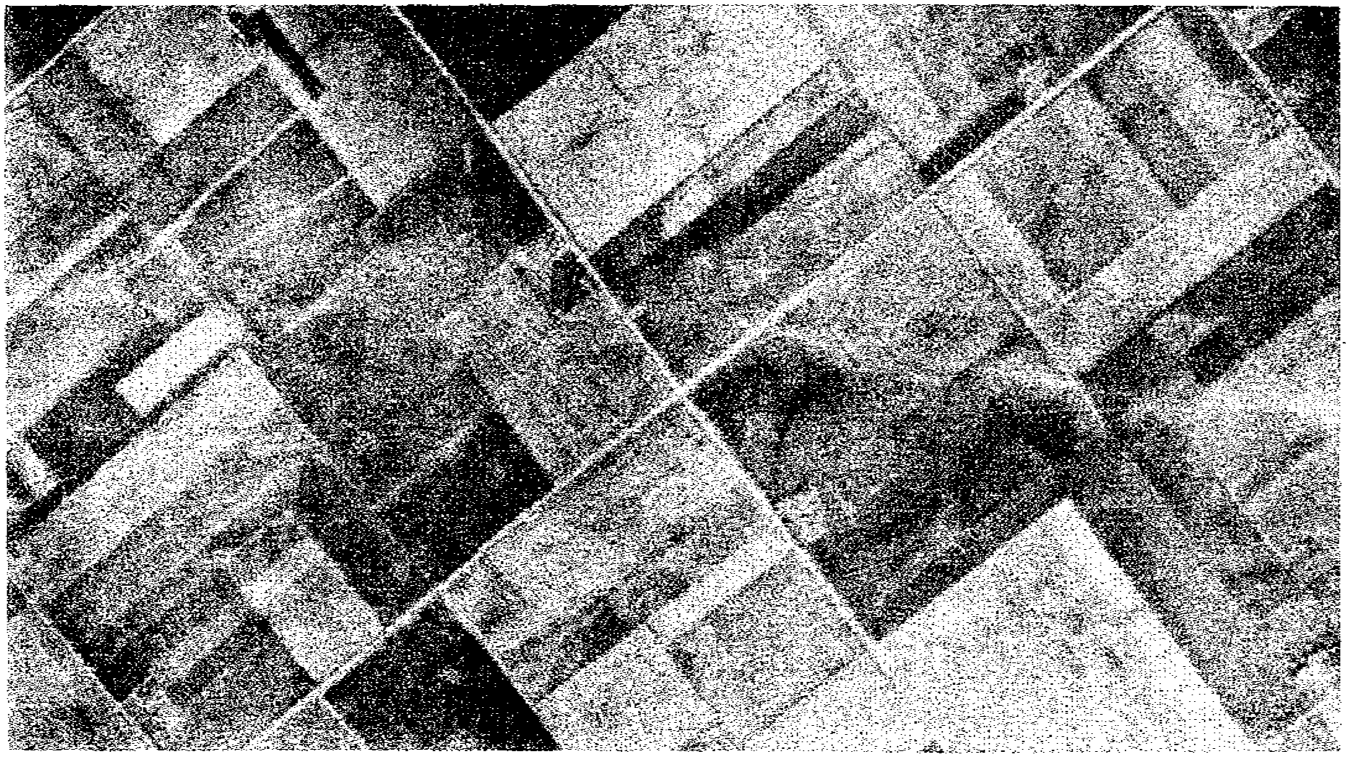

Fig. 153. Track of tornado of May 5, 1964, Nebraska. Track of tornado a white, narrow belt; to left, rectangle at site of damaged farm. Airphoto (Prosser, 1964).

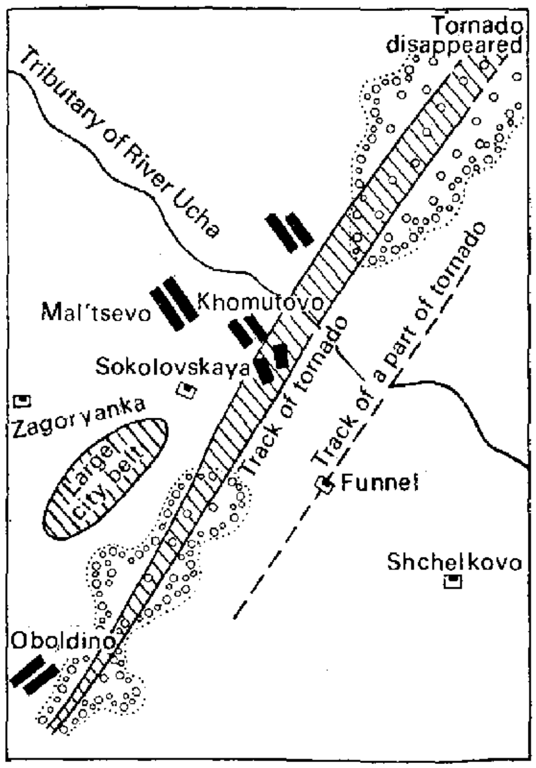

Fig. 154. Track of tornado of September 2, 1945, near Moscow. Length of track was 12–15 km (Kolobkov, 1951, Fig. 86).

well-developed. It was accompanied by terrific noise, a peculiar smell and lightning without thunder. It killed five people and there was large-scale destruction.

The second tornado occurred recently, on July 21, 1965. It passed over the experimental botanical garden "Wisli" in Surrey (southern England). Each tree in the garden was marked and therefore the track of the tornado could be traced in great detail. The track was not continuous: the tornado moved in bounces. Large damaged areas alternated with small undisturbed zones (see page 350).

The deadly French Moneuil tornado of August 19, 1845, had a peculiar track. Even its beginning was remarkable: the funnel did not touch the ground; instead it touched the surface of the River Seine, not far from the city of Rouen. Immediately an enormous cascade was formed but it lasted only for a few minutes. The funnel left the Seine and lifted over the steep bank of dense, ancient forest. An enormous number of trees were damaged but the damaged belt was narrow. The funnel dipped again in the valley of a small tributary of the Seine and moved over it. Here it damaged two small towns and in one of them, in Moneuil, it smashed several spinning mills and killed hundreds of workers.

After this, it again lifted over the high bank and moved over the forest. After six kilometers it dipped over the valley and moved on. Here its track became completely erratic. It started with sharp zigzags and then the tornado branched out. These zigzags and branches were so erratic that it looked like two funnels had passed over the area simultaneously.

After covering a distance of 30 km from Moneuil the funnel became diffuse, littering the surface with debris, pieces of branches and paper, etc. There is evidence that the tornado later moved up to the edge of Dieppe, another 30 km to the north.

The diameter of the funnel was around 10 m in the beginning, then increased to 30 m, became 300 m in Moneuil and later contracted again (Zurcher and Margolle, 1883). The damage is described below (p. 340).

A typical tornado track was seen in Minnesota on June 18, 1939. Starting from the right bank of the Mississippi, upstream, it passed over the city of Anol across the river. The funnel sucked up so much water that the bottom of the river was exposed along the track of the tornado. A similar feature has been observed in the rivers Moscow, Rhine, etc. After passing over the city of Anol the tornado moved over the suburbs causing large-scale destruction. Its speed was 45 kmph. It killed 10 people. The track of the tornado was mapped in detail (Hovde, 1939).

Valuable data on the relative tracks of the groups of tornadoes that occurred on May 29 and 30, 1879, in Kansas, Missouri, Iowa and Nebraska have been provided in the work of Finley (1881). These tracks are shown in the map in great detail and can be considered typical of the tornadoes of the United States. The maximum length of track was 160 km. This tornado lasted for three hours and moved at an average speed of 53 kmph, more at one point and less at another. The width of the track was only a few hundred meters, but the width of the zone of destruction was 1.5–3 km. The track had an overall northeasterly direction with local, relatively small areas of destruction. In general the track of the tornado followed the path of the thunderstorm tornado cloud on the ground.

WEIGHT OF THE TORNADO

It is difficult to determine the weight of a big thunderstorm cloud. It is still more difficult to determine the weight of the funnel of the tornado drooping from the thunderstorm cloud. Its volume is negligible as compared to the volume of the cloud but its weight is generally quite large—more than half a million tons. The tornado that passed over Lake Wascana in western Canada sucked so much water up that the level in the lake dropped by 0.6 m. As the area of the lake was known it was easy to calculate the weight of the water sucked up by the funnel: the figure was about half a million tons (Lowe and McKay, 1962).

If the funnel of the tornado weighed half a million tons, the weight of the parent cloud was immeasurably more. This shows that the weight of the cloud is hundreds of millions or even several billion tons.

Of course, the weight of the tornado fluctuates over a wide range. The invisible tornado, consisting only of air, weighs very little but the weight increases considerably as soon as it starts collecting dust, fine debris and water.

The gigantic, dark columnar funnel saturated with water, dust and debris weighs much more than the Canadian tornado. The figure of a few million tons is quite reasonable.

The enormous weight of the funnel to a great extent explains the extensive destructive power that these tornadoes exhibit.

NUMBER AND DISTRIBUTION

Tornadoes are widely distributed over the world. In some regions they are a common and frequent phenomenon. In these regions, in spite of their small size, the tornadoes have a significant role in the distribution of rain.

The wide plains over which the cold and warm fronts move are most favorable for the development of tornado clouds. An example of such plains is the central States of North America.

Important data are given in the monograph by Flora (1953, p. 29–36). During a period of 35 years, from 1916 through 1950, in all 5,204 tornadoes were recorded. They killed 7,961 people and the loss of property was of the order of 500 million dollars. An overwhelming number of tornadoes were in the central and western plains of the States: Kansas—587, Iowa—512, Oklahoma—369, Arkansas—299, Missouri—237, Alabama—190, Nebraska—184, Minnesota—179, Illinois—168. The number of tornadoes fall sharply on the eastern and western fringes of these States. The Rocky Mountains have a strong influence. The number of tornadoes is negligible to the west of the mountains: Utah—2, Nevada—1, California—4, Oregon—3. In the eastern States the number of tornadoes drops to 20–50 and never goes beyond 100. The number of tornadoes in the southern States, along the coast of the Gulf of Mexico and the Atlantic Ocean, increases: Texas—461, Louisiana—156, Mississippi—207, Alabama—190, Florida—153, Georgia—153. The number of tornadoes passing from the Atlantic Ocean into the continent is considerable. On the other hand, the rocky coast of the Pacific Ocean is free from the formation of tornadoes.

From the geological point of view 35 years is an infinitesimally small period. Even a period of 3,500 years is not a large period, and the number of tornadoes during this period increases by 100 times. For Iowa it will be 51,200 tornadoes, for Texas 46,100, for the southern state 15,000–20,000. These are quite large numbers: they show that tornadoes are an important geological factor and should be taken note of.

This is once again confirmed by the latest data (Spohn and Waite, 1962).

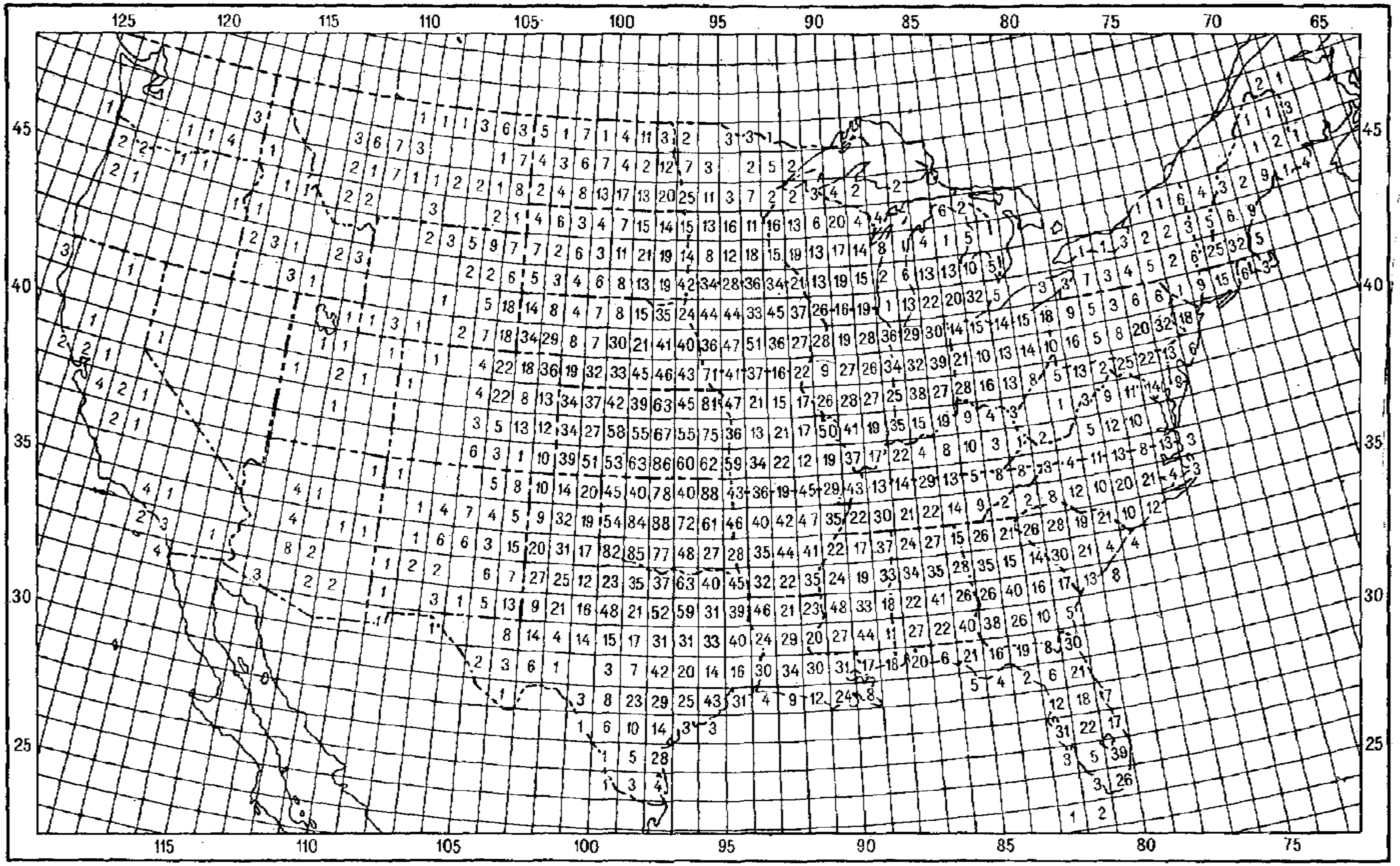

Fig. 155. Distribution of tornadoes in territory of the USA. Central States have been selected. Tornadoes are almost totally absent from Rocky Mountains. Total number of tornadoes recorded is 11,053 (S:ohn and Waite, 1962. Fi . 1).

From 1916 through 1961, 11,053 tornadoes were recorded in the USA. This increases Flora's data twofold. The distribution of tornadoes by latitude is given in Fig. 155. In general it coincides with Flora's data. The central States are the main region of formation of tornadoes. The tornadoes on the shore of the Gulf of Mexico are often associated with hurricanes (hurricane-tornadoes). This increases the transportation of marine microorganisms from sea to land.

An annual review of tornadoes in the USA is given in the journal *Weatherwise* (Beebe, 1958, 1961). As an example, the year 1961 may be considered (Hardy, 1965b). Over a year, 717 tornadoes were recorded and the average number during the period from 1953 through 1963 was 595. This average figure is not only more than Flora's but also more than Spohn and Waite's. According to this review, the total number of tornadoes in 35 years, which was worked out by Flora as 5,000, is 21,000, and the total number of tornadoes in 45 years, which is given by Spohn and Waite as 11,000, is 27,000. Considering the detailed observations of recent years, such an increase seems quite likely. The distribution by states, as per Hardy (1965a), remains the same.

There were 73 deaths and 1,076 injuries caused by 717 tornadoes in a year. The loss in property was several tens of million dollars.

The maximum number of tornadoes was observed in 1957: 864 (Wolford, 1960) and in 1965: 927 (Hardy, 1966).

Interesting maps for each State were prepared by Finley (1890). These maps show the position and length of track of all the tornadoes from 1835 through 1888. The direction of the track is almost always northeast. Rarely, the tracks cut across this direction, perpendicular to it, i.e. northwest. The length of the track varies widely, i.e. the short tracks vary from a few kilometers to a few tens of kilometers. The tracks of a large number of tornadoes often cover an entire state (Papers on tornadoes, 1920).

Tornadoes are fewer in other parts of the world and it may be due to this that they have not been studied as thoroughly as in the USA. Exact figures are absent and therefore the figures given below are approximate and qualitative in nature.

In Europe, the Russian plain is geomorphologically more or less similar to the plains of North America. The cold and warm air masses meet over the plain, giving rise to tornado clouds. Therefore tornadoes occur over a large segment of it fairly often, e.g. the tornadoes in downtown Moscow in 1904, 1945 and 1951. Eight other tornadoes have been recorded in the work of S.S. Gaigerov (1939b). Three of them occurred near Arzamas, one in Murom, one in Kursk and one in Nolinsk-on-Vyatka. The locations of the other two are not given. The large number of tornadoes listed for Arzamas perhaps can be explained by the fact that at that time S.S. Gaigerov was working at the meteorological station of Arzamas. There is no doubt that the actual number of tornadoes is much greater, since many of them have not been recorded. S.P. Khromov (1964, p. 426) writes: "In the European territory of the USSR each summer at different places in the south, in the central area, a few tornadoes are recorded." He believes that they do not move north of the 60th parallel. The northernmost tornado has been observed on Solovets Island and the southernmost in the Black and Azov seas. According to D. K. Starov (1935) there were 24 tornadoes in six years in the Black Sea.

In the summer of 1953 four tornadoes occurred over the Yaroslav region. In Belorussia 33 tornadoes occurred between 1844 and 1953. Some of them attained great force (Voznyachuk, 1954b).

In Western Europe tornadoes occur more frequently, no less than in the USA. A brief account of these tornadoes is given in the monograph by Wegener (1917). The tornado does not occur north of northern Scotland and southern Norway, Sweden and Finland. L.N. Voznyachuk (1954a) showed that the northernmost point in Siberia, marking the northern limit of tornadoes, is Kondiansk Village on the Obi (latitude 62°N).

Flammarion (1888) has written on a number of tornadoes in France. One of these occurred on August 19, 1845, over Normandy and struck Moneuil with great destructive force. Another tornado of August 19, 1890, started from France and passed over Switzerland, over the valley of the River Zhu, where large-scale destruction took place. The tornado at Zhu showed unusually strong electrical phenomena in the accompanying parent cloud. The lightning, hail and downpour attained unusual intensity. The numerous flashes of ball lightning were of special interest (they have been described on page 310).

A number of other tornadoes in France, Sweden, Germany, Switzerland, Sicily and Vienna that occurred during the first half of the last century have been described by Zurcher and Margolle (1883). A tornado occurred over Vienna on June 29, 1873, and damaged a considerable part of the exhibition building. The exhibition had just started. The tornado was interesting in that its funnel was diffuse, though the indication of whirling wind was quite clear. It was, however, not clear whether it was an extratropical hurricane of small dimensions or an ill-defined tornado like that of the Three States. The tornado can be clearly seen in Fig. 136.

Tornadoes occur quite frequently over the valleys of the Alps. They are associated with small, sharply defined cumulonimbus clouds, developing at a great height. They are of average diameter and last a few minutes. The local people have a special name for it—Radlwind (Ficker, 1937).

The tornadoes of England have been described in the book by Lane: *Angry Elements* (1966). According to him, 60 destructive tornadoes have been recorded in the last 80 years. In addition to these, many others of weak and local nature went unrecorded.

The tornado of October 27, 1913, covered a track of 150 km and its width was of the order of 300 m. It displayed considerable strength, removed roofs and damaged structures. At one place it engulfed a herd of cows, three of which were carried over a fence and killed.

The tornado of May 21, 1950, was of big size. The track of the main tornado was almost 100 km long. It was covered in 2.5 hours. The width of the track was not more than 80 m.

The description of the tornado of October 21, 1638, in Dartmoor, as given by Lane, is of considerable interest. The tornado destroyed the church where a service was going on. The roof was ripped off and the funnel burst into the church. Many people were removed from their seats, spun in the air and hit the walls of the pillars. Some of them remained unhurt but the skull of one person was broken into three parts, the brain was scattered on the flour and the hair stuck to the wall.

The confusion was even greater when ball lightning struck the church and burst in the air with a big bang. Many people were bruised and burned. The church was filled with the smell of sulfur "as if from the presence of the devil".

Tornadoes have been repeatedly observed in North Vietnam (Fig. 156), in the Indian subcontinent (Fig. 118), in Japan (Ota and Sawairis, 1953), China, Australia (Carr, 1965), Africa, New Zealand, the Hawaii Islands and Fiji. There is no doubt that, though unrecorded, they form in many other regions also.

The absence of tornadoes in the high latitudes—in the Arctic and the Antarctic—deserves attention. There are indications of waterspouts off the

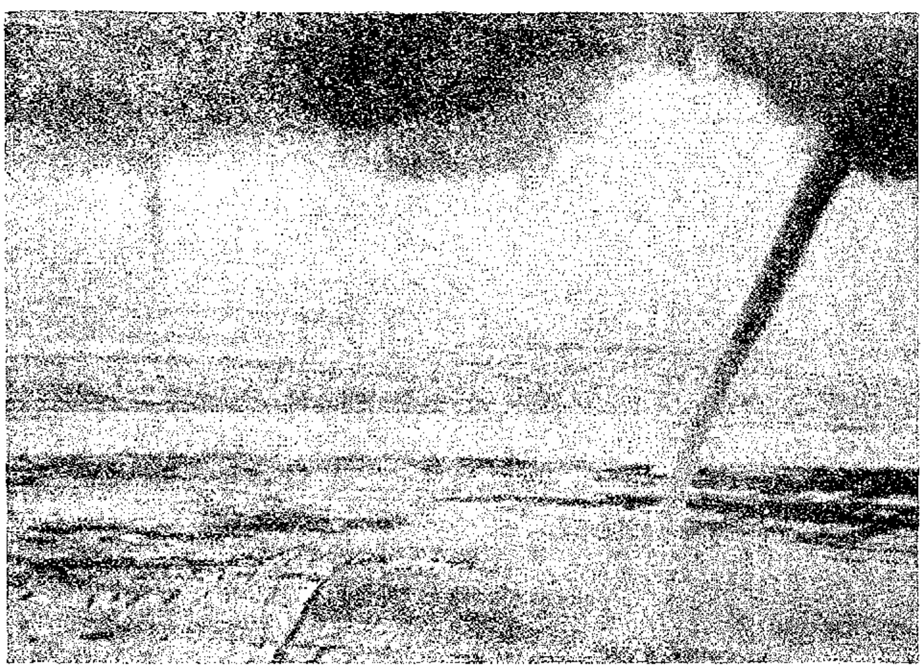

Fig. 156. Two tornadoes over North Vietnam. Cascade of dust can be clearly seen in tornado on right. Photographed from helicopter (Lane, 1966, p. 13).

south coast of Alaska, which is in the same latitude as southern Scandinavia and Solvets Island. Tornadoes are not known north of the Arctic Circle (or south of the Antarctic circle). The reason is not clear, as strong cyclonic hurricanes occur quite often in the Antarctic. A tornado occurred very near the Arctic Circle in 1958, in Fairbanks (Beebe, 1959a). This is the northernmost point.

Tornadoes do not form in the belt near the equator. Nor do cyclones.

Because of the absence of tornadoes, local vortex formations are also absent from the cumulonimbus clouds. We can definitely say that in the subpolar and equatorial belts, vortex formations do not develop in cumulonimbus clouds. Why? Of course, the reason is of a planetary nature but difficult to specify.

The absence of tornadoes results in the absence of thunder. It may be said that not only tornadoes but also thunderclouds do not form. This further complicates the prediction of the phenomenon.

Thunderstorms in Alaska have been described by Alexander (1924). They occur everywhere, even over the north coast (Barrow). They are generally weaker than the average and almost always without hail. This shows the relatively small height of the thunderstorm clouds.

7
Atmospheric Phenomena

The atmospheric phenomena accompanying tornadoes, like the tornadoes themselves, are both common and hard to explain.

SOUND EFFECT

The sound during the passage of a tornado often attains unusual intensity. It is quite varied.

The sound waves undoubtedly originate either inside the tornado or in its immediate neighborhood but data on the mode of occurrence and pattern are not available. The information is quite scanty and unscientific.

In the countryside of Ilin Yaroslav region the streets became dark before the beginning of a tornado. People saw a dark, circular formation moving very fast across the countryside with a roaring sound. Houses were blown away. In one house a woman watched with horror while a neighboring rooftop was torn off and a big tree was uprooted. The terrible roar continued. When the roar stopped and the tornado moved away, the woman came out of her house and said triumphantly: "Thank goodness my house is intact." Imagine her surprise when she looked back and saw that the roof of her own house was gone! She had not heard anything (Chizhikov, 1956).

The roar and thunder often accompanying tornadoes cause sound waves to originate, possibly within the cavity of tornadoes. With continuous reflection and superimposition the waves attain great intensity (Anderson and Freir, 1965).

Some observers have compared the sound phenomena accompanying a tornado with the boom of guns on the French front during the First World War (Oliver, 1931). To others it sounded like the hissing of a thousand snakes and to others again like the noise of a hundred trains. Though the comparisons are diverse, it is clear that the noise, increasing gradually, becomes strong or weak with the approach or withdrawal of the tornado and ceases with its disappearance. Even when there is lightning the usual sharp, sudden thunderclap is absent.

The second phenomenon was observed many times during the numerous tornadoes of May 30, 1879, which occurred over Kansas and Missouri. It is described in the monograph by Finley (1881). Of the numerous comparisons, none is with the noise of thunder. It is compared with anything familiar, especially underlining the great intensity, but not once is it compared with thunder. Obviously, the nature of the sound waves from tornadoes and thunderstorms is quite different.

The intensity of the sound in the immediate vicinity of the tornado is terrible, but fades sharply at a short distance from it. However, there is at least one case where the roar of the tornado was heard at a distance of a few kilometers.

It is quite likely that the sound is associated with the funnels touching the ground and that the suspended funnels are without sound.

Sounds like the hissing of a thousand snakes or the buzzing of a million bees are to be explained by the vibration of the air mass rotating in the tornado. This has been shown by number of mathematical calculations (Abdullah, 1966). They satisfy Anderson's postulate given above (Anderson and Freier, 1965).

It is quite clear that the sound accompanying the tornado causes sound waves but the nature of these waves and their origin are not yet very clear. It is quite likely that there are waves (in addition to the waves in the range audible to the human ear) whose range goes beyond the audible range—waves giving rise to noise inaudible to the human ear. Such sound, quite likely, originates in hurricanes as well. Probably these waves have a role in the destruction accompanying tornadoes and hurricanes.

ELECTRICAL PHENOMENA

The electrical phenomena, often strong and peculiar, are varied but show the usual lightning. Occasionally, however, lightning is altogether absent. Actually the electrical phenomena are not related to the tornadoes, but to the thunder cloud. There is evidence to show that the powerful vortex motion giving rise to the tornado considerably intensifies the electrical phenomena and lends them a special character and unusual intensity.

One such phenomenon is ball lightning. It was repeatedly observed during the famous tornado of Zhu on August 19, 1890 (see page 306). Even when the tornado clouds passed over France they were associated with numerous fireballs. The air was so saturated with electrical charges that the tapered iron railings of one building gave off sparks (aigrettes electriques). In Switzerland, during the formation of a tornado, ball lightning entered a room, where there were two boys, through a broken window. The lightning had the form of a fireball of fist size of violet-red color. It drifted slowly through the air, approaching the children. They were terrified and ran to the next room. The younger one hid himself under the table and the other one ran around the table. The ball lightning followed them, crossed the room, passed through the open door and floated out across the street without any trace of sound.

Ball lightning is observed during thunderstorms without tornadoes, but the latter intensifies it. Fayé (1897) showed that in France alone, in at least four cases, tornadoes were accompanied by ball lightning. He believed that the ball lightning is analogous to a Leiden jar, consisting of a whirling mass of gas, having positive charge inside and negative outside.

The nature of ball lightning is discussed in the paper by P.D. Kapitza (1955).

A discussion of the various theories of formation of ball lightning is contained in the book by Lane (1966, pp. 106–114).

The descriptions of incidents where ball lightning penetrated aircraft in flight are quite interesting.

In conclusion, Lane writes that ball lightning is now being studied at a number of laboratories as a potential weapon, capable of destroying intercontinental rockets.

The other electrical phenomena related to tornadoes are no less striking. Often short, broad sheet lightning surrounds the tornado. Often the entire surface glows with an awful yellow brilliance. Often spherical, bluish formations of ball lightning, but of larger size and diffused outline, are observed in the tornado cloud. Many a time slow-moving columns of fire have been seen (Frankenfield, 1896).

Undoubtedly there is an association between tornadoes and other vortex formations and atmospheric electricity, but its nature has not yet been studied in detail. It should not be forgotten that in the vortex formation, the friction between the particles, especially dust particles, attains unusually large intensity. Friction is one of the important sources of electricity. This phenomenon has already been discussed on pages 182–183 in the description of auto-electricity.

A peculiar phenomenon observed in the tornado thunder-cloud is the pulse generator, described by Jones (1965). It is the center of the electrical activity observed in the tornado cloud in the form of circular spot of light blue color. It appears for 30–90 minutes before the tornado is formed.

In their paper Vonnegut and Meyer (1966) give a night photograph of illuminated columns, resembling tornadoes in form and situated in the zone of origin of a thunderstorm cloud accompanying four tornadoes (Fig. 157). They believe these columns are related to the tornadoes and that "electrical force and electrical heating may initiate the tornado wind" (Vonnegut and Meyer, 1966, p. 68). The descriptions of the light phenomena by eyewitnesses of tornadoes are equally interesting: "Fireball...Lightning in the funnel... The yellowish-white... Bright surface of the funnel... Continuous radiance... Fire column... Illuminated cloud... Brilliance in the form of a ring... Bright, illuminated cloud of flame color... Rotating belt of dark blue color... Pale light blue cloud belt... Brick-red brilliance... Rotating light belt... Exploding fireball... Fire flux... Light spot...".

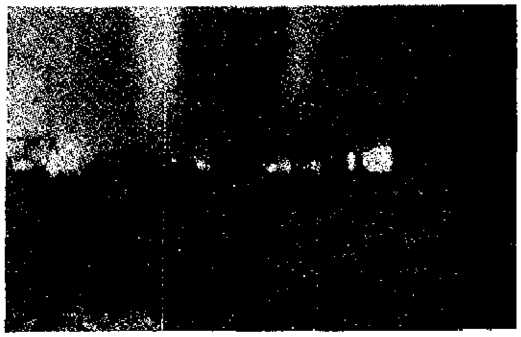

Fig. 157. Illuminated columns in zone of origin of tornado on April 11, 1965, Toledo, Ohio (Vonnegut, 1960).

These descriptions by eyewitnesses are primitive and approximate but there is no doubt that light effects in tornadoes have been repeatedly observed and these are related to atmospheric electricity.

In his papers (Vonnegut and Moore, 1958; Vonnegut, 1960) Vonnegut discusses electrical phenomena in detail as a cause of the formation of tornadoes.

THUNDERSTORM SHOWER

The thunderstorm shower accompanying the tornado is probably from the tornado cloud, differing in its unusual strength. Often it turns into what is known in English as a "cloudburst". No Russian equivalent is available but the literal translation is "bursting of the cloud". This is a common term and in meteorology it is used for rains with an intensity of 100 mmph and more. At the time of rain individual drops of rain can be seen. At the time of a cloudburst it is a continuous, uninterrupted stream of water. On striking the ground these streams cause hemispherical pits. During one such downpour in the foothills of the Rocky Mountains, on the slopes 22 such pits were formed within a small distance of each other. The width of the pits was about 5 to 6 meters and the depth 0.5 to 1.5 meters. The trees at these points were carried down the slope of the hillside in the stream of dirt, branches and boulders.

In deserts, semi-arid regions and dry valleys, an enormous amount of rain falls during a cloudburst. In Montana State a cloudburst occurring in the upper valleys charged downhill in a 10 m high wall of water. Herds of sheep were grazing in the valley. The shepherd escaped somehow but 800 sheep died (Ferrel, 1890, p. 431–432).

Such sudden streams often occur in typical countryside and display all their features and the corresponding geological results.

The cloudburst and flood caused by tornado clouds are as strong as the cloudburst and flood accompanying a hurricane but the area of distribution is one-tenth as much. Tornadoes and the associated phenomena are of local nature but their frequency is 10 times greater than the frequency of hurricanes. Therefore the total activity of tornadoes where they occur quite frequently, is an important factor in the sedimentation and in the formation of discontinuities and sharp changes in the sedimentation. There is no doubt that these are reflected in the structures of Quaternary deposits, especially Holocene, but the geologists have yet to assess the effect. Geologists often divide the depositions by time scale, floods, etc. but no correlation with tornadoes has been attempted.

HAIL

Hail, often of unusual size, almost always accompanies the tornado cloud. This is explained by the high turbulence in these clouds. The ascending currents of air reach a great height, where the hail is formed. In tornado clouds, as established by direct aerial measurements, the ascending currents have a vortex character. They differ in their large lifting capacity and stability. Therefore they can contain large hailstones at great heights. Due to this the hailstones rotate in the vortex at great heights for relatively long periods. The rotation gradually increases the layers of ice and ultimately the hailstones attain enormous size. Often individual hailstones join together to form a larger one. The vortex motion holds a colossal amount of hail in the air. It is due to this that the hail from a tornado cloud falls in unusually large quantities and in unusual sizes. In the center of one hailstone a piece of alabaster 1 cm long was found. The most surprising of all is that in another hailstone a tortoise 15 × 20 cm in size was found (Abbe, 1894b) and in a third a small carp, 4 cm long (Gudger, 1921, p. 616).

The vortex cloud must have lifted the tortoise to a height of several kilometers and a hailstone of unusual size with the tortoise as nucleus was formed.

An interesting drawing (Fig. 107) of the ascending currents of bursting thunder clouds is given by Davis (1899).

Large hailstones have been repeatedly observed in the central regions of the USSR. According to eyewitnesses tumbler-size hailstones fell when a tornado passed through the Yaroslav region.

Still bigger hail occurs in the central States of North America, where tornadoes are widely distributed. Hailstones 30 cm in circumference have been repeatedly observed. Hailstones 40 and 45 cm in circumference have been found. One hailstone made a pit 17 × 20 cm (Finley, 1881, p. 67). This was a hailstone of the size of a man's head. This was retained in the air in fully grown condition only due to the strong vortex motion.

In 1888, in Texas, hailstones fell in unusual quantity. This continued for 8 minutes and spherical hailstones of hen's egg size fell. The entire slopes of hill looked white due to the hailstones even three hours afterwards.

In the valley a small river of hail 2 meters deep was formed. It was calculated that "the hail was sufficient to form a layer 6 ft deep and 10 acres in area". In the steppe, hail killed six horses (Ferrel, 1890, p. 432).

On April 25, 1893, in Oklahoma a tornado was accompanied by very strong hail. One hailstone shattered the skull of a girl caught in the open (Abbe, 1893).

Such hail of gigantic size has been described repeatedly in American literature. Within the last 10 years such a huge quantity of hail has fallen that at many points cars could not move. The streets in the cities were covered by 1 meter or more of hail. It had to be cleared by bulldozers. Such tornado conditions have occurred repeatedly. The loss due to hail is great, especially in the case of crops and fruit orchards.

A special description of hail in the USA is given in the book *Hail in the United States* by Flora (1956), with interesting photographs.

Often the vertical tower vortex has such a speed and size that it lifts large objects into the zone of freezing. These objects are coated with layers of ice. The weight increases and the object falls to earth. For example, a frozen duck fell to earth during a strong storm in Massachusetts.

Still more surprising is the freezing of aviators. In 1930 five German pilots went up in gliders into a thunderstorm cloud over the mountains. The aviators encountered the turbulent zone, the gliders broke and the pilots parachuted to earth. The moment the parachute opened it was engulfed by unusually strong ascending currents, probably the vortex circulation. All the pilots were lifted to a great height, to the zone of freezing. Here they were covered with ice and became the nuclei of gigantic hailstones. Soon they were covered with ice and froze to death. Only one of them, surprisingly, survived to tell the story. A similar tragedy, over the same mountains, was repeated in 1938 when another pilot froze completely (Lane, 1966, p. 68).

Lastly, the largest "hailstone nucleus" is the airplane flying through the zone of freezing. The freezing of airplanes has been studied in detail and described in a number of special papers.

8
Special Forms of Tornadoes

INVISIBLE TORNADOES

The tornado is a vortex movement of air. It is visible only when the air contains water, dust, smoke, ash or other finely dispersed matter. If these are absent and the air is clean then the tornado is invisible, "ripe". More frequently the middle part is invisible. The funnel, lowered from the cloud, can be clearly seen with the corresponding undertow of dust or cascade of water but the central part, connecting the funnel and the cascade, is invisible.

There are numerous examples of such tornadoes: for continental tornadoes, see Fig. 158, for waterspout, Fig. 162 and for fire tornadoes Fig. 172.

Invisible tornadoes develop in the initial stages of tornadoes. After being saturated with dust or water they are transformed into the usual, visible tornadoes.

An "invisible" waterspout was observed on November 14, 1878. It is described on page 285.

Descriptions of invisible continental tornadoes are rather rare. Such a tornado, which occurred in 1896 in Kansas, has been described earlier (p. 284). The greatest wonder, observed by a farmer, was the cascade of dust filled with debris. The upper part of the cascade merged into the invisible part of the tornado. The farmer did not notice it. Such cascades, creeping and crawling over the surface, have been described and photographed repeatedly. All are associated with invisible tornadoes.

WATERSPOUTS

Tornadoes passing over the sea or large lakes are known as waterspouts. In the Soviet literature, and in many important foreign monographs the distinc-

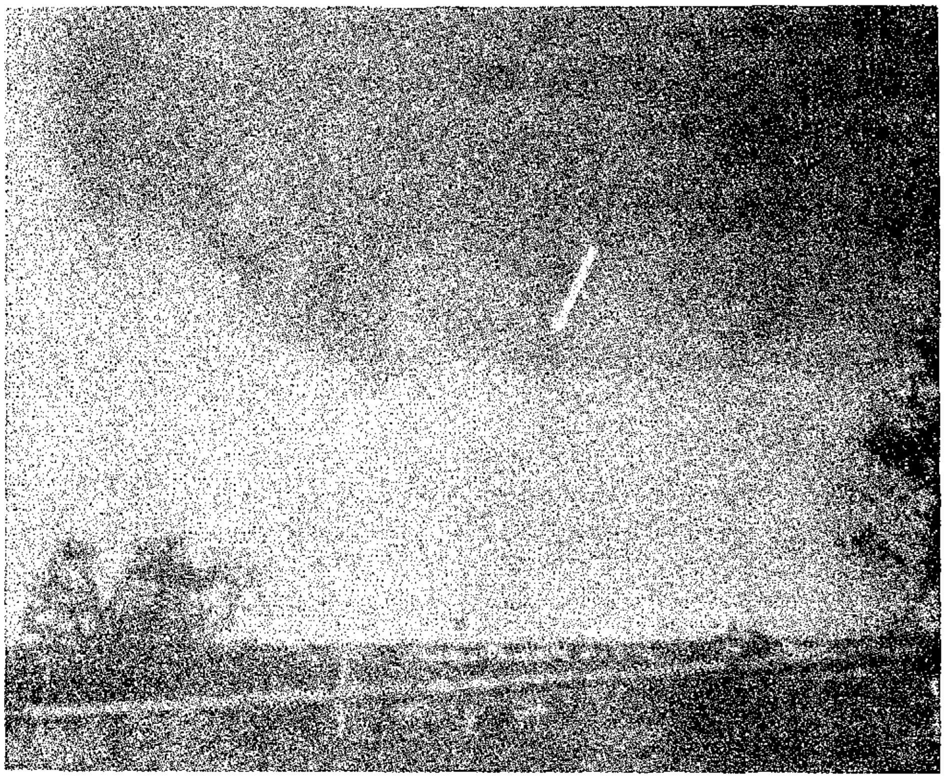

Fig. 158. Tornado of April 2, 1957, Dallas. Invisible stage. Rotating parent cloud separates invisible funnel, shown by arrow. Below arrow debris of house flying through air (Beebe, 1960a, Fig. 7).

tion is not made since tornadoes whether passing over water or land in principle are the same. Moreover, in many cases the same tornado originating over the sea moves over land and vice versa, i.e. a tornado originating overland then passes over a big lake, e.g. the Rostov tornado of 1953, or over the sea.

The tornadoes of the Black and Azov seas have been described by D.K. Starov (1953) and N.I. Popov (1955). According to them, 25–30 tornadoes occur in 10 years. All are associated with thunderstorm clouds. Most of them are formed in the Azov Sea and on the Caucasus coast of the Black Sea.

The identity of waterspouts and continental tornadoes is completely clear, since their growth clouds are the same and do not change during passage from the sea to the land or vice versa. The difference is only in the material saturating the tornado. Over water it is water, over land, dust. The tornado, however, does not undergo any change due to this.

The water-continental tornadoes passing over water and land are important in the geological sense. They transport marine organisms many tens of kilometers to the land and continental organisms to the sea, giving rise to wrong demarcation of the coastline. A jellyfish that fell with the rain from the clouds over the village Kavelerovo, not far from Vladivostok, 50 km from the coast, in fossilized form suggests a position of the coastline 50 km away from the actual line.

Good examples of waterspouts are given by N.I. Popov (1955). They were observed on the Caucasus shore of the Black Sea in the region of Tuapse-Novorossiisk. The first tornado occurred on July 21, 1954, and was located by radar. The thunderstorm cloud giving rise to the tornado moved parallel to the coast at a speed of 40–45 kmph. The duration of the tornado was 40 minutes.

The second tornado, of September 9, 1954, was located by radar and photographed. An eyewitness gives the following account: "In the second half of the day, to the south toward the sea, a lead-black thunderstorm cloud was observed moving toward the coast. Unexpectedly, at 1640 hours an enormous gray trunk descended slowly to the surface of the sea from the clouds. As soon as it touched the sea a column of foam and dust was lifted up. Then everything became one water column (Fig. 159). The gigantic top gradually widened and menacingly approached the coast. It appeared as if the sea was connected to the sky and water poured up as in a strange hose. Before reaching the coast the tornado gradually became weak and at 1659 hours it was diffused. It was observed for 19 minutes only" (Popov, 1955, p. 35). The vertical thickness of the cloud causing the tornado was 8.5–9 km. It moved at a speed of 6 kmph. During the passage of the tornado the thunderstorm recorder noted a significant increase in the discharge of lightning.

The next tornado occurred on September 26, 1954. Like the previous cases, the thunderstorm cloud was strongly curved along its length, along the direction of movement. Its length was about 50 km, width 10–15 km and speed 47 kmph.

The last two tornadoes were of September 29, 1954. The observations with radar are quite interesting (Fig. 160). The photograph quite clearly shows the outline of the part filled with water. The body of the tornado exhibited a circular outline with the free cavity inside (small circle). The peculiar wall branches are of the same size as the tornado. Their existence and functions are not clear. A tornado always exhibits closed, circular transverse section, without any branches. The radar photo of the branches shows that part of the water sucked up by the tornado moves to the side.

Such branching resembles the tail cloud often accompanying the parent cloud of the tornado (Fig. 161).

The Black Sea tornado often strikes the coast, not weakening but, on the contrary, increasing its strength. On July 14, 1924, a tornado that covered 2.5 km up the coast turned inland at Temruk. Moving inland it lifted three shepherd boys. One was killed and the other two disappeared. On the coast the tornado lifted a rowing boat and a canoe into the air and carried them a distance of 100–150 m along with the people in it—a family of fishermen.

Fig. 159. Waterspout of September 9, 1954 in Novorossiisk, with full development (Popov, 1955, Fig. 3).

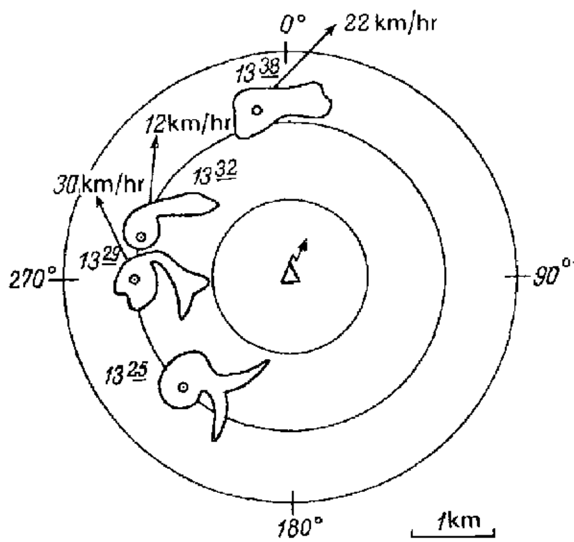

Fig. 160. Waterspout of September 29, 1954, in Novorossiisk. Radar echo. Peculiar branching of walls, probably in cloud (Popov, 1955, Fig. 5).

Only one was killed (Starov, 1935).

A waterspout in the Gulf of Finland in July 1796, is described in the monograph by Wegener (1917, pp. 17–20). It was observed by Professor Wolke sailing in a boat from Kronshtadt in Lubck. During total calm a

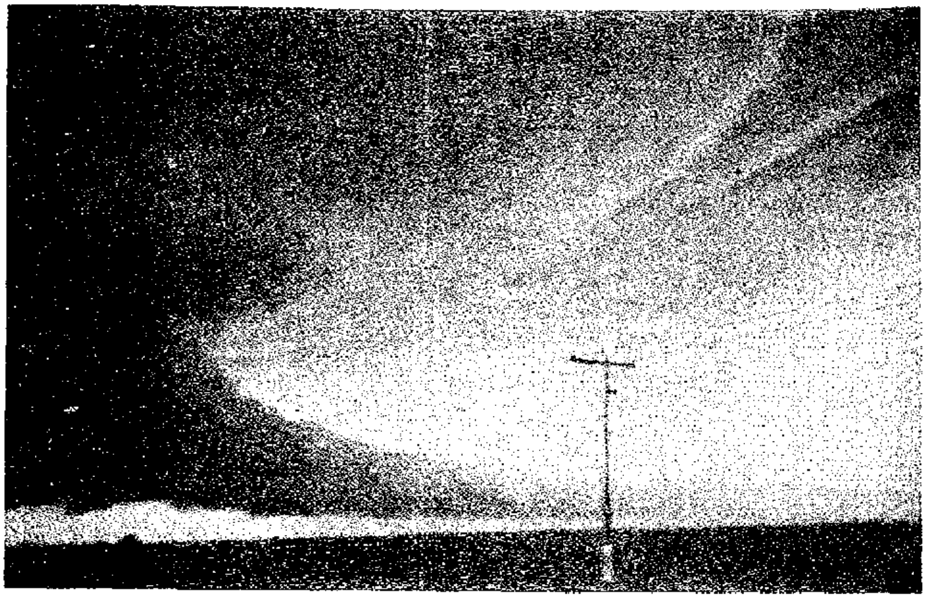

Fig. 161. Rotating parent cloud; low diffuse tornado and long wall branchings, "tail-cloud" (Lane, 1966, p.12).

black-gray thunderstorm cloud appeared in the northwest. Two terrifying branches dropped from it and soon developed into columns. The wind got up and a water column connecting the sea with the dark cloud quickly moved toward the boat. The cascade of water was lifted to a height of 3–4 meters.

The frightened passengers and the professor hid in the cabin. With a great noise the tornado passed over the boat longitudinally, without causing any injury, dropping only a few drops of water and leaving behind a peculiar sulfur smell. Professor Wolke came out of the cabin and observed with awe that six more columnar tornadoes had formed over the sea (Wolke, 1802, p. 482).

Waterspouts have been described in great detail by Wegener (1917), Gordon (1951) and Hurd (1928, 1950). Their distribution is extremely wide, from the Baltic Sea to the St. Lawrence Gulf. They are seen in the Atlantic, Indian and Pacific oceans, from Japan to the coast of Australia. Often they originate in groups from one parent cloud.

Often waterspouts are formed in thunderstorm (cumulonimbus) clouds and the maximum strength is attained here. They are frequently associated with other types of cloud. Tropical cyclones are often accompanied by waterspouts. Cloudbursts and lightning are often observed simultaneously with tornadoes. Though not connected directly, they are formed in the same thunderstorm cloud. As in the case of tornadoes of the continent, waterspouts are often accompanied by a big sound—terrifying roars, howls and hissing.

The strength of the wind varies widely, but generally it is not very high and the wind is weaker than in continental tornadoes. Passing over small craft the waterspouts spill water, make holes in the cover and carry away lighter objects. They destroy or break up small boats.

Often the waterspout is stationary or moves slowly over a small distance. Sometimes it moves at a speed of 45–60 kmph and rarely at a speed of 150–250 kmph.

The duration of a waterspout is short, generally 15–20 minutes, often less and rarely an hour or more (Gordon, 1951).

Its structure is the same as that of the continental tornado. The internal cavity has two walls. The absence of dust and debris makes the tornado partly and sometimes entirely invisible. It has the base in the cloud, the small funnel on the surface of the water, the cascade, and clear air in between. A waterspout in Malacca strait exhibited this feature for 5 minutes until the tornado had sucked up enough water to become visible (Waterspouts ...., 1929).

"Cascade", "fireworks" are different names of the mass of water, moist dust or foam that is lifted into the air to the base of the tornado, especially when it initially touches the surface of the water. The size of the cascade and its shape vary widely and change, depending on the strength and direction of movement of the air at the base of the tornado. Often the water is lifted up the walls in the form of high cones or even columns (Fig. 138). In the periphery, on the contrary, the columns of water rise to a height of tens and even hundreds of meters (Fig. 139). The situation becomes interesting when the cascade originates in the visible tornado. The raging water is lifted up the column, splashing in circles for no visible reason (Fig. 162). The cascade has been described on pages 281–286.

Waterspouts are essentially the same thing as continental tornadoes. The main differences are the smaller dimensions, shorter duration and lesser strength of waterspouts. These things are unimportant since they fall within the range of usual variation of tornadoes.

In their structure, strength and nature the track of the waterspout and that of the continental tornado, as already mentioned, are similar. For example, let us consider the form of the waterspout. Generally it is trunk-shaped, rarely almost column-shaped, with a height of 300–600 m and width of 10–20 meters. On the coast of Australia an extremely high tornado (1,500 m) with a uniform width of 3 m was observed. Over the water it merely widened slightly at the top. A more peculiar, whip-shaped tornado occurred in Rabat (Africa). Its height was 300 m and diameter 1 m. But a waterspout off California had a height of 30 m and width of 210 meters. The gigantic destructive tornado of 1896 on the coast of Massachusetts had the following dimensions: height of more than 1,000 m, diameter in the cloud 250 m, in the middle 42 m, in the water 70 m, diameter in cascade 215 m and height of cascade 120 m.

The Massachusetts tornado of 1896 occurred three times in succession, approximately at the same place and from the same cloud. The size of the second tornado is given above. The funnel, narrowing at the middle, is quite a typical feature. The third tornado was of small size but exhibited a tail-shaped funnel. Its width in the cloud was 180 m, in the middle 90 m and in the water 45 m. Its cascade was of enormous size—230 m in width and 180 m in height. Before disappearing, this tornado became narrow, long and curved and took on the whip shape. The tornado of 1896 has been described in detail by Bigelow (1906). Even today this account is important. The tornado can be considered typical.

A waterspout of large size and form occurred on June 25, 1964, in the Tampa Bay, Florida (Fig. 139). It was almost straight and probably two-layered and gave rise to an enormous cascade. The main tornado was accompanied by other, small tornadoes, originating from the same cloud. The photographs show a peculiar formation like a horizontal vortex cloud (A Weather Fan, 1964).

Some aerial observations on waterspouts deserve attention (Hale, 1929). Initially the rotating funnel of one waterspout was visible only in the cloud. Then it lengthened and came out of the cloud, aligning almost horizontally below the cloud. It then bent into a big arc and reached the water in 20 seconds. A long, gently bent, narrow column 60–80 meters in width was formed. After 6 minutes, it became long and narrow and took on a rope-like form. Then it broke and one part withdrew into the cloud and part of the cascade dropped to the surface of the sea.

The waterspout of August 29, 1937, in the city of Tissov on Rügen Island has been described in great detail. It differs in its regular, almost straight cylindrical form and clear hollow, probably formed by the splash of the cascade (Kaschmieder, 1940a).

The tornadoes of the Hawaii Islands are quite peculiar. They are quite frequent, but always of small size, causing little destruction and rarely any loss of life. They strike in various ways. One kind develops over the land, another over the sea, a third moves from the land to the sea or vice versa. Many of these tornadoes probably show a vertical vortex and are not connected to the parent cloud; the second kind are typical tornadoes and the third represent a transitional form (Price and Sasaki, 1963).

A typical waterspout observed in 1958 off the coast of Florida (Miami) is shown in the monograph by Dunn and Miller (1960, Fig. 3). It is big in size and is shown at its full development. There is another waterspout to the left, almost disappearing and displaying a rope-shaped form (Fig. 115).

Another typical example of a waterspout, but in the initial stage of growth, is given in the monograph by Wegener, 1917 (Fig. 162). The ship was off the coast of Central America. A black thunderstorm cloud moved in. A circular, rotating heap of cloud or parent cloud was formed underneath. Soon two long, narrow curved funnels emerged from it and quickly dipped to the sea. The longer one reached approximately one-half the distance from

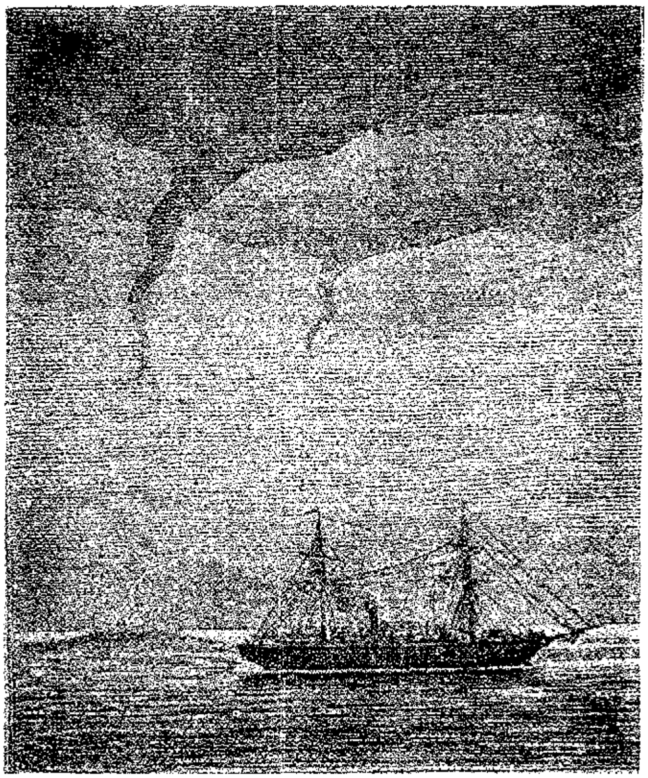

Fig. 162. Initial stages of two waterspouts, Caribbean Sea. For tornado at left, middle part is invisible but cascade has formed underneath (Wegener, 1917, Fig. 25).

the cloud to the sea. During this time the surface of the sea raged, lifted and formed a typical cascade. Suddenly from the middle a narrow waterspout funnel emerged. It rose up to meet the funnel hanging from the cloud (shown in the diagram). Very quickly the two funnels joined up, forming a waterspout in the fully developed stage and moving to the surface of the sea. The diagram shows the two funnels as they came into being. Actually they are invisibly connected: the central part of a tornado also consists only of air. It became visible when filled with water.

The description of the growth of a vertical water vortex and its transformation into a tornado in the South China Sea in 1877 is interesting (Ditmar, 1877). The splash in the immediate neighborhood of the ship was so intense that it appeared as if it had been made by flying fish. Soon the quantity of splash increased, became massive and started moving in zigzag fashion. Suddenly a twisted column 6 m in height and 10 m in width rose up. Anticlockwise rotation was clearly visible within the column. The column grew fast and the cascade or waterfall poured through the walls. At first there was no cloud but after some time, when the vortex had reached a considerable height, clouds appeared above it, at first small and gray. The cloud started growing, became dense and changed to a dark color. The water column linked up with the cloud and took on the form of a waterspout. This took place not far from the ship and was observed continuously.

Generally the tornado forms a vertical vortex (funnel) which is lowered from the cloud. Here, on the contrary, the vertical vortex rose and linked up with the cloud. Such situations are relatively rare, but still have been repeatedly reported. They are especially frequent in fire tornadoes and vortices originating over large fires (these have been described on page 333). In a well-known case (Wobus, 1940) the tornado broke off from the parent cloud, moved forward and in a few minutes formed a new large cloud above it.

It is not very clear whether such new clouds display the horizontal vortex motion typical of the parent clouds of tornadoes. The possibility is not ruled out. Then the fundamental difference between the tornado and the vertical vortex is no longer valid.

Some waterspouts dissipate by the time they reach the coast but many, the more intense ones, penetrate a considerable distance inland. The gigantic Massachusetts tornado of 1896 came inshore a considerable distance and ended up as saline rain transported from the sea (Bigelow, 1906). There is no doubt that marine organisms fell along with the rain. In this case the presence of marine organisms was insignificant but they have been observed in other cases, e.g. the jellyfish in Vladivostok (see p. 407).

In 1880, on the coast of France, a tornado originating at sea struck the village Saint-George-la-Riviere and the entire village along with the church was turned into heaps of ruins in no time. All the rooftops were dismantled, broken and carried away. Walls crumbled and toppled. Trees were uprooted, broken and bent. A belt 300 m in width was filled with mixed up, broken fragments of material that could not be identified. Many of the fragments were carried away to a great distance (Zurcher and Margolle, 1883).

When a tornado moves along the coast and is split it becomes a waterspout and a continental tornado simultaneously.

On September 5, 1935, a tornado was formed near the city of Norfolk (Virginia) and moved northeast. First it destroyed a few buildings near the city. Then it crossed the water, intersecting a small river, exposed its bottom and cut a big trench on the clayey bank. A few boats were lifted up into the air and thrown on the bank. Part of the pier was broken and tossed aside. Coming to the land, the tornado destroyed a few more houses and a garden. It encountered a small bay, crossed it and struck the rail station, derailing several freight cars. It again spread over the bay, then over the peninsula with an airdrome. After destroying a few hangars, the tornado passed over to Chesapeake Bay, where it ultimately dissipated.

The Lorain tornado of 1924 in the State of Ohio (Hunter, 1924) is an example of a big, destructive tornado which started over land, then for half its track (40 km) passed over water (Lake Erie) and ended again on land. The total length of the track was 80 km. Covering a distance of about 20 km and destroying the city of Sandusky, the tornado moved out over Lake Erie for a distance of about 40 km. On the other side of the lake it lashed the city of Lorain. After destroying numerous structures, killing 73 people and causing a loss of 13 million dollars, the tornado moved on, covering another 20 km (Fig. 163). The speed was considerable, about 100 kmph (Varney, 1924). In the lake the tornado passed near a motor launch. An eyewitness said: "We saw a very black cloud 2–3 km wide. It moved very fast and was full of lightning. Not far from us the funnel popped out of it and reached the water. The water was lifted up in the form of a cone. The barometer dropped sharply. The tornado went over our stern, pouring water over us. It sucked up the top of the pipe and tore off the awning which was nailed down. With a terrifying roar the tornado headed straight for Lorain, accompanied by heavy downpour and enormous waves."

Fig. 163. Waterspout of June 28, 1924, Lorain, Ohio. Tornado came from lake (visible on horizon) to land and caused large-scale destruction. *On skyline*—damaged rooftop, broken glass panes and heap of debris (Hunter, 1924, Fig. 3).

In their popular scientific work, Zurcher and Margolle (1883) described a number of waterspouts observed in different regions and at different times. The first was in the 17th century and was observed by the well-known explorer Dampier. The tornado was observed in 1688 over Celebes Island in Indonesia. A dark thunderstorm cloud appeared. At places in the sea, over an area 100 steps across, the water started raging, the splash became higher and higher and suddenly a high, sharp cone formed. A funnel descended where it met the cloud and the two joined up. The tornado started moving slowly along (Fig. 164). It could be seen distinctly that the water in the funnel of the tornado was lifted into the cloud. The cloud became larger and darker. Several tornadoes were formed. A bird flew out of one of the tornadoes. After almost half an hour the tornado ended and the large amount of water from it dropped into the sea with a thunderous noise and a fountain of splashes.

Dampier writes that if the boat had been under the falling water it would certainly have been damaged. In support of this he cites the note of the English captain of the frigate *Blessing* of 300 tons with 16 cannons, which was sunk by the tornado of 1674 off the coast of Guinea. The frigate swung dangerously from one side to the other and one mast broke and three sailors fell overboard. They were rescued and the ship as such was not seriously damaged.

A third description is by the well-known explorer Captain Cook. In 1775 a black thunderstorm cloud moved in toward the coast of New Zealand. After waiting for the storm to abate, the boat sailed but suddenly six tornadoes appeared, 60–80 steps in diameter. They slowly moved across the sea, inspiring awe and fear. However, the ship escaped all of them. The formation of the tornado started with the cascade and when it met the cloud, the funnel descended. Cook also records the movement of water upward to the funnel.

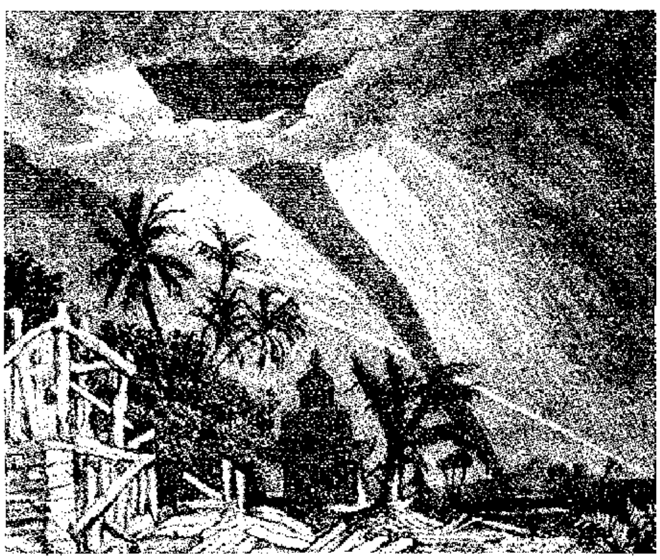

Fig. 164. Waterspout of 1688 off coast of Celebes Island (Zurcher and Margolle, 1883, Fig. 9).

The next description belongs to the 18th century and concerns the tornado observed in 1780 in the Mediterranean Sea, not far from Nitsy. The interesting feature of this tornado was the very wide envelope, falling just short of reaching the cloud (Fig. 143). The tornado slowly moved on the city but gusts of cold wind were blowing from the mountain. The tornado fluctuated, bent, stretched and then ceased. The tornado was followed by a cloudburst with hail. All these have been briefly described and do not differ from the other descriptions. Cook even considers the possibility of a tornado forming due to the electrical activity of a thunderstorm.

One more diagram, given earlier (Fig. 142), shows three tornadoes, simultaneously originating in the Mediterranean Sea off the coast of Algeria. It, too, was observed from a warship in 1840. The cascade is well-developed in the background and the black parent cloud is clearly seen.

Waterspouts, especially small ones, often form in a group. The occurrence of six tornadoes has been recorded in the Baltic Sea. Six funnels were photographed during the war off the coast of the Philippine Islands (Fig. 165). Two of them reached the sea while the other four remained hanging in the air (Colton, 1943).

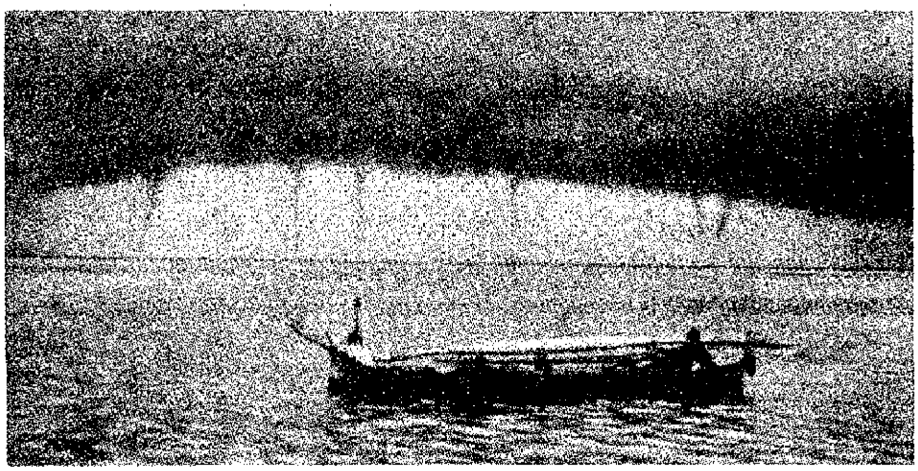

Fig. 165. Six funnels over Sulu Sea in Philippine Islands (Colton, 1943).

Waterspouts over big lakes do not differ from sea waterspouts. They are similar in form, size and origin. In August, 1898, in Lake Erie a dark, low thunderstorm cloud developed. Suddenly part of it descended in the form of a funnel. The water raged underneath and the water splash lifted into the air and moved upward in the form of a cone. Soon it was connected with the funnel, forming a black column about 3 m in diameter. It rotated fast, slowly moving forward. Soon six other tornadoes formed and all of them moved across the lake, sometimes straight, sometimes zigzag and at times like a drunkard (Busk, 1927; C.L.M., 1920). The tornadoes of October 14, 1928, in Issyk-Kul have been described on pages 229–230.

An interesting and important survey of hundreds of waterspouts is given in the work of Hurd (1950). Many of them have been described above, but some others also deserve attention. Hurd underlines the extreme changeability of waterspouts. In size and strength they change from a small, transparent, column (2–3 m in diameter), showing only fine saturated dust, to a thick column of water, capsizing craft with sea water, throwing different objects on deck, and to an enormous funnel hundreds of meters wide, overturning small boats and causing large-scale destruction onshore (Fig. 163).

The maximum width observed in a waterspout is about 1.5 km. It is quite likely that it was associated with a low, very widely diffused tornado. Such funnels are rare. The overwhelming majority of funnels are dense, sharply defined, narrow and high.

In one instance a bright, phosphorescent tornado was observed at night. It originated due to the suction into the funnel of glowing microorganisms, floating on the surface of the sea.

An enormous, almost black, dense, sharply defined tornado with a large, high cascade was observed on June 25, 1964, in the Tampa Bay, Florida (Fig. 144). The size of the funnel can be compared with the structures on the coast.

It has already been mentioned that the color of the waterspout depends on the quantity of water it contains. The darker the tornado, the more the water in it and the greater the destructive power.

The shape of waterspouts often becomes complicated with the formation of the envelopes. On September 2, 1965, off the coast of Spain a tornado with a well-developed envelope was photographed (Fig. 167). It is possible that in this case the envelope was a very high cascade, surrounding the main funnel. This tornado was of enormous size. Its funnel was almost white.

The speed of rotation of the funnel fluctuates considerably and this decides the quantity of sea water sucked up to the top. In many tornadoes it is an insignificant amount. This has led to the impression that waterspouts do not suck in sea water and consist only of the water contained in the parent cloud. This conception ignores the existence of the enormous funnel, sucking in a large quantity of saline water with marine fauna, into the parent cloud. It gives rise to rain with jellyfish, crabs and sea fish up to a distance of tens of kilometers inland.

At the beginning of their development many waterspouts are either totally or partially invisible due to the absence of dust and the small amount of sucked-up water. A small tongue hanging from the parent cloud and the big cascade underneath are only partially visible. The central part is generally invisible.

At the end of the development of the funnel it takes on a whip-like or rope-like form, very long and curved. In one case it was coiled in several loops but as soon as these coils touched each other the tornado crashed into

Fig. 166. Waterspout in Adriatic Sea. Thick funnel sucks sea water into thunderstorm cloud (Hurd, 1950, cover).

the sea in spray. In another tornado four circular bulges were formed in the long, narrow curved funnel, seen clearly in the photograph (Fig. 168). What are these bulges? How were they formed? These are some of the many problems relating to tornadoes that remain a mystery.

The sequence of the growth of a waterspout was drawn by Reid (1850) almost 100 years ago. In the initial stage of growth the black rotating parent cloud is projected at the base of the large thunderstorm cloud and the narrow funnel is seen hanging from it. It is still small and the cascade is absent. At one side, the ship is drawn to scale. At the stage of full growth the funnel takes on a trunk-like form, reaches the surface of the sea and forms a big cascade at its base. The lower part of the trunk is without water and is invisible. Finally the funnel breaks off from the sea and rises up to the cloud. The cascade is retained. After a few more minutes, the funnel withdraws into the cloud, the cascade falls and the tornado disappears (Fig. 169).

Hurd describes an interesting fact which according to him is a mystery. Generally inside the cascade, under the funnel of the tornado, the water is lifted up to a certain height, forming a step. This means that inside the

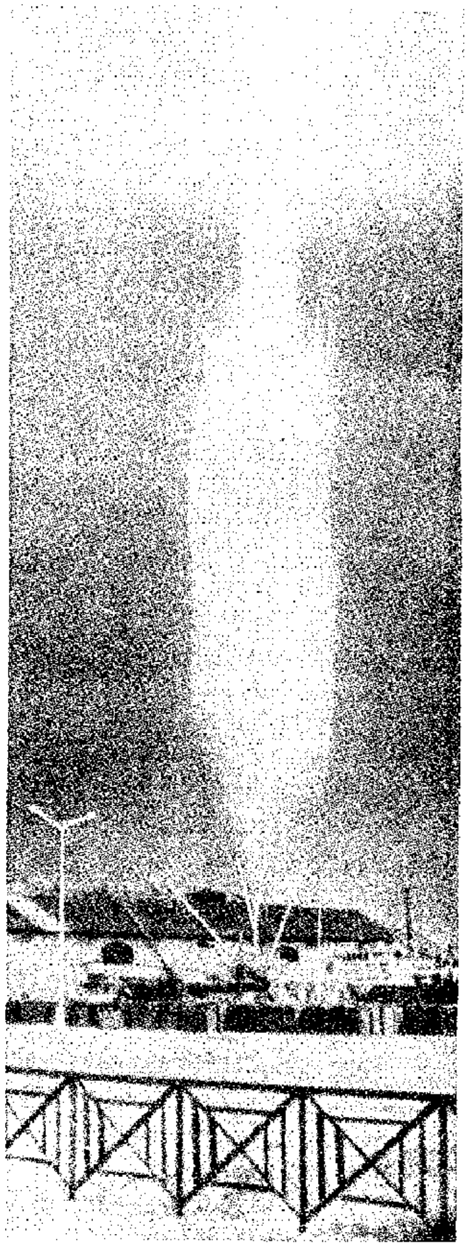

Fig. 167. Waterspout of September 2, 1965, off coast of Spain. Enormous white envelope (Lane, 1966, p. 25).

tornado there is a cavity with low pressure. The water is lifted up inside this cavity. However, in some cases, a step is formed in the middle of the cascade, under the funnel, due to pushing. Hurd believes it is formed due to the strong current of air below, in the lower part of the funnel. This current pushes the water and makes a depression.

These air currents, directed from below, are identical to the current in

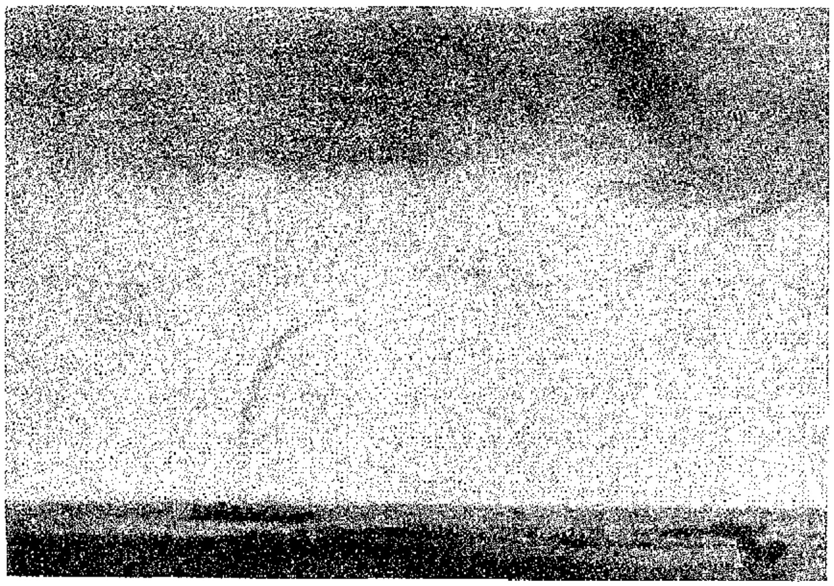

Fig. 168. Unusually well-defined waterspout with bulging. Last stage of growth (Hurd, 1950, p. 75).

continental tornadoes, pressing plants to the ground, throwing planks to the ground, bending back a hat, etc. (see p. 409).

In the waterspout of 1933, on the River Yangtze in Shanghai, a peculiar cascade, tapering below and widening at the top, was observed (Fig. 141). Such a form indicates that the higher pressure is at the top but the size of the cascade is so great that it is unlikely that this pressure alone is sufficient to form it.

A special group of waterspouts accompanying the cloud, forms in volcanic eruptions. This has often been described. One of the latest descriptions is of the new volcano Surtsey, which formed in 1963, in the middle of the sea, off the coast of Iceland (Thorarinson and Vonnegut, 1964). Each intense eruption of the volcano gave rise to an enormous, dense cumulus cloud. From each cloud, on its leeward side, emerged tornadoes of different forms and sizes. Often they did not reach down to the sea and were drawn back into the cloud. Some of them were connected to the sea, forming significant cascades. The usual long, funnel-shaped forms predominated (Fig. 170). In one instance a tornado was observed with horizontal loops in the cloud (Fig. 171).

Tornadoes are formed independent of the composition of the cloud ejected by the volcano. They have originated when the cloud was black, saturated with volcanic ash, and also when the cloud was white, composed only of steam. In the first case all the tornadoes were very visible and were often accompanied by lightning. In the second case the tornadoes had a white or cloudy tinge, but at times were transparent and almost invisible. They were not accompanied by lightning.

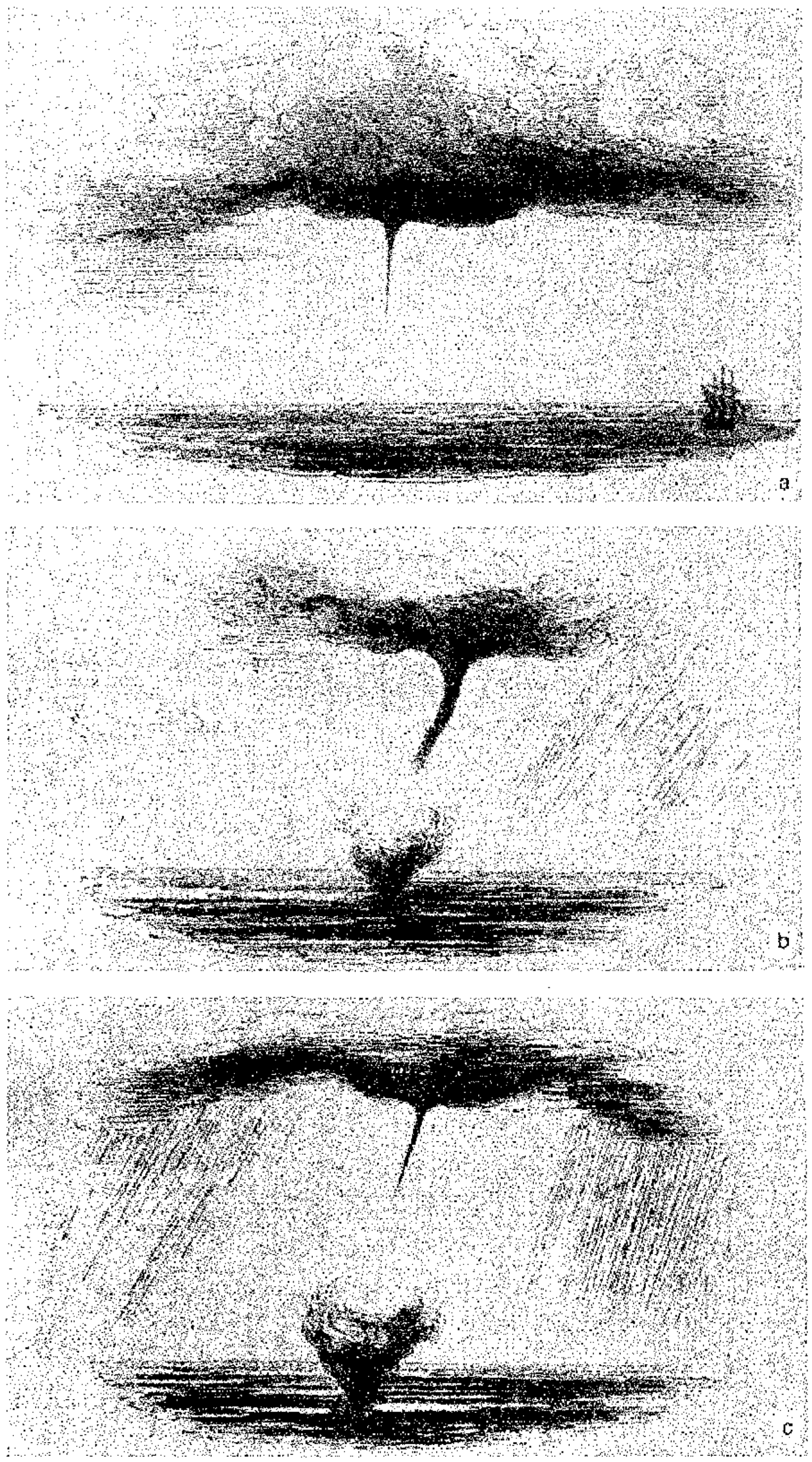

Fig. 169. Growth of waterspout (Reid, 1850, p. 465).
a—initial stage, funnel does not reach water; *b*—fully-grown stage, funnel forming cascade is connected to sea; *c*—final stage, funnel is drawn into cloud, invisible part causes formation of cascade.

Fig. 170. Eruption of volcano Surtsey, off coast of Iceland, 1963. Enormous cloud of ash and gas. At left, white waterspout; at its base, cascades (Thorarinson and Vonnegut, 1964, Fig. 2).

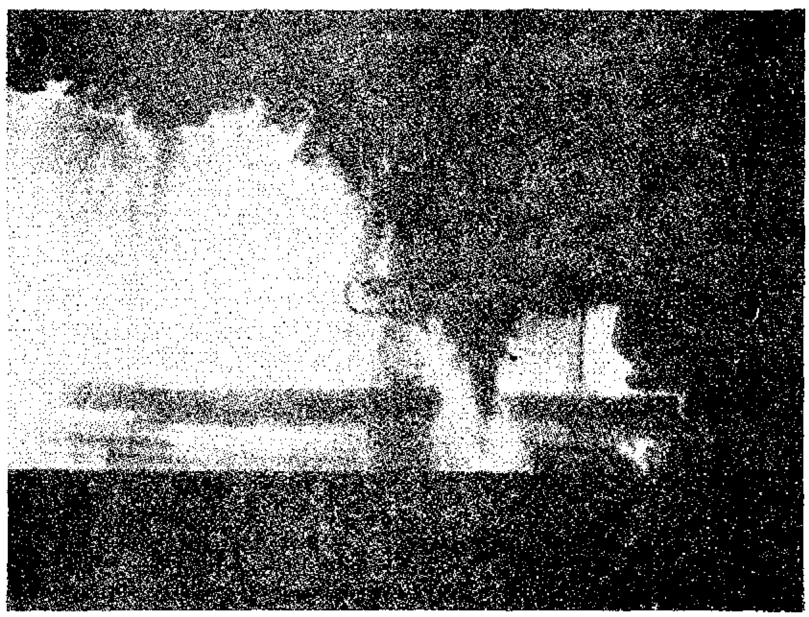

Fig. 171. Eruption of volcano Surtsey, off coast of Iceland, 1963. In one tornado, unusual horizontal loop vortex in cloud is visible (Thorarinson and Vonnegut, 1964, Fig. 3).

The clouds ejected by volcanoes are interesting in the sense that they often show circular vortex formations. These formations are clearly seen in films. They are similar to the "smoke rings" that some smokers blow when smoking. These rings, like all vortex formations, differ greatly in stability and speed. They persist and are visible in the air for a longer time than tobacco smoke. Possibly, the mouth of the volcano, filled with lava, carries out the function of the lips of the smoker, giving rise to the vortex ring in the clouds. As already mentioned, such a ring is the main cause of the formation of tornadoes, coming out of a volcano.

Generally, the tornadoes produced by volcanoes are related to the peculiar group of vortices known as "fire vortices".

FIRE TORNADOES

Fire tornadoes earned the name because they are always accompanied by an enormous amount of heat. They can be grouped under volcanic eruptions, fires and explosions.

It has been observed repeatedly that the cloud thrown out during an eruption gives rise to tornadoes. Thorarinson (Thorarinson and Vonnegut, 1964) only recently has shown such cases, e.g. the eruption of the volcanoes Miojin (Dietz, 1954) and Parikutin (Schrock, 1945). He himself observed the formation of a vortex over molten lava during the eruption of Hekly (1947). It is quite likely that the vertical vortices were formed over the lava on the lines of dust vortices. The tornadoes only descended from the cloud.

The tornado that formed due to the fire in an oil tank in California in April, 1926, is well known (Hissong, 1926). During a thunderstorm accompanied by strong wind, lightning struck the big oil tank. A very loud explosion took place and the petrol spilled. Then the next tanker caught fire and the petrol burned for five days. The fire spread the maximum on windy days and the maximum number of tornadoes were observed on those days.

According to the photographs, in some cases, e.g. the Surtsey volcano, the tornado is transparent and invisible (Fig. 172). In the photograph only the cloud and the cascade are visible. A little later, the tornado formed and assumed a clearly defined form (Fig. 173). All the tornadoes occurred near the fire, never more than 4–5 km away. Some of them were very strong: one of them lifted a farm house 1–1.5 m into the air and carried it a distance of 50 m. The house was destroyed and the owner and his son killed. Another house was lifted 9 m and moved a distance of 30 m and was also destroyed.

Fire tornadoes are explained by the ascending movement of air over the fire. This explanation is not complete. Such ascending motion gives the fire a vertical smoke vortex and cumulus cloud (see p. 447).

The fire tornadoes described above came down from the clouds, making horizontal vortex movements in the newly formed cumulus clouds.

Fig. 172. Tornado that originated during fire in oil tank (right), California, April, 1926. Initial stage; middle part of funnel is invisible; cascade underneath (Hissong, 1926).

Fig. 173. Same tornado as in Fig. 172. Funnel with full development (Hissong, 1926).

9

Vertical Motion of Tornadoes and Destruction Caused by Them

Vertical motion is the main feature, a property of the tornado, without which it cannot exist.

Each tornado has a vortex motion, in which air, water, dust, debris and various other objects, animals and plants, etc. are in motion. The destruction due to tornadoes is closely related to this motion.

Another quite important feature of the motion is its lift and the reverse of this—squeeze. All kinds of objects from houses, bridges and big rail cars to dust and microorganisms are lifted up.

The third feature is transference and transportation. Heavy objects are easily transferred great distances. The displacement over a large distance is transportation.

The consequences of motion—destruction, lift and squeeze, transference and transportation—caused by tornadoes are exceptionally interesting and unique.

DESTRUCTION

Destruction cannot take place without transference. The description of destruction is always accompanied by a description of transference. In any case, individual cases of transference, e.g. the transference of people, are so remarkable that this will be dealt with in a separate section.

Soviet Union

Sevastopol tornado of 1820: A detailed description of the tornado that occurred over Sevastopol on September 8 (August 27), 1820, is given in the "Note by the State Admiralty Department" of 1823.

"After a few hot days (24–26°R), on September 8 a thunderstorm was seen and heard to the northwest. At 0540 hours the wind became stronger from the south. Thick clouds formed on different sides and rain, thunder and lightning intensified. Along with this came the vortex or the so-called coastal typhoon.[1] This terrifying phenomenon due to the interaction of all the winds, which were unusually erratic, followed all sorts of random directions. At the same time, the thunder crashed so frequently that the rumble of one clap merged into the next with continuous flash of lightning. There were 70 major lightning strikes over Sevastopol in 8 minutes, of which 16 unfortunate cases were recorded in the city."

The description gives the characteristics of the tornado noise. Here no comparison with the thunderstorm noise is drawn as in the analogous situation, in spite of the presence of "strong thunderstorm discharges" and "thunderstorm strikes". An anonymous author has been quoted as saying the "tifon gives a sharp sound like an echo, a shrill noise as from a piece of metal".

The tornado caused large-scale destruction all along its track. Coming from the southwest it moved to the north. "Descending into the ravine, it enveloped the dry artillery cellar, tore off the tiled roof and large cornice stone and overturned the clock tower, which was carried a great distance with little damage to the clock. Crossing the ravine, it suddenly deviated to the northeast due to the strong wind. In that direction it traveled up to the second-hand market and the barrier; tore up or damaged shops, scattered the shopkeepers and their products; tore up the chief's cabin and damaged it; uprooted the thick columns and the fencing attached to it; toppled the clock tower and, proceeding farther in that direction, particularly through the administrative workers' barracks, tore off the iron and tile rooftops; then, taking an easterly turn, it dropped below the steep cliff in the South Bay, enveloped 14 launches standing off the coast and carried them down to 30 fathoms; over the water this coil enveloped the entire coast with the 14 launches and quite likely the surrounding air, as the caps of everybody in the launches were removed due to the wind. The people aboard were frightened by what happened; to escape the wind they moved far from their mooring in the middle of the bay and suffered no injury. The typhoon, following its previous direction, on the other side of the South Bay lifted into the air and capsized six boats with seven people, carrying them a great distance. Six people were rescued, though injured, and one was drowned. The frigate *Ezelgoft* was dragged from the shore and thrown into the water. Thus traversing from bay to mountain it showed its destructive action by destroying the forest, carrying tiles, stones and other materials to the other side of

[1]The term "typhoon" was used in the first half of the 19th century as a synonym of "tornado".

the bay and smoothing stones and shells weighing 10 to 40 poods.* The transportation of material across the bay was observed by a noncommissioned officer. Moreover, it was noted that it passed over the South Bay, whirling the water, which raged with a great noise, and throwing waves to the side. The splash was as high as 7 fathoms."

The further description covering 13 pages is summarized and only the main points are mentioned here. The two-storied barracks with the main walls as thick as 1 arshin 4 vershek (1.3 m) were destroyed. A stone wall in Ushakov ravine was thrown a distance of more than 50 m. About 50 young oak trees were uprooted. At the exit of the Ushakov ravine a second wall was destroyed "to a few sajenes but not down to the foundation." Walls, roofs, gates, doors, frames, etc. were destroyed at many places and in many houses glass panes were broken. The lightning killed six and injured 27 people. The author notes that the deviation of the path of the tornado from the initial northerly direction to northeast considerably reduced the fatal effect of the vortex. The tornado did not touch the ships and frigates of the Black Sea standing at anchorage either in the bay or at the pier. Two boats standing in the road were only damaged. The workers living in the damaged barracks did not suffer as they had gone to work.

The following description concerns the external form of the Sevastopol tornado: "The typhoon had a changing form, at times cylindrical, often a conical column. In the latter case, the base was always at the top and the upper end was vertically downward. It often changed to other forms, at times to an inclined column and often to a cylindrical figure. It was generally thin at the top and often in the lower or in the middle part as well. The color also changed: at first, when the typhoon appeared over Sevastopol, it was bright; then it became gray, resembling ash color. Its movement was quite rapid and circular. The raging clouds appeared turning from right to left. At first it was quite high in the air and then it came down lower." The author estimates that the tornado was 30 fathoms (64 m) across. In all, the time taken for its passage through the city was 8 minutes. The destruction of the tornado was due to the impact of stones from the high cliff (between the sugar plant and Graf pier).

The author specially underlines the intensity of the electrical phenomena during the tornado and after its passage. "The tornado was preceded and also accompanied by continuous thunderclaps and lightning, which were so frequent that the flashes and rumble did not stop even for a second. According to old people such terrifying thunder and lightning were never heard or seen in their lifetime."

After this dreadful event all Sevastopol was filled with a strong sulfur smell which remained for some time. "The atmosphere was dense and filled with electrical charges. The people felt unnatural evaporation and also

*1 pood = 16.38 kg—General Editor.

felt somewhat weak". In the evening the weather was quiet and cloudy but the continuous flash of lightning continued in the east till 1100 hours.[1]

Moscow tornado of 1904: On June 29, 1904, a cyclone passed over the central part of the Russian platform in the usual northeastern direction.

In its right sector an enormous cumulonimbus cloud of very great height developed. This cloud, coming from Tul'sk province, crossed Moscow province and then moved over to the Yaroslav province. Judging from the belt of rain and hail, the width of the cloud was not more than 15 km.

When the cloud was over the suburb and eastern end of Moscow a tornado funnel appeared and disappeared repeatedly at its base.

On the high, steep right bank of the Moscow River, in the region of Besedy Village, in the eastern sector of Moscow-Kursk railroad, the teacher of a local school observed the enormous thunderstorm cloud moving from the west. At its base a small, rather bright cloud moved chaotically from side to side. Gradually the motion became spiral and suddenly a gray, sharply pointed funnel protruded from the spiral. The teacher looked at his wristwatch and it was 1638 hours. The funnel lasted for a short time and quickly went back to the cloud.

After a minute another funnel appeared which rapidly increased in size and hung over the ground. As it met the surface it lifted a column of dust which became bigger and bigger. After some time the column and the funnel linked up and the teacher was horrified as he realized that a tornado column had appeared before him.

Fortunately the tornado moved away from him, in the direction of movement of the cloud, to the northeast. The column widened at the top, the outline was diffuse and became wider and wider, soon attaining a width of half a verst (about 500 m). It moved on Shashino Village and the first cottage was blown away, then the second, then the third, etc. The air surrounding the funnel was saturated with debris, branches and scraps of trees.

During this time, a few kilometers away to the west, another tornado occurred and was also accompanied by continuous destruction. It followed the Moscow-Kursk line and was recorded over the stations Podol'sk, Klinov and Grivno.

It is possible that a third funnel also formed, causing destruction far to the northwest, in Petrov-Razmumov. But it was very short-lived.

The diffuse outline of the funnel, its great width, large area of destruction and low parent cloud, etc. were the reason a large number of people did not know about the tornado. Even the newspapers and journals referred to the phenomenon as a "hurricane" and the name "tornado" figured rarely.

The eyewitness accounts, including that of the teacher mentioned above,

[1] A description of earlier Sevastopol vortices, or the so-called "costal typhoon", has been given by L.A. Vitels.

their drawings, and lastly the clear and distinct photograph (Fig. 174) prove that it was not a hurricane but a tornado. Only the speed of rotation and the swath of destruction were like a hurricane. The drawing by an eyewitness from the window of an apartment is really interesting (Fig. 175).

The track of the tornado was not accurately established and there is no map. The length of the track was believed to be 40 versts. This is possible, if it is remembered that it went from Podol'sk to Sokol'nikov and beyond, but the reliability of the estimate is not known. Possibly this track was covered by several funnels, changing from one form to another. Each funnel crossed Moscow, almost parallel, for a distance of 10 km.

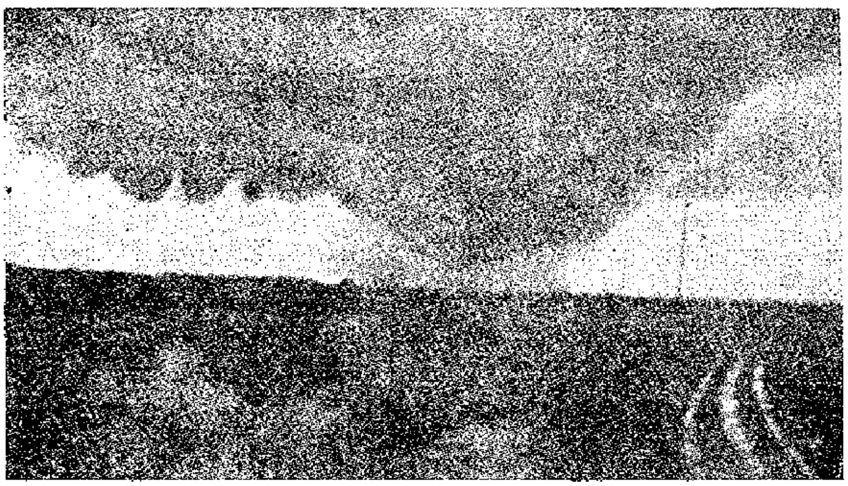

Fig. 174. Tornado over Pererva station on Moscow-Kursk railroad, 13 versts from Moscow. Diffused outline can be clearly seen from photograph.

The main funnel in Moscow started its destruction in Lyublino, then engulfed Simonov monastery and Rogozhskii. The maximum damage occurred in Lefortov, on either side of Yauzy. Passing over Gavrikov (Spartakov) corner, it quite likely lifted up into the air. It again appeared in front of Sokol'nik. In Sokol'nik, in the park, it covered a width of 200–400 steps. Then via Lisino Island it passed over the Mytisheham and moved away from Moscow by this route.

The second funnel, originating in Besedy Village, near the Moscow River, went to Gaivoronovo, Karacharovo (Fig. 176), Izmailovo and Cherkizovo.

The width of the track in each funnel was considerable, as is generally the case with diffuse tornadoes. The width of the traverse in Sokol'nik was 200–400 m, if each step is taken as equal to one meter. The width of the funnel in Kupotin was about 500 m; for other points the figure varies from a few hundred meters to a kilometer or more.

In spite of the diffuse funnel the boundary of the track was quite distinct

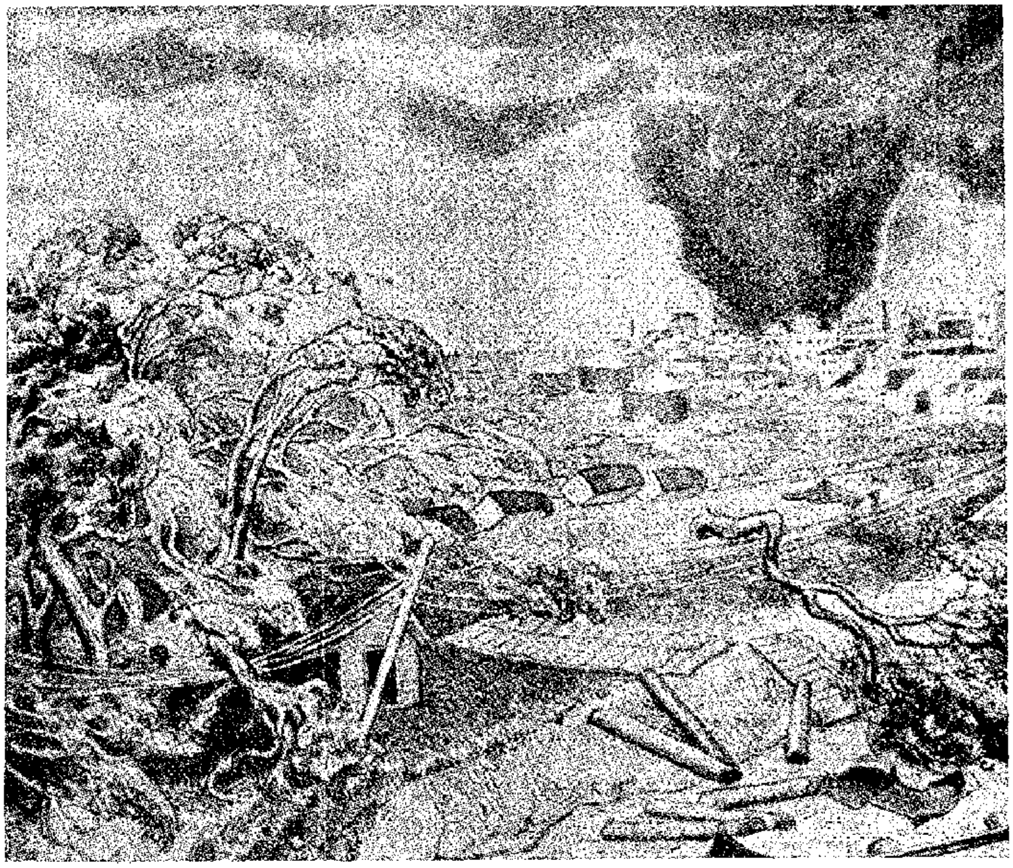

Fig. 175. Moscow tornado of 1904. Drawing is of view from window of apartment. Kazan railroad. Tornado in distance; in foreground, destruction in its wake.

and sharp. Structure at a distance of a few tens of meters from the edges of the track remained undisturbed.

According to the meteorologists, the speed of the parent thunderstorm cloud and that of each funnel with it was 60 kmph. The speed of vortex rotation in the funnel was 20–25 m/sec. The last figure is quite low. The bent staircase, the lifting of boards, beams, logs and even entire roofs into the air, lifting up of people, cows, etc. to tens of meters show that the speed was much more than 25 m/sec and was as good as the speed of the vortex in enormous diffuse vortices in the USA, which attain a speed of 100 m/sec.

The accompanying phenomena were also characteristic of strong tornadoes. When the funnel moved darkness fell all around. In one street two carriages collided. The darkness was accompanied by terrifying noise, roar and whistling, drowning everything.

The electrical phenomena attained unusual intensity. The frequent, massive lightning killed two people, burned several others and caused a number of fires. Ball lightning was observed in Sakol'nik. It entered an apartment through a window, broke the door, entered the other room and

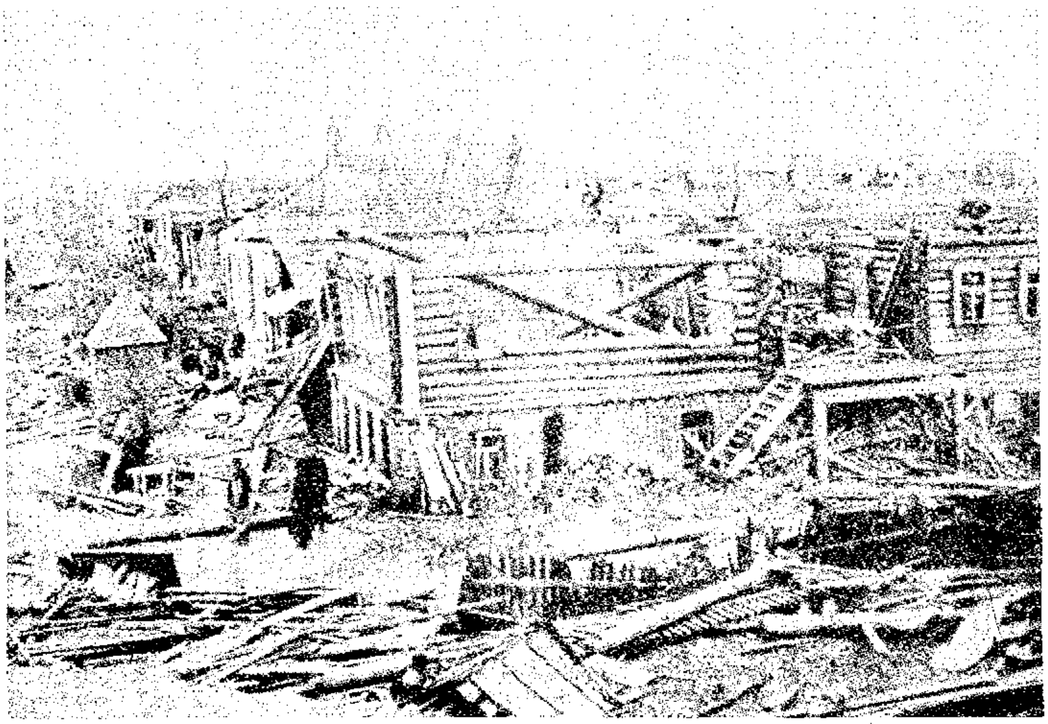

Fig. 176. Karacharov Village, uptown Moscow, after the tornado of 1904.

left through another window. The family pressed against the wall and remained unhurt.

The rain and hail were also unusually intense. According to the observer at the Atmospheric Physics Institute, 162 mm of rain fell during the passage of the cloud. Hail fell at several places and at some points the size and quantity of hailstones were quite considerable. Hailstones of egg size were observed at many places, e.g. in Cherkizovo. Individual hailstones of star-like form attained a weight of 400–600 g. The hail killed several people uptown and severely damaged crops and gardens.

We give here details supplied by an eyewitness, an old lady, who was on Khapilov street, not far from the German market: "It became dark and lightning flashed. I was terrified and hid in a massive stone gateway. At this time a vortex appeared, there was such a crackle and thunder that it seemed the sky would fall. In front of me, in the street, a roof of iron sheets, broken trees, pieces of log, board, bricks and other materials fell to the ground. All this continued for two minutes and then ceased abruptly.

"The solid stone wall in front of me was destroyed. The entire street was littered with debris, trees, boards, bricks, iron sheets, etc. I came out of the gateway and gasped: the enormous, massive, thick, metal factory chimney was bent and the top was lying on the road."

The destruction caused by the Moscow tornado was considerable. It was terrifying to eyewitnesses. The Moscow newspapers described it as the strongest in recent times, but it can be categorized as medium when compared with the tornadoes of the USA. The number of deaths did not exceed a few dozen people. The loss was of the order of 1 million rubles. The big, solid stone houses remained unaffected and only their roofs were damaged.

The photographs and descriptions of the destruction, especially in the villages, were frightening and it was terrible for those who had to live through it. A few small hamlets of 25–30 huts were destroyed, e.g. Ryazanovka and Khokhlovka, at the southeastern end of Moscow. Nothing remained except debris. Some of the cottages were carried away in one piece. Trees in the gardens around the houses were damaged and often uprooted (Fig. 177). A farmer's head was smashed and in another case a thick beam was pierced through.

The destruction in the neighboring villages was considerable. At Kapotna 200 houses were damaged, at Chagino 150 houses. The majority of them were debris.

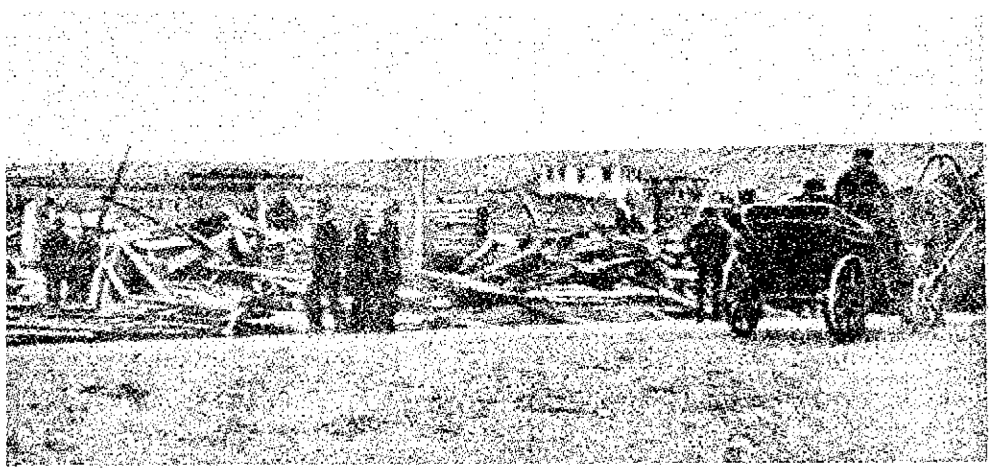

Fig. 177. Khokhlovka, uptown Moscow. Seltykov Estate debris.

The eastern funnel passed over the outskirts of Moscow, over the villages and workers' housing estate. The Moscow newspapers were full of descriptions of the damage. In Petrov, 20 people ran into some cottages. The cottages were carried away and heavily damaged.

The main, western, funnel crossed Moscow. A solid stone house in its path was not damaged by the funnel but everywhere roofs were damaged, rafters were broken and at places the top floor was damaged.

In Lefortov many old buildings were badly damaged. The roof of the Petrov Palace was damaged and the upper floor of the cadet sector and the military hospital were also badly damaged. The roof of the Fel'dsher School was damaged, the rafters were broken and there was terrific chaos inside. The massive metal railings between the stone columns were overturned. The great garden was destroyed. The barracks, where the students lived were destroyed. One student was killed and many were injured. Another student, Khvostenko, was lifted into the air, carried a distance of 80 m in the garden, thrown on the grass but was hurt only slightly.

The vortex in the funnel, penetrating the lower floor, reduced it to total chaos, breaking windows, doors and furniture. In the cadet sector, not only the entire interior was destroyed but from one apartment the furniture was thrown outside. In the neighboring Gavrikov side street not only the furniture but also the tenants were thrown out.

Causing similar destruction in nearby streets, the tornado passed over the Moscow River, exposing its bottom, and destroyed the German market area to the north. Here the houses were small, low and mostly made of wood and the destruction was much greater. Not only the roofs but entire upper floors were removed. At places the entire structure was removed, fences were overturned and trees were broken. Everything that was in the path of the tornado was destroyed.

In the Gavrikov side street, in the freight yard of the Kazan rail station, there were a few timber yards. What happened when the tornado hit the place is difficult to say. An eyewitness wrote: "There was total chaos in the timber yard. Logs were in the fence, in the streets, in the houses, protruding out of windows. Everything was in a mess. Enormous heaps of logs were damaged and thrown aside. The vortex threw big logs into the air like splinters. From the timber yard on Gavrikov side street many of the logs were carried away to Sokol'nik highway (a distance of several hundred meters—D.N.). One board struck the wall of logs of the school with such force that the logs broke."

Descriptions of the destruction covered whole pages of the Moscow newspapers and there is no point in repeating them. They were strikingly alike. In large, strong stone buildings the roofs and windows were damaged. In inferior houses the upper floors were damaged. Wooden houses were destroyed. Light structures, e.g. the pavilion of the "Zolotoi Yakor'" restaurant in Sokol'nik, disappeared, as if it had never existed, but in the main solid building only the roof was damaged and the top of the dome was carried a distance of tens of meters. The total number of buildings damaged was not counted, but it would be of the order of a few thousands if the cottages in the villages are included.

The strength of the tornado was distinctly visible in the gardens, parks and forests. In Lefortovo the splendid Annegof grove, among the century-old trees planted before Anne Ioannovna, was destroyed in a few minutes. An eyewitness recounted that "in place of the dense avenue of large trees a bare belt was exposed with the undamaged skeletons of trees here and there" (Fig. 178).

In Cherkizov, "suddenly a black cloud completely covered the ground and the Mitropol Garden and grove with an impenetrable shroud. All this was accompanied by terrifying noise and whistling, thunder and the continuous rattle of the large hailstones. There was a deafening noise and an enormous lime tree fell on the terrace. The fall of this lime tree was quite surprising: it fell through the window, the thick end first. The hurricane threw it into the air to a considerable distance.

"The grove was badly damaged. In three to four minutes it turned into forest: it was completely covered with fragments of big birch, at places uprooted and thrown a great distance. The brick wall around the grove was destroyed and a few bricks were thrown a distance of a few sajen" (*Moskovskii listok,* No. 170, 1904).

Still more surprising is the lifting power of the tornado. Cases of transportation and lifting of quite large, heavy objects weighing a few tons were not recorded, but objects of average weight, from roofs, trees and logs down to people, cows, etc. were quite numerous. Small objects and fragments of big objects were carried through the air with great force, killing and destroying everything in the way.

The lifting and transportation of roofs, big trees, logs and beams has been repeatedly observed at different places. Some examples are given below:

The lifting and transportation of people and animals are usual phenomena and repeatedly observed. One man in the German market of the city was standing right under the vortex. He was lifted high into the air, pelted with hailstones and thrown to one side. When he came to his senses he found that two men, a woman with her head smashed and a horse were lying on top of him.

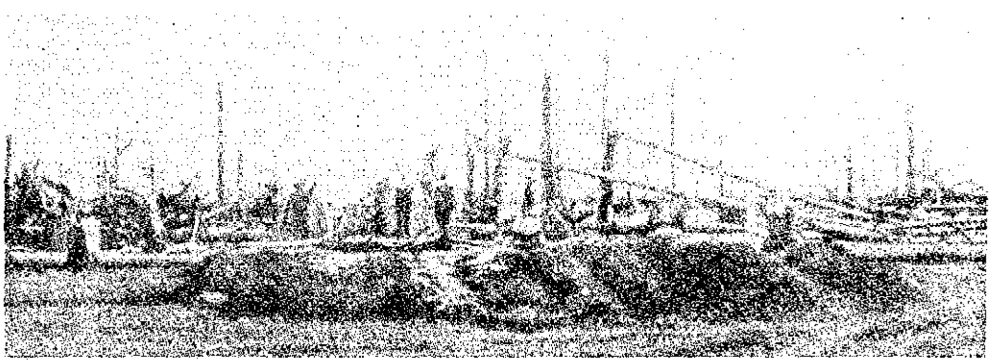

Fig. 178. Annengof grove in Lefortovo after tornado.

Near the German market, in addition to two other people, two firemen were thrown aside. Next day one of them died of his injuries.

Another man standing near the post opposite the emergency ward of the military hospital in Lefortovo was lifted 5 m into the air, carried a distance of 100 m in the garden and dropped on the lawn. He received minor injuries. The plastic cover under him broke into pieces.

Not far from hospital street a cart driver was lifted into the air to a height of 10 m, along with the carriage and the horse, and thrown to one side. He was injured and the horse was crippled.

It has already been mentioned that in the Fel'dsherskii School a student was lifted into the air, carried a distance of 80 m across the garden and dropped on the lawn.

In the same Gavrikov side street a landlord was thrown outside through a window along with his furniture, but he received no injury.

In the same area two children were lifted into the air, hurled over a fence and dropped on a bridge without injury.

The second, eastern funnel showed less transporting strength. From one of the houses in Gaivoronov a child was thrown out with the cradle and later found dead.

The most surprising thing occurred near Mytishch. Farmer Selezneva had gone to the fields along with three of her sons. The tornado appeared and the farmer along with her baby and the eldest son was thrown into the ditch, from where they were rescued. Another child, Petya, 6 years old, was engulfed by the tornado and carried away. He was located next day at Sokol'nik, a distance of a few kilometers from the place where he was lifted. The child did not remember what exactly happened: "He was pushed to the ground, there was a terrifying noise and he lost his senses. He regained consciousness in a pit formed by the uprooting of an enormous pine tree." Petya was found unharmed and complained only of hunger.

In this case the most surprising, rather paradoxical, fact was that the boy was not carried in the direction of the tornado as is generally the case, but a distance of several kilometers backward to a place where the tornado had not been for some time. What current transported him? How was it formed? What force supported him? This remains a puzzle. It is quite likely that it was a peculiar air "tail" which has often been noticed on the radar screen (see page 318). The length of the path of transportation in this case is almost unique.

The transportation of large animals has been observed a number of times. The case of the horse that was lifted into the air in Lefortovo, as mentioned earlier, resembled the lifting of the herd near Lyublino, in the southern outskirts of Moscow. When the main funnel approached the herd the cows and herdsmen were thrown aside in different directions. Two cows were lifted into the air and carried a distance of about 10 m.

Each tornado not only lifted various solid objects but also sucked up water. The main funnel, crossing the Moscow River, exposed its bottom in a few seconds and formed a trench with walls of water. In Lyublino it crossed a big pond. During that time the water from the pond was lifted several meters and the water in the pond raged like water boiling in a saucepan. Another funnel, passing over a pond in Cherkizov, also lifted a "mountain of water".

The small objects, debris, fragments of wood, iron sheets from roofs, bricks, branches of trees, etc. were carried into the air all the time in enormous quantity and at unbelievable speed. This drew attention only when it killed people and animals. In Sokol'nik a road signboard was lifted into the air and hit a young man on the side. A piece of iron sheet from a roof disfigured another man. A third man was hit on the shoulder by a brick. In Ryazanovka a fragment of a beam pierced a farmer and smashed the head of another man.

Lastly we will describe one tragicomic event. In Lefortovo the tornado devastated the chamber of a divisional judge. All the proceedings, conclusions, decisions, warnings, receipts, and indictments were scattered all over the courtyard, garden, roof and all around the building. Two defendants, who were to appear next day, came to know happily that all the evidence and materials against them had completely disappeared.

The Moscow tornado of 1904 was described in detail in contemporary Moscow newspapers. The details are given especially in the newspapers *Moskovskii listok*, Nos. 168–175, *Novosty dnya*, Nos. 755–757, and *Russkaya Pravada,* No. 76. More systematic, scientific data are provided in the papers of eyewitnesses—meteorologists Prof. Ye. Leist (1904) and Prof. V. Michelson (1904). All the diagrams (Figs. 174–178) are taken from the *Supplement to the Moskovskii Listok,* No. 175, June, 1904.

Other tornadoes: Another terrifying tornado passed to the north of Moscow on September 2, 1945. It appeared from the south from the Valentine North rail station, struck and passed over Oboldino Village (Fig. 154). Farther on it crossed the railroad, moved on Khomutovo Village, then came to an open field and struck the grove, 5 km from the village. The length of the track was 12–15 km, its width 50–300 m, its speed around 60 kmph. All along its track it destroyed and damaged structures, trees and telegraph poles. There was loss of life. In Khomutovo the tornado lifted a straw stack and dumped the compact mass a distance of 3 to 4 kilometers from the village.

On August 17, 1951, another tornado passed over north Moscow, via Skhodyna station on Oktyabrsky railroad line. An enormous thunderstorm cloud, black with a reddish tinge, appeared. It was accompanied by frequent lightning and heavy downpour and hail. The funnel of the tornado descended and lifted from the base of the cloud, at its right edge. The length of the track was about 10 km, width 200 m in the beginning and 1,000 m at the end, but it is quite likely that at this time two funnels occurred simultaneously. The tornado exhibited considerable strength, twisting and breaking big trees, tearing off roofs and damaging light buildings, but there is no account of heavy continuous destruction or loss of life (Remizov, 1954).

The next tornado occurred in the Moscow region in August, 1956. The group of tornadoes was accompanied by a strong storm on August 25. The storm was accompanied by intense thunderstorm activity and heavy hail, causing drifts at places. The storm was almost exactly in the north-northeastern direction. Its track has been traced from Naro-Fominska to the Kryukov station on the Oktyabrsk line. The strip that sustained damage was

5 km long but the belt of fallen wood typical of the tornado, had a width from a few tens to 200–300 meters. It showed successive individual spots 2–3 km long, demonstrating that the tornadoes jumped. At no point was there less than two tracks parallel to each other. The total length of the storm in the Moscow region was not less than 80 km, but it is quite likely that it started in the Kaluzhsk region and moved north from the Oktyabrsky line. No tornado funnel was observed. Eyewitnesses said that it was "a very dark whirl of cloud, frightening to look at". The possibility that the tornado was low, with diffuse outline cannot be ruled out. The damage in the forest was considerable. The roofs of houses, telegraph poles, etc. were damaged and trucks were overturned.

On August 31, in the city of Bronnits near Moscow, a second storm occurred. A dark cloud moved in and lifted dust which circulated and whistled all around. The entire destruction, concentrated in the region of Bronnits, did not show any linearity. Possibly it was not a tornado but a squally vortex storm. This is an example of how it is often difficult to differentiate a tornado from a squall storm (Dyubyuk, 1957).

One more tornado occurred over Moscow in 1957. Over the Golitsyn station, on the Kalinin railroad line, an enormous, gloomy, low cloud appeared. A strong thunderstorm started and darkness set in accompanied by the roar of the wind. Everything disappeared after a few minutes, leaving behind large-scale destruction. The sharply defined funnel was not immediately visible, but chaotic movement of small clouds was observed at the edge of the thunderstorm cloud, which was possibly the parent cloud of the tornado. The fallen timber in the forest confirmed the presence of two funnels (Kolobkov, 1975a).

The "hurricane" that hit Moscow on May 28, 1937, should be added to these cases. It sharply differed in size and form from extratropical hurricanes and it was either a squall or a diffuse tornado.

If we consider the tornado in Yaroslav region, the four tornadoes in Arzamase, the tornadoes in Murom and Kursk and many others, then it becomes clear that our country is certainly the center of considerable tornado activity. There is no doubt that many tornadoes, especially the diffuse kind, are generally taken as storms and do not receive special attention: "a storm has no special significance". Special attention is not paid to the formation of these tornadoes and the destruction caused by them. although they are quite considerable at times.

The other areas where considerable tornado activity takes place are the Pribaltic areas—Estonia, Latvia and Belorussia.

The first account of a tornado in Latvia was in 1795. It had a very long track of 160 km and width of 1.5 km. It is quite likely that it displayed a diffuse outline. Next, in 1796, six waterspouts were observed in the Gulf of Finland by Prof. Volke (described on page 318). Tornadoes and waterspouts formed relatively frequently.

On May 10, 1872, a tornado cloud of great height occurred over Latvia in the northeastern direction. It was accompanied by a heavy hailstorm. The tornado connected to the cloud brought about considerable destruction. The most interesting was the ice-coated tree branches and pieces of brick that fell from the cloud along with the hail. These showed the growth of a vertical tower vortex, going very high, in the zone of ice formation (Schweder, 1873).

On August 18, 1956, a tornado occurred over the Minsk region. The length of the track was 20–22 km. It changed all the time, bending and at times high and at times low. Moving on the collective farm, it totally destroyed all the buildings. Sixteen big cans of milk were lifted and carried away. Some were recovered beyond the village and the rest could not be traced. A horse was lifted into the air to a considerable height, carried away to a distance of 1.5 km and ultimately killed (Peryshkin, 1957).

There were 33 tornadoes in Belorussia during the period 1844 through 1953. Some of them attained great strength (Voznyachuk, 1954b). There were about 24 tornadoes in six years over the Black Sea during the thirties.

The northernmost tornado was observed near the Solovets Islands. The southernmost waterspout occurred in Tupas. Tornadoes are not rare over this long stretch, although they are not numerous either. Big, destructive, catastrophic tornadoes occur, though rarely. The tornadoes have not attracted considerable attention as they are not very dangerous to the national economy.

Western Europe

Tornadoes are numerous in Western Europe, though not as numerous as in the USA. The majority are small, with little destructive strength, but some of them in their ferocity are as good as the American tornadoes.

The first place among these is occupied by the Moneuil tornado of August 19, 1845, mentioned earlier. On a warm autumn day, on the lower Seine, an enormous, low, black thunderstorm cloud with heavy downpour and hail appeared. It moved slowly north. South of Rouen a funnel formed at the base of the cloud and quickly reached the ground. At first it was of small size. The width was about 100 m and the destruction was small. Soon it became enormous and terrifying. The width of the track became 300 m and at this moment the tornado struck the small town of Moneuil in the neighbourhood of Rouen, a paper center. Suddenly it moved on the big plant and smashed it in seconds. The plant, employing a few hundred workers, was destroyed and many people died. Boards, paper and small sheets of paper were carried a distance of 25–38 km, almost to Dieppe. Many trees were damaged. The zone of destruction was 15 km. The width of the zone in the beginning was 100 m, in the middle, in Moneuil, 300 m and at the end 60 m. This tornado was as strong as any North American tornado. Generally tornadoes in France are quite weak and do not cause large-scale destruction.

Faye (1897) has described in detail the Moneuil and other French tornadoes. The Moneuil tornado was accompanied by strong hail and thunder. It had the form of a funnel, moving at terrific speed. It struck the four-storied building of the plant and turned it into heaps of debris within seconds. The workers were left in the ruins. After a few seconds the second plant, of small size, situated near the first, was wiped out along with the workers.

Farther on the tornado turned to the left and with a slight uplift destroyed the upper and third story of the new plant building. The tornado dipped again and reached one of the best paper plants of France. The solid, massive building was made of brick. In the twinkle of an eye it was destroyed and 200 workers killed.

After destroying the three plants and killing hundreds of people the tornado climbed over the hills up slopes covered with forest and ravaged a zone of a few kilometers long. Not a single tree survived along this track. Big oak trees were broken like straws. In the middle of the forest the tornado lifted into the thunderstorm cloud and disappeared.

Very few tornadoes in the USA could destroy an enormous four-storied building in a few seconds.

The track of this tornado has been shown by Zurcher and Margolle (1883). In their paper they describe the terrifying phenomenon of the three plants reduced instantaneously to flying fragments. The tornado killed hundreds of workers; uprooted and damaged thousands of trees. All the destruction occurred in much less time than is required to read these lines. The owner of one plant had returned to his residence, 100 m away. Hearing the crash behind him, he went back and found that the plant was in ruins. He returned to his residence in a semiconscious state. His home turned to ruins before his eyes.

The descriptions of French writers are always vivid and may be somewhat exaggerated. Anyway, there is no doubt that the big brick building of the plant was demolished and that hundreds of people were killed. The demolition of the four-storied stone building of the plant is rare even in the history of tornadoes. It can be compared only with the destruction of two isolated buildings of Topeka University, which occurred in 1966.

Another strong French tornado has been described on page 323. Though it formed over the sea, it came inland and destroyed an entire village including the church.

In 1967 an intense tornado developed over northern France on June 24 and 25, to the north of Paris, and moved to northeast to Belgium and the Netherlands. The tornado was accompanied by a violent thunderstorm, hailstones up to 8 cm in diameter and very strong winds. Two individual tornadoes originated on June 24 and 25. The length of their tracks exceeded 100 km and the width varied from 100 to 150 m. They caused great loss. In just one out of the three tornadoes five people were killed, 76 were injured and 997 houses were destroyed in addition to the loss of cattle, forest, harvest and other material. One incident will suffice to describe the intensity of the tornado: 24 cows were lifted into the air and carried a distance of 300 to 600 meters; one got entangled in a tree at a height of 2 meters (Rozenan, 1968).

No destructive tornado like the Moneuil one has occurred in England. The tornado of October 27, 1913, is quite interesting. It covered a great distance: for 5 hours it moved at an average speed of 50–60 kmph and covered a distance of 290 km. The tornado was enormous, low, diffuse and galloping. It was accompanied by terrific noise, a sulfur smell and flashes of lightning without thunder. The destruction was considerable and the death toll five.

On July 21, 1965, in southern England, in the experimental botanical garden "Wisli", two student botanists noticed a large thunderstorm cloud approaching. Soon it was hanging over them and the students, turning their heads up, saw the dark, tattered fragments of cloud and the rotating tower overhead. They heard the thunder. They looked to the side and at a distance saw a flock of birds rolling in the air at enormous speed. After a few seconds, the flock came near them and the students with horror discovered that it was not a flock of birds but the funnel of a tornado, filled with branches and debris.

They started shouting a warning but it was too late. The funnel started its work and the botanical garden was badly damaged. Each tree in it was numbered and the track of the tornado could be traced in great detail. This helped greatly in determining the strength and direction of the air current in the funnel. In one tree the entire root system came out, though the trunk and the branches were not damaged. This shows that the suction upward was quite strong, but without any whirling. It looked like some giant of English fairy tales had caught hold of the large tree from the top and pulled it out of the ground. In another case a big tree 2–3 m in height was unbelievably broken and thrown aside. In front of a ragged, broken apple tree stood another tree without damage. The funnel jumped along the garden destroying one zone without damaging the next (Gilbert and Walker, 1966).

Tornadoes are seen in the rest of Europe also, but in the north they are rare and weak and in northern Scandinavia they do not occur.

One interesting episode took place during the passage of a tornado across the Rhine. At first the small funnel formed an unusual water trench with almost vertical walls of water and exposed the clay bottom. As the water got deeper, say 5–6 m, the funnel was not strong enough to expose the bottom, and as it passed over the river the entire trench (the wall and the bottom) consisted entirely of water. The bottom was again exposed on the other bank of the river.

The River Moscow is smaller than the Rhine and when the funnel of the tornado of 1904 crossed it the bottom of the river was exposed all along its track. The funnel acted as a remarkable pump. It is interesting that this gigantic water-pump—the funnel of the tornado—has its limitations. In the Rhine the water trench was not deeper than 6 m.

United States of America

The United States of America is a country of classic vortices. Numerous terrible hurricanes, enormous and destructive vortex storms and very strong and frequent tornadoes occur there. According to the latest data, more than 700 tornadoes occur every year. Many of them are accompanied by loss of life and catastrophic destruction. In 1957, 864 people died.

The duration, track, passage and area of destruction of these tornadoes are all very great. In this field the USA undoubtedly occupies first place in the world. The tornadoes are disastrous events. Mostly ordinary people are killed. In the last 10 years tens of thousands of farmers have buried thousands of their near and dear after the passage of a tornado, rebuilt their business and often started a new life.

Even in the cities the tornadoes affect the poor, living on the outskirts. The light wood, often plywood huts and houses fly into the air during strong tornadoes and break into small fragments. The owners lose their lives. The rich people live in solid stone buildings. It is true that in these houses, too, the roofs and top floors are also damaged but the owners remain unhurt. There have been cases where only the foundation of the damaged house remained and the frightened owner would emerge from the cellar or heaps of debris.

In the United States tornadoes are recorded and studied in detail. In North American meteorological literature one frequently comes across detailed descriptions of tornadoes.

We will start with the description of the most terrible tornado of the past century, the Three States. It occurred on March 18, 1925, over the three States Missouri, Illinois and Indiana (see pages 250–251; 268–270).

The funnel of the tornado was diffuse and often indistinct. Its outline was still visible at the beginning of its path but later it was obscured by cloud, saturated with dust and fragments. The black, terrible, fiercely rotating cloud moved over the ground, destroying everything in its path. Its track was remarkable—wide, sharply defined and without any break for the entire length of 350 kilometers. The tornado did not bounce, did not lift from the surface and moved forward at the speed of a train, damaging and destroying everything.

The destructive strength of the tornado was unbelievable. The photograph (Fig. 128) mentioned earlier shows the ravaged coalmine pithead and the workers' village in front. In the photograph the high, exceptionally strong, stable steel cage tower can be seen still standing but it is bent and unusable. Whatever could be torn off and taken away disappeared without trace. In front of it stood a structural frame of reinforced concrete. The frame remained, but nothing else was left in it except air and small fragments. The workers' village was a terrible sight. It is awful to see, even in the photograph. Nothing remained there—neither the buildings, nor the streets, nor the gardens. Everything became a continuous cover of debris and people were buried under the debris. Among the trees, one bare trunk remained; all the leaves and branches including the biggest were stripped off.

The toll of deaths and injuries during the tornado was 695 and 2027 respectively. The loss was of the order of 40 million dollars. Such was the action of this terrible tornado.

Very little detail of individual events survives but even the dry official statistics of destruction are quite terrifying.

The complete description of the tornado of May 29 and 30, 1879, is quite interesting. It is given by a sergeant of the Signal Corps of the US Army, John Finley (1881)—a meteorologist. The description is official and detailed, without color, but in any case it is quite horrifying. A brief summary of the description follows. The original description covers 116 large pages with a series of illustrative maps showing the tracks of the individual tornadoes. The maximum destruction and loss of life were associated with the strongest and longest-lasting tornado "Irving", named after the township that was totally destroyed. Figures 179–193 have been taken from this book.

Irving tornado: On May 30, 1879, at 4 in the afternoon, to the south of the small town of Irwing north of Kansas, over the high plains two unusual clouds, black and dense, appeared hanging over the ground. Soon they merged into one cloud in which violent rotation started. Individual bits of cloud with lightning moved quite fast. Rain and strong hail started. The funnel originated after 15 minutes in the base of the cloud. It quickly lengthened, took on the form of a large trunk and reached the ground. Slowly the destruction started. It continued for 3 hours during which the tornado covered a track of 150 km (Fig. 179).

There were not many farms in the plains and they were situated to one side. The tornado's track was such that it tore up three buildings and destroyed many outhouses.

During this time another funnel of small size appeared and this moved to the ravine east of the track of the main tornado. The second tornado was also quite strong. One house was slightly lifted up and turned over. In two other houses the roofs were damaged and in a third the kitchen wing disappeared. It vanished at such speed that no one saw what became of it.

From the watershed, each funnel crossed the small valley, where the city of Randolf is situated 13 km to the east. Trembling, the inhabitants of the town heard the terrible roar, resembling the noise of thousands of freight

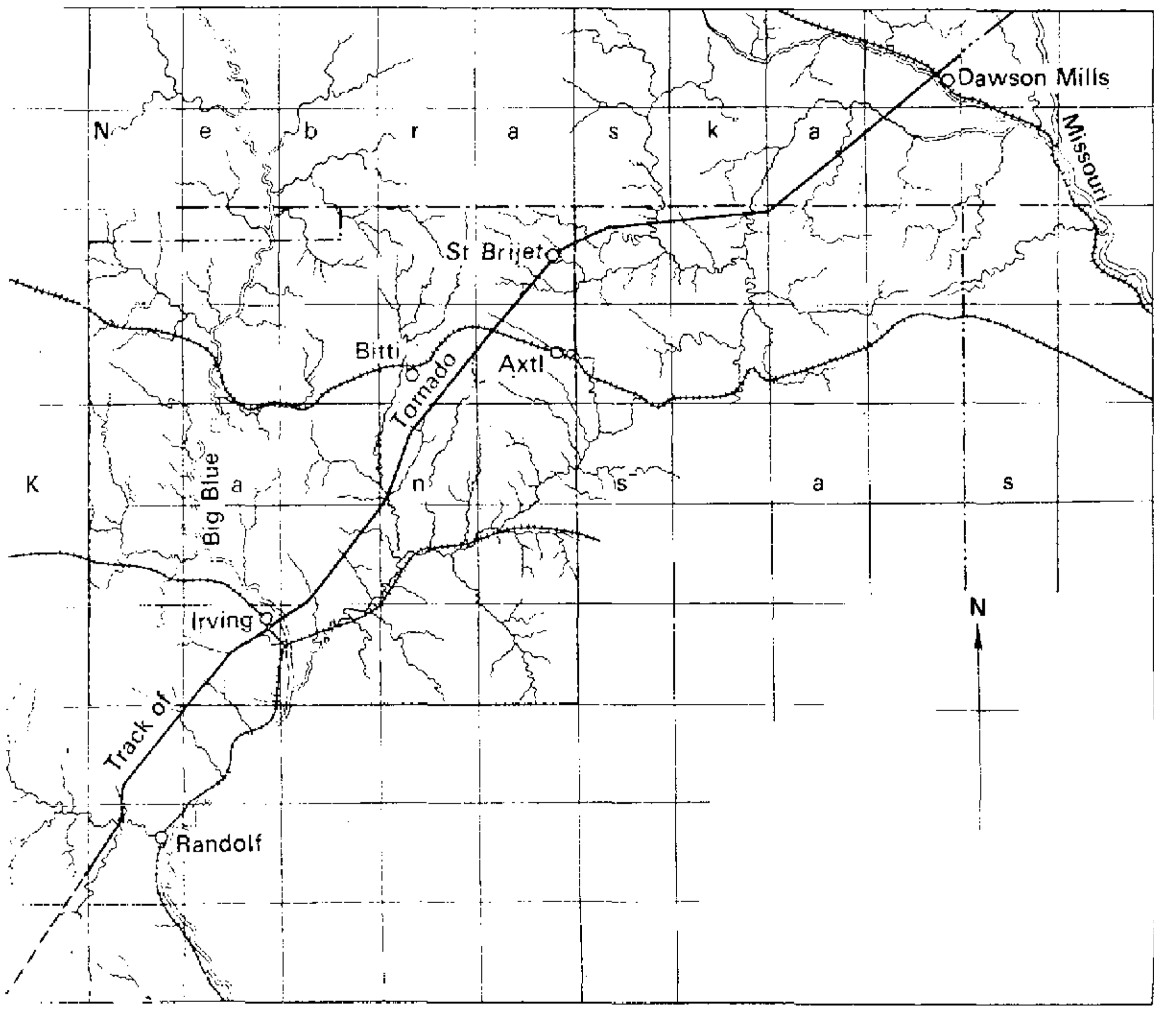

Fig. 179. Track of Irving tornado (Finley, 1881).

engines going down the street, and observed its fury in the thick forest. Big oak trees more than 1 meter across were broken like twigs. The thick, supple elm trees were twisted like ropes. The recently-built stone church and the big threshing barn also of stone, were destroyed. The main funnel struck the big, two-storied building made of solid stone. It did not destroy it completely but the roof was blown away and the first floor was ravaged. Large stones weighing up to 100 kg were carried away to a distance of 80 m. This is one evidence of the unusual strength of the tornado. Fortunately Randolf City was to one side.

On the other side of the valley, the two funnels joined up, but from the side of the main (left) funnel two more funnels originated. They did not reach the ground. They disappeared on the other side of the valley.

The main funnel turned into the adjoining valley, went a little way up it and again lifted to the plain near the edge of the ravine. The destruction was continuous. The new building of the school made of stone stood in its path in the valley of Nors Otter. Its roof was torn off and one wall collapsed and fell partly inside. Fortunately the tornado had been noticed earlier: the students had run to the next house and were saved. But none of the neighboring houses remained intact: the stone house of Adam Swein with a wooden upper story was damaged instantaneously. His father was seriously hurt. His mother had minor injuries but the baby in her arms was killed instantaneously. The little girl's head was smashed against a rafter. The remaining five children and three school-going children had minor injuries. The furniture was destroyed and clothes torn to shreds. Some of them were found on tree branches 2 km from the house. The cots, linen, vessels, etc. were damaged and strewn all over the path of the funnel. The trees standing near the house were transformed into smooth, stripped sticks.

After destroying the school and Swein's house the tornado cut a terrible swath through the forest covering the valley. The width of the track was about 80 m and everything was destroyed: trees and bushes, big and small, high and low, without distinction were broken, uprooted, twisted and stripped.

Coming to the plains, the funnel was so oriented that the roof of a house not far from its track was carried away. In the plains the grass was ripped up as if it had been plowed. Now the funnel lifted up into the air, temporarily suspending the destruction. It did not go very high in the air, occasionally hitting the tops of trees or buildings. In all cases the mark of the air blast was a straight line oriented along the movement of the funnels. The mark of rotation, generally very distinct, was absent.

After traveling a few kilometers above the ground the funnel came down to the surface again and started terrible vortex destruction. There were four houses on a small path of low land and not one board could be traced there afterward. In the house of Robert Reed a very unusual, almost unbelievable, fairy tale-like event occurred: the single-storied house of 5×8 m was lifted up almost whole into the air along with the owner. The air was filled with thick dust and it was quite dark. The owner, not realizing what had happened, wanted to leave the house, opened the door and stepped out. He fell from a height of 10 m and was seriously injured. Even after describing it, one finds it difficult to believe. But everything is possible with tornadoes. In another house the owner was killed by a log.

Coming from the depression, the funnel rushed down to Irwing along the valley of Gem Fork. Here another group of small houses stood in its track. All these houses were destroyed and one of the owners was killed. A remarkable thing occurred in the old house of Henry Wilson. The house was made of heavy logs and had an enormous chimney, made of stone, with a width of 2–3 m and a height of 6–8 m. The entire house was lifted into the air and broken into pieces. Surprisingly, the large family of 13 survived. This can happen only when the explosion takes place from within. All the logs flew outward. If even one log had fallen inside it would certainly have crushed someone.

The funnel dashed downhill. Eyewitnesses were shocked to see its terrifying form. The black, enormous column swept the steep side with thick vegetation which instantaneously became yellow, exposed ground.

In its track, the funnel encountered a new single-storied house. Of this house only 5–6 stones of the foundation and a few slabs remained. The rest of the material disappeared. The house owners were rescued from the cellar.

But a serious tragedy took place in the neighboring house of one Backmaster. He had come to the place recently and had built a small, wooden house in the meadow. They postponed digging of the cellar and no one warned them. When the terrible funnel struck, they were unprepared. The house disappeared as though it had not been there. Not a single board was left behind. The entire family was swept away. One girl was carried a distance of 150 m to the east, another 200 m to the south, the third 125 m to the northwest and the fourth 165 m to the northwest. The mother was carried a distance of 225 m to the northeast and thrown to the ground. They were all dead and lying stark naked on the ground. The father was dropped not far from the house and was seriously injured. He had only a piece of cloth on him.

Soon the tornado moved away from the valley and struck the small, quiet locality of Irving, with 300 people, situated on the bank of a big, calm river, having the poetic name The Big Blue. It was not far from the locality when the funnel of the tornado lifted and tossed into the water the big iron bridge across the river. The horror was intensified because another funnel originated here and passed through the same locality by another track (Fig. 180).

The first house destroyed by the main funnel (No. 1), is marked No. 1 in Fig. 180. It was an old house and nothing remained of it. A baby was carried away to a distance of 150 m and deposited in the field. A little girl was found at the same distance but in the ravine. The other four members of the family, including the father and mother, were thrown to a distance of 50–75 m. Their clothes were torn to pieces. All of them were carried to the east and all of them died.

Soon the tornado moved to another, stronger, single-storied house (No. 2). It was lifted to a height of 6 m in the air and carried a distance of 35 m to the northeast. The family of five members were inside the house. Then the house literally collapsed: the walls, roofs, pipes—all were thrown aside in different directions and the family along with the floor dropped to the ground. The mother was carried to a distance of 200 m, two children to a distance of 100 m to the east, and the father with the third child to a distance of 75 m. Their clothes were badly torn and they were thoroughly smeared with black soot. But everyone was alive.

After going a certain distance the funnel struck the house (No. 3) of Captain Armstrong. The big, solid, new, two-storied house was first pushed

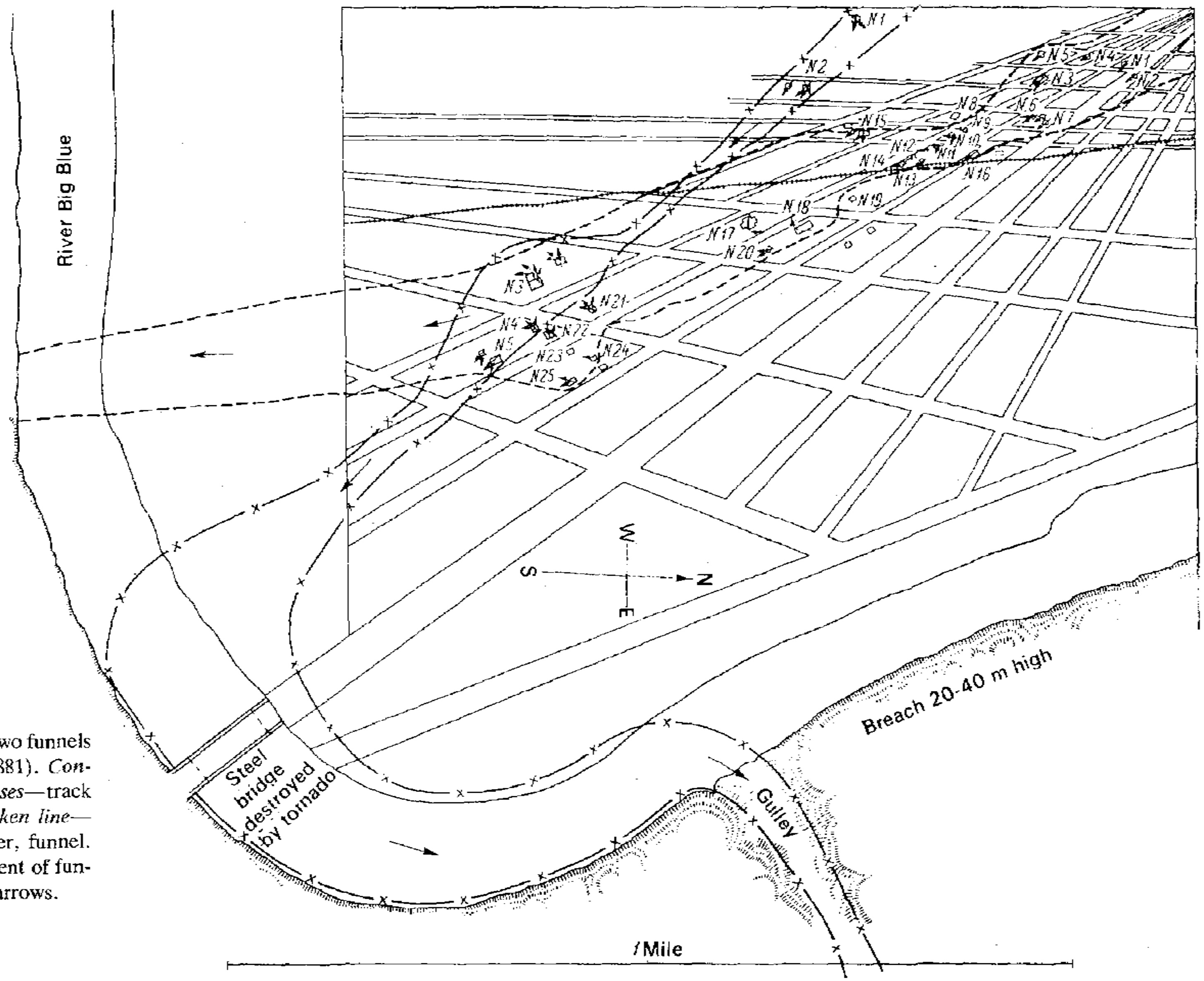

Fig. 180. Tracks of two funnels in Irving (Finley, 1881). *Continuous line with crosses*—track of main funnel; *broken line*—track of second, later, funnel. Direction of movement of funnels is shown by arrows.

to one side and then turned into debris, carried to a distance of 400 to 1,200 m. A large, heavy wagon loaded with logs to the top, disappeared as if it had not existed. From a well-to-do, well-furnished house, only the lower part of the bare walls remained. Everything was carried a distance of not less than 150 m and destroyed. Letters were blown to farms 10 km away. The lightning conductors and thick cables were twisted like ropes. All the solid objects were either broken or badly deformed. What took 10 years to build was destroyed in a few seconds.

Farther along the tornado destroyed either partly or completely two small structures (Nos. 4 and 5) and then moved over the open fields towards the river. The most surprising thing happened here. After crossing the Big Blue the funnel encountered the steep bank, but could not surmount it and deviated to the west. Meanwhile its strength increased rapidly and when it encountered the new iron bridge in its path, it was lifted up and tossed into the water. The funnel now traveled along the cliff to the first ravine, turned toward it and resumed its former northeastern direction. Here we will pause to look at the bridge.

The iron bridge was new. It was 75 m long and the track of the tornado lay right across it. The funnel just touched it and lifted it up so fast that the stone pillars on which the bridge rested were not damaged at all. On one pillar even the top layer of cement was intact and from another only two stone blocks were removed. The funnel lifted the enormous steel structure into the air, and twisted it beyond recognition with exceptional strength. The entire bridge became a thick bundle of steel plates and cables, snapped and bent in a fantastic way. The bundle was so compact and of such small diameter that it totally disappeared in the water, though the depth of the river was only 1.5–2 m. The bridge blew off the pillars into the water in a few seconds: in this time, the complex, beautiful, solid structure became just a long bundle. Such was the strength of rotation in the walls of the funnel. Its speed was undoubtedly supersonic. According to Finley the destruction of the Irving bridge shows that the power of the tornado here was the strongest among the well-known tornadoes.

The second tornado hit Irving 10 minutes after the first and differed considerably from the former. The funnel was not sharply defined but its destructive strength was greater. Probably it was a low, wide tornado with diffuse outline. From a close distance it resembled a black cloud, a strong storm, moving straight along, but the signs of rotation were obvious. Its track was in a northeastern direction and the width varied from 100 to 300 m. The destruction was terrible. At places the track widened to 1,500–2,000 m.

A heavy downpour occurred after the passage of the first tornado and it was accompanied by a gusty wind, literally lifting people off their feet. After this everything was quiet and there was sunshine, but then once again enormous thunderstorm clouds appeared all around. After 40 minutes an unusually dense black cloud appeared on the horizon. As it came nearer it got darker and darker, terrifying even the bravest. The unfortunate inhabitants, who had just recovered from the shock of the first tornado, lost their wits at the appearance of a new tornado and there was terror everywhere. Many thought this was the end of the world. The moving cloud was enormous. The towering black cloud was 2 km wide and it reached from the ground to the sky. The thought that it would inevitably strike the city terrified the inhabitants.

At first the tornado struck a group of 18 houses to the north of the railroad track (Fig. 180). Almost all of them were destroyed from the foundations. Destroying the first two houses (Nos. 1 and 2), the tornado moved to the big, two-storied stone building of the school, damaged the south corner of the building and carried away the roof. The school teacher wrote: "Our first feeling was as if the entire building had been lifted, roughly shaken and let down again. In the next instant all the doors and windows were broken, the furniture was thrown about in the room and broken into pieces. I was engulfed by the gusty wind; whirled in the air, carried to the neighboring room and slowly lowered to the floor. My clothes were torn to pieces but my body had no bruises. When I stood up on my feet it was so dark that I could not see anything."

Two neighboring wooden buildings (Nos. 6 and 7) were carried away, leaving behind only fragments. From one house the father, mother and grandfather were carried away a distance of 200 m and thrown to the ground almost dead. The mother's head was thrust into the ground to the shoulder, her dress was torn and the entire body was smeared with dirt. Three children were carried to a distance of 100 m, their clothes were torn and smeared with mud but none of them was seriously injured.

A neighboring building (No. 8) belonged to the rich local banker and was exceptionally strong, meant for "Kansas weather". The house was slightly to the side of the main track. Even the edge of the funnel broke the steel bolts connecting the wall to the foundation, like threads, lifted the corner of the house so that the inside of the building could be seen, jerked it and put it back in the original place. The family was rescued from the cellar.

A big stone building (No. 9) stood near the track of the tornado and was turned into heaps of debris; the roof was torn off, broken and carried away. The house was empty. Nothing remained of the frame house nextdoor (No. 10). The mother and four children were thrown into the street and were seriously injured.

Four frame houses (Nos. 11, 12, 13, 14,) now stood in the path of the funnel. Here the destruction and loss of life were maximum. The first house with the entire family was lifted up into the air, whirled a number of times and then broke into pieces. The members of the family were dropped on the ground and were seriously injured. A hired laborer was carried several meters in the air and his ribs and hands were fractured. The second house was seriously damaged and carried to a field in the form of very small fragments. Nothing was left behind at the original site. The occupants were carried a considerable distance and were seriously injured. The woman's dress was torn to shreds and she was covered with a thick layer of dirt.

The third house was lifted into the air, carried over the fence and broken into pieces. From the trees standing near the house not only the leaves and branches but also the bark was removed. Bare sticks were left standing with pieces of cloth, long plains grass and papers. All around to a distance of 150–200 m pieces of chairs, sofas, cots, plates and vessels mixed with fragments of bricks, planks and pieces of glass were scattered.

An interesting thing happened to the house (No. 15) of an another banker, which was the strongest in the entire town. The house was empty at the time. The entire house, the two stories and the attic, was lifted up, turned upside down and broken to pieces. The kitchen annex was first lifted up and then dragged a distance of 30 m and broken into pieces. Part of the roof was carried a distance of 800 m. The most important sign of this tornado here is its sharp definition. A light shed standing at a distance of 15 m from the kitchen remained undisturbed. A small fruit tree at a distance of 10–15 m from the house was not damaged.

After crossing the banker's house the funnel approached the rail station (Fig. 180). An elevator (No. 16) was destroyed; the depot 100 m to the north was badly shaken but remained intact. The freight cars, standing next to the elevator were lifted, turned in different directions and thrown on the ground. Neighboring cars remained on the rails.

After crossing the rail track the funnel moved across open ground where the school (No. 17) was situated and the church not far from it. The funnel moved in between. The school was a solid stone building in the form of a cross (Fig. 181), 10 × 15 m in size and almost of the same height. There was a church tower in front and three women standing inside observed the whole thing. They described how the funnel moved on the school and engulfed it in a madly whirling black cloud. The fragments whirled around at terrific speed but were not thrown out of the funnel. When the funnel disappeared, the debris remained on the foundation, forming a conical heap (Fig. 181). Fortunately there was no one in the school.

The destruction of the church (No. 18), standing at a distance of 70 m from the school was peculiar. Only one wall of the main building remained intact: the remaining walls were all destroyed (Fig. 182). The church tower, standing in isolation, was leaning over slightly as the doors and windows did not open and cracked in the middle. There were three women in the church at that time. They could hardly have been expected to survive but they were not even hurt.

According to eyewitnesses, when the tornado cloud passed over this area it formed two funnels. One of them destroyed the school and the other the church.

In this area stood the last group of six houses. One of them (No. 20) of

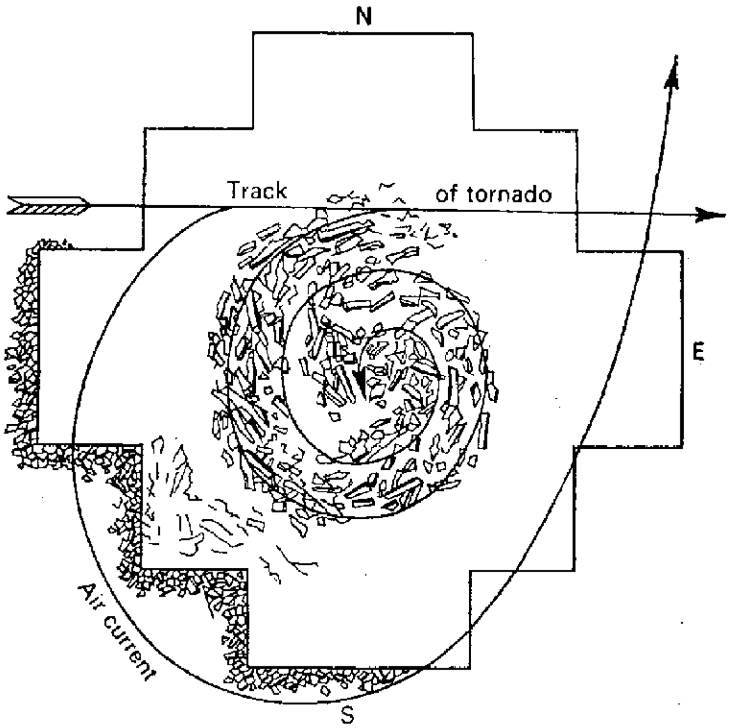

Fig. 181. School in Irving. Debris left on and near foundation (Finley, 1881).

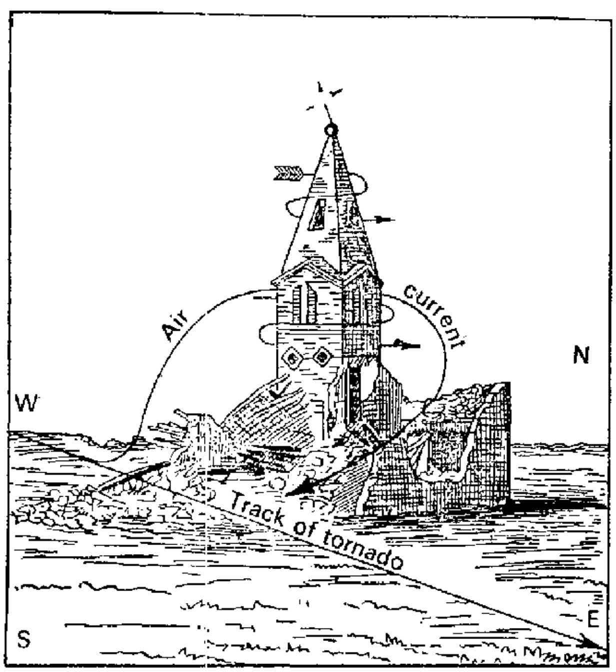

Fig. 182. Church destroyed by tornado. Church bell was turned over (Finley, 1881).

5×6 m size was lifted whole into the air, carried a distance of 45 m and turned into heaps of debris. The second (No. 21) house was also destroyed. The same thing happened to the third house (No. 22) but the annex to the kitchen, where some families had taken shelter, remained undisturbed. Only the woman of the house, who had gone in search of her children, was in the main building, which was destroyed at that moment. One woman was killed but the baby in her arms was unhurt. The kitchen was only 9 m away from the main building.

Farther on the track of the funnel sharply narrowed down; a frame house (No. 23) was entirely covered in dark cloud and shaken but remained intact. It was on the edge of the tornado's track.

The rear of the next house (No. 25) fell in the middle of the track. Nothing remained of it. The debris was thrown on the ground but some was carried 5 km to the plains.

In the next house the threshing floor was destroyed but the house was almost intact.

Farther on the funnel came down over an open field, moved to the Big Blue River, crossed it, cut a swath of fallen trees and climbed over the steep bank. After crossing the plain for a short distance it became bright, broke into a few clouds and disappeared.

The main funnel continued its long traverse, but before coming to that let us have a look at one of the surprising incidents in Irving—the flight of a cow over the forest. This happened when the tornado approached Irving and was deep inside the valley. A farm was situated on the eastern edge of the track and a cow was tethered nearby. When the tornado hit, the cow was lifted up and disappeared. After a while it landed on another farm on the opposite side of the valley with the rope still tied to its horns. Its body was badly smeared with clay. The flight path showed that it first flew through the air for a distance of 100 m. In the middle of the valley the cow was thrown into a mud patch. Then the air current again lifted it and carried it over a forest of trees 9 to 18 m high. It soft-landed at a distance of 700 m from the original place and was found there. Unfortunately no one saw it flying over the forest. The spectacle must have been unusual. The flight of a cow over a forest is after all not so common. The forest, which it flew over was so dense and thick that it could not possibly have come through it. It could not have covered this distance by any other means except by flying through the air. The length of the flight was 500–750 m. It was a narrow, windbreak type forest (Fig. 183).

Approaching the valley via the ravine, the tornado moved to the north-east, almost in a straight line (Fig. 179). It passed over hilly terrain with scanty settlements, without towns or villages. Only a few farms, far from one another, were lost. However, the damage here was quite severe and several lives were lost.

The tornado destroyed the farms and outhouses and machinery in cover-

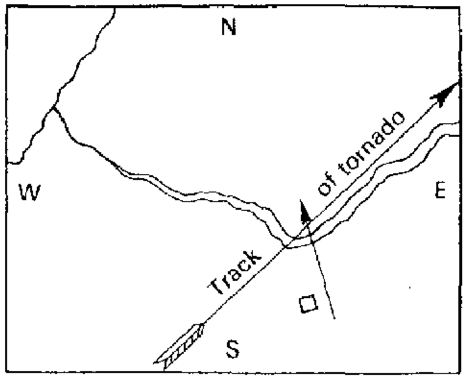

Fig. 183. Track of flight of cow over forest, via river (shown by arrows) (Finley, 1881).

ing a few kilometers in the valley. Only the debris scattered in the wake of the funnel and the family of a farmer that survived in the cellar, trembling with fear, were left. Another house stood nearby, but on its side. Only a corner of the roof was damaged. Farther on an entire farm was destroyed but the neighboring house was only turned on its side and remained intact.

The funnel descended on the valley of Johnson Brench and carried away a complete house including the foundation. Only the bare land remained. The house nextdoor was damaged but the debris remained at the site.

An incident took place on the other side of the river which is as good as the cow episode at Irwing. After destroying the house of a Mr. Fitch, the funnel engulfed his son and lifted him up. The boy was blown over the forest and the river and then dropped gently without suffering any injury.

Another six houses were removed downstream along the river. Returning to the plains, the funnel approached the next river, destroying another farm on the way. The funnel lowered over the valley and then lifted again over the plain with a small current of air. Many houses of farmers, big and small, stood in the valley of this river and its water channel. The width of the track of the tornado here was enormous, 1–1.5 km, and the destruction was also considerable.

Three farms in Vermilion were destroyed. There were many chickens in a fowl house on one farm. The fowl house was damaged and the feathers of the chickens vanished. Some of them were alive and ran about in that condition. Dead chickens were found along the track of the tornado.

The city of Frankfurt stood 5 km below. The tornado was not felt here, although the thunderstorm cloud passed over it, accompanied by storm, rain and hail. There was no major damage. This shows that the thunderstorm cloud, to which the tornado was attached, had attained a large size.

After crossing Vermilion the funnel rose up over the low-lying watershed between the two rivers (Fig. 179). Here a rather rare phenomenon occurred:

the width of the zone of destruction was about 2.5–3.0 km. However, besides this funnel an additional vortex of great strength had developed around it and caused large-scale destruction.

The first house was destroyed and the housewife was killed by a falling log. The second house was partly destroyed. The third house, standing on a small hill, was destroyed and nothing was left behind. The occupants were carried away a few hundred meters and killed. The fourth house was badly damaged. The owner was engulfed by the wind and he, too, was killed. The fifth and sixth houses were carried to the northeast, the seventh and eighth houses, standing a few kilometers away, were carried north and northwest. The roofs of the next three houses were torn off. The twelfth and the thirteenth houses were thrown on different sides, and this underlines the rotation of the funnel. The fourteenth house also disappeared.

The width of the destructive zone here was unusual: 4 km to the east of the center of the tornado and 2.5 km to the west. Fortunately, the tornado here returned to the desert plains and there was practically nothing to destroy.

Still, the tornado destroyed two farms and one district school. Only the foundation of the latter remained. Next the walls and roof of a house were lifted whole and turned into debris over the heads of a family of three who were in a field and escaped with minor injuries. An interesting thing happened to a round 2 kg weight. It was carried a distance of 200 m. A tin sheet was carried a distance of 2.5 km and its corner penetrated 1.5 cm into a tree.

In the high plain the track of the tornado again narrowed down and passed between two small towns—Bitti in the west and Akstl in the east (Fig. 170). The strength remained what it had been. Passing over a farm, it lifted up an entire house. The house disappeared into the whirling mass of black cloud. The farmer with his family had taken shelter in the cellar and saw the house flying over their heads.

The town Bitti is on a hill from which the entire plain where the tornado passed could be seen. An old man, a resident of Bitti, described the funnel as "hanging obliquely in the air (Fig. 184) for some time, then it lowered to the ground, became straight and its base formed a wide, low cone of the dust. During this time a distinct whistle, like that of several trains, was heard".

The thunderstorm tornado cloud here was of enormous size and covered each town. It was accompanied by stormy wind, a heavy downpour and large hailstones.

After crossing the rail track near Bitti and Akstl, the tornado changed direction and for 15 km traveled over areas almost devoid of habitation. The funnel could be seen clearly from Bitti. It lifted up, immediately bent and again moved over the ground. Only one farm was encountered on the way. One house stood in a clearing in the forest. It was lifted up, carried over the trees whole and broken into pieces.

Then the tornado struck a small place. North Bridget. As the name

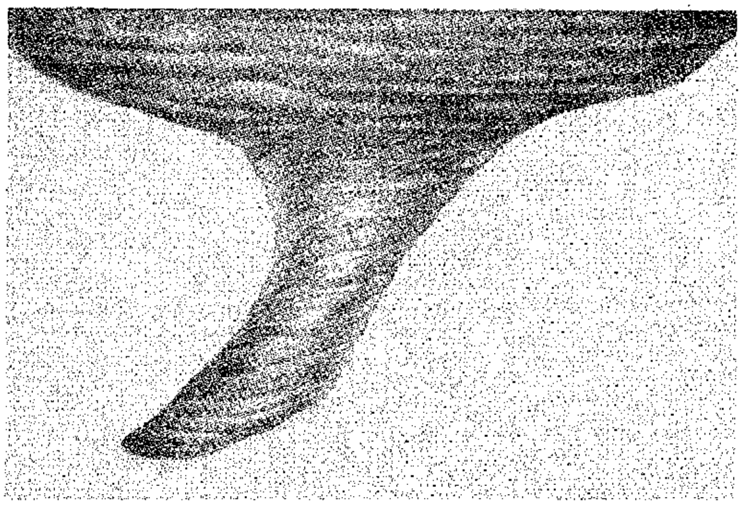

Fig. 184. Irving tornado over Bitti town. Funnel hangs obliquely in air, almost touching ground (Finley, 1881).

suggests, a small Roman Catholic mission was situated here. The monk heading the mission said that the tornado struck at 6.30 p.m. with a terrific howl and whistle. The wide, basket-shaped funnel (Fig. 185) furiously rotated and abruptly enveloped the mission in darkness, wrapping it with impenetrable black cloud. After a few seconds the cloud disappeared, but the old building of the school disappeared along with it. The new two-storied building would also have been blown away, but fortunately the walls were joined strongly to the foundation with big bolts. The building shook and the pipes collapsed, but it remained intact thanks to the bolts. Only all the doors and windows were blown out.

The tornado now passed over a thinly populated area, covering a distance of 5 km from the mission, and destroyed a small house. After a few kilometers an exceptionally strong house made of big logs was damaged. Near the slope the funnel struck a small stone building. Nothing remained of it. Individual stones were carried a distance of 250–400 m.

A forest of big old trees was situated up the slope. The funnel cut a swath of broken trees 3 km long in a few seconds. There was considerable damage to the trees. They fell one on the other in spiral form, showing that this was the pattern of air circulation (Fig. 186).

Crossing the forest, the funnel again came over the open plain. The new district school was located here at a road intersection. The vortex struck the southern end, broke the door, lifted the building from the foundation and carried it a distance of 18 m to the north. Here the building disintegrated and the fragments were carried north and northeast.

A big stone building was situated at a distance of one kilometer from the school. It remained intact but the roof was removed. Part of it was found not far from the building, but the rest disappeared altogether. It could not be traced in spite of a thorough search.

The width of the track here was about 300 m. When the tornado struck at 1845 hours the sun was low. The sunset was calm but it was quite cold.

Destroying one more building, the funnel lifted up and traveled 2 km south to the small town of Cincinnati (Fig. 179). Though it had started getting dark it was clearly visible from the town in the form of a long keg hanging from the cloud. There was no sign of destruction on this track.

Crossing Cincinnati, the funnel lowered to the ground for a short time, formed a swath of fallen trees, again lifted up and changed direction to northeast. It moved in the air over the plain for 15 km before dropping for the last time and wreaking destruction in the small town of Dawson Mills on the River Nemakh. At 1910 hours it was dark and the funnel was not clearly visible, but the destructive force was as great as at Irving.

Two houses at Dawson and Riley stood on a small hill. The house at Riley was exceptionally strong, made of big oak logs and beams. The vortex lifted it from its base and broke it to pieces. Some fragments were found at a distance of 1 kilometer and two-thirds of the massive floorboards altogether disappeared. The enormous beams flew a distance of 200 to 300 m. On the other side of the track of the tornado was the big Dawson threshing barn. This was stronger than the house at Riley. Nothing was left of it. The grass, hay, pieces of boards from the house at Riley, etc. were thrown along the track of the funnel for not less than 1 kilometer. The house at Dawson and the firewood kept not far from the threshing barn remained untouched.

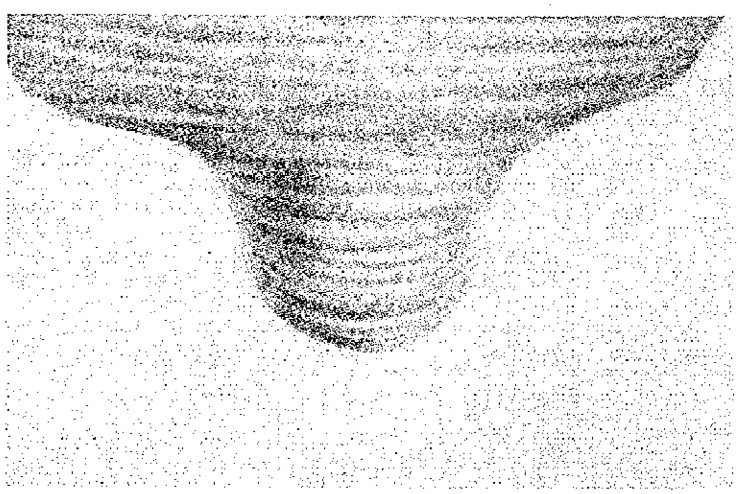

Fig. 185. Basket-shaped funnel North Bridget (Finley, 1881).

The last and most surprising incident concerned the Catholic church. The big wooden building of 8 × 15 m size was lifted whole from its base and carried a distance of 4 m. After landing on the ground the building continued to move over the ground for a distance of 2 m, digging a trench 0.5 m deep.

After this the building disintegrated. A service was going on in the church and there were about 50 people inside when the tornado struck. The feeling of the people when the entire church was lifted and then moved over the surface can well be imagined. Fortunately many soon realised and shouted "tornado, tornado" and wisely crawled under the benches where they had been sitting. This saved them from the bits of ceiling falling from above. There were many injuries, some quite serious, but there was no loss of life.

With this surprising incident, the Irving tornado concluded its destructive activity, lifted up into the air and disappeared in the darkness.

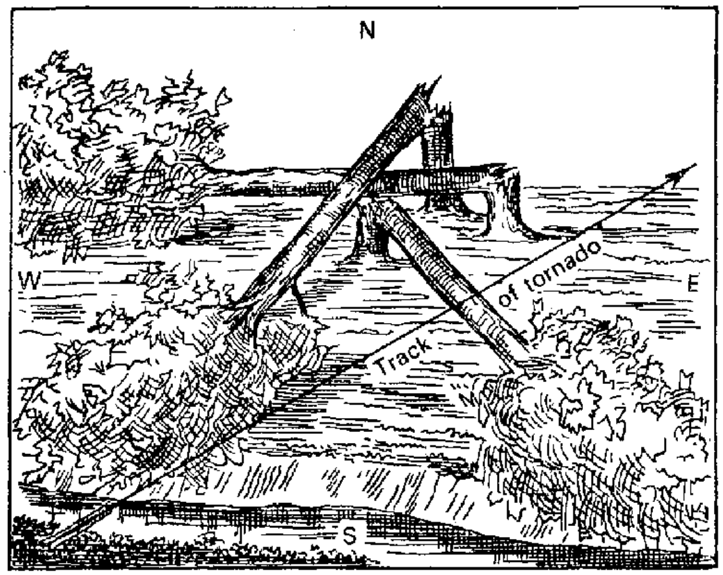

Fig. 186. Trees, broken by spiral air circulation (Finley, 1881).

The parent tornado-thunderstorm cloud continued its journey to the northeast. It was accompanied by squally winds and caused destruction at a number of points, but it had ceased to be a tornado.

The epic Irving tornado had a strikingly long track with continuous destruction. It damaged hundreds of buildings, killed dozens of people, carried a cow and a boy over a forest, lifted an enormous iron bridge and threw it into the river and left plucked chickens running about the fields. But for a big tornado these are usual phenomena.

Delfos tornado: The Delfos tornado is named for the locality of Delfos in Kansas. It is related to the group of tornadoes of May 29 and 30 and the Irving tornado. It is quite likely that it is related to the same enormous high thunderstorm cloud that spawned the Irving tornado and eight others, killing 42 people and causing large-scale destruction (Fig. 187). This cloud appeared over Kansas after midday. The first funnel was formed around 2 in the afternoon, the next, around 6 p.m.

The Delfoss funnel originated at 3 o'clock and disappeared at 4.25 p.m.

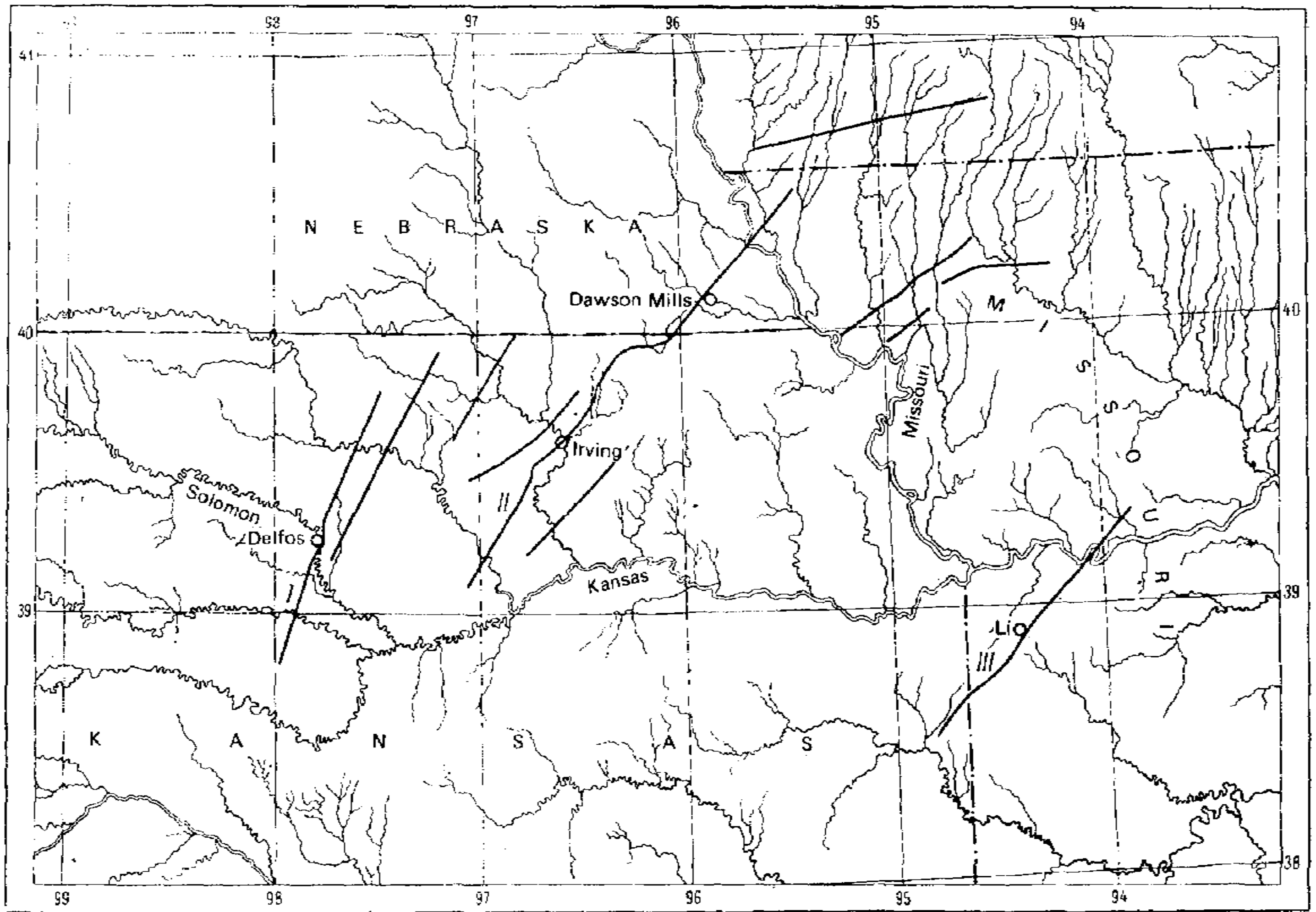

Fig. 187. Map showing tracks of tornadoes of May 29 and 30, 1879 (Finley, 1881). *Thick straight black lines*—tracks of tornadoes. *I*—Delfos tornado; *II*—Irving tornado; *III*—Li tornado.

During this time it covered a distance of 70 km at a speed of 50 kmph. It was second in fury only to the Irving tornado.

It is also described by Sergeant Finley (1881), who described the Irving tornado.

There was a terrible drought in the second half of May. The first half of May 30 was especially hot and humid, as before a thunderstorm, and at about 3 o'clock in the afternoon the black thunderstorm cloud appeared to the southwest of the big city of Minneapolis. It increased in size, moved fast and violent rotation started like a whirlpool. Many inhabitants of the town, including the editor of the local newspaper, watched what was happening in the sky. The area of rotation decreased, its speed became still greater, and funnels, big and small, started appearing from the cloud. It became clear that a tornado was forming and one was not afraid of tornadoes in Kansas.

The funnels appeared and disappeared. At least one of them touched the ground, immediately lifted and again touched down. Crossing the River Salin, it damaged the tops of trees but did not form a zone of fallen timber. It rushed past, high over one building and did not damage it. The funnel lowered down after it crossed the river. The roof of a house falling in its path was at first damaged and then destroyed altogether. The storage shed of the house nextdoor was destroyed but the house itself remained intact.

The funnel lifted from the surface again, but this time it was for a short while. It again lowered and moved almost in a straight line to the River Salt Creek.

New, unusual, phenomena occurred on this stretch of the track. An observer described how after the prolonged drought, the enormous, low, black thunderstorm cloud appeared on a heavy, hot morning. At this time he was working in the fields. Suddenly a big mass dropped not far from the cloud and hit the ground, causing a pit 17 cm long and 20 cm wide. A chunk of ice of angular, irregular form had fallen. It weighed 3 pounds. Then another dropped nearby, slightly smaller, then a third. Then a severe hailstorm started but it also ended quickly. Another man observed a few hailstones of unusual size. One had a circumference of 32 cm, another 38 cm. This is the size of a child's head.

Crossing Salt Creek, the funnel tore off the roof of a house and the storehouse nearby and moved over the open plain. The most devastating destruction started over the River Solomon and continued all the way to the locality of Delfos. The locality, however, remained intact.

The first house before the River Solomon stood in the middle of the path of the tornado. The single-storied house of 5×9 m size was lifted whole into the air, carried a distance of 30 m and thrown to the ground, transforming it into a heap of debris.

Two houses were situated not far from the river (Fig. 188). One of them belonged to one Mac Braide. He took shelter in the cellar but his father died of injuries received from a falling beam. A worker was carried away from the house to the west and then dropped on the ground, fracturing his hands and legs. The house, 6 × 9 m in size, was first thrown a distance of 3 m to the north, then 4 m to the northwest and destroyed at this place. Logs fell in the well and all the water was sucked up. A few bundles of dollar bills had been kept in a heavy, sealed, iron box. The bundles were carefully tied and placed in a bag. The tornado broke open the box, tore up the bag and scattered the bills all around.

Another house, belonging to a Mr. King, was lifted whole from the foundation and carried a distance of 90 m to the bank of the river (Fig. 188). It remained almost intact, with slight damage, after this flight.

Crossing the river, the track of the tornado widened to 2.5 km and passed over the forest. Big old trees were broken and the younger trees were twisted like ropes. Many trees were stripped of leaves and branches and only the bare trunks were left. The mass of fallen timber dammed the river, forming a small lake. Many observed that when the funnel crossed the river its bottom was exposed along the track, like that of the Moscow River during the tornado of 1904.

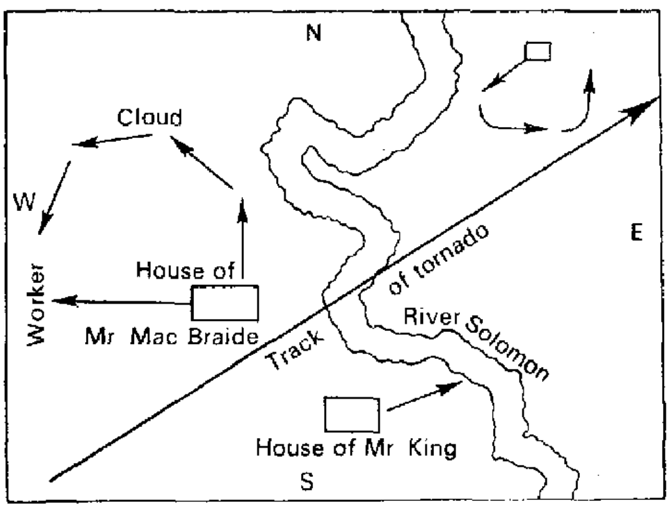

Fig. 188. Position of destroyed houses on River Solomon (Finley, 1880).

Sucking water and mud from the bottom of the river, the funnel of the tornado turned into an enormous mass of air, water and mud, rotating at furious speed. Its destructive strength increased steadily and when it passed over the house of one Mr. Kron the picture was inconceivable.

The entire surface was saturated with water and covered with black, dense dirt. Animals and human beings were left in the same condition. They were also covered with dirt, an enormous mass of debris and fragments. Women and children with torn clothes were lying among pigs and horses. From time to time hands and legs lifted from the mass of debris and moans were heard. The moaning of people and the cries of animals were drowned in the howl and crackle of the tornado.

Kron came out of his house after hearing a distant whistle, like that of 100 locomotives. At a distance of 3 km he saw the gigantic dark funnel, with sharp definition, moving along the ground and saturated with fragments. It thickened and thinned continuously and bent regularly. He returned to his house shouting "tornado, tornado, get out of the house immediately". There were 20 people in the house. Everyone started running, but it was too late. The gigantic funnel engulfed the owner, threw him onto the ground, lifted him up and rolled him along the ground. Kron himself, though alive, was seriously hurt. With others it was much worse. His daughter, running with her father, was lifted into the air, carried a distance of 200 m and thrown on some barbed wire fencing. Her clothes were shredded and her body and hair were smeared with dirt. She died on the spot. The stakes on which the barbed wire was fixed were uprooted, the wire was snapped and coiled into an irregular ball. Mr. Kron's son was carried into the field in the twinkling of an eye and died there. A wooden plank pierced the leg of another daughter and made a 15 cm long cut. The wound was full of nails, dirt, etc. Women were particularly badly hurt. Their clothes were badly torn and their hair was so dirty that it could not be washed and had to be cut altogether.

Two men in search of shelter were hurt in tragic circumstances. One crawled into the storehouse, which was lifted up along with him. It was thrown on the ground, again lifted up and then dragged along the ground like a sack of grain. He was disfigured and killed. Another hid in a stack of straw, but the stack was blown away, the straws disintegrated and the man was carried through the air. How high he went he never knew. In the air he caught hold of a flying horse in front of him, but lost his grip and dropped to the ground with his hat in one hand and a bunch of horse's hair in the other. He was alive, though injured. At this time Mr. Kron was lying on the ground and watched a horse and cart fly over him. Later it was learned that the cart, harnessed up with two horses, had been standing in the barn. The cart and the horses were lifted into the air and carried away. At this point the man flying in front tried to grab the horse but failed. The cart could not be traced. One of the horses vanished and the other died.

The big solid barn was scattered like wood chips (Fig. 189). The barn contained six horses, 18 pigs, chicken and cats. Two horses died immediately, and the rest had to be shot as they were seriously injured by flying fragments. All the pigs were killed. One of them, weighing 120 kg, was pierced by a beam 2 m long and 15 cm wide, another by a fence plank. A third was pierced through by a sharp pipe from the fence; a fourth was carried a distance of 300 m to the fields and died there. All the chickens had their feathers plucked and one was carried a distance of 5 km by the tornado. The cat was the worst affected. It was carried a distance of 1 kilometer and thrown to the ground with such force that it was literally smashed.

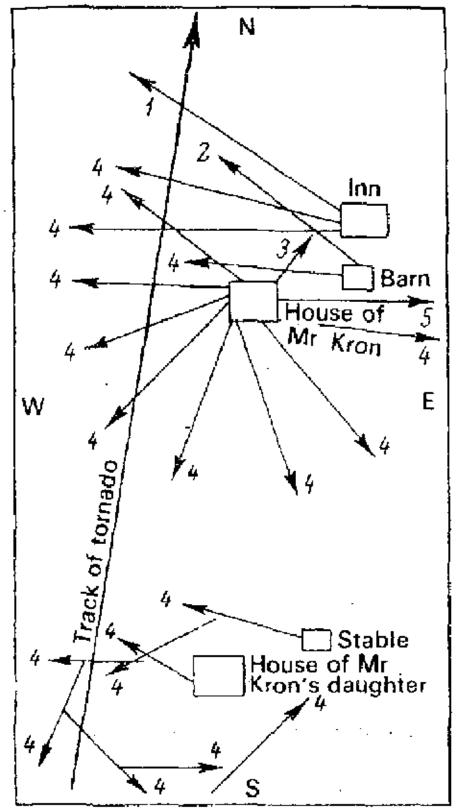

Fig. 189. Destruction of property of Mr. Kron (top) and his daughter (bottom) (Finley, 1881).
1—movement of fragments of barn; *2*—movement of Mr. Kron's daughter; *3*—movement of Mr. Kron; *4*—movement of fragments; *5*—movement of Mr. Kron's son.

It is difficult to conceive what happened to the machinery and other material stored in the barn. The steel frame of one cart was bent like a loop. Big beams flew through the air like feathers. The fence around the farmyard was full of debris, pieces of cloth and fragments of furniture.

The big, strong house disappeared in a few seconds. Nothing remained but bare ground, not even the foundation.

Kron's house takes first place, even in ill-fated Kansas, for destruction and horror following a tornado.

Kron's daughter's house was in front of his. This house could not be traced either. The tornado reached its maximum strength here. The next house, though it stood slightly to one side of the center of the track, like the strong house and the barn was reduced to small fragments flying through the air.

Farther on, the funnel passed over a group of three houses, strong and new. Nothing remained of them. The completeness of the destruction was striking. The owner of one house tried to escape by running out but was killed by flying fragments. Another family escaped in the cellar but it was difficult for them to take in the situation when they emerged and found a vacant plot of land in place of their house.

After traversing the plain for a short distance the funnel struck the house of a clergyman, standing 2 km from Delfos. The big building was shifted in no time and the fragments from it disappeared into the air. Here a tragicomic situation took place. The preacher and his family took shelter in the corner of a big cellar, running under all the houses. The cellar was full of old furniture, other material and grain. Darkness fell all around when the funnel moved in. The horrifying roar and crackle were beyond description. Something made a terrible noise overhead. Dust and rubbish dropped on their heads and something heavy dropped in front of them. After a minute it became clear and bright and the family was surprised to see before them two pigs, happily eating grain. Nothing was left behind on the floor of the house or the roof of the cellar. The pigs were conveniently dropped in the cellar by the tornado.

The clerk's two horses also followed interesting routes. Each of them flew through the air along a circular path. One covered a distance of 1.5 km over the river and a wood. When it returned to the house it was staggering and moving uncontrollably as if its head was reeling after the flight. It was hardly hurt. The other horse flew a distance of 1 kilometer and remained intact.

The neighboring three houses were somewhat to one side of the track of the tornado and sustained only minor damage. Only the barn and stable of one house were destroyed. The horse was lifted into the air and thrown to the ground with such force that its legs and ribs were crushed.

The township of Delfos (Fig. 187) was 2 km off the track of the tornado. The frightened inhabitants watched the movement of the funnel with horror. It passed over the plain destroying farms. The township did not even feel the wind. Rain fell 10 minutes after the tornado, then came a hailstorm, at first small and in abundance, then sparse with big hail-stones up to 25 cm in circumference. The irregular hailstones were of the size of a fist.

The funnel of the tornado caused terror in the hearts of the people of Delfos. The gigantic black trunk all the time swayed and rotated at incomprehensible speed. Nothing could withstand this force. Anything it encountered on its way was lifted up by the powerful vortex and thrown aside. The funnel moved quite fast, in a straight line, to the northeast. Its base in the cloud was somewhat brighter, but it also rotated at enormous speed.

After passing Delfos the tornado encountered another house beyond that of the clergyman. This house and a neighboring structure flew in different directions. A big, heavy beam flew 800 m away. The heavy slab of the kitchen hearth weighing 20 kg, was carried a distance of 400 m.

Another farm, 500 m away, had a similar fate. The strength of the tornado was much more terrible. First the stable and barn were blown away (Fig. 190) and the fragments fell on the house. Then the house was literally broken to pieces. Its fragments described an arc. A calf was tied by a long rope to a stake driven into the ground in the barn. The calf was lifted up and moved around the stake. Its head was almost snapped off but along with the stake it remained in the same place. But the most surprising thing happened to three foals. They were grazing in the meadow in a corral. The tornado lifted them up, carried them over the fence of a wheat field and then dropped them on the ground. They were rotated several times on the ground, then lifted into the air again and described a complete circle. When found they were completely covered with dirt.

The next farm, at a distance of 1 kilometer from the track of the tornado, was destroyed.

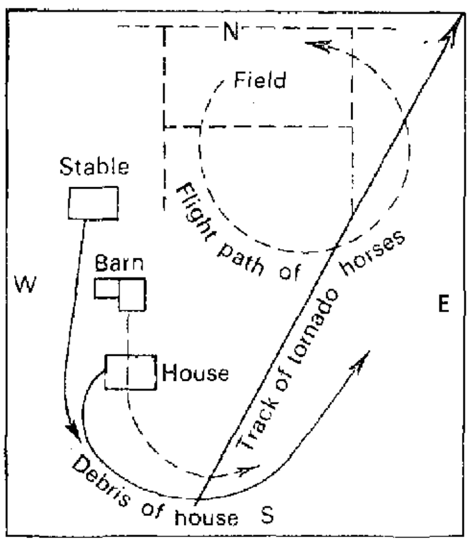

Fig. 190. Destruction of farm with three foals (Finley, 1881).

The big, solid, two-storied stone house of one Ostrander was situated one-and-one-half kilometers away. The tornado had weakened by this time and therefore could not destroy the house. It tore off the roof on three sides and almost destroyed the walls of the top floor. A farm hand was standing on the wall of the house. He was lifted into the air and thrown into a rivulet, and this saved him. He was badly bruised. His mouth, eyes, ears and hair were smeared with mud, but he was alive.

The roof was torn off the next house too. A small cabin stood at the end of the track. The owner was standing in front of the cabin, awaiting his end with horror but the funnel lifted over the cabin before him and he remained unhurt.

From the cabin the tornado moved over the open, unpopulated plain for 6 km, gradually weakening and the width of the track decreased. The fragments, rubbish, etc. of different materials fell constantly from the funnel on this sector of its track.

Finally the tornado narrowed, disintegrated and went into the cloud, having completed almost 70 km of wandering.

When the tornado approached Delfos one observer from the town by the name of Maclaren was on a hilltop from where he could see to a great distance. He calmly observed the tornado. As described by Maclaren, at first a black, low, dense cloud came and then rain with an unusually strong hailstorm. Thereafter at the base of the cloud, almost horizontally, some peculiar movement occurred at different places. Soon it took on a spiral form and numerous small funnels descended from the spiral (Fig. 93). It continuously changed form, appearing and disappearing instantaneously in the cloud, gracefully swinging and bending. It reminded him of a "fairy dance".

After some time it reappeared, lowering an enormous, dark trunk to about 150 m altitude, not reaching the ground. After a few minutes the trunk struck the surface and lifted a conical cascade of dust. Merging together, it took on the form of a sandglass. The tornado moved forward in this form, destroying everything it encountered.

It sucked up water and mud when it crossed a small river. This engulfed the main funnel in the form of an envelope. The tornado took on a rare shape, resembling a peg (Fig. 191). Soon the water and dirt were deposited on the ground and the tornado moved forward in the usual form. A large part of this water and mud was dropped over Kron's farm, causing unforgettable distress.

The book by Sergeant Finley describes in detail another destructive group of tornadoes of May 29 and 30, 1879. They are more or less similar but differ in severity and strength. It was known as the "Li summit" tornado at the end of the track.

The house of farmer Harris stood in a hollow not far from the river in a big plum orchard. The house of size 5 × 5 m was single-storied and had an annex for the kitchen (Fig. 192). The funnel struck the corner, turned it over and destroyed it. All the fragments were carried away by the vortex to a distance of 1 km. The wind leveled the site where once the house stood. Clothes and furniture could not even be traced. Only here and there, on trees and fences, small fragments of cloth, etc. could be seen.

The orchard was seriously damaged. The trees on the eastern side were bent, broken and stripped of leaves and branches. The side that faced the force of the wind had a ravaged look. Harris' neighbors looked at the trees for a long time but could not make out what exactly had happened to them.

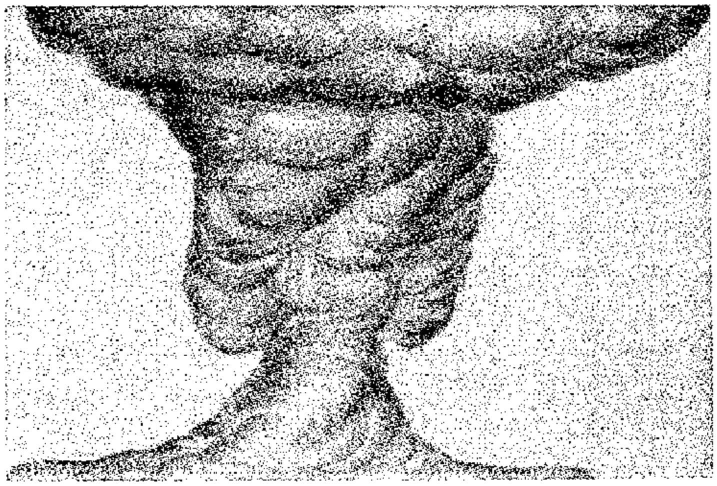

Fig. 191. Funnel after crossing rivulet. After lifting water it took on shape of peg (Finley, 1881).

A group of trees to the east of the house remained undamaged. This proves the sharp definition of the funnel.

The family suffered very badly. Their fate had many things in common with the fate of Kron's family destroyed by the Delfos tornado. With the approach of the tornado the entire family came out of the house and took shelter in the orchard. Instead of running away from the path of the funnel it was trapped by it. The funnel engulfed them, lifted them up into the air and carried them away (Fig. 193).

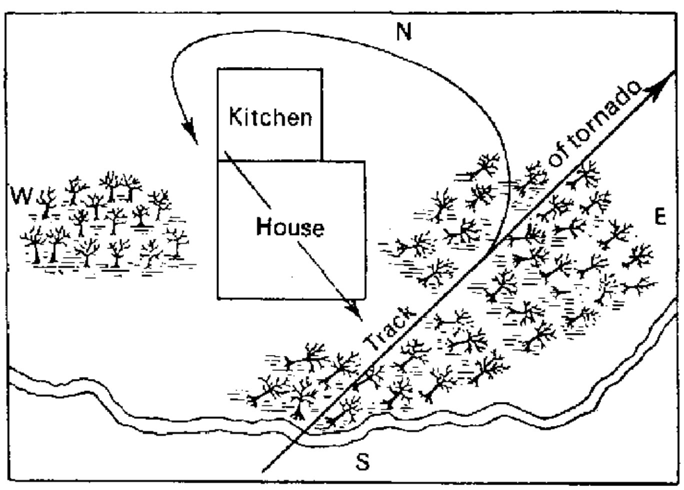

Fig. 192. Orchard and house of farmer Harris (Finley, 1881).

The father with the baby in his arms was carried a distance of 150 m in the fields, thrown on the ground and covered with dirt. He had the agony of

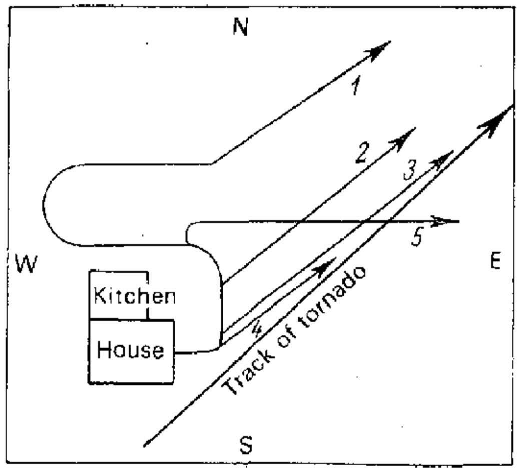

Fig. 193. Path of transportation of Harris family (Finley, 1881)
1—transportation of father with child; *2*—son; *3, 4*—daughters; *5*—mother.

death. The mother flew a distance of 75 m, but she was thrown on a tree, literally twisted around it and had her skull smashed. Her body was completely naked and covered with dirt. The eight-year-old girl was carried a distance of 50 m from the smashed house; she was naked and dead. Another girl traveled farther in the middle of the path of the funnel—a distance of 80 m—but remained alive. The boy, who was thrown on a stack of hay, was saved.

When the bodies of the dead were cleared it was found that the side of the body that received the initial impact of the wind was blackened, like the blackened trees. The doctors who studied the bodies established that this blackness was caused by the continuous bruising from the very strong impact of wind.

Burelom: The destructive strength of tornadoes is clearly visible in forest regions. There are many such regions in the USSR. They are wide and the occurrence of fallen trees is quite frequent. There are long, narrow belts where the trees are either broken or uprooted. Often, these belts are the tracks of tornadoes. All the trees, especially old ones with big trunks, which give maximum resistance to the wind, are broken. They are either uprooted or twisted or broken off the stump. They provide important information because the width corresponds to the width of the tornado and the length to the length of the track. At places where the tornado gallops the swath of fallen wood is interrupted. It reappears in the direction of the track of the tornado cloud. The track of the tornado of May 10, 1920, in Estonia, described earlier (p. 298) serves as an example.

Belts of fallen timber are of no special significance in the USSR. In the USA they are more significant and therefore have been studied in greater detail. Aerial photographs have been taken in many cases. It has been repeatedly noticed that in the case of tornadoes the position of the trunks of the trees indicates the direction of the strongest flow of air in the tornado.

This feature can be seen in a number of aerial photographs in the work of Hall and Brewer (1959). Figure 194 is the aerial photograph of part of the track of the tornado of June 4, 1958. The positions of the funnels are quite distinct. Attention is drawn to the sharp boundary of the zone of fallen timber and, correspondingly, the sharp edge of the track of the tornado. Figure 194 is a sketch of the route of the tornado for a length of about 7 km. The letter A shows the spot in the aerial photograph. The direction of the arrows exactly corresponds to the position of the fallen trees. The regularity of the position is quite distinct.

Another example of detailed study of a tornado, covering a length of 8 km in thick forest, is described by Budney (1965). The aerial photograph correctly located the fallen trees. All the data show the exact point of intersection of the tornado with the ground at a distance of a few hundred meters from the center of the track. The wind at ground level converged at this point, as is clear from the photograph. Such convergence proves the strong ascending current in the tornado.

With this we conclude our review of the destruction of tornadoes, mainly in the countries of their origin. Now we will pass on to the causes of destruction.

CAUSES OF DESTRUCTION

After going through the descriptions of tornadoes, which run to thousands, it appears as if all is clear and everything has been studied. Even many meteorologists share this feeling and very few among us nowadays study tornadoes.

As such it is well known that tornadoes destroy. But nothing is known as to how they destroy. What is the tornado's strength and what are the causes of destruction? Even such questions as whether tornadoes suck up different materials to the top are matters of dispute. Some specialists believe that there is no suction and everything is lifted up due to the push of the walls. Why do they think that? To be very frank, it is not very clear why they ignore the very obvious phenomena. For the moment we will close our study with a look at these unsolved problems.

First we will look into the problem of wall thrust, i.e. the wall pressures caused by funnels, and then look into the suction by tornadoes of various objects in greater detail, from houses and iron bridges down to live fish and jellyfish. At the end of the section, we will discuss the transportation of unusual objects by tornadoes and such aerial and intangible phenomena as the tornado cloud.

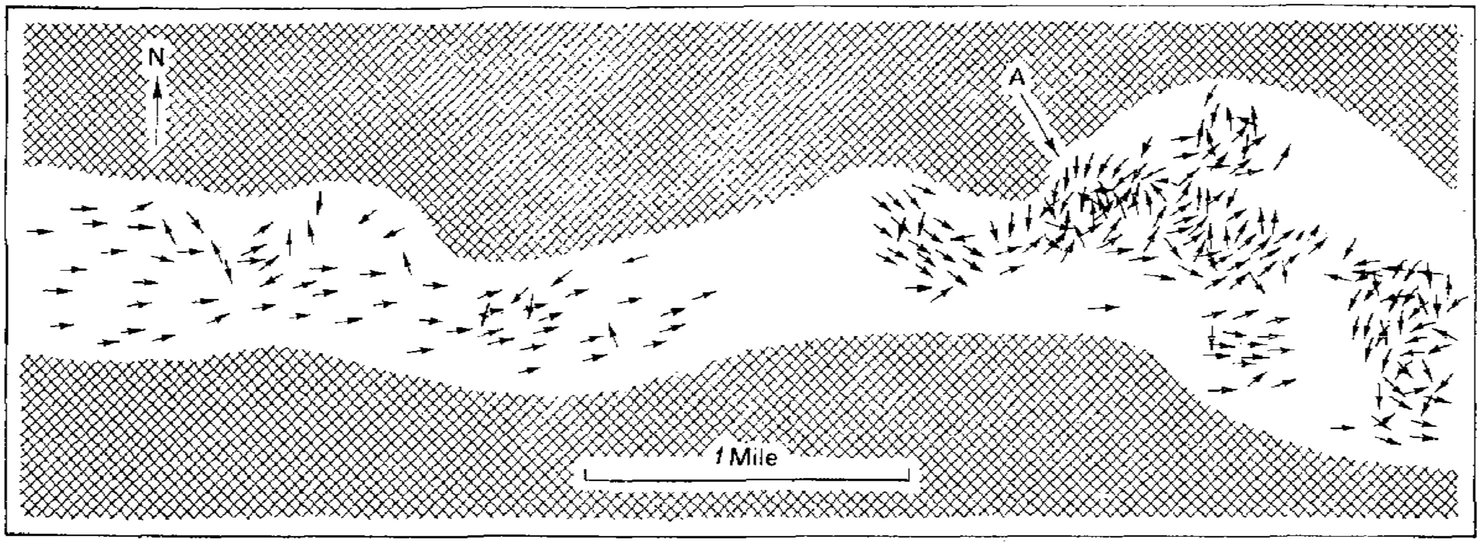

Fig. 194. Track of tornado of June 4, 1958. Arrows show position of fallen trees. Aerial photo of point A, see Fig. 195 (Hall and Brewer, 1959, Fig. 7).

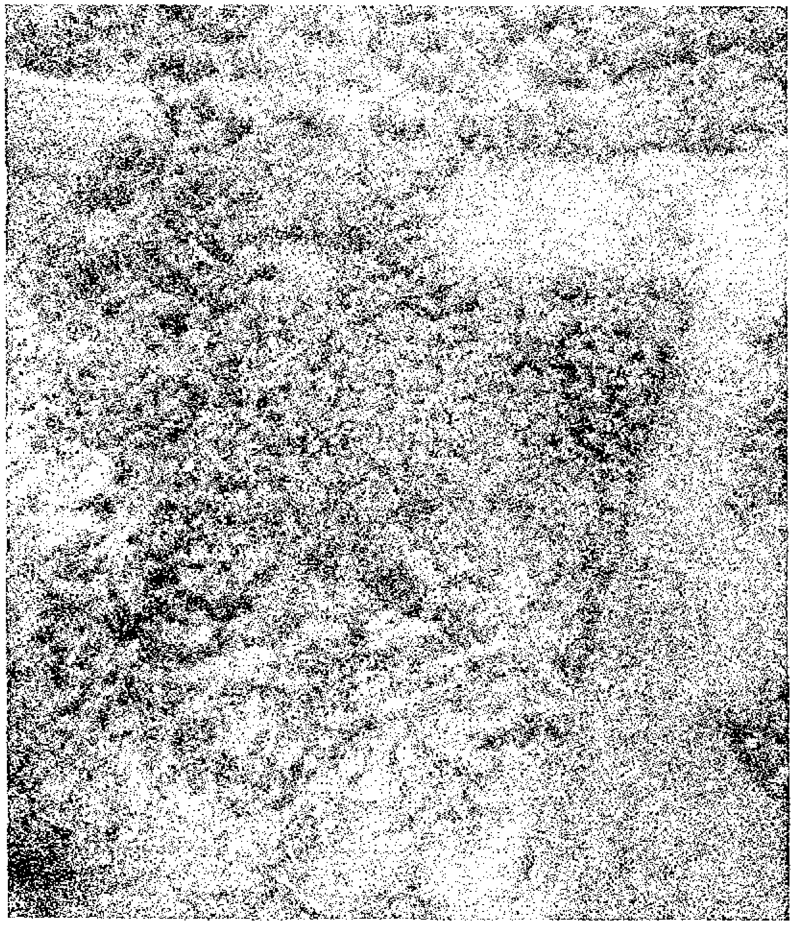

Fig. 195. Track of tornado of June 4, 1958. Aerial photo of point A. Sharply defined track of tornado (Hall and Brewer, 1959, Fig. 6).

Wall Pressure and Thrust

The funnel of a tornado consists of air filled with water, dust, dirt, rubbish and fragments. Due to the unusual and often supersonic speed of rotation, the mass becomes denser. It acquires a sharp, smooth outline and moves at great speed.

The average speed of movement of the tornado depends on the speed of the tornado thunderstorm cloud with which the funnel is joined. Generally it varies from 50 to 80 kmph; often it goes up to 100 to 120 kmph and in one case it went up to 240 kmph. The funnel, large and heavy due to water and dirt, is transported at such an enormous speed that it can easily inflict a destructive strike on any house.

It is not without reason that the Moneuil tornado in France could destroy, in the twinkling of an eye, an enormous, four-storied brick building of a paper factory. According to an eyewitness, "it squeezed the floors like paper bundles".

In the United States a number of cases have been recorded where the funnel of a tornado, striking a house or, to be precise, subjecting it to wall pressure, simply overturned it, without tearing off the roof or leaving any debris.

One such case occurred in the city of Sharon in Pennsylvania (Fig. 196). A big, two-storied, new strong frame house was overturned and came to rest against the next house. The overturned house was almost undamaged. Even the roof remained intact, which would generally fly off first. Only the window frames with their glass panes and doors were blown out. Overturning of wooden houses has occurred in a number of other tornadoes.

Fig. 196. Destruction in Sharon, Pennsylvania, in tornado of June 7, 1947. See Fig. 110 (Flora, 1953).

The thrust of the funnel of the Irving tornado has been described earlier (p. 365).

The wall thrusts and pressures have been recorded repeatedly. These overturn, lift slightly into the air, move structures, damage walls but never turn the structures into heaps of fragments flying in different directions. This is done by the vortex with rotating motion.

Ascent and Splinters

Lifting and splintering in the air is one widely occurring form of destruction caused by tornadoes. During a strong tornado lifting of an entire house is a common phenomenon. Houses with people inside kitchen annexes, barns, threshing barns, etc. are lifted to a height varying from a few meters to a few tens of meters. One complete roof flew a distance of 60 m, but such cases are rare.

The fate of the flying objects varies. Some disintegrate into fragments in the air and are then carried in different directions, though most of them are carried in the direction of the funnel. Some others, the heavier ones, drop to the ground and form heaps of debris. A few fragments, rather rarely, are gently let down to the ground without damage.

The ascent is often so smooth that it even goes unnoticed. A well-known case dates from the Irwing tornado (p. 354).

During the Irving tornado, which lasted 3 hours, 14 different structures were lifted whole into the air, as earlier described. At the beginning of its track a Mr. Reid's house flew away, unnoticed by the owner. At the outskirts of Irving another house was lifted with the family inside. It was lifted so intact that even the pipes remained in place. It was literally torn up after flying for 40 meters. The family dropped to the ground along with the floor. In the next house only the upper floor and roof blew off. Then the fourth house, owned by one Kini, was lifted into the air, overturned and disintegrated.

After covering a distance of a few hundred meters the funnels slightly lifted a Mr. Sabin's house along with his family. The house turned round several times in the air but was not overturned. Then it disintegrated and the family dropped to the ground. Another house, also made of wood, standing nearby, was surrounded by a fence. It was lifted up, carried over the fence and ultimately broken up in the air.

The next house belonged to Barden, the banker. It was a solid, two-storied wooden structure 9 × 12 m in size. Adjoining it was a big single-storied structure housing the kitchen. The house was lifted whole into the air, carried a distance of 5 m, the floor was turned upside down and the house disintegrated into parts. The kitchen structure flew independently for 9 m, then fell to the ground, moved over the ground for another 6 m and then disintegrated. The barn, standing in front of the kitchen, flew 30 m and dropped gently to the surface, remaining almost intact.

Another small house (No. 19), 3 × 4 m in size came next. A gust of wind engulfed it, shaking it repeatedly the way a dog might shake the lid of a pot. The clothes, linen and part of the furniture in the house blew away, but the house and the family living in it remained intact. Such a case is rare. The nextdoor house 4 × 6 m in size fared worse. It was lifted up whole carried a distance of 50 m. Finally the house disintegrated in the air. The family had taken shelter in the cellar. Traversing a small vacant lot, the funnel lifted the next house (No. 21) and broke it up.

The tornado hit oddly a house (No. 22), standing at a distance. The stone house was destroyed but the wooden structure in front, where several families had taken shelter, remained intact.

The next small house (No. 23) was completely enveloped by the black cloud, badly shaken, but left intact. The nextdoor house—a solid, two-storied, strong wooden building—was lifted up, carried a distance of 12 m, thrown to the ground and turned into fragments. Some of the fragments flew a distance of 5 km. The next house (No. 26) in Irving in the track of the tornado was also shaken but was not damaged.

After crossing Irving the tornado moved over the plains and destroyed whatever it encountered on its way—farms, schools and other structures. Some of them were overturned or squeezed. In some cases the roof was torn off and in others they were destroyed completely. The fragments were thrown in all directions. Its track has been described earlier.

After covering a considerable distance it struck the house of farmer, Mr. Sample. The walls of the house and the roof were blown into the air and became small flying fragments. The floor and the family standing on it stayed put. As Mr. Sample described it afterward, first the wind struck the house and broke the doors and windows. Then there was silence. But another gust of wind lifted the house over the heads of the family, injuring several of them.

To the east of the city of Bitti (Fig. 179) the family of farmer Morgan noticed the funnel from a distance and took shelter in the cellar. In no time they saw the amazing trunk approaching. Moving along, it lifted an entire house over the heads of the frightened family, who saw it disappearing into the black, whirling cloud.

Beyond the rail track the funnel approached a house surrounded by small trees 5 m in height. The house was lifted up whole, carried over the trees and then thrown to the ground.

The school building came next. It was lifted from the foundations, carried a distance of 18 m and thrown to the ground, whereupon the house disintegrated.

At the end of its track, in the city of Dawson Mills, a number of houses were destroyed from the foundations and the Catholic church, as mentioned earlier, moved along the ground under the pressure on the wall with the priest and the congregation inside.

With this, the Irving tornado completed its destruction. It may be mentioned that for strength it comes in the average category. In very strong tornadoes the destruction is much worse.

Vortex Destruction

Vortex destruction is the third and most widely distributed form of destruction. Structures are not lifted up, not transported but destroyed on the spot, at the foundations and often including the foundation.

There are several categories of destruction, depending on the speed of vortex motion. Slow destruction is described thus: "The house was damaged, crumbled and disintegrated." The second category is described as: "The house was carried away before the eyes of eyewitnesses. The fragments of the house flew over them. The destruction was quick and complete." Lastly, the third category: "The house disappeared, the house was destroyed beyond recognition, and it was blown away at lightning speed".

These categories, of course, are provisional but show that the destruction of structures and the transportation of fragments take place at different speeds. It is well known that the funnels of tornadoes rotate and travel at different speeds.

Actually the direction is demonstrated by the transportation of fragments of destruction by the vortex motion. These directions add up to anticlockwise motion, often in full circles, generally for the major part of the track. This can be clearly seen in the disintegration of Mr. Crown's house. The fragments flew literally in all directions except the direction of the tornado (Fig. 189).

Often the spiral motion in the funnel can be observed in the pattern of the debris at the point of destruction (Fig. 181), forming spirals. Three foals, engulfed by the funnel of the Delfos tornado, described an almost complete circle in the air (Fig. 190). The cow flying over the forest, flew not in the direction of the track of the tornado but across it (Fig. 183). The hired hand engulfed by the funnel of the Delfos tornado flew not in the direction of movement of the funnel but almost opposite to it (Fig. 188). Another laborer described a complete spiral in the air. A third worker flew across the track of the tornado.

The spiral vortex motion could be clearly seen in the destruction of gardens and in the fallen trees. It has been noticed many times in the case of trees. In gardens not only do the trees fall over one another in a spiral pattern (Fig. 186) but often twist like a rope.

The direct flow of air, though very strong, often forms tornadoes but it cannot cause the phenomena described above.

We will now describe a few cases of vortex destruction.

In the Irving tornado the house of one Baits (wooden structure) disintegrated and the fragments were carried in two directions.

The big frame house was removed from the foundations and the bigger part of the fragments flew to the south and southwest, i.e. opposite to the direction of movement of the tornado. The house, stable and barn were torn from their foundations.

Someone sitting at the window related that he was amazed at the extraordinary thunderous roar and howl as if a train were passing at terrific speed. A very strong gust of wind struck the house like a cannon ball, turned it to the side and then in no time reduced it into fragments. The narrator was thrown outside to a distance of 30 m, but he soft-landed. He was safe but his hair, mouth, nose and eyes were full with dirt.

The lightning speed of total destruction has been recorded repeatedly by others.

A remarkable example of vortex destruction is the destruction of the

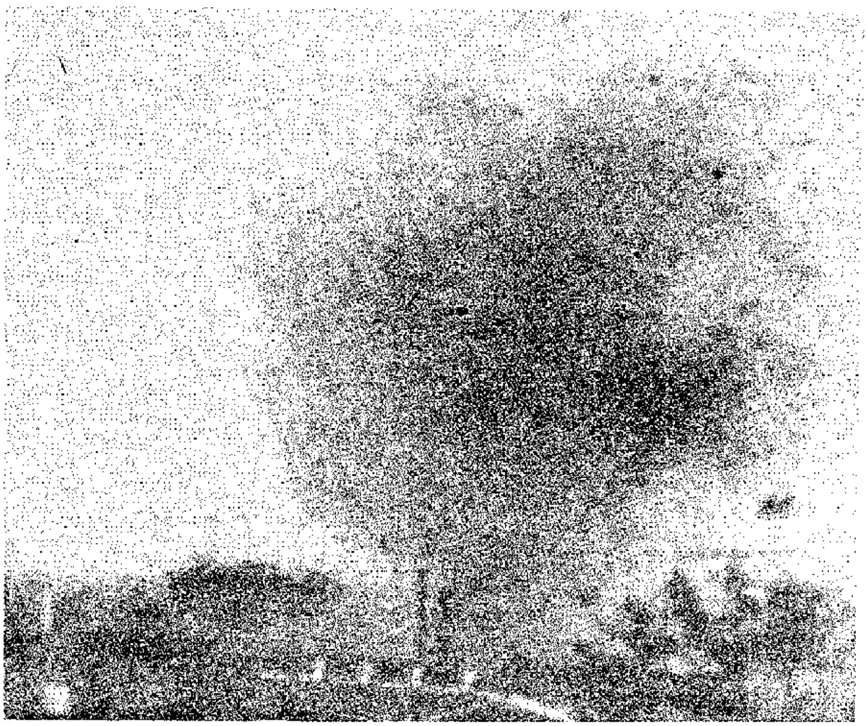

Fig. 198. Dallas tornado of 1957. Explosion of house hit by tornado. Rare photo (Beebe, 1960a, Fig. 22).

What is surprising is the great height to which the fragments rose. On the basis of comparison with the trees to the right, the height was not less than a few tens of meters.

What is not clear is the disappearance of the funnel. The house exploded at the touch of the hollow inside the funnel but no such thing is visible in the photograph. Where was it? It is quite likely that it was not yet filled with dust and therefore remained invisible.

It should also be noted that the fragments remained suspended above the ground. It is likely that the house disintegrated not on the ground but in the air. This has been frequently observed with other tornadoes, particularly with the well-known Irving tornado. A building would be lifted whole into the air and only then disintegrate.

The destruction is not always so complete. Often one wall flies away due to the explosion but it flies as a whole, like a cutting knife (Fig. 110).

A phenomenon difficult to explain was observed during the Michigan tornado of 1896. In a garden to one side of the track the bark was ripped off small trees not only from the trunk but also from the branches. The observer writes: "The bark was stripped thoroughly and neatly as though it had been done by a horticulturist" (Conger, 1896). The trees otherwise remained intact.

It is quite likely that there was an air gap between the bark and the trunk of the trees. At the touch of the hollow inside the tornado the barks were neatly removed.

Another tornado, crossing a kitchen garden, tore off the branches of all the fruit trees. Simultaneously, the bark was removed from the trunks (Abbe, 1893).

The trees minus their bark had a burned look. The phenomenon of apparent burning has been noticed in the case of other tornadoes as well. The birds and chickens killed in tornadoes and deprived of feathers looked like they had been roasted.

It is quite likely that there was no burning in these cases, though the temperature may have gone up to that level. It is probable that they were not cases of burning but of dehydration due to suction of water. This is quite natural for tornadoes.

Combined Destruction

Quite often the destruction is accentuated by the actual cause. The thrust of the wall combines with the vortex destruction and simultaneously the explosion takes place.

It has often been found that the corner of a house has been lifted or damaged by the thrust of the wall, the house has been turned or overturned and then the vortex has blown in, turning everything instantaneously into small flying fragments.

It would not be an exaggeration to say that much of the destruction is due to a combination of causes. Destruction due to just one cause is rare.

On May 27, 1931, an express train was traveling across the plain of Minnesota in the scorching sun. It was driven by a big new locomotive weighing 134 tons. It had six long, heavy passenger cars. Each weighed 65 tons and accommodated 117 passengers.

The driver and his assistants observed a big, low thunderstorm cloud approaching the train. The train had to be kept out of it. The train was moving at a speed of 80 kmph. After a few minutes the cloud moved overhead. It became dark and they heard a terrible hissing like that of a thousand snakes, above the noise of the train. They looked through the window and froze. The enormous black trunk had appeared very near the train, linking the ground with the sky. Shouting "tornado, tornado", the frightened driver applied the brakes. The train came to a creaking halt, but it was too late. The gigantic, heavy funnel full of water and dirt struck the train in the middle, almost perpendicular to its line of travel.

By stopping the train the driver saved it from a terrible crash. If it had been moving at speed all the cars would have telescoped into one another and the train would have turned into a heap of fragments. But with the almost stationary train, the funnel pulled out the car that had received the thrust, lifted it into the air along with the 117 passengers, carried it a few meters and then gently deposited it on its side. Other cars were also pulled out or derailed but not carried away.

Though the train was crowded, only one passenger died. He could not close the window while the car was in the air and fell out under the falling car.

Figure 199 shows the rescue work: the steam locomotive has been detached, brought to the side and coupled to another with the help of a crane. Two cars have been placed on the rails but the car that was blown off remains where it was deposited by the funnel. The car has been thrown a considerable distance, as can be seen when it is compared with the size of the people standing around. One end is not less than 10 m from the rails (McClurg, 1931).

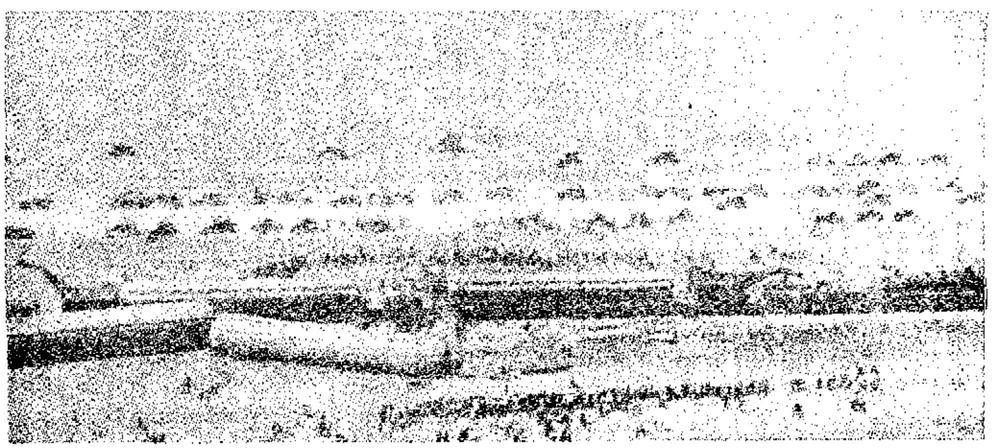

Fig. 199. Express overturned by tornado of May 27, 1931, Minnesota (McClurg, 1931, Fig. 1).

Many trains travel across the plains of the USA and many tornadoes occur there. Therefore the incident of 1931 described above is not an isolated event. On June 22, 1919, in Minnesota a tornado pulled out the caboose from a train and dumped it across the rails. The rails underneath were dislocated and bent.

In 1913, in Illinois, a tornado derailed a freight train. The heavy locomotive and tender remained on the rails. The 21st car at the end of the train also remained on the rails. The first 20 cars were derailed and almost totally destroyed. There are many cases of overturning of single freight cars (Colyer, 1913).

To derail cars may not be that difficult: it could be done by the wall thrust of the funnel. But to carry them away with hundreds of passengers and to softland them on the side could only be the work of vortex rotation. Vortex motion alone could twist a car across the rails.

When the Irving tornado approached the station and depot a passenger train was just coming in. The driver saw the funnel approaching the station. He had the presence of mind to stop the train. Thus he averted a tragic accident. The Irving tornado was quite strong and no one knows what it would have done to the cars full of passengers.

Destruction of Cities and Villages

When one building or a small farm is destroyed, in almost all cases the form and cause of destruction can be determined. But when a block, a street or even an entire village is destroyed, it is difficult to say how and what caused the destruction. It can simply be said that the destruction is due to the tornado. We will now describe such destruction.

In the plains, the population of the agricultural states is relatively scanty and the towns are small, like our villages of a few hundred inhabitants. The wooden frame houses are single-storied and very rarely two-storied. When the funnel of a tornado passes over such a village the destruction is total. It is not mere destruction but annihilation.

On June 8, 1951, a tornado passed through the small city of Kron in the State of Oklahoma. The destruction was total. Figure 200 shows how unfortunate the inhabitants must have been. Heaps of debris, not of houses but of transported materials, are standing on the sites of the original houses amid green trees. The man's house was blown away to some other place. A heavy bathtub and a jerrycan from somewhere else can be seen in the picture. The trees and lawn around the original house were also turned into

Fig. 200. Destruction of house and transportation of bathtub and jerrycan, Oklahoma, June 8, 1951. Debris of entire block (Flora, 1953).

miserable wreckage. Many trees were broken, uprooted or twisted like rope. In the middle of the photograph, a house can be seen standing outside the track of the tornado: it remained intact (Flora, 1953).

The photograph of another small township destroyed by the well-known Mattoon tornado of 1917 is no less horrible. The diffuse envelope of large size took a toll of 110 lives. The photograph is similar to the previous one and each may be considered as typical of the destruction of small townships, as well as of the Irving tornado of 1879. The destruction is total and terrible. It is not clear where the heaps of debris came from. The stripped trees and the houses that were in the track of the tornado make a horrible sight (Fig. 129).

The total destruction of whole streets, rather of whole towns, becomes apparent when one considers the aerial photograph of Judsonia in Arkansas. The tornado of March 21, 1952, practically destroyed the small city in a few seconds. The main street bisecting the photo was completely destroyed. There was not a single house left intact and many were blown away or turned into heaps of debris (Fig. 201) covering the street. All the trees were broken and uprooted. Fifty people were killed, 325 injured and 945 houses destroyed (Flora, 1953).

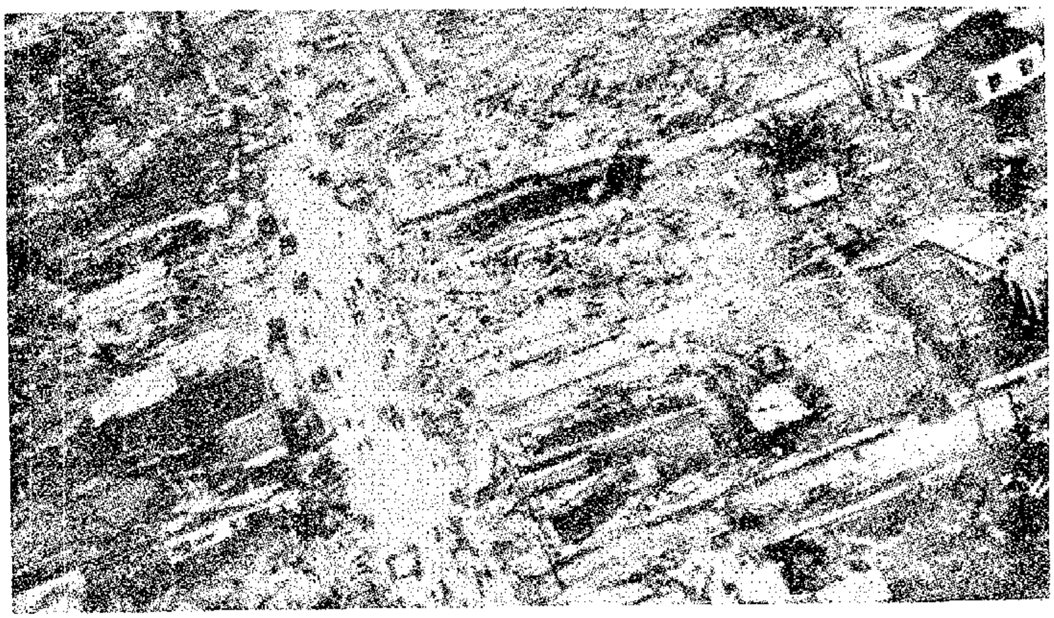

Fig. 201. Aerial photograph of Judsonia, Arkansas, after tornado of March 21, 1952. Continuous destruction (Flora, 1953).

The picture of Fevralsky street, Rostov, in the Yaroslav region, looked like this after the tornado of August 23, 1953 (Fig. 202). The arrows in the map show the movement of the tornado and the destruction of houses. The funnel entered the city at Dostoevsky street, not far from Fevralsky street. The black rectangles show total destruction and the black triangles, severe damage. The continuous block of black rectangles and triangles, the belt of complete destruction enveloping Fevralsky street, compares with the main street of Judsonia. Then the funnel moved over the fields, forming a new path. Massive stone walls of the old stone houses and church were left intact but the roofs of the houses, main church, light structures, etc. all disappeared. The funnel moved onto Lake Nero.

The tornado of April 12, 1927, almost totally destroyed the city of Rockspring, Texas. Only six houses remained intact in the city. Of 1,200 people, 72 were killed and 240 injured, i.e. 26% of the population was affected. Many buildings were carried away whole. Even solid concrete or stone structures were destroyed. The exceptionally strong reinforced concrete church remained intact but all the walls leaned out by 0.3 to 0.9 m due to the pressure from inside. All this destruction took 90 seconds (Jarboe, 1927).

Horrible destruction is caused by the enormous low, wide, diffuse tornadoes in the USA. Figure 129 shows the destruction caused by the Mattoon tornado of 1917 but fiercer still was the tornado of 1925 in Three States, which killed almost 500 people.

Its action was almost unbelievable. Figure 128 shows the enormous field covered by a frightening blanket of debris under which nothing is visible. A flourishing mining village with streets, houses, shops and church full of life once existed here. But everything disappeared. Even the enormous, strong, reinforced concrete building of the pithead was very badly damaged and rendered unusable. Dozens of miners and their relatives were buried under the debris.

One wall, heaps of debris and stones—that is all that remained in the wake of this deadly tornado, but 33 children were buried under the debris (Fig. 203). The photograph gives a modest idea, but how terrible it is!

We now come to the big, more solid cities. There the devastation of tornadoes is unbelievable. Figure 163 shows the main street of Lorain City, standing on the shore of Lake Erie in Ohio State. A big tornado had just passed on June 28, 1924. Along the wide, straight streets with streetcar tracks stood solid, ornate, two- and three-storied stone houses. The first floor of each building housed shops, stores or offices. At the end of the street the endless gray expanse of the lake could be seen. Its width here was about 40 km.

The entire street was the scene of thorough destruction. There was not a single house intact. Mostly roofs and parts of the upper floors were damaged. All the shops were destroyed. Glass panes and doors were broken and torn out. Nothing remained inside. Everything was mixed up, overturned, reduced to pieces and carried onto the street by the terrible vortex. There were very few people left to see the blocking of the streets by the debris. The automobiles, which were not so numerous at that time were turned upside down and badly twisted (Hunter, 1924).

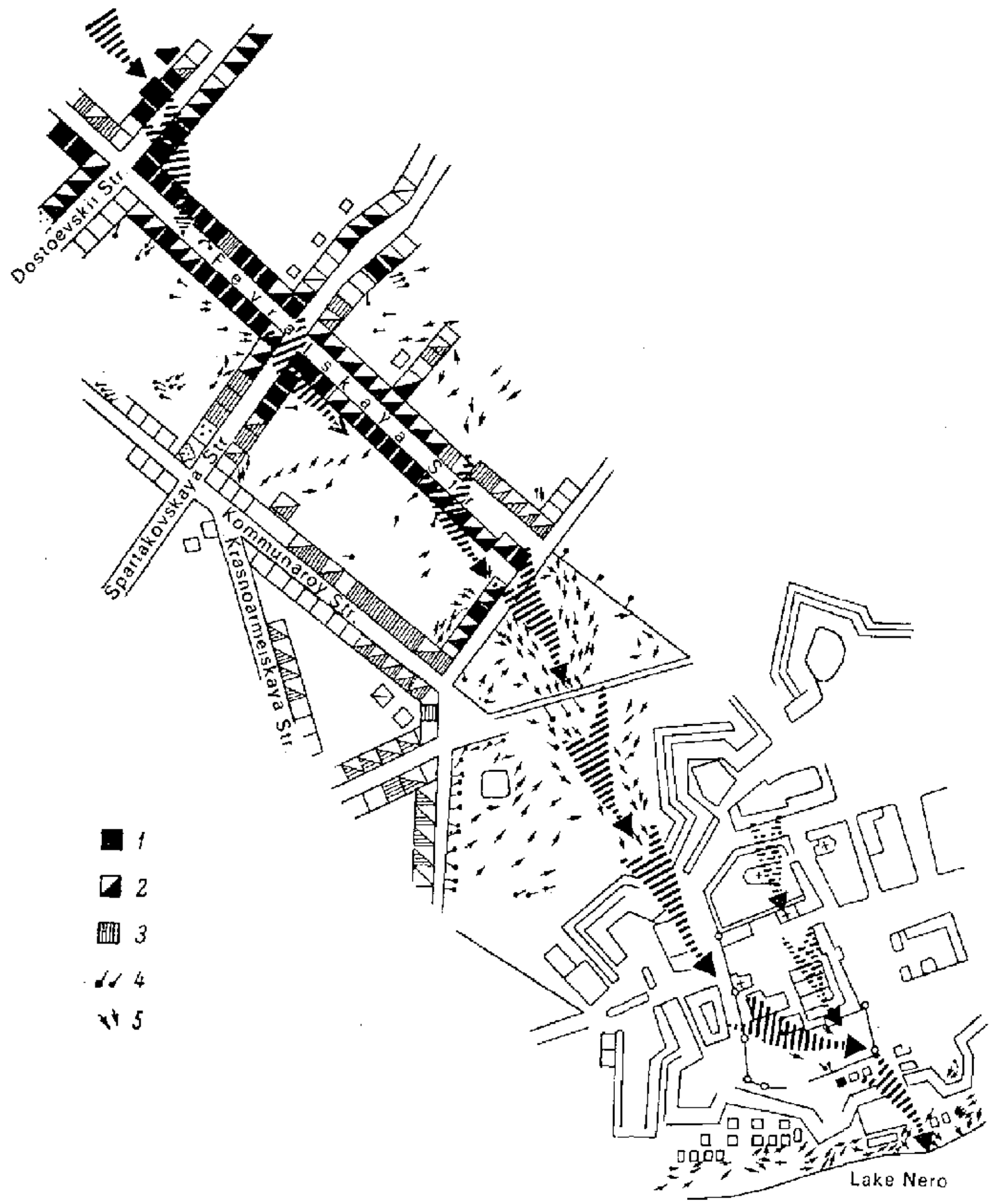

Fig. 202. Route of tornado of 1953 in Rostov (shown by arrows) (Chizhikov, 1956, p. 72). *1*—thorough destruction; *2*—considerable destruction; *3*—slight destruction; *4*—broken trees; *5*—flattened grass.

However, the main outline of the street was retained. Almost all the houses stood in their places and were not totally destroyed as was the case in the coalmine village. This shows the strength of stone houses. Actually these buildings standing close to one another form a continuous stone massif. The strength of even a large tornado is not sufficient to destroy it completely.

The track of the Lorain tornado has been described earlier (p. 323). The destruction by the Lorain tornado can be taken as typical for big cities with

Fig. 203. Three States tornado. Damaged school with 33 children under debris (Changnon and Semonin, 1966, Fig. 7).

continuous terraces of stone houses.

It is difficult to say why tornadoes rarely move into cities with stone structures. In the states of the central plains of the USA, the breeding ground of tornadoes, there are a number of big cities, but only a small number of cities are struck by tornadoes. In most cases the tornado comes near and then deviates due to the structures.

On September 29, 1927, the big city of St. Louis with a population of a million was struck by a big tornado. The city is on the bank of the Mississippi and occupies a large area. Most of the city is occupied by the usual American two-storied buildings. The houses are either of stone or of brick, quite strong and close to one another. In other words, it was the typical "two-storied America" that one would have seen in the America of 1930. I was also in St. Louis around that time, and nothing had escaped the fury of the tornado of 1927.

The destruction was large and typical. The tornado crossed the city limits, leaving a more or less discontinuous belt of damaged buildings. The funnel acted only on the upper stories of the houses (Fig. 204), where they were close together, but the action was quite effective. The funnels moved over the roofs, as a rule, damaging the tops of the buildings, e.g. the house in the middle of the photograph. The doors and windows were blown away. The heaps of debris can be seen in the street in front of the buildings.

An isolated house was damaged rather badly (Fig. 205). The funnel possibly enveloped the entire house and the consequences were terrible. All of the front portion, including the first floor of the house shown in the photograph, was destroyed. The trees around the house were also badly damaged (Hayes, 1927).

A comparison of the photograph of St. Louis with that of Lorain (Fig. 163) shows how extraordinarily the cities are alike ("two-storied America") and the action of tornadoes on them. The action is horrible and catastrophic.

Chicago is a city a few times bigger than St. Louis but its suburbs are quite poor. Here the houses are small, one-storied, wooden, light and set in

Fig. 204. Tornado of September 29, 1927, in St. Louis, Mississippi. Not only roofs but also part of brick walls were destroyed (Hayes, 1927, Fig. 8).

Fig. 205. Tornado of September 29, 1927, St. Louis, Mississippi. Lower part of wall of isolated building remained intact (Hayes, 1927, Fig. 9).

gardens. The picture of destruction by tornadoes is not different from the small towns of the plains States.

It was cold when the tornado occurred on March 28, 1920. The photograph shows the inhabitants staring at the front of one of the houses. The house is no longer to be seen. Here stood a church and a house in front of it. Only an insignificant part of the floor remains. The lighter houses were destroyed much more completely and no trace is left behind. Not only the house but also the garden was destroyed. At the edge of the photograph a few undamaged single-storied houses can be seen. They were off the track of the tornado. In front of them an overturned, but not shattered, house can be seen (Fig. 206). However, there was loss of life. The tornado killed 10 people and injured many. It was almost unbelievable in its strength. A bell weighing 1 ton hanging at one place was carried a distance of 30 m.

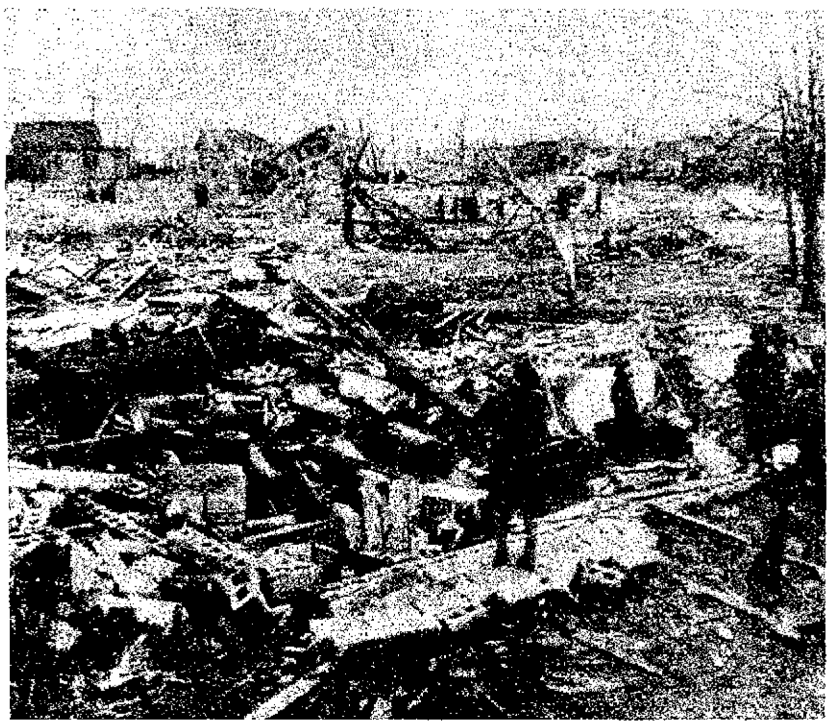

Fig. 206. Church and house in front of it in outskirts of Chicago destroyed from foundations by tornado of March 28, 1920 (Mitchel, 1920, Fig. 3).

The clearest picture is to be had from the aerial photograph of part of the big city of Toledo in Ohio State, on the shores of Lake Erie. The tornado occurred on April 11, 1965. The photograph (Fig. 207) shows part of the track of the funnel, moving from left to right, from the lake to the land. The big asphalt highway on the left of the photograph runs right on the shore of the lake. To the left of it are three long branches linking up with the small pools. The pools are numerous in between. They are shown by white patches in the photograph. The debris and parts of buildings float in the water or are washed up by the wind. The quantity of it is unbelievable. To the right of the road at the top three big trees can be seen. Below, at the intersection, one more tree. These are badly disfigured. All the leaves and branches have been removed and only the lower part of the trunks remains.

There were eight fine two-storied houses on the right of the road. Three houses stood not far from the main highway, between the two side roads. These were in the middle of the track of the tornado and nothing remained

Fig. 207. Destruction due to tornado in Toledo, Ohio, in 1965 (Palm Sundays..., 1965, p. 122).

of them. The upper house had three trees on the lot and they blew away completely. Only the bare concrete foundation remained. Even the fragments were blown away, quite likely into the lake. In the middle house, half of the foundation was exposed and other half was covered with a mass of logs, boards and fragments of furniture. In the heap, the long, oval, thick, probably enamel bathtub can be seen. The fragments have been carried far from the side roads to other areas (black zone). The third house near the road was also turned into heaps of fragments but they almost cover the foundation. Part of it has been carried far to the right, beyond the side road.

The house at bottom right of the photograph, beyond the side road, blew away completely, leaving behind the white spot of its concrete foundation From the size and shape of the foundation it can be seen that the house was big with numerous verandas, a garden and swimming pool. All the structures disappeared altogether and what is interesting is that the wreckage is not to be seen in the neighborhood, they were carried so far. Only in the middle of the foundation of the house, in the piazza and in the swimming pool, rather large, irregular fragments can be seen. It is difficult to imagine more complete destruction.

At bottom left of the photograph the debris of two other buildings can be seen. A big tree stood on the lot of the upper one and can be seen in the photograph. These two buildings were probably crushed. Part of the wall with holes for the doors and windows can be seen.

Lastly, the upper part of the aerial photograph covers the edge of the track of the tornado. The house at the top of the photograph is almost undamaged. It is a big, low, wide, single-storied structure of ranch type with an enormous roof. The roof is intact but in front of the house long pieces of plank are scattered. It is not clear where these have come from. Slightly south of this house, which is almost undamaged, there is another house which fell in the zone of destruction. It is clearly seen that though this house is in place, it is already half-destroyed. The fragments, though not much, are scattered all around. The northern edge of the track of the tornado passed in between these two houses (Palm Sundays..., 1965).

I have seen the aerial photograph of Ashkhabad, damaged severely by the earthquake of 1948. In Ashkhabad the picture was horrible and conveyed the idea of total destruction. The aerial photograph of Toledo is much more horrible. In Ashkhabad, a few buildings were undamaged, others were partly damaged and the others that were damaged remained in their places. The gardens and trees along the streets were not damaged at all. In Toledo, the destruction was complete. Even the debris of some of the houses disappeared. The gardens disappeared and big trees were disfigured. A tornado is much more terrible than an earthquake. A thing that cannot be overcome by tornado or earthquake is special structures, specially strong buildings, inseparably connected to the foundations and the ground. Such buildings are not affected by either tornadoes or earthquakes.

To date there is no incident, even in the USA, of a tornado blowing away a skyscraper. Present-day skyscrapers mainly consist of strong steel structures, the bottom of which goes deep into the ground and is firmly reinforced there. I think in such an encounter the funnel and not the skyscraper would be destroyed.

The recent well-known Topeka tornado of June 8, 1966, confirms this. It exhibited a diffuse outline, large dimensions and considerable destructive power. The destruction started a few kilometers east of Topeka, the main city of Kansas State (Fig. 208). Moving almost in a straight line, the tornado crossed the entire city and its center. It lifted up over the River Kansas and disappeared.

On the outskirts of the city the funnel encountered on its way the usual single- and two-storied buildings. They were destroyed either completely or partly. In the case of strong buildings, only the roofs were damaged. The

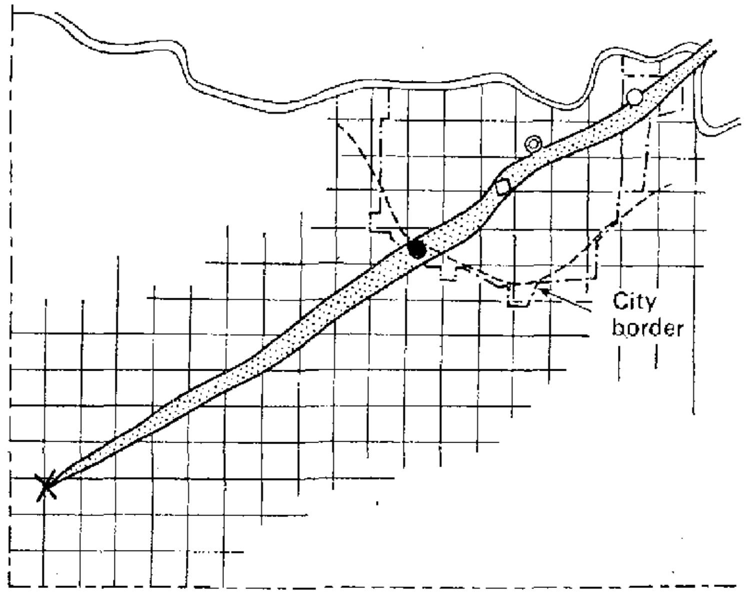

Fig. 208. Track of tornado of June 8, 1966, in Topeka, Kansas (Galway, 1966).
Straight lines—streets; *cross*—beginning of destruction; *solid circle*—city limit; *open rectangle*—university building; *double circle*—State Capitol; *open circle*—weather bureau; *double winding line*—River Kansas. Length of track 12 km.

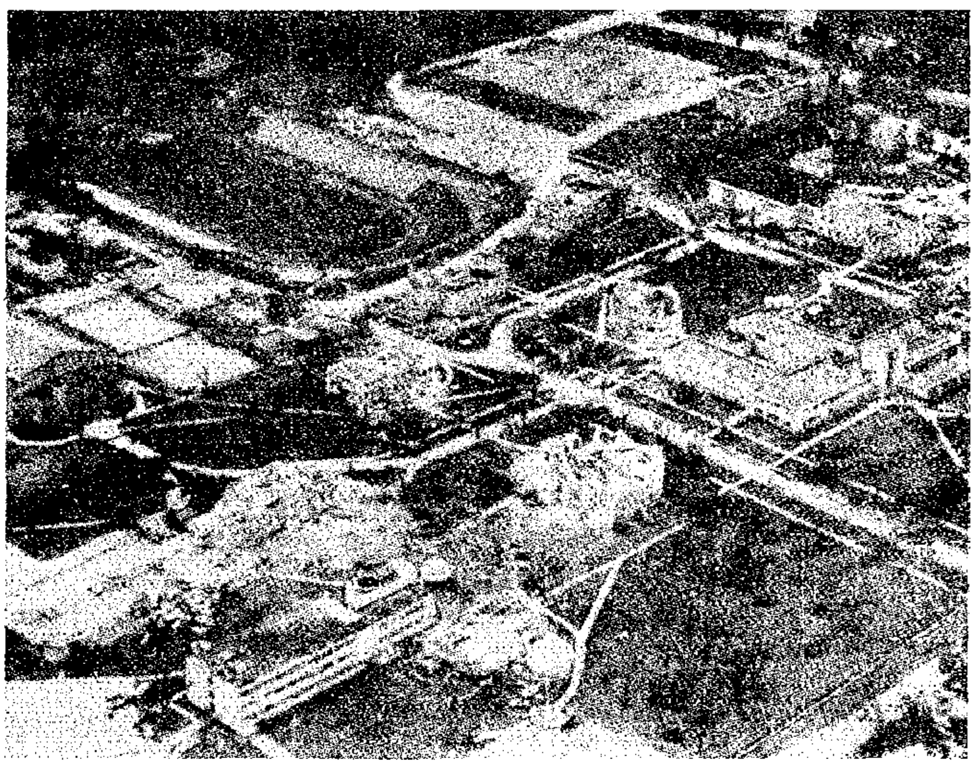

Fig. 209. Damage of large building of university, Topeka, Kansas, June 8, 1966 (Galway, 1966).

fragments of structures were blown into the air (Figs. 130–132).

In the middle of the city the tornado passed over a building belonging to Kansas University. It was a big, solid brick building three or four stories high. Whatever fell in the path of the tornado was badly damaged (Fig. 209). The tornado tore off the roofs and the upper floors. The ground nearby was covered with debris and rubbish. In spite of this, the main building more or less retained its outline. This is clear in the aerial photograph.

In another photograph the center of the city and the destruction are shown (Fig. 210). Homes have been turned into a continuous belt of debris. Two very high, twelve-storied buildings protrude from it. One of them, with a peculiar cylindrical form, is almost undamaged. The other, with the usual rectangular form, stands without considerable damage but the roof has been removed. The other high buildings and the Capitol (top left of photograph)

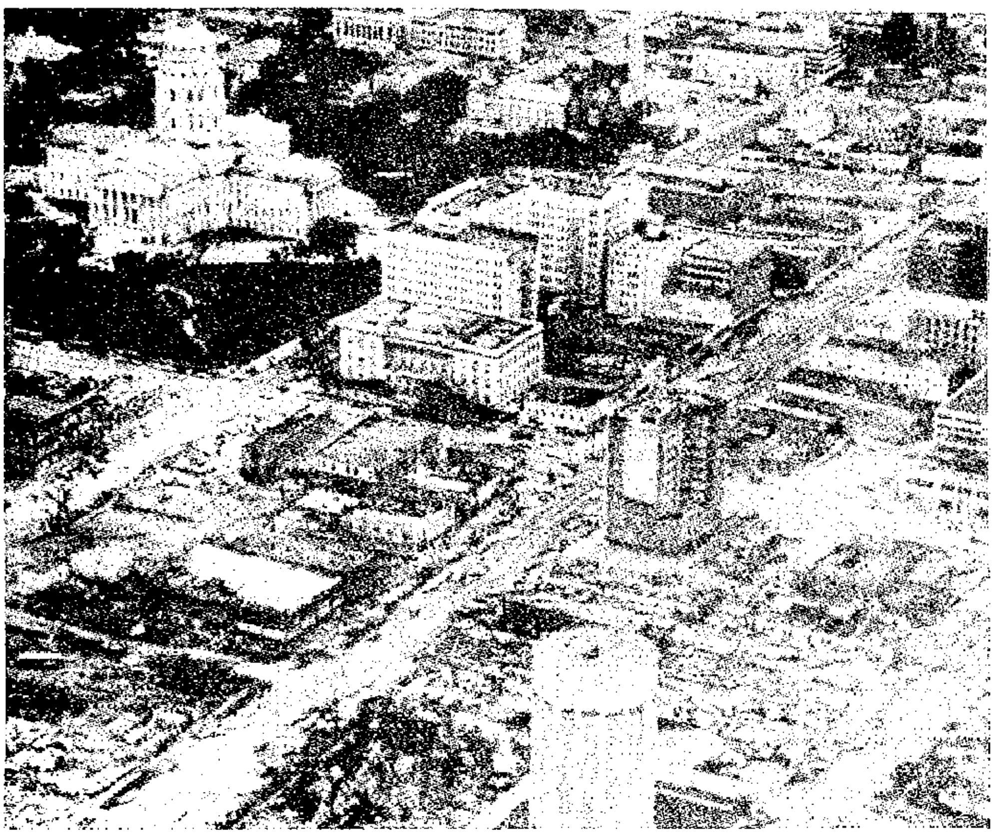

Fig. 210. Destruction in center of Topeka City, Kansas, June 8, 1966. *Left top*—Capitol (Galway, 1966).

were off the main track of the funnel and were not damaged.

Moving farther to the northeast, the tornado struck the building of the weather bureau. The small solid building was little damaged but the roof and the measuring devices were carried away. The speed of rotation of the funnel could not be measured here. The routine instruments were simply blown away. But the tornado weakened. The destruction became less and less and on the other side of the River Kansas the funnel climbed into the parent thunderstorm cloud, which continued northeast.

A detailed analysis of destruction in Topeka revealed two important facts. A tornado cannot destroy high reinforced concrete buildings and buildings cannot destroy a tornado. Its funnel continues to move ahead (Galway, 1966).

10
Ascent and Pressure

Lifting and pressure are caused by the vortex motion. This important feature of the tornado, caused by a number of individual phenomena, occurs at the surface of the earth and in the atmosphere. The lift of gaseous and liquid mass, often carrying solid objects, is effected by suction.

ASCENT

The funnel of the tornado-vortex often shows high, supersonic speed. This intensifies its lifting power. The tornado can lift many objects that cannot be moved by a wind of the usual strength.

Very heavy objects, weighing 50 to 200–300 tons, may be lifted several meters by tornadoes but this is rare when the object has a large surface area and the wind is normal. The heaviest object that has been lifted is the iron bridge over the River Big Blue in Irving (p. 357). Its weight was 108 tons. There was another case of lifting of a heavy bridge of almost the same weight. The passenger car lifted by the tornado in 1931 in Minnesota weighed 65 tons, its 117 passengers with an average weight of 60 kg per head would have weighed another 7 tons and therefore the total weight lifted was 72 tons.

Lifting of 200–300 tons of weight can be achieved by the strongest tornadoes. The lifting of very heavy objects is never more than a few meters and generally of the order of tens of centimeters. The horizontal shift is 25 m or less.

Heavy objects are lifted up quite frequently. These objects include buildings of various types—two-storied, single-storied with verandah, simple single-storied, big and small, heavy and light. Generally they are of wood, logs, boards and plywood. Their exact weights are difficult to assess. It never occurred to anyone to weigh his own house.

On April 15, 1921, in Arkansas, a farmer's family was relaxing on the bench in the porch of their single-storied house. A low, black cloud moved toward the house. No attention was paid to it and the conversation went on. Then a rumble was heard at a distance. The sound became stronger and stronger. The farmer turned around and found that his house had been lifted into the air. It parted company with the porch, still intact, and then exploded in the air. The porch and the family were unhurt.

It is quite likely that figures of the order of a few tons are frequent. A big two-storied house, lifted completely with floor, roof, stove, pipes, furniture, etc. may weigh 10–20 tons or maybe more.

Of the same order is the weight of the freight car, lifted from the track and deposited on the ground or overturned several meters from the track, and the caboose lifted into the air, carried a distance of 9 m and dropped across the rails.

Cases of lifting big, heavy iron and brick roofs off big stone houses have been cited many times.

The Irving group of tornadoes passed over a two-storied stone building, an exceptionally solid structure. The building was almost intact but two watchers on a nearby mound saw how the big, heavy roof of the house was lifted almost vertically into the air to a considerable height, 60–70 m. At this height it was probably caught in the horizontal vortex and in no time was reduced to small fragments. The fragments were lifted almost to cloud level by the walls of the tornado and they were thrown out of the funnel in all directions.

Often the roofs of buildings are carried to a small height and dropped to the ground or get stuck in trees almost intact.

In 1963 a tornado transported 10 people a distance of 400 m and they all lived.

More surprising is the transportation of heavy, compact material. Tornadoes lift and transport tens of meters or more such objects as heavy steel barrels and large bathtubs, as was observed during the tornado of June 8, 1951 in Oklahoma (Fig. 200). Against the general background of horrible destruction the barrel and bathtub do not appear significant. Actually their transportation is greater testimony to the strength of the tornado than the destruction of wooden houses in a particular zone. Comparable transportation by the tornado of August 17, 1956, in Minnesota involved a grader weighing 27 tons. It was thrown a distance of 30 m (Slamon, 1946).

A heavy beam 12 m in length and 15 cm in width was carried over the roofs of the houses to a distance of about 400 m (Ferrel, 1890).

A large number of remarkable incidents have been described in the monograph by Flora (1953). In April, 1936, an unusually strong tornado struck the city of Gainesville in Georgia. The downtown area was completely destroyed, killing 203 people. The transportation of a bell weighing 1 ton to a distance of 300 m was quite surprising. This feat was not as easy as the shifting of the steel barrel or the grader.

The famous Lorain tornado (1924) in Ohio, coming from the lake (see page 323) moved with such a strength that it carried trees, telegraph poles, big fragments of houses, parts of roofs, men and horses through the air. In one place even an automobile was seen in flight.

In May, 1927, in Hutchinson, Kansas, a tornado lifted and transported two steel bridges a distance of 30 m. A case of transportation of an iron bridge has been described earlier.

An automobile with four passengers was lifted into the air and carried a distance of 300 m. It was wrecked when it fell to the ground and all the passengers died (Hovde, 1939).

The Rostov tornado of 1953 lifted an iron frame weighing more than a ton from a 5 ton truck and threw it a distance of 10–12 m to the side. There it overturned two heavy freight cars. At one place the heavy metal dome of a church was torn off and blown into the air like a sphere (Chizhikov, 1956).

The lifting power of the Moscow tornado of 1904 was quite strong (see pages 338–346).

The Moscow tornado of 1951 tore off roofs, pushed over the lighter houses, etc.

The Arzamass tornado of 1938 passed over the fire tower. The tower flew in one direction and the bell in another (Gaigerov, 1939b).

The height objects of average weight are lifted to is also small, generally a few meters. Very rarely it is tens of meters. A lift of 60 m, as for the roof in the Irving tornado, is the maximum recorded.

Small objects weighing a few hundred kilograms are lifted by the funnels quite easily and in large quantities even in fairly small tornadoes. When they strike the city or a group of buildings, the air is generally saturated with fragments of different materials and compositions.

The height they climbed is considerable. The fall of objects in the funnel from a height of 90 meters has been recorded factually. Objects with large areas of resistance, e.g. thick, heavy branches with leaves, are lifted up by the parent cloud.

The most striking cases involved an ice-coated tortoise, fish, pieces of plaster and small bare branches of trees, etc. along with hail of enormous size (page 313). They were lifted to a height of 5–7 km or more. Only at this height could they be coated with ice. The discovery of a tortoise or a fish in hailstones, though unbelievable, is a fact, since it has been reported in renowned meteorological journals.

Very rarely have tornadoes been accompanied by intense snowfall, as was reported in the newspapers at the end of January, 1968.

One tornado struck the locality of Young in southwestern Sweden. It was very narrow and the total track was only a few hundred meters. But it reduced a big inn to rubble. The owner said: "We thought when the courtyard collapsed that some plane had crashed."

The tornado uprooted telegraph poles and removed the roofs of offices. The destruction was complete. A curious thing happened at the local football stadium. In the stadium the tornado engulfed and lifted the goalkeeper along with the goalposts a few meters above the ground. However, the goalkeeper landed back on the ground safely without injury.

Among the individual odd happenings is the case of a shirt which had contained a watch in the pocket. The shirt was carried a distance of 20 m but the watch was removed from the pocket and carried a distance of 50 m. It was completely covered with mud. The feathers of birds in flight were completely plucked. In one mountain valley the tornado blew over a herd of sheep. The sheep were tossed down the slope and their wool was removed the way feathers are removed from chickens.

At the beginning of the last century numerous herds of buffaloes roamed the plains of Kansas, Nebraska and elsewhere. Of course, tornadoes also occurred, lifting individual animals and killing them. In recent times two cases involving buffaloes have been described. They were found dead, every bone in the body broken, the skin removed and the flesh exposed (Lane, 1966).

With the passage of a tornado through populated areas lifting of heavy objects and animals is inevitable. Often with the help of objects rotating in the tornado the speed of rotation has been determined with cinecameras. As an example, the film taken during the tornado of April 12, 1937, in Dallas can be cited (Fig. 149). The tornado passed in a good light and was photographed by still and cinecameras. An enormous amount of material was published in 1960 (Hoecker and Beebe, 1960).

In another case a fowlhouse and chickens were thrown into the air.

One of the incidents in the tornado of May 25, 1955, in Oklahoma may be mentioned. The housewife of a two-storied frame house heard an unbelievable howl and noise. She saw from the porch that a terrible black wall of cloud was moving toward her house. Terrified, she took shelter under the stairs. There was a terrific noise and she was lifted into the air along with the staircase and floor and smoothly carried over the block. Nothing remained of the rest of the house.

In Missouri, in 1879, a horse was lifted up and carried a distance of a few hundred meters without injury.

In Louisiana a woman was lifted into the air, spun around the house and then dropped to the ground without injury. Similarly a child was transported in Oklahoma and remained unhurt (Asp, 1950).

The action of the tornado of June, 1906, in Minnesota was more delicate. A small wooden house was broken into pieces and carried away. But the kitchen shelf with vessels, though lifted into the air and carried a distance of 20 m, was dropped on the ground so gently that all the vessels remained intact. Some furniture from the house was carried a distance of 7 km and one leg of a chair pierced a treetrunk in such a way that it stuck out on both sides of the trunk.

There are many such cases and they are all alike. A tornado may lift heavy objects of considerable size into the air but the height of the lift of such objects is not much, from a few meters to a few tens of meters. The horizontal shift is also not large—from hundreds of meters to 1–2 kilometers.

Lighter objects are lifted to greater heights and often sucked up into the horizontal vortex formations of the tornado clouds. The tornado itself carries it a small distance.

This rule is possibly applicable only to the narrow, sharply defined tornado with very high speed of rotation. The wide, diffuse, more slowly rotating formations of the Three States type of tornado carry fine objects tens of kilometers without lifting them to the cloud. On March 23, 1917, an ill-defined tornado crossed New Albany, causing large-scale destruction. Crossing the city, the thunderstorm cloud moved on northeast into the State of Kentucky. At a distance of 40 km from New Albany the tornado disintegrated, strewing the ground with small objects picked up in that city (Walz, 1917).

In New Albany 45 people were killed and a few hundred injured. Some died of injuries. About 300 houses were destroyed and some of them were quite big.

Similar cases of transportation of small objects to tens of kilometers have been recorded in the case of many other tornadoes. An example of transportation to 120 km has already been cited. Unfortunately, part of it remains doubtful: whether these objects have been transported by the tornado or by the horizontal vortex of the tornado cloud is not clear. Actually it is not that important. The tornado and tornado cloud constitute one vortex formation.

The process of transportation of rather heavy objects to a distance of 2–3 km by wide-funnel tornadoes of tens of meters and a belt of destruction a few hundred meters wide is not very clear. In Oklahoma, the bodies of two women living in the same house were carried away along with the fragments of the house to a distance of about 3 km. The transportation of heavy fragments to a few kilometers is quite usual (Asp, 1950). All these objects obviously were not lifted up by the tornado cloud but carried away by the wind accompanying the funnel.

The mechanism of this transportation and how it takes place are not clear. Probably the transportation is carried out by a special vortex rotating around the funnel. The throwing off of objects by the centrifugal force of violently rotating funnel is less likely. This force no doubt exists. In a number of photographs it can be seen how different objects are thrown out of the funnel. But they are thrown out to tens and hundreds of meters, never kilometers.

There are a number of problems related to the transportation strength of tornadoes which are unsolved. Even such phenomena as cascades are not yet clear. There is no doubt that the cascade is formed due to the funnels reaching the ground or the sea but the funnel is frequently lowered relatively slowly. It is unlikely that one strike will form a cascade 100 meters in width and height. Obviously, here one must assume the existence of some additional horizontal vortex, rotating around the funnel. What is this vortex? How does it originate? When is it formed? Like many other phenomena accompanying the tornado, all these questions have still to be answered.

SUCTION

As described above, the Moscow tornado of 1904, crossing the River Moscow sucked up water and in a few moments exposed its bottom. The Muscovites saw the mud bottom of the riverbed full of pots, bottles, old boots, etc. which had all accumulated over the centuries. Not everyone saw this as the funnel had already reached the other bank and the water in the river had closed up.

The suction of the water and exposure of a riverbed have been described repeatedly.

A very strong tornado occurred on September 6, 1869, in Kostrom province. It had the form of a dark gray column with a diameter of 40 m in the beginning and later, five times that size. In the villages of Zabelikh and Lind the tornado carried away 36 stacks of hay. In the village of Ladygino it overturned a mill and in the village of Yakushino not a single house remained intact and 175 stacks of wheat were scattered. One such stack was removed and dumped in the forest, a distance of more than 300 m. When this tornado passed over the River Semindyaev it sucked up the water. It had a long traverse to the bank of the Volga. Then gouging out the water of the Volga to its bottom, it passed over the village of Voronikh and destroyed it.

A similar tornado occurred over Ivanov station, between the rail stations Tambov and Kirsanov. Encountering a lake on its way it sucked up water and moved on in a northeastern direction, destroying farm buildings.

On June 18, 1939, over the small city of Anola, situated on the right bank of the Mississippi, an enormous low thunderstorm cloud appeared. With horror and shouts of "Tornado, Tornado!" the inhabitants of the city saw the meandering trunk, hanging from the cloud and touching the surface. At the point where it touched a structure a column of dust lifted the cascade up and the structure disappeared. The tornado relentlessly approached the city but its path was blocked by the wide, shallow river. The hope lay here. But what is this? The funnel approached the river, crossed it and moved to the other bank without any reduction of speed. The water of the river disappeared, exposing the wet, dirty bottom. A wide trench formed with a bottom of mud and walls of water. The trench lay across the entire river, from one bank to the other. The funnel was already raging over the city, causing continuous destruction, pouring out the water and smearing everything with black, moist mud. There was no trace of the trench after the funnel crossed the river.

These unusual ditches—trenches with water walls and clay bottom—have formed in many other small rivers, on the tracks of tornadoes. The water of small ponds, swamps and lakes, slime, mud, frogs, fish and water-plants etc. disappears in the trunk of the tornado. After a few kilometers and often tens of kilometers, dirty rain falls with fish, frogs and waterplants before people who cannot believe their eyes.

Once the funnel of a big tornado approached the bank of the Rhine downstream, where the big, wide river reaches a depth of 20–25 m. The tornado moved over the river and the bottom was exposed. When the tornado was 7 m deep in water it was not strong enough to go deeper and crossed the river through a 7 m deep trench whose bottom and walls were of Rhine River water. Reaching the other bank, it encountered the shallow bottom and exposed it. The funnel reached the other bank and the strange trench disappeared. After crossing the Rhine, the funnel became noticeably dark. It was saturated with water and mud (Batalin, 1854).

Marine tornadoes are diverse in size and speed of rotation. In many of them the speed is so low that they do not have sufficient strength of suction. They have nothing except fresh water from the clouds. But there are gigantic marine tornadoes which are as good in size and speed as land tornadoes.

In 1933, in the village of Kavalerovo, not far from Vladivostok, an enormous thunderstorm cloud moved in without any tornado. The surprise was that at its peak there was saline rain and along with it fresh, live jellyfish were dropped. Kavalerovo is 50 km from the coast. A marine tornado had sucked up sea water with jellyfish into the cloud and they traveled for 1 hour, as the average speed of the thunderstorm cloud with the tornado was 50–60 kmph.

The farmers of Kansas living near the tracks of the Irving and Delfos tornadoes had found to their surprise that the dead bodies were smeared with mud. The farmers could not understand where such a lot of mud had come from, but the explanation is simple. There was a small rivulet near Mr. Kron's farm. While crossing the rivulet the funnel sucked up a mass of water and mud and smeared it on those unfortunate people. There have been quite a number of such incidents and each and every time the funnel crossed a river or rivulet.

In 1918, in Ohio, the family of a farmer with a dog took shelter in a trench after seeing an approaching tornado. When the funnel passed over them they were lifted up with irresistible force. They caught hold of each other, grass or whatever they could lay hands on. The dog was lifted and carried a short distance. It came back limping but half of its hair had been removed. Another family took shelter in a cellar. The door of the cellar suddenly opened and the whole family started soaring up as if they had lost their weight and started flying through the air. They escaped by holding onto the wall of the cellar. This lasted a few seconds (Strong, 1905; Hardin, 1918).

In 1919, in Oklahoma, a young man was overtaken by a tornado in a farmyard. Lying on the ground, he saw five heavy bales of pressed cotton lifted into the air to a height of 2 meters and then carried through the air. One of the bales struck the wall of a house with great force.

In the outskirts of Paris the castle of Châteney stood in a beautiful, old park. On June 19, 1839, in the big plain a few kilometers from the castle, a funnel lowered to the ground from an enormous, dark thunderstorm cloud. The funnel, resembling a trunk, was of bright color and very sharply defined against the background of cloud. Slowly it began terrific destruction. First it destroyed a big apple orchard. Passing over a big field filled with stacks of wheat and hay, it lifted up whatever came in its way and scattered it all over the field.

Reaching the moat surrounding the castle, the funnel moved parallel to it for a short distance and literally sucked up the moat. The wall collapsed not due to the tornado but due to the water being removed. The massive building of the castle was damaged only slightly. But such was not the case with a small house nearby, where a large number of fine stone slabs were stored, meant for repairing the roof of the castle. The building and the slabs were lifted up and destroyed.

In the corner of a park there was a pond surrounded by trees, bushes and flowers. The pond contained waterplants, waterlilies, insects and fish. The funnel struck the pond. After a few seconds when it had crossed the pond and the bank all around there were dirty wet patches and broken trunks and branches of trees.

In Minnesota, in 1919, the family of a farmer was relaxing in a single-storied wooden house. The family consisted of the father, mother, elder daughter and a baby on the father's lap. A tornado struck. The house disappeared altogether. All the members of the family were killed except the baby, who was lifted from the father's lap and carried to a distance of tens of meters. She was unhurt and what is surprising is that one shoe was sucked up by the tornado (Tornado at Fergus Falls, 1919).

During this tornado a box with linen was lifted into the air and carried more than two blocks over the attic of another house. It is unlikely that this can be explained by wall pressure alone.

Suction alone can form an enormous pit in the soil, which may be as wide as ten meters. The mud from the pit along with the grass, etc. is strewn all around. This was observed in 1927 at Getchinson, Kansas (Flora, 1953) and in other localities.

During the famous tornado of May 27, 1896, in St. Louis, Mississippi, the funnel came very close to an observer. Though he stood back from the path of the tornado, he was completely drenched with water and smeared with mud thrown from the funnel of the tornado. He compared the funnel with a geyser, which ejected water upward and then to the side, drenching everything all around (Frankenfield, 1896).

During the tornado of March 11, 1917, in Ohio (Young, 1917) the funnel passed over a solid single-storied stone building. The roof was slowly torn off and removed but the walls remained unaffected. The most surprising thing was that all the furniture was sucked up from the house and carried away.

"The funnel passing over the asphalt road exposed the soil underneath. Pits were dug in the wet soil. Plugged kegs burst out, boxes broke open and the contents were thrown all over. The bark of trees was removed, automobiles were damaged, the loads of horses and often their hair were removed as well. It removed people's clothes, leaving them stark naked.

"During the tornado of June 9, 1953, in Massachusetts, a farmer was walking on the street with a basket containing eggs and the eggs burst out of the basket like shots from a pistol. Two women saw a child floating before them in the air. They caught hold of him like a balloon with a cord, and pulled him to them" (Lane, 1966, p. 43).

In another case, a tornado passed over a well with water 6 m deep in it. The housewife had placed two buckets of milk in it for storage. These two buckets and all the water were sucked up from the well. There are a number of cases where water has been sucked up from deeper wells.

In Utah a tornado passed over a field covered with snow. It sucked up so much snow that the funnel became completely white.

All these cases and the numerous cases of suction of water with animals from ponds and small lakes cannot be explained by wall pressure. In many cases these things were lifted up into the tornado cloud.

The upward lift or suction is one of the main features of the tornado, but there are cases where the same tornado that lifted up the roofs of houses also squeezed the stems of plants in the kitchen gardens, as was the case during the Rostov tornado.

In tornadoes, besides the predominant ascending currents there are occasionally descending currents, but they have been studied only sketchily.

The lifting strength of the tornado, though important, is an unexplained phenomenon. Accurate observations are not available. In many cases even the eyewitnesses do not mention the height of lift of various objects. For tornado Anol of 1939 the figure for lift of debris was 90 m and transportation of clothes, papers, bits of furniture, etc. was to a distance of 80–110 km. According to the photographs, the bigger fragments are not lifted by more than a few tens of meters. It is at this height that the teacher with his students, the cow, horse with foal, people and other heavy objects flew. There is no case where some big heavy object dropped from a height of several hundred meters. These things are all lifted a few meters and carried over houses, low trees and fences.

The lift near the surface vortex forms the cascade of water, dust and fragments.

Objects of average weights and sizes, e.g. big fragments, boards, bricks, iron sheets and small animals are lifted to a few tens of meters, often up to 100–150 m. They are thrown out of the funnel of the tornado at this height.

PRESSURE

The walls of the funnels of the tornadoes display a vortex, spiral-like flow of air with great speed. Its activity has been discussed in great detail. Though very rare, a strong flow of air sometimes occurs in the opposite direction, vertically downward. Whatever is on the surface of the earth is pressed and pounded and a peculiar path is formed.

This pressure was exhibited quite sharply in the track of the Rostov tornado of 1953. The tornado moved over the garden on Fevralsky street (Fig. 202). The black currant bushes were stripped of leaves and the bushes were pressed flat to the ground and squeezed. The stems of tomato, beet and potato plants were also squeezed. An observer wrote that they were all squeezed by the "base of the tornado". What this "base" is, however, remains a mystery.

When the tornado, approaching Rostov, passed over a field, it swept up all the sheaves, as usual filling the air with straw. But the most surprising thing is that wherever the funnel went, it formed a straw path 60–80 m wide and one kilometer long. It made a layer of straw, flat and sharply defined through which the ground could not be seen. In the lowland and between hillocks the layer of straw thickened and the straws were squeezed to the ground. This is what is referred to as the "base of the tornado" (Popov, 1954).

Similar phenomena were observed during the tornado of 1893 which occurred over Cleveland, Oklahoma. The black thunderstorm cloud came over the city. Funnels of different sizes appeared and disappeared from its smooth base. One of the funnels was stretched, reached the ground, moved over it and caused large-scale destruction. Thirteen people lived in the first house falling in the path of the tornado. In one moment the house turned into heap of debris and 11 people were killed. Farther on more houses were damaged and 30 people were killed (Abbe, 1893).

Even against this horrifying background, an observer noted that the tornado passing over a field squeezed the wheat crop to the ground. Planks not only flew high in the air but pierced the ground deeply.

On May 25, 1896, in Michigan, USA, the track of a tornado had a width of 200 m. Observers were surprised, and rightly so, that in the middle of the track, over a few wide zones, the grass was not removed as was generally the case, but squeezed to the ground (Conger, 1896). The phenomenon was exactly the same as that observed during the Rostov tornado in 1953.

Between 1896 and 1953, some 60 years have passed. During this period there has not been a single case of squeezing along the track of tornadoes either in the USSR or in the USA. It is quite likely that some such cases have been missed. It can, however, be said with certainty that pressure in the track of the tornado occurs rarely. The nature of this pressure, the "base of the tornado", is a riddle which is not likely to be solved soon.

and 30, 1879. The sinister Irving tornado blew away a house on the outskirts of the city and the family living in it. The father received severe injuries at the hip. Nothing remained of the house. The mother was carried a distance of 225 m and the four daughters to 200, 125, 175 and 200 m respectively. All died.

The local inhabitants are thoroughly familiar with tornadoes and as soon as they approach they run to the cellar (Figs. 119, 130). This saves them.

The raw seasonal hired hands may not be familiar with tornadoes and often think they will "blow over". Actually it is they that are blown over and not the tornadoes. The house of one McBride was struck in the late evening. The owner took shelter in the cellar but the hired hand thought, "This is silly, it will all be over". He was lifted into the air, carried 50 m to the west, thrown to the ground and had his legs and hands fractured. He was sorry he had not followed the example of his boss.

On the same day the neighboring Delfos tornado carried away the house of one Ostrander. The owner took shelter in the cellar and emerged after the house was blown away. The spiral current of the funnel blew away a worker to a distance of 60 m and then dropped him in the middle of a slimy rivulet. The worker was thoroughly smeared with mud. His hair got a coating of mud but he was unhurt.

A third worker, falling in this group of tornadoes, without realizing it demonstrated the spiral rotation in the funnel of the tornado. He accomplished a traverse in the air, remaining unhurt (Fig. 188). When the funnel hit the enormous barn he jumped out of it, was engulfed by the gusty wind and carried around the barn in a spiral. After flying more than 100 m he was slowly lowered to the ground. His head was reeling and he did not remember anything about the flight. He flew for a few seconds. It is easy to calculate: if the speed was 50 kmph it would take 1.1 second to fly a distance of 150 m.

Generally people are lifted up and then dropped. But there is a case where a farmer was lifted up, then after a few tens of meters lowered almost to the ground and then again lifted up and lowered to the ground. It is surprising that he remained intact, but he regained consciousness after a long time.

Unfortunately such "polite" tornadoes are rare. Generally the air current suddenly stops, the victim drops to the ground and is killed. Often still worse things happen. The air current throws the victim to the ground with force and the bones are also crushed. One woman was thrown with such force that her head and shoulder were reduced to powder.

The distance people are carried is quite diverse. Generally the transportation of people varies from a few tens of meters to a few hundreds of meters.

A farmer was sitting on a fence observing the funnel in the belief that it would pass by. Though it bypassed him, on its way it lifted the farmer along with the fence and transported him to a meadow, a distance of 25 m. The farmer got up bewildered, smeared with dirt from head to toe with torn clothes but, as he expressed it, "wiser".

Very rarely the distance of transportation is in kilometers. In Oklahoma a farm was destroyed. Two women along with the fragments of the house were carried a distance of 3 km. They were killed.

In Arkansas, on April 12, 1927, a tornado lifted a child, carried him a distance of 4.5 km and dropped him on the ground with minor bruises only. Farther on this same tornado accomplished an almost unbelievable feat. It lifted and transported a woman a distance of 11 km. She was killed. Transportation to such a distance is difficult to believe but it has been reported in a quite authoritative meteorological journal of the USA (Shipman, 1927). The duration of such a journey would have been 10 minutes. During all this time, the woman's body rotated in the funnel of the tornado, moving along with it at a speed of 50 kmph.

TRANSPORTATION OF ANIMALS

The transportation of animals is much more diverse and interesting. The most unusual is the flight of the Irving cow (1879, p. 352). The maximum number of cases concern the flights of horses. They flew either singly or in pairs. But there is one case where three foals described almost a full circle of 60 m diameter in the air. They were transported just above the ground. At places they tore gaps in the hedge and at places they were dragged over the ground. In any case, they described a full circle and were carried back to the meadow from which they started out, but were thoroughly smeared with dirt.

Two horses with foals were grazing in another meadow. The animals disappeared as the funnel of the tornado engulfed them. They were located next day in a dense wood more than a kilometer away. The track of the route followed by these animals showed that they were lowered temporarily to the ground and lifted up again. They were carried over a meadow, a maize field and a few fences. The horses remained unhurt but the foals were badly injured.

In the Soviet Union, too, the best-known flights involved horses. On August 18, 1956, on one of the collective farms of the Minsk region, 16 enormous milk cans were lifted and carried to the ravine in badly twisted form (p. 348). Simultaneously the funnel engulfed the horse and carried it to a great height. The twisted body of the horse was found 1.5 km from the farm.

Comparing numerous cases of ascent and travel through air suffered by horses and cows one has to admit that even for sizable funnels these animals are rather heavy to carry. There is no doubt that these objects fly but just above the ground, often being lowered to the ground and again lifted up. The lift certainly depends on the weight but the main factor is the weight plus a smooth aerodynamic form. Enormous, heavy roofs fly very high, but cows weighing much less are raised just over a wood of 15–20 m height. There remains nothing of the roofs but cows generally soft-land without injury. The area of resistance of the roof is very large and for the cow it is very small. As a rule, women in flight suffer more than men because their dresses have a larger area than men's clothes.

The flight of dogs and cats is relatively rare. They are treated as members of the family and therefore take shelter along with the family. In the well-known painting by the American painter-naturalist Kerry, the eldest boy drags the puppies to the cellar and their mother runs after them. The black cat is struggling in the arms of the youngest boy. The chicken, standing before them, gets no attention (Fig. 119).

The flight of a dog sucked up from a canal has already been described (p. 407). He flew but came back safely. For one cat the flight was disastrous. It was badly mutilated and turned into a lump of flesh, as though it had been squeezed. A mutilated body like that is really unique. There is not a single description among the various descriptions of tornadoes where an object was so deformed. It can happen only when the air current drops it on the ground with unusual strength, crushing its bones or when it drops from the cloud.

Of all the animals, chickens have been destroyed in the largest numbers by the tornadoes. More or less every farmer and the poor inhabitants of provincial towns keep chickens in large or small numbers. The fowlhouses are weak structures and offer a larger area of resistance. Even when the funnels are relatively far off, the fowlhouses and the chickens fly into the air with striking ease (p. 370).

ASCENT AND FLIGHT OF TREES

The lift and flight of trees is quite peculiar. Though a tree is relatively light and displays an enormous area of resistance it does not fly well. Many tornadoes have badly damaged gardens and forests and their effects have been studied in detail. In the botanical garden in England the effect on each tree was recorded. The trees were damaged, uprooted, twisted but not one of them blew away. Each remained where it stood. Why this happens is a riddle, like the riddles of the squeezing of stems of vegetables and garden plants and the straw path leading to the city.

The funnel often passes over distant fields and meadows. What happens there? This is the third riddle.

Before concluding the section on lifting and transportation, it can be said that the above examples, often striking, only cover a small portion of the surprising effects. In special meteorological journals and publications, especially in American publications, many other surprising incidents can be found.

12
Transportation

The transportation phenomenon is no less important and puzzling than lifting and carrying. The riddle is much greater here. To the transportation by the funnel and the accompanying vortices, transportation by the thunderstorm cloud should be added. The last is full of puzzles. Detailed descriptions of rain of fish, crabs, jellyfish, silver coins, etc. are available but from where these are collected and how they are transported by the cloud cannot be explained.

TRANSPORTATION BY TORNADOES

Transportation—this is also carrying over, but to a considerable distance, of the order of tens or hundreds of kilometers and more.

The main point is that the heavier the object and the less the area of resistance, the shorter is the distance of transportation.

The heavy iron bridge was dropped into the river with the piers. The big rail car with 117 passengers flew a distance of 10–25 m. The Catholic church with 15 people was carried a distance of 4 m.

Transportation of materials of average weight does not take place. Automobiles, tractors, horses, cows are generally carried not more than a few hundred meters. Only in exceptional cases does the transportation of human beings reach 3–4 km or even 11 km. Tornadoes do not carry them tens or hundred of kilometers.

What does this signify? It is still a puzzle. The powerful, unusually strong funnel of a tornado travels many tens, often hundreds of kilometers but heavy objects and objects of average weight cannot be carried to such a distance.

This can be explained only by the short-period, quickly disappearing powerful flow of air which lifts the bridges, cars, churches, etc. The flow that lifts people and animals is also not of long duration. The duration, as calculated above, is only a few seconds.

Thin, light objects with a large area of resistance are transported by tornadoes a few tens or even hundreds of kilometers.

The record is that of an insurance receipt which was transported by a tornado to a distance of 120 km and a letter with a cheque to a distance of 136 km. Each case needs verification. It is quite likely that the transportation was not by the funnel but by the tornado cloud. The verification is relatively simple. If the tornado touched the place where these papers were found, then they were transported by it, but if the funnel disappeared tens of kilometers away from this place, then the transportation was by the cloud.

On March 23, 1917, an enormous diffuse tornado occurred over the city of New Albany, causing large-scale destruction. The gigantic funnel was filled with fragments, rubbish, papers and torn pieces of clothes. Crossing the city, the funnel was suspended from an enormous greenish-black thunderstorm cloud. It moved on into the State of Kentucky. The last time the funnel was observed was when it was 16 km away. It is quite likely that it survived for another 25 km, since the fine material captured over the city started falling 40 km away from New Albany. It is not clear if it dropped from the funnel or from the cloud along with the rain. The ground was covered with torn clothes, pieces of board, roof tiles, splinters of furniture and other refuse. Among this the door of a kitchen cupboard, paper, a letter, a family photograph and a glass jar with pickled cucumbers from a damaged house were found. The groceries from the same house were mixed up with all this. The glass jar was intact. These objects fixed the distance of transportation as 40 km from New Albany. It was not clear if they were all transported by the funnel or by the cloud. It is quite possible that the door of the kitchen cupboard was suspended in the cloud, but its transportation by the funnel is also possible. The last object was recovered at a distance of 65 km from New Albany.

The fall of small objects from a dissipating funnel has been observed repeatedly. Many of these objects are transported tens of kilometers. The length of the track attains 300–500 km and often more. Only small objects can be transported such a distance. However, exact observations are not available.

Small objects and animals weighing not more than a kilogram and not more than tens of centimeters in size are lifted many hundreds and even thousands of meters into the clouds and the vortex cloud transports them tens and hundreds of kilometers, as is described below.

The enormous significance of transportation by the wind of big, small and especially microscopic animals and plants has been underlined by the well-known zoo-geographer Darlington in his work (1966). He believes that the transportation by the wind is a leading factor in the formation of the organic life on islands. He substantiates this claim with the example of the Antilles Islands.

TRANSPORTATION BY TORNADO CLOUDS

The vortex ring formations in the lower part of the cloud rotate quite slowly in the tornado and retain in the air only small, light objects with a large area of resistance or of small weight, from a few grams to one-third of a kilogram or so.

In 1907, in Switzerland, fishes weighing up to 16 kg dropped with the rain. They had been transported from a lake 20 km away. Fish rain is described below in detail on pages 422–429. Straws, hay, small branches, small animals and even small coins are easily transported. Transportation to a few tens of kilometers is quite usual for small fragments and objects.

The total weight of the transported material is enormous. This is primarily related to water. Tornadoes crossing lakes and rivers suck up into the cloud an enormous amount of water with all the organisms in it. This water goes into the vortex, the rotating ring of cloud. Often a waterspout, starting out to sea and saturating the vortex ring with sea water, reaches the land. When the ring ceases to rotate, the sea water along with the marine organisms drop over the ground in the form of saline rain. The weight of the water in the vortex ring depends on its size and the size of the cloud. The fact that the water is retained in the air goes to prove the great speed of rotation. As soon as the rotation slows down, the water drops to the ground in the form of a downpour, often of catastrophic magnitude.

The duration of transportation depends on the life span of the tornado cloud or the vortex ring inside. Often it lasts longer than the tornado. The marine water with jellyfish dropped in the form of rain, considerably after the disappearance of the tornado. Rain with fish also frequently occurs when nothing remains of the tornado. In any case, the distance of transportation is relatively short, of the order of tens of kilometers. In individual cases, the figure goes up to 100–120 km, but the tornado, and consequently the tornado cloud, travel up to 300–500 km or possibly more.

McAtee (1917) gave an interesting and full review of rain with organic matter, especially fish. He classifies rain into rain with plants, vertebrates and invertebrates.

Rain with Plants

Rain with plants and plant residue has occurred many times. Some cases are not related to tornadoes, e.g. the yellow rain with spores and pollen of pines and other plants. Others are due to the suction into the thunderstorm cloud by the tornadoes or transportation by the dust vortex. The latter forms a dry rain of hay or plant dust, generally transported a few kilometers.

Tornadoes lift up various plant residues, from microscopic diatoms to tree branches as thick as a man's arm. All these are transported tens and even hundreds of kilometers and dropped from the cloud along with water, without any relationship to the tornado, far away from its track, when the tornado has already disappeared.

Manna is a mealy, edible lichen growing in the dry regions of Asia Minor. The "heavenly manna" rain has been described in the Bible but it has been observed in relatively recent times too.

Rain with grains is relatively rare. McAtee gives examples of rain with wheat transported by hurricane from Northern Africa (Tetuan) and falling in Andalusia, Spain.

Rain with pollen and spores is a common phenomenon. Rain with the pollen of pine has attracted greater attention.

This pollen has a bright yellow, sulfur color, is highly inflammable, has a strong smell and is therefore often mistaken for sulfur. Such rain is referred to as "sulfurous rain".

It is well known that sulfur supposedly comes from hell, with its sulfur smoke and smell. Naturally, superstitious people thought the "sulfurous" rain meant the end of the world.

My country house near Leningrad is situated in a pine forest. With the appearance of dawn a fine yellow dust fills the air. One cannot get rid of it. Even by closing the windows the deposit on everything cannot be checked.

Once smoke appeared over the forest in the evening of a June. Everyone was frightened and thought that the pine forest had caught fire. Suddenly a strong wind blew and 50 columns resembling smoke appeared all around. The columns rotated like tornadoes. The wind quickly stopped and everything was clear. What looked like smoke was actually the pollen of pine. The amount was extraordinarily large.

It is not only tornadoes and storms but strong winds that lift the pollen to a great height. The clouds can transport it several hundreds or even thousands of kilometers.

Rain with hay and straws, of course, is rare but not that rare. The dry hay is lifted into the clouds not only by tornadoes but also by "vertical vortices". "It was extremely quiet. Suddenly in front of our field rotating air columns appeared, connecting the top and the bottom and a mass of dry hay started going up. The bales of hay dropped throughout the evening over the meadow and our garden. The phenomenon continued for four hours." The transportation of hay by the Moscow tornado of 1945 has been described on pages 346–347.

On June 30, 1892, large amounts of hay were lifted up into the cloud by the tornado in southern England. The hay dropped with the rain 5 km away from the place it was lifted.

There are numerous cases of such lifting. There is no doubt that the clouds transport not only hay but dry and green plants and their seeds. The transportation of the latter to hundreds or even thousands of kilometers is a usual phenomenon.

Rain with Invertebrates

Rain with microorganisms is quite frequent and found in all cases where the tornadoes occur over fresh water pools and over the sea, sucking up the plankton floating on the water. The microorganisms containing plankton are invisible to the naked eye. Special observations are rare and exact data on the fall of microorganisms are quite sparse. The most detailed work is that of Ehrenburg (1849), which is more than a hundred years old. He shows that the composition of microorganisms falling with the rain is quite diverse. Both freshwater and marine forms fall to the ground. A brief account of the work of Ehrenburg is given on pages 502–509.

Very occasionally a tornado lifts into the cloud the moss accumulating on the bottom of lakes, lagoons and swamps. This drops with rain in the form of a dense, sticky mass similar to jelly. In England, during a storm with heavy rain, balls of jelly-like material comprising eggs, masses of larvae of infusoria, etc. fell. A boy on whom it fell was covered with the jelly-like matter (McAtee, 1917, p. 220).

Rain with earthworms cannot be established but it takes place not infrequently. In all cases where a tornado sucks up into the cloud a considerable amount of moist, loose soil, it lifts up along with the soil the insects present in the soil and certainly, therefore, earthworms. In the cloud the soil is washed out and clean earthworms fall with the rain To notice such a thing is quite difficult but McAtee reports two such cases. In the first instance he reports that many earthworms were found after a short spell of rain inside a cart standing in a courtyard. The other case is more striking. McAtee's father living in North Dakota returned home through heavy rain and found several earthworms on his stetson.

Rain with jellyfish was observed only once. This was in 1933 in the village Kavalerov, not far from Vladivostok (see page 407).

A large number of cases of rain have been observed with various insects in Germany, Australia and France. On the outskirts of Turin a violent storm with rain dropped thousands of insects from Sardinia (McAtee, 1917, p. 220).

Though rare, rain with mollusks is quite interesting. In 1834, in the United States, during one strong storm, there was rain with shells weighing up to 2 ounces and in France there was rain with continental gastropods (Bulimus).

Rain with gastropods occurred over Worcester in England on May 28, 1881. Gastropods are marine creatures with shells 2–3 cm in length and are edible. This rain attracted a lot of attention. It was the subject of articles and was discussed in detail in the newspapers. The city is situated 160 km from the west coast of England. It is interesting that the shells fell with the rain for two hours until the main thunderstorm cloud appeared.

When the westerly wind with the unusual rain came men, women and children started collecting the mollusks. The mollusks were everywhere—in the gradens, hedges, roads. The quantity was considerable, almost half a ton. In one garden, two bagfuls of mollusks were collected (Lane, 1966, p. 63).

Rain with crabs is not rare on the seacoast. In England in Reihat, 55 km from the seacoast, live marine crabs of small size fell with the rain after a strong storm (Reid, 1850).

Rain with Vertebrates

Rain with vertebrates is quite frequent but the size of the falling creatures is small. It is almost always aquatic animals, frogs, fish, etc.; continental types like toads, tortoises, rats are rare.

Rats dropping in large numbers with rain has occurred only in Norway. McAtee (1917, p. 223) says this happened during one of the massive migrations of rats.

A tortoise 15 × 20 cm in size, completely covered with ice, dropped along with the hail in the United States (see page 314).

Rain with fish is of more frequent occurrence. It occurs where the tornado sucks up water with fish into the cumulonimbus cloud.

The oldest description dates from the 16th century. It is by the Swedish Bishop Olaf Magnus (1555). In his account he has a chapter "On precipitation or rain with fish, frogs, rats, worms and stones from the clouds". The drawing by him show fish swimming in the clouds (Fig. 211) (Gudger, 1929).

After two years, in 1557, a monograph on various rare events was published by Konrad Lycosthenes. He describes rain with fish and frogs (Fig. 212). Rain with fish was observed in Saxony in the seventh century (689 A.D.).

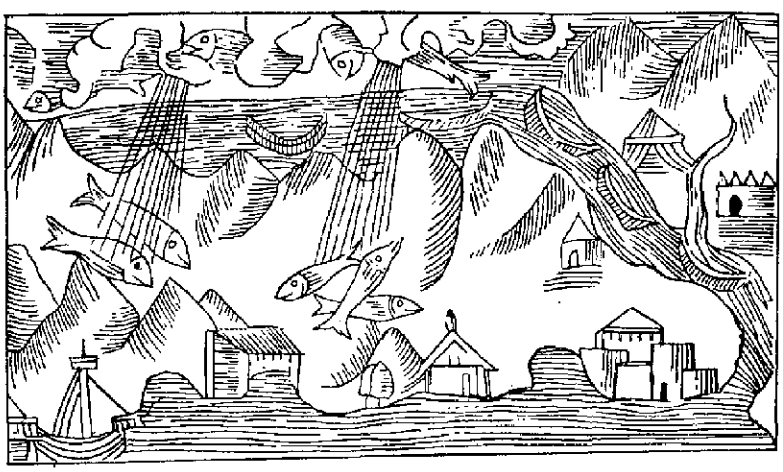

Fig. 211. Rain with fish, 1555 (Gudger, 1929, p. 3).

The next description dates from the 17th century, in 1667. The Jesuit scientist Kaspar Shott recollects that in Germany there was rain with fish. On Farer Island, in 1655, many fish were found during mid-summer on a hill 300–400 m high. The explanation is quite interesting: "These fish are transported over the ground by the vortex known as "typhoon" or "oes" in the Dutch language. This type of vortex is formed in the cloud and from there strikes the sea and the ground with such force that trees, bushes, stones, etc., whatever is encountered on the ground, is lifted up. The bigger structures are thrown to the ground and disintegrate. If it strikes the sea it lifts up so much water that the surface of the sea looks like a valley, which is again quickly filled up by water. The fish along with water are lifted up" (Gudger, 1929, p. 7). This explanation remains valid even after 300 years and the description of the tornado is also complete.

It is of interest that even Dickens in a paper published in the journal of 1863 cites a few cases of rain with fish.

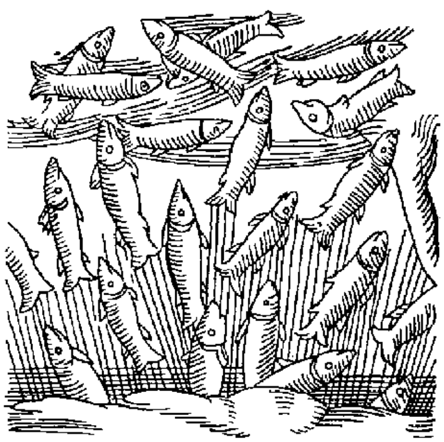

Fig. 212. Rain with fish, 1557 (Gudger, 1922, p. 84).

The rain with fish that occurred on the night of June 30, 1841, in North Germany has been described in detail. There was such a heavy downpour during the heavy thunderstorm that the entire place was inundated in an hour. Next day the herdsmen returning home with their herds collected plenty of fish. In one high meadow where the herds grazed the ground was completely covered with small fish. Sixty storks and numerous crows greedily swallowed the fish. After two days the owner saw in big pools and ditches in the field that had been filled with water, a large number of small fish not more than 10–12 cm in size. Many were alive and swimming. The field covered by the fish was 200 steps in length and 50 steps in width. The field was oriented along the direction of movement of the thunderstorm cloud. The neighboring fields and adjoining lowlands, though full, were devoid of fish although the water channels passed through these lowlands. The fish belonged to various categories: young pike, perch, roach, ruff and other freshwater varieties. They had been carried a long distance by the clouds as there was no indication of any tornado (Gudger, 1921).

The next example is important in that it was visible throughout its passage, starting from the tornado and ending with the cloud from which the fish dropped onto the fishboats. On June 11, 1921, off the shores of the Gulf of Mexico, several big boats were collecting oysters. The day was hot and sultry and the air altogether still. At a distance, a large thunderstorm cloud with continuous lightning flashes could be seen. It approached and suddenly its base lengthened, forming a narrow, curved funnel, quickly reaching the sea. The waterspout lasted for 20 minutes and was 5–6 km away from the fishermen.

When it dissipated and withdrew into the cloud the latter started moving quickly toward the fishermen. The sea was still unruffled. As the cloud moved away a strong wind started blowing and there was a heavy downpour. The boats filled up and the water had to be pumped out continuously. Everything got wet, water was everywhere and the fishermen found to their surprise that it was saline.

On the roof of the cabin where the observer was located about 50 small fish 5–8 cm in size fell. They dropped on other boats as well. All of them were of one type, found near the surface of the sea. All five men in the boat grabbed the fish and all of them confirmed that the rain water was saline.

The observer concludes, without a doubt, that the fish were sucked up by the tornado cloud, transported a distance of about 5 km and dropped over the boat from the cloud along with the sea water lifted with the fish. He concludes: "Of course, if the downpour had been over land it would still have been a rain of fish" (Gudger, 1929, p. 73).

In India rain with fish was recorded for the first time in 1809. Lt. John Harriot wrote that when the army was not far from Pondicherry heavy rain with fish occurred, to everyone's surprise. Some were hit on their caps. They were not flying fishes, but were dropped dead. Harriot did not know where they came from and how they were lifted.

Two incidents show how large the quantity of fish could be. The first of the incidents also occurred in India on May 16, 1834. After a violent storm the ground in a village was completely covered with fish and the number was not less than 3,000–4,000. All the fish were of one type, of palm size, and all were dead and dry. The latter observation, however, appears doubtful.

The other incident occurred in Singapore on February 22, 1861, and was observed by the French scientist Castelnau (1861): "I lived in a zone surrounded by a stone wall. After a strong storm, continuing for three days, the area was completely covered with water and then the storm turned to the sea". Next day there was bright sunshine and he saw to his surprise that a few Malays and Chinese were collecting fish from the water pool of his area in baskets. When they were asked where so many fish had come from they replied that the fish had dropped from the sky. An old Malay added that he had seen such rain earlier.

"Examining the fish, I could see that they belonged to one type found widely in the fresh water of neighboring regions. They were all 25–30 cm long. These fish could have survived without water and survived on the land for a long time but they could never had crossed the high wall" (see McAtee, 1917, p. 223).

We will give two examples of rain with fish, again observed in India.

On July 29, 1829, Mrs. Smith in Moradabad observed how small fish dropped along with the rain. She made a drawing and like Cyprinus determined that the size was 5–6 cm.

On February 19, 1830, near Faridpur* rain with a large amount of fish was observed by a few local people. Chanderi Ahmad said that at about 12 o'clock he was working in the field, the clouds moved in and there was a short shower. Then all of a sudden he felt that something had dropped on his back. He turned around and found a fairly large fish. He was surprised and looked around and found more fish. In all he collected 10–11 fish and other farmers near him collected as many. There were five varieties of fish. Some were intact and fresh, others crushed without heads. A boy of 12 said he saw a few fish drop onto the roof of the house. One of them was big—about 40 cm long and three pounds in weight. Another man saw a few fish drop but he did not eat them. The third said the roof of his house was covered with fish of different types and sizes. A few were fresh and intact, others without heads. Everyone confirmed that the rain started at noon. Lastly, an Englishman found fish in his rain gauge. In this rain of fish, what is interesting is not only that a large number of fish were of relatively large size but that along with fresh, whole fish, fish without heads also dropped. It is difficult to imagine a lake where simultaneously fresh fish lived along with fish without heads. And where is the place from which some tornado simultaneously sucked up these two types of fish? Could it be the wide sloping shore of a big lake?

On September 20, 1838, not far from Calcutta, fish fell during a strong, short-lived downpour. All of them were similar, small (about 10 cm) and alive. The ones that dropped on the grass were alive and swam well in the pond where they were ultimately thrown (Reid, 1850).

It is not only in India that fish have fallen along with rain but wherever tornadoes have occurred. Admiral Pigo saw fish drop on the deck of a warship in Toulon harbor. The fish were slightly longer than a hand. Once in Scotland, after a heavy downpour, a number of trout were found on the grass. Some were found in a bucket placed under a drainpipe. Trout were not to be found in the nearest river. They might have been brought from the big river 3 km away. Another observer wrote that the fish were 3 cm long and there had been a tornado that day.

* Now in Bangladesh— Translator

Rain with herrings occurred on Ula Island. The herrings were small and found in large numbers on the ground. Some were still alive. Similar downpours with fish were recorded in other places in England. In all cases the fish were of small size and dropped from the cloud, not from the tornado. The tornado had disappeared in some nearby area.

Rain with fish was recorded for the first time in England in 1666. Near Pakshi, close to the Stensteid terminal, far from the sea or lakes, rain fell from the thunderstorm cloud during a violent storm. After the rain the pool was completely covered with various types of small fish of finger size. They weighed about a bushel (40 kg) and were later sold in the market.

An English farmer was working in his field during the rain. As he tells it: "Suddenly I felt that something had fallen on me, on my head, on my shoulder and under me. I stretched out my hand and caught hold of a small fish. Looking around I found that the ground was full of fish. I took off my hat and found it was full of fish. We found that fish had covered an area 80 m in length and 10 m in width. After the rain we threw them into the pool and they started swimming. Their length was not much, only a few were 10–12 cm long. A few of the fish were kept in an aquarium in the zoological garden in London for a few weeks. The wind was not strong but it was cloudy and raining" (McAtee, 1917, p. 222).

In June, 1927, near Serpukhov, not far from Moscow, a tornado occurred over a small lake. It sucked up into its gigantic trunk almost all the water of the lake along with the fish and other animals. After a few kilometers, in the outskirts of Serupukhov, rain with fish occurred, to the great pleasure of the children (Kolobkov, 1957b).

At the end of 1907 there was similar fish rain, continuing for an hour, in Switzerland. The local people collected about 12 tons of fish. The fish were of various types—from 50 g to 16 kg—and a few were still alive. It is presumed that the fish were drawn into the cloud by a tornado which passed over a lake 20 km away from the place.

On the night of July 22 and 23, 1892, a thunderstorm cloud with strong wind and rain occurred over Belina (Bosniya) and numerous live fish fell. The rain gauge of the meteorological station caught two live, swimming fish (Tiron, 1964, p. 218).

Gadger (1921, 1929), the bibliographer of the Museum of Natural History of America in New York, wrote a number of articles on rain with fish. In two of his main works he gives 71 examples. Some of them have been described by McAtee but the rest are new. The most important thing is that in addition to the material obtained from books he had numerous letters on such rain not reported in the books. The letters very clearly show that rain with fish is certainly more common than is usually reported. The number of tornadoes in the last 45 years in the USA alone is 2,700 and the number is very high for the whole world. Many of them passed over the surface of the sea, big lakes, pools, swamps and rivers, sucking up large or small quantities of fish. It can definitely be said that the number of tornadoes with fish is not less than 100. This is only a fraction of the total number of tornadoes. Unusual phenomena like rain with fish are not so rare.

The material given by Gadger show that in all cases the fish drop over a relatively small area. In England, in 1918, rain with fish covered an area of 60×30 m, in Scotland a belt of 80 m length and 15 m width; in Africa, in Natal, in 1909, the area was 400 m in length and 100 m in width; in Singapore in 1861 the area was 50 acres.

The description by Gadger of rain with fish occurring on May 15, 1900, in the outskirts of Providence, Rhode Island, is quite interesting. His friend was engulfed by a thunderstorm accompanied by a heavy downpour and strong wind. Soon he felt that not only rain but also some small, soft objects were falling on him. He found that it was nothing but fish. They were freshwater fish, 5 to 12 cm long. The rain of fish was quite concentrated over a small area, about one-fourth of an acre (about 0.4 hectare). The children collected them in buckets and samples were displayed in the showwindows of stores as an unusual catch (Gadger, 1929).

Tornadoes suck up fish from a relatively small area. The vortex circulation that holds the river water in the clouds is also of small size. This explains the small size of the area on which the rain of fish occurs.

The size of the fish is also small. Generally they are not bigger than a few centimeters. Examples 10–12 cm in length are considered large. The big sizes of 25–30 cm are very rare and only in one case did a boy see a fish as big as 40 cm long. The accuracy of his measurement may be doubted.

Fish in the near-surface layers in coastal waters, large lakes and rivers are relatively rare, but one variety is encountered in large schools. The concentration of fish is somewhat bigger in pools, small lakes and irrigated paddy fields. The quantity of fish falling with rain varies considerably. Often the fish cover the ground completely and are collected in buckets and bags. At times only a few dozen average-size fish are strewn on the ground.

The specific type changes in different countries. The types found are mostly from local waters. Within the continent, freshwater varieties fall; near the seacoast, marine types. Some types can be determined exactly only by specialists.

There have been interesting debates when fish falling on the grass from the clouds from a great height have been kept in the aquarium and displayed before the public. Some people argued that if the fish actually dropped from the cloud they should have died. To this the reply was that some of the fish did die, especially when they dropped on hard ground, but when they fell on grass, leaves, etc. they could be alive and moreover their weight was small, almost like worms. Further, it should be remembered that generally fish dropped with rain and a large quantity of water, and this served as some sort of buffer. So in many cases fish dropping with water, especially small ones, remained unhurt.

The regions where rain with fish has occurred are in the middle latitudes. Rain with fish has not occurred where tornadoes do not occur—in the equatorial and polar regions. According to the report by Gadget (1929) with appendix, there were 13 cases in the USA and one in Canada. There were numerous cases in Europe: in England—8, Scotland—9; Germany—11; France—2; Greece—1, Holland—1; Russia—1, Switzerland—1; Yugoslavia—1. In Asia: India 13; Ceylon*—3; Malaya—2. In Australia—7. In South Africa—1, In South America—2.

These figures have no quantitative significance. They only show the places where rain with fish occurred. As has already been mentioned, the actual numbers may be a hundred or even a thousand times more. Almost each tornado crosses reservoirs, lakes, pools and rivers or the sea and each such traverse ends with rain with fish. Such traverses must be in the thousands.

These figures pertain mainly to the last 300 years. On the geological scale this is negligibly short. Rain with fish, among unusual events, is considered as an ordinary phenomenon. Unfortunately, the fish on land do not survive and in ponds they are taken as native to the ponds. There are plenty of fish with rain but nothing is retained.

The observations and conclusions of the Australian ichthyologist McCulloch (1925) are quite important and interesting. He writes that without transportation by the wind it is difficult to understand how in Australia certain fish occur in reservoirs and rivers isolated from one another by a wide belt of desert. If it is admitted that the migration of these fish had a sporadic character and that they were transported by tornado clouds and dropped along with rain the isolated habitats can be logically explained.

Generally isolated habitats are taken as relics of earlier general distribution. McCulloch argued that often they may originate due to transportation by the wind from tornadoes, tornado clouds or hurricanes.

This important conclusion is valid not only for fish but also for frogs, crabs, snails and other organisms of small size.

Rain with frogs and toads has been described quite frequently. All the toads falling from the sky are of small size, not more than the size of a walnut or chestnut. Solid, heavier animals bigger than the size of a fist have not yet been reported.

In the summer of 1794 Napoleon's army camped in northern France. It was very hot. A very heavy downpour occurred about 3 o'clock. The guardsmen, afraid of drowning in the lowland, started climbing a slope. Suddenly they felt that certain objects were dropping on their clothes and hats. Looking around they found small toads the size of nuts. They dropped from the sky and scattered all around. One officer, not believing what he saw, took out his kerchief and spread it over his head with the help of his

* Now Sri Lanka—Translator.

colleagues. The kerchief was soon filled with small toads. Many of them had tails, i.e. they were in the stage of tadpoles. The toads fell for half an hour, the duration lengthened due to the storm with rain. When it had passed over many of the guardsmen found toads in their triangular hats.

Another observer, in June, 1833, was in a field near Versailles. "I saw toads falling from the sky. They struck my umbrella. I saw how they were scattered on the path. Toads dropped for 10 minutes longer than the raindrops.

"During my youth I lived on the banks of the Somme. A storm moved in and there was a heavy downpour. Suddenly I saw that the main area in the village was covered with small toads. I was surprised by this event. I stretched out my hand and immediately a few reptiles dropped on it. The next street was also covered by them. I saw how they struck the roofs and then jumped to the road. I cannot explain their transportation but the memory remained ineffaceable throughout my life."

A French naturalist-scientist writes: "On June 23, 1809, it was very hot and I was engulfed by a storm with rain. With the large drops, small-size toads the size of nuts also fell. They covered the ground in no time. Examining them, I found that they were toads. The second incident took place in August, 1822, during the summer period. I was again engulfed by a storm with rain of large drops and toads the size of walnuts dropped along with it. Some of them hit my hat as well. I was a few kilometers away from the nearest rivulet, river or marsh."

If it was toads with the French, it was frogs with the Englishmen. They were observed during Agricola's time.

The rain with frogs occurred on the outskirts of Mósley during a strong storm over Birmingham on June 30, 1892. They were found in several gardens over relatively small areas. They were of white color and obviously lifted into the cloud by a waterspout (McAtee, 1917).

In 1846 frogs fell with rain on the deck of a ship sailing in the English Channel. Another case of rain occurred with thousands of small frogs dropping on buildings and roads (Reid, 1850).

One of the latest cases of rain with frogs occurred after the thunderstorm of August 2, 1939, in Alexandria, Ontario, Canada. The frogs were so large in number that the streets were covered with them (Rue, 1940, p. 97).

The most peculiar rain with frogs is described by the Greek historian Athenaeus in 200 A.D. "...There were frogs dropping in such a large number that people found frogs everywhere and one could not walk without stepping on a frog."

Rain with frogs was also recorded in the middle ages. Two cases of rain with frogs, in addition to rain with fish, are described in the book by Konrad Likosphen. One of them occurred in 1345 in Germany.

Another such rain was in 1549, in Alsac. This gave a peculiar picture. Here one found that after dropping from the cloud the creatures were engaged in friendly conversation (Fig. 213). The frogs and toads were in abundance and could be killed with sticks. Afterwards they gave out so much stench that special arrangements had to be made for their collection and removal.

Fig. 213. Rain with frogs, 1549 (Gudger, 1922, p. 84).

McAtee cites eight rains with frogs and toads. A few others are mentioned in the works of Gudger. As regards their frequency, the same thing can be said as has been mentioned earlier about the rain with fish.

Frogs are found not only at sea. They are encountered everywhere—in freshwater lakes and on land. They are numerous in the places where tens of thousands of tornadoes occur. There is no doubt that they are sucked up by the tornado clouds and dropped from them along with the rain. They are simply not noticed. When fish are found on land it excites attention but nobody bothers when he encounters frogs after rain.

Rain with Various Objects

It is not only animals that drop from the clouds along with rain. In Spain, to the great surprise of people, wheat dropped from a cloud. In Germany, on a quiet day, even branches and thick knots of trees started dropping, so much that a stack of brushwood was formed.

On August 19, 1890, a strong tornado struck the north of the Lake of Geneva. The width of its track was small—tens or hundreds of meters—but the width of the thunderstorm cloud was of the order of 10–20 km. The character of the objects (linen) lifted by the tornadoes into the cloud established that these objects had been transported by the cloud a distance of 30–50 km and dropped from it 16 km to the left of the track of the tornado.

The second example is that of the tornado that occurred on June 29, 1764, near the village Vol'dek, in Meklaenburg. The tornado occurred over thick forest, leaving the usual narrow belt of fallen trees. The branches lifted into the cloud were as thick as a man's arm and as long as 4 m. The branches were dropped from the cloud in an enormous quantity, 10 km to the left of the swath of fallen trees. The distance of transportation was 30 km (Wegener, 1917, p. 240–243).

Another important and interesting incident occurred during the tornado of 1764. One branch of a tree, as thick as an arm, was dropped on the ground with a coating of ice as thick as a finger. It dropped in front of the house of a woodman in the belt of hail. Such incidents of ice-coated material falling from a tornado cloud are rare. The fish and other animals that fall from tornado clouds are not frozen but alive. The ice-coated branch of the tree shows that either it was lifted to a height of more than 3,000 m or that it was covered by ice in the hail cloud to a height of about 2,000 m (Wegener, 1917, p. 243). Such was the fate of the tortoise falling with a coating of ice in the USA (p. 314) and the small carp in Germany.

An interesting tornado (storm) was observed in Latvia on May 10, 1872 (Schweder, 1873). In Riga, on the basis of the hail, the width of the thunderstorm cloud was 10 km. The cloud moved in a northeastern direction. The tornado was formed in the Wenden region, on its right side, after crossing a distance of 80 km. A board 2 m long was lifted up into it, transported a distance of 25 km and dropped 10–15 km to the left of the track of the tornado.

The most peculiar rain accompanied the tornado of June 17, 1940, in the village of Mescheri in the Gorky region. During the thunderstorm 16th century silver coins dropped from the sky. The schoolboys gladly collected about 1,000 silver coins. These evidently came from a hidden treasure buried at a shallow depth in the ground, sucked up by the tornado and lifted into the thunderstorm cloud. The coins dropped not from the tornado but from the cloud.

Rain with stones is rare but has been observed a few times. Especially interesting is the rain with gravel that occurred recently in Kiev. The fine angular quartz grains falling with the rain were 3–5 mm in diameter. An observer accurately contoured the area on which the gravel fell. It was of small size, about 1 km in diameter (Lipovetskii, 1966).

Descriptions of such rain with stones are very few. It can be concluded from these descriptions that the dimensions of the falling grains are not big, not more than 1–2 cm. The fragments are angular. It has always been said that stones dropped and not pebbles. The area on which the stones dropped was small.

Angular fragments and grains, consisting of stone chips and gravel, present considerable resistance to the wind. Due to this, they are lifted into the cloud by tornadoes, then transported and ultimately dropped on the ground along with the rain.

tornadoes. The bodies of these three types of formation are not similar and unique. On the contrary, their main feature is that they comprise an enormous quantity of diverse jets, flows of air (system). The changes in these jets give rise to what is known as "gusty wind".

The air jet of hurricanes, as of storms and tornadoes, differs in the length (duration), width (propagation) and form of transverse section.

They have been studied in great detail in hurricanes by radar echo, photographs from satellites and aircraft.

The length of the jet is many tens or hundreds of kilometers. In spite of it, the duration is insignificant. It is measured in seconds, tens of seconds, minutes and very rarely in tens of minutes or more. This explains the enormous speed, often supersonic in tornadoes, attaining hundreds of kilometers per hour. It is quite likely that the duration of a few jets lasting for a few seconds is relatively less.

The dimensions and forms of transverse section and the general form of jets are still not very clear. Radar echoes and photographs give a general picture of the width. The form is quite close to the form of the area of destruction. It is exceptionally diverse. The edges exhibit mantle form and radial jets. The width and thickness of the former differ sharply from jet to jet like sheets of paper. In the second, it is almost similar and small, like a fine ray. The intermediate forms are of similar width and thickness and are of average dimensions.

It is the jet structure of the hurricane, as well as storms and tornadoes, that is essentially responsible for the various types of destruction connected with it. In one place a short, narrow, unusually fast jet lifts heavy objects and transports them tens and, rarely, hundreds of meters. In other places even relatively minor destruction can be traced without a break for tens of kilometers.

The objects caught up in hurricanes are numerous. Individual gusts of wind have been recorded that attained extraordinary strength but the speed is generally fitful. Similar short-duration weakening or calm is also noticed when the air jet abruptly weakens.

It may be repeated once more that the inhomogeneous, gusty wind accompanying hurricanes is its main feature.

Compact Vortex Jets (Systems)

It has been mentioned above that all the vortex formations—hurricanes, storms and tornadoes—are inhomogeneous and consist of numerous diverse air jets.

Tornadoes differ in that they have small dimensions, high speed and sharp outline. These features are well developed in dense tornadoes. In diffuse tornadoes they approximate to the comparable features of squall storms.

These three features have received the attention they deserve, have been discussed in the literature and have been described above. But there is a fourth feature, no less special, which receives no mention in the literature. It can be called compactness.

Compactness of the vortex jet is observed not only in the funnel but also in the parent cloud. It is important in the sense that the jets formed in the walls of the funnels are transferred to the parent cloud where they persist for a long time.

Direct observations and measurements on compactness are not available. Its existence and characteristics can be envisaged from the objects transported by compact air jets. Such objects are numerous, diverse and often exceptionally specific.

The hidden treasure of 16th century silver coins in the Gorky region (p. 430) can be placed in this category. The air jet in the funnel of the tornado sucked up the coins from the pot, lifted them a few hundred meters into the air to the tornado cloud and transported them a distance of several kilometers in the cloud. Throughout the journey the coins moved as a compact mass and dropped from the cloud as a compact mass when the jet carrying them ceased.

It might seem that in such a long and complicated journey the coins should have been scattered in the air. Nothing like that happened. The treasure was lifted as a whole, followed its path and dropped from the cloud also as a whole. The compactness of transportation is striking.

The compact transportation of hay observed in the USSR and England is no less striking. On September 2, 1945, to the north of Moscow, in the village of Khumotovo, a stack of hay was lifted up by a tornado. After some time the compact mass of hay dropped from the cloud 3 km to the side of the track of the tornado, whose width was not more than 300 m. In 1892, in southern England, a tornado lifted a large quantity of hay. It was dropped from the cloud 5 km to the north, also in compact form along with rain.

The dry grass forming hay is very light. It might seem that a vortex jet of great speed should scatter it in all directions. But actually the grass was stacked on the ground as a dense mass, it was lifted into the cloud as a dense mass, transported by the cloud a distance of 5 km as a dense mass and dropped on the ground as a dense mass. It looked as though the stack was on a cart which was lifted into the cloud, moved 5 km in the cloud and then dropped to the ground. Such a peculiar cart was the compact vortex jet of air (system).

In Kavalerovo village, not far from Vladivostok, 50 km from the sea, rain with jellyfish occurred. The jellyfish were lifted from the surface of the sea from a small area, corresponding to the width of the funnel of the tornado. They dropped from the cloud over a similar small area when there was no tornado around. The air jet, instead of scattering the fish all over, carried them like a pot of water and dropped the whole lot together on the ground.

In North Africa, in Tetuan, a tornado lifted many dry wheat grains. The air jet, instead of scattering them randomly all over, carried them compactly over the Mediterranean Sea and dropped the entire lot, along with rain, in Spain (in Andalusia).

In 1927, not far from Serpukhov (p. 426), a tornado sucked up a small pool with its entire population. After a few kilometers, on the outskirts of the city, the pool with all the fish and frogs was dropped from the cloud, over quite a small area. The pool was transported in the form of a compact unit.

The incident of the Serpukhov pool is a complete repetition of what happened in 1839 over France with the pool in the Chateauneuf courtyard (p. 408) and undoubtedly in many other localities. All these pools retained their compactness throughout their trajectory. This could happen only because of the compactness of the vortex jet.

The numerous cases of rain with fish and frogs described on p. 423 et seq. occurred over small areas, approximately of the same size as the area of sea, lake or river from which they were lifted.

The last example is that of the rain of coarse sand and fine fragments (p. 431). The area over which it rained was measured. It was 1 km in diameter. There is no doubt that the sand and fragments were sucked up from an approximately similar or maybe slightly smaller area. In this case, small, heavy objects had to be transported. They traversed the whole path as a compact mass.

Analysis of the above examples and many others undoubtedly shows the existence of compact vortex jets, generally moving a few kilometers and often tens of kilometers. These are compact, possibly sharply defined bodies, moving along with all the objects contained in them throughout the length of the track.

It is significant that such a compact vortex or jet, developing in the funnel of the tornado should withdraw to the parent cloud and rotate in it for a considerable time, of the order of one hour, or maybe more.

These jets in the funnels of tornadoes exhibit very high speed—almost supersonic speed. This is the reason for their sharp definition, power of retention and large transportation power.

A compact vortex jet along with the objects contained in it, especially water, is no doubt dangerous for aircraft owing to its speed and density.

It is surprising that the meteorologists studying tornadoes have not paid attention to compact vortex jets. It is not mentioned in the literature but these jets occur and are quite interesting.

The transportation of objects by an individual air jet or "gusty wind" is confirmed by the fact that fragile material is lifted into the air, transported a few kilometers and dropped to the ground undamaged.

Nothing remained of a house, but the kitchen cupboard with the vessels inside flew several hundred meters and dropped to the ground so gently that all the vessels remained intact. A mirror flew several kilometers and remained intact. A basket containing books, weighing 25 kg, flew a distance of 3 km and struck the branches of a tree but all the books remained intact. Jars with pickles and a family photograph that disappeared from the house of a grocer flew a distance of 40 km and remained intact.

A flower vase with flowers was carried away intact but the windowsill on which it had stood broke into fragments.

There are numerous well-known examples of transportation of animals, people, etc. unharmed. It is enough to recall Petyu Selezneva, who was transported from Mytishchei in Sokol'nik without bruises by the tornado of 1904.

If tornadoes were a homogeneous, single, columnar rotation of air mass, then these cases of transportation would not have been possible. These incidents are possible only with individual jets.

13
Vertical Vortices

GENERAL FEATURES

Vertical air vortices are extremely numerous. They occur everywhere, before our eyes—on the streets and vacant lots of cities, on snow-covered fields, along dusty highways, on dry plains, on the snow over the vast ice cover of Antarctica and Greenland, on the surface of the sea and big lakes, on dried-up plowed fields, but most of all in the scorching heat of deserts and semideserts.

The dust, fine rubbish or snow starts revolving fast in one direction. Gradually the rotation increases and the dust or snow is lifted into the air, forming a fast-rotating column. The column rises higher and higher, wider and wider, lifted to a height of tens of meters and in deserts—hundreds of meters and starts moving in the horizontal direction. The diameter of the column fluctuates from a few meters to a few tens of meters and in one case to many hundreds of meters (Fig. 215). Such a vortex reminds one of a tornado and often is incorrectly referred as such. The tornado is always associated with a thunderstorm cloud, is lowered from it and moves with it. The vortex originates under a clear sky, grows from bottom up and moves quite independently.

The tracks of such vortices are quite diverse but their length is quite short as compared to tornadoes, generally not more than a few kilometers, rarely tens of kilometers.

The vortices dissipate as abruptly as they appear. The rotation of the column comes to a standstill, sharply decreases in size, and finally it completely disappears. In its place a heap of dust, rubbish or snow is left. The characteristic feature is the exactly symmetrical conical form. They differ from the accumulation of sand formed horizontally by the blowing wind. The latter is always asymmetrical, with one side sloping and longer than the other—steep and short. In India, in the great semidesert plains, conical hills of sand and dust attain diameters of 4 m. At places they are to be seen in thousands and cover the entire surface.

Fig. 215. Dust vortex of large size. Tucson, Arizona (Sinclair, 1964, Fig. 1).

The composition of the transported material was divided into sandy (dusty), snowy and watery components more than 100 years ago in an interesting paper by F.A. Batalin (1854). He also described the invisible vortex formed by clear air.

The forms of vertical vortices are as diverse as their dimensions. Most often they have columnar, irregular, more or less curved forms. Sometimes they have conical or bulb-like forms, widening at the top (Fig. 216). Like tornadoes, they are hollow inside.

Their duration is short. Often it is in seconds or minutes and very rarely in hours.

There are various causes of origin. Mostly they are due to the intense heating of a particular part of the surface of land or water. In some cases such heating causes fire as well. Often vortices originate due to the convergence of air flows from different directions or due to the meeting of air currents because of obstacles on the surface of the earth.

The vertical vortex is quite widely distributed, is generally weak and therefore not a thoroughly studied phenomenon.

DUST VORTICES

The dust sand vortices, or dust devils, are vortex formations, resembling tornadoes and often referred to as such. However, as already mentioned, they have no relationship with tornadoes. A tornado is always connected with the tornado cloud. The dust vortex is formed under a clear sky. The

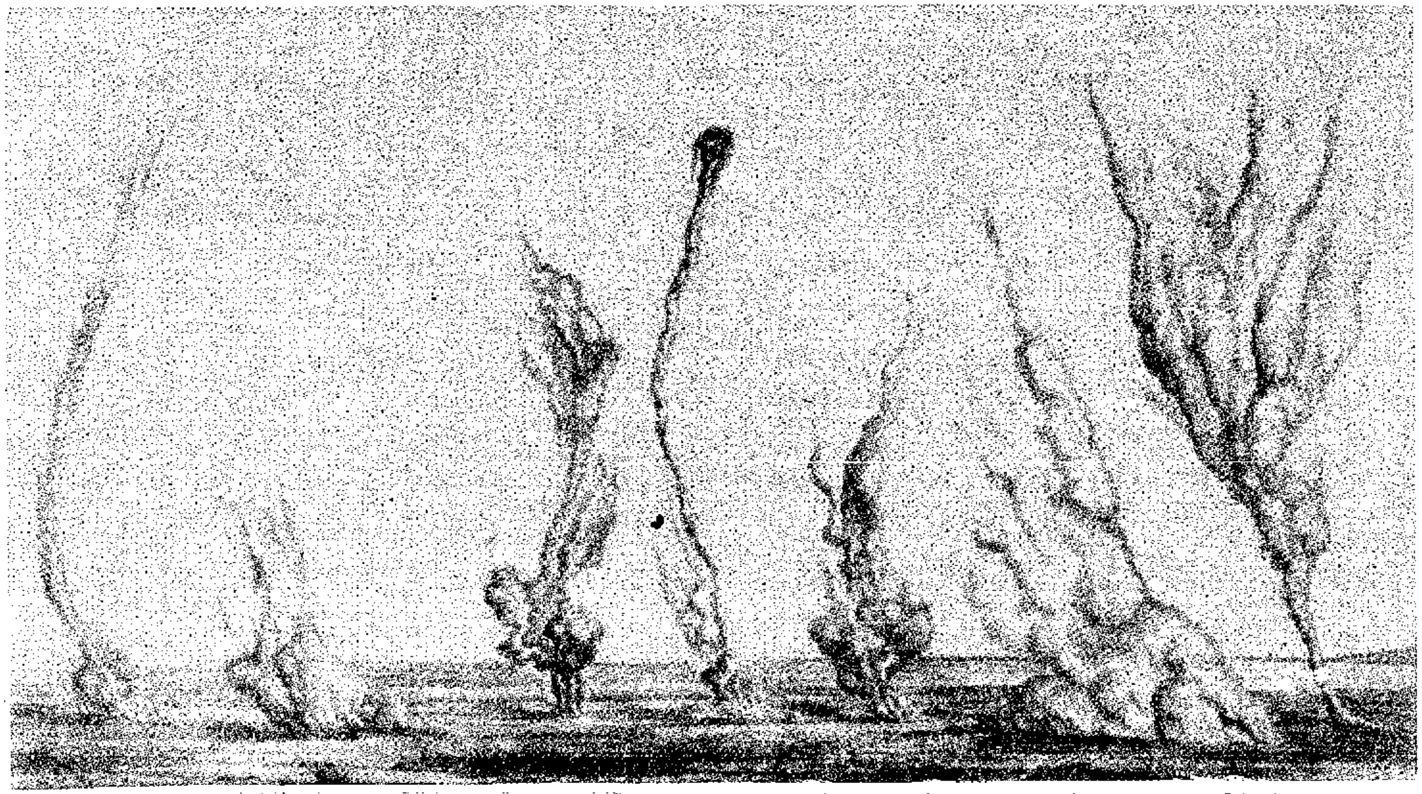

Fig. 216. Dust storm in Tsaidam. Drawings by V. Roborov (Przheval'skii, 1883, p. 162).

resemblance is only in the rotation and ascending movement of air with dust. The dust makes the ascent visible (Brooks, 1960).

Dust vortices are formed due to the intense heating of the top layer of earth in hot or warm weather. Their heights vary widely and often reach 1,000 m. But in such cases the destruction they cause is insignificant. Often such vortices form in large numbers, moving quickly, bending and overtaking each other. They have been called "dust devils" due to their vagaries.

They are quite frequent in the South, where there is scorching sun on the deserts and semideserts of the dry plains and on the dusty highways. In North Pamir there is a special valley known as "valley of tornadoes". Tornadoes do not originate here but dust storms in large number occur in clear, bright weather, which is quite common in Pamir. The wide, flat, socky, sandy valley is aligned south-north. It is almost devoid of plants. I went there in daytime and before my eyes sand vortices of relatively small size with a height of a few tens of meters and width of a few meters kept on appearing. They would capture dust from the surface, whirl rapidly and be driven away by the south wind, following one after the other. In spite of their large number and considerable size the quantity of dust they transported was not large. They moved sand and even small stone chips on the ground.

N.V. Kolobkov describes a big dust vortex which originated before his eyes near the meteorological station Mikhnevo (near Moscow). The vortex passed over the station on April 6, 1929, and the values of the meteorological indices were registered by the recorder.

"The day was exceptionally clear with scorching sun. A weak southerly wind was blowing. About 1 o'clock a loud noise was heard coming from the lime park where a bright meadow was situated (Fig. 217,—D.N.). It was observed that a group of trees near the station was being stirred by a strong wind but at the same time the neighboring trees remained unaffected as there was no wind there. Soon it was noticed that the wind had engulfed dry leaves, rotating and lifting them up. After a few seconds the vortex emerged from the park and started moving slowly to the north, toward the station. The vortex was 10–12 m in diameter. The anticlockwise rotation was distinctly visible as also the lifting of objects that it engulfed, which at that moment attained a height of 50–60 m.

"After approximately half a minute the vortex passed over the station building and damaged the ventilators. Farther on it passed over an area where it damaged a few tiles of a roof and also the venetian blinds of the meteorological booth. At this time its height was about 100 m. Then the vortex struck a belt of snow where it was trimmed down. After 200 meters it disintegrated, scattering all the materials it had captured" (Kolobkov, 1951, p. 197). The speed of the wind reached 20 m/sec in the vortex. Instantaneously the barometer dropped by 1.4 mm. The cause of formation of the vortex was intense heating of the area around the park and occurrence of strong ascending and rotating air currents above it. The vortex was moved

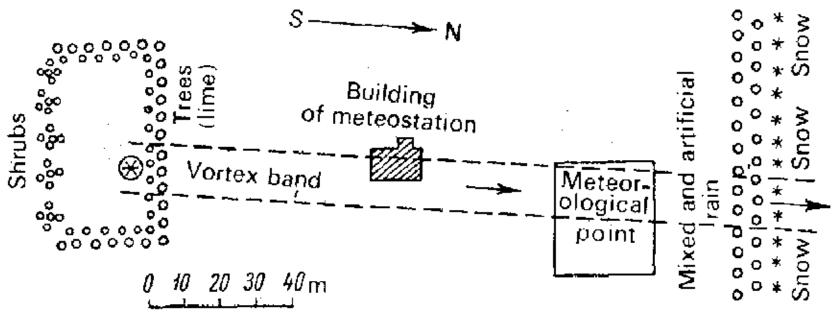

Fig. 217. Dust storm of April 6, 1929, in Mikhnevo, near Moscow. Point of origin and track (Kolobkov, 1951, Fig. 80).

north by the southerly wind.

The dust vortex described above was of small size and duration. In deserts it attains a considerable size, reaching 1,000 m in height. Such vortices almost resemble tornadoes in strength, but they are rare. As such the activities of dust vortices are much less than those of tornadoes.

In our sandy deserts dust vortices are formed in the summer due to the strong heating of the slopes of sanddunes exposed to the sun. A dust vortex in the Repetek region is described by B. Orlov (1928). They originate on the slopes of sanddunes oriented southeast. The hot air rises, carrying dust with it and forming a fast-rotating dust column. This column grows and moves at great speed over a winding route. Its existence is discontinuous. After traveling one or two kilometers it disintegrates over the obstacles presented by the relief of the locality. The lifting power of the vortex is not great, but it often lifts heavy objects, such as cushions and mattresses lying on the roofs of single-storied buildings.

The transportation of sand by a dust vortex is not significant, but the blowing of sand and transportation of dust is considerable. The number of dust vortices is quite high and they always move in one direction in Repetek —from north to south.

The transported dust, of course, carries microorganisms along with it. As dust is formed due to the blowing of anthropogenic alluvial, their composition will be of the fresh water variety, mostly with diatoms.

Dust vortices are not only formed in Repetek. F.A. Batalin (1854) showed that in Turkmenia they attain specially large size in the valley of the River Murgab. They are numerous over the Aral Sea, still more in Kyzylkum and widely distributed in the dusty plains of Kazakhstan and Altai border, especially after deep plowing. Here they carry fragments of black soil, making it a black soil vortex.

It may be said that wherever the black dust storms occur, black dust vortices also occur. There are numerous dust vortices and they form quite easily.

Wherever there are red and yellow dust storms dust vortices form continuously, generally for a short period but also for a long time in the vast deserts.

If the simoom occurs anywhere, the dust vortex is also present there. In Mesopotamia, in the dust plains in the Baghdad region, dust vortices similar to tornadoes in form constantly arise. Differing only in the coloration, the columns of dust move over the plains easily and swiftly. Their tops are invisible in the gray, cloudless sky. They are more frequent in summer. Groups of dust vortices often follow each other with the northwesterly wind (Schlafli, 1870, p. 470).

They are not rare in the deserts of East Africa. A typical dust vortex of average size is seen in Fig. 218. The column was photographed in the desert plain of Somali (Rue, 1940). High and narrow column fluctuating and rotating quickly, moves over the smooth surface of the salt marsh.

The monograph by Feet (1958, p. 128) gives a few examples of dust vortices. Wegener observed it over the lava plains of Iceland, where it had a diameter of 10 to 200 m. They are frequent in the deserts of Africa and North America, where they are often referred to as "sand hose" or "dust tornado". Here they are 5 to 50 m in diameter and 100 to 2,000 m high. They transport a considerable amount of dust. Though they resemble tornadoes in form, they differ sharply in that there is no connection with clouds, they have a considerably lower speed of rotation and correspondingly a less sharp and more variable outline.

In the United States, in the central plains and desert regions, dust vortices are numerous. Their average height is 200 m, but in the desert it reaches 600–700 m. The duration is short but often goes up to 7 hours. At times they cover a distance of 60 km. The vertical and horizontal speed is above 30 kmph. Small animals like rats, etc. are lifted up (Ives, 1947).

In the USA, more exact and accurate observations have been made on dust vortices (Sinclair, 1964). Special aerial surveys have been made. The place of observation was the desert plains of Arizona, not far from Tucson, bordering low hills. A typical example of a big dust vortex is shown in Fig. 215. Sinclair (1964) believes that the main feature of the dust vortex is the fast, spiral, ascending motion of air and the inner core. The latter corresponds to the "eye of the storm" of hurricanes and the inner belt of tornadoes. As in tornadoes, a fall of pressure by as much as 2.5 mb is associated with dust vortices. The sharp rise in temperature is also quite characteristic: it is 9°C for big vortices and 3.5°C for small ones. The forward speed of the vortex is relatively low, of the order of 10–30 kmph, but often considerably more, up to 50 kmph. The speed is determined by the speed of the wind carrying the dust vortex. In the absence of wind the vortex may remain stationary at one place for some time.

The aerial observations are quite interesting. They show that the visible height of the vortex determines the height of dust is lifted to. The ascending

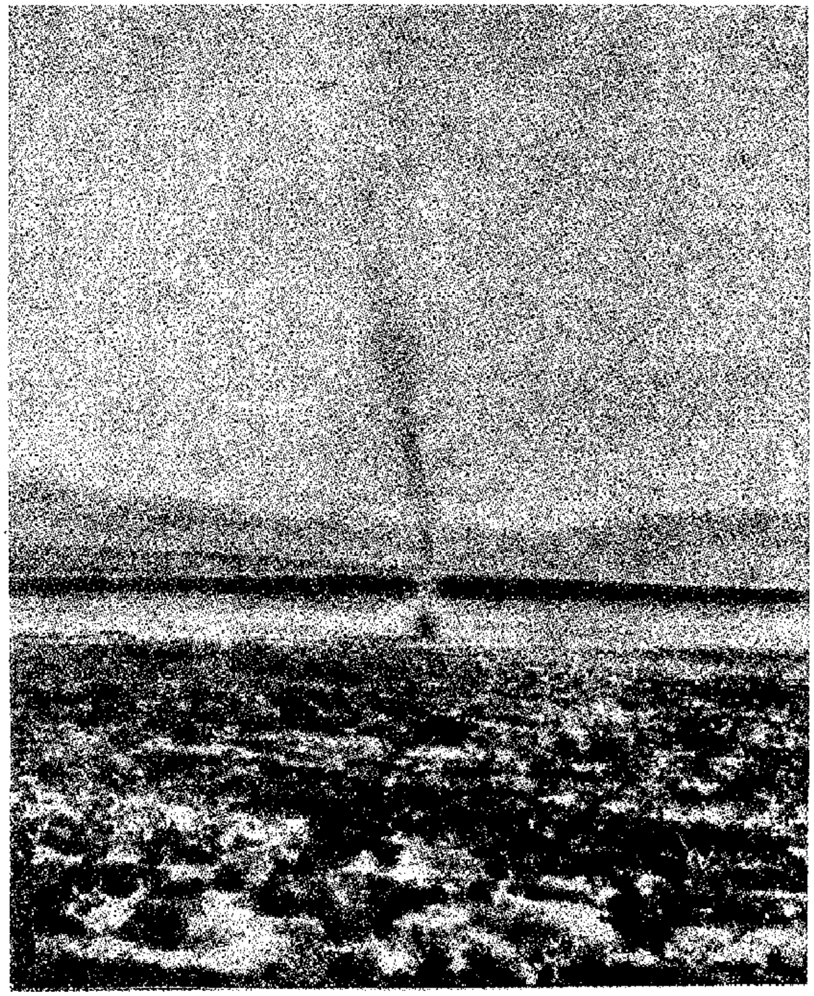

Fig. 218. Dust vortex in desert plain of Somalia (Rue, 1940, p. 1).

spiral motion of air, without dust and therefore invisible, has been established to a height of 4,000–5,000 m. The width of the vortex at such a height reaches 1.5–2 km.

Sinclair showed that apart from the transportation of dust, the dust vortex plays an important part in the propagation of hot air, especially in the hot part of the year.

Observations carried out on the border of the desert in California showed that from May through August, 1946, hundreds of dust vortices occurred in the area. Detailed measurements of 22 vortices showed that their height varied from 3 to 1,200 m and their diameter from 6 to 60 m. The speed was governed by the speed of the wind and it was modest. As a rule, the vortices occurred in a group and followed one after the other (Williams, 1948).

In deserts and semideserts of Sudan dust storms are numerous, diverse in nature and reach great dimensions. Unique dust vortices are associated with Haboob (Farquharson, 1937). They are like dust screen which is intimately associated with thunder clouds, rising from the ground and reaching almost the base of the cloud (Fig. 70). Accordingly their height is great—hundreds of meters; their diameter too is great, particularly in the upper parts. In size they are close to tornadoes but differ in spreading and changing outlines and lesser lifting force. Despite this their contribution to formation of dust storm is significant, thanks to their large number. These dust vortices are transient formations to tornadoes and are often erroneously called tornadoes.

In the vast deserts of central Asia dust vortices are especially numerous and diverse and attain enormous size. V.A. Obruchev (1951), who repeatedly traveled in Central Asia, writes that in the deserts and semideserts of Middle and Central Asia, on hot summer days, the dust vortices appear on the horizon at several places at once and ultimately rise up into the air whirling. In the plains, the columns of dust stand straight, like a mast, bending only at one place. They have been described by different explorers, recording their abundance and the height of the lift of dust. A Hungarian geologist states that the vortex causes vertical movement of air, strongly heated at the surface of the earth. Its diameter reaches 5–10 m and it picks up a large quantity of dust from the surface of the earth and carries it to the upper layers of the atmosphere, where the dust floats for a long time and is transported a great distance by the wind.

N.M. Przheval'skii (1883) observed dust vortices in the desert of the Tsaidam valley, north of Tibet. They are of large dimensions, diverse and numerous here. Unfortunately the descriptions are few but the drawings by V. Roborov are exceptionally interesting (Fig. 216). The majority are columnar, irregular, curved-type and narrow at the top. The other unusual types, wide at the top, resemble the dust vortices associated with the Haboob.

Dust vortices are widely distributed in the deserts and semideserts of India and Pakistan. On hot, calm days they originate in dozens and follow one another, bending and changing continuously. They raise a considerable amount of dust into the air and carry the dust a great distance. The place where the vortex disappears, the dust settles to the ground, forming a small, low, conical hump.

Often the vortices attain large size, e.g. a vortex that occurred on February 28, 1941, on the airdrome at Karachi (Rao, 1942). Its height was about 900 m but the dust went still higher and then, engulfed by the wind, was carried to the cloud and moved horizontally. Other vortices have been described in the work of Baddeley (1860) and Veryard (1934). Veryard gives photographs of two vortices 100 and 150 m high with widths of several meters—a common phenomenon in the semidesert areas of Pakistan.

"Dust devils" are not rare in Egypt, Palestine and Trans Jordan. The height here fluctuates from 2 to 1,000 m, the width from 2 to 100 m and the duration is up to 20 minutes.

A desert dust plain is almost a prerequisite for the formation of a large dust vortex but a warm climate is not a necessity. Figure 219 shows a vortex 60 m in height and 9 m in width at the base, originating well within the Arctic, on Ellesmere Island.

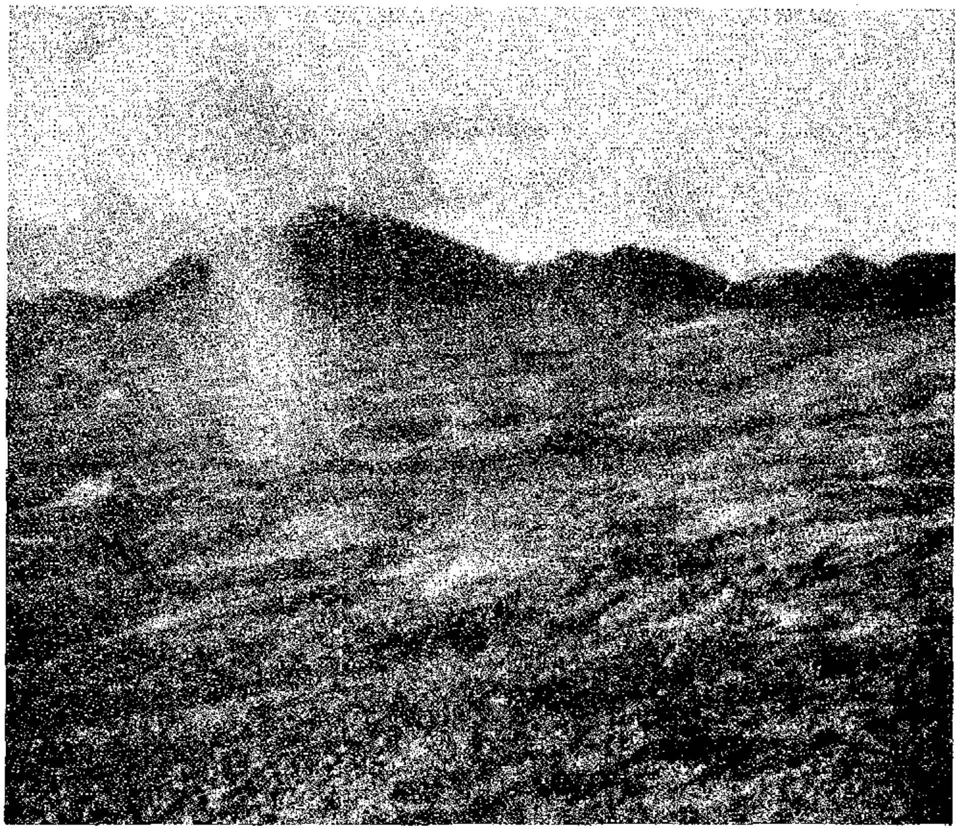

Fig. 219. Dust vortex in the Arctic. Northern part of Ellesmere Island. Height of vortex 60 m, width at base 9 m (*Weather,* vol. 18, No. 3, 1963, cover).

In the descriptions above, we dwelled on the giant-size formations and deliberately paid attention to the formations in the deserts and vast plains. There are, however, numerous dust vortices, a hundred or a thousand times smaller, of a height from a few meters to a few tens of meters. They originate everywhere, literally under our feet, on dusty roads, on football fields, on the streets of villages and cities, in fields, on the banks of rivers and lakes—everywhere, wherever there is dust, dry sand or dry soil. Their number is so large that we do not notice them. We irritably spit out the dust and rubbish that is blown in our faces, even on the streets of cities.

The size of these dust vortices is small and they last for a short time, but their number is so large and they are so widely distributed that in totality they are an important factor in the shifting of dust and even sand.

SMOKE VORTICES

The so-called "smoke vortices" originate during a fire. Small fires are accompanied by small vortices which go unnoticed. A big fire gives rise to vortices that can be as strong as tornadoes. F.A. Batalin (1854) describes how a vortex formed at Stockbridge (England) during a big fire, damaged trees and lifted them into the air. The other examples of "smoke" vortices that he decribes are quite interesting.

Vortices due to fire, and often tornadoes, generally accompany big forest fires (Graham, 1952), city fires during bombing (Landsberg, 1947) and even large firework displays (Glaser, 1959) as well as the explosion of large outlets of hot gas in the Sahara (Dessens, 1963). Vertical vortices were formed during special experiments conducted for the extraction of oil (Dessens, 1962). In all these cases, vertical vortices were formed and sometimes clouds with tornadoes hanging from them were also formed.

Even such a small event as the burning of stacks of hay in the fields forms clouds up to 500 m height (Fig. 220). In England such fires frequently occur and are always accompanied by clouds. Occasionally fire vortices and often tornadoes are also formed (Ride, 1965).

More than 120 years ago Redfield (1840) described the vertical vortices caused by a fire of a large mass of brushwood collected after clearing a forest in the USA. During the fire the flames engulfed the entire field where the brushwood was stacked and the vortex originated in the center of the flames. The flames stretched right across the field, forming an enormous column, wide at the bottom and narrow at the top, standing vertically and attaining a height of 45–60 m. The smoke vortex formed above the flame, rising high into the sky. The vortex rotated at great speed. This awesome sight was accompanied by a thunderous sound resembling thunder. The strength of the vortex was such that it lifted big trees into the air. The day was clear and calm.

A similar phenomenon developed in Oregon during a largescale forest fire. Over the forest a fire column 30 m in height was formed. Rotating at great speed, it sucked up all the new sites of fire. Above, it gave way to a still more enormous smoke column about 9 m in diameter. The vortex was almost stationary. The strength of rotation was so great that the vortex easily felled trees and lifted them into the air. Graham (1952), observing the phenomenon, referred to it as a "fire vortex of tornado intensity". The formation of a rain cloud over a forest fire is quite common (Carpenter, 1919).

Landsberg (1947), described how during the bombing of Hamburg in the last war fire broke out at three points. The fire columns rising into the sky at first hung separately, then combined into an enormous, fiercely rotating vertical fire-smoke vortex. Its height was about 4,000 m and width at the base around 2,000 m. The rotation over the ground was so strong that it

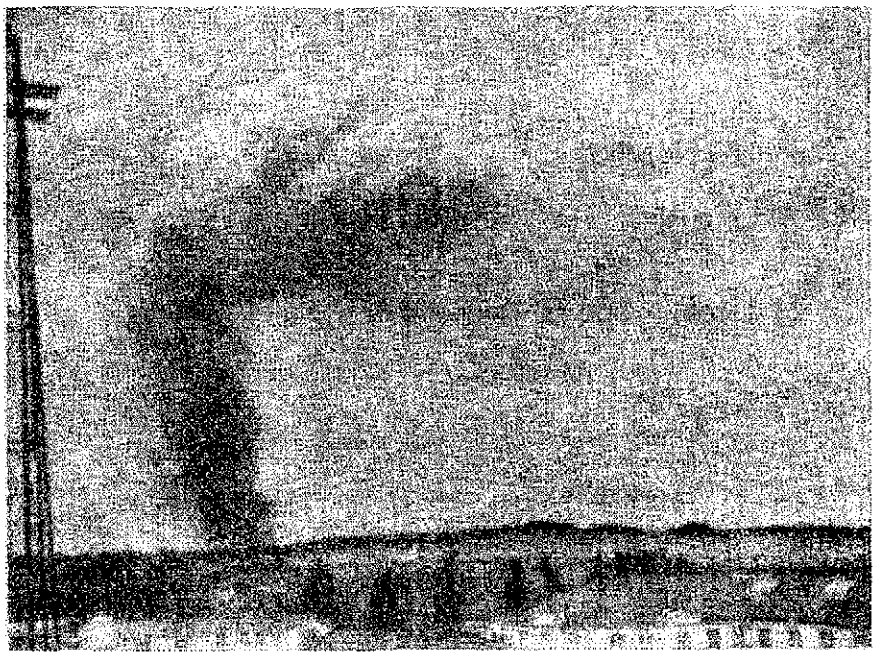

Fig. 220. Fire vortex and cloud over straw fire, England (Ride, 1965).

uprooted large trees. All the buildings engulfed by the base of the fire vortex were reduced to ashes.

On August 6, 1945, during the fire caused by the explosion of the atom bomb over Hiroshima, an enormous fire-smoke vortex was formed, lifting large trees into air and sucking up water from pools.

In his second paper Graham (1955) describes how during a big forest fire the fire columns of several points combined into a single fiercely rotating fire vortex. In this case, the fire became so intense that people feeling the warmth had to flee. The diameter of the vortex reached several hundred meters and the height was 1,200 m. The vortex easily felled and lifted big trees into the air.

Fire vortices are so strong, numerous and peculiar that Lawrence (1963) gave them a special name—'fumulus', and for the clouds due to them—'cumulofumulus'.

He showed that fire vortices originate from grass fires as well. There is no doubt that they are formed due to the rushing movement of fires and reach enormous size in central Asia and Kazakhstan.

The conditions for the formation of vertical vortices and other such formations are given in the work of Williams (1948).

ARTIFICIAL FIRE VORTICES

An enormous artificial fire vortex and tornado were encountered by Dessens' father and written about by Dessens (1962). He invented a special oil burner giving an enormous flame and called it a "meteotron". Simultaneously burning 15 and often 40 meteotrons, he obtained striking results. It not only gave rise to fire vortices but fire tornadoes were lowered from the artificial cloud.

The experiments were carried out on the outskirts of the deserts to the south of Algeria, where a spur of the mountains protrudes into the Sahara. The experiments were carried out under different meteorological conditions. The group of 15 meteotrons, placed in a circle, gave a rotating fire column, a fire vortex 40 m in diameter. The top of the fire column changed into a smoke column, crowned by the newly formed cloud.

Then the number of meteotrons was increased to 40. The gigantic fire column accompanied by a black cloud was not of the same type as the cloud accompanying the eruption of Sartsey and Miojini or the cloud from the oil fire in California. The artificial oil fire—the flame and the cloud—did not attain the size of natural ones. The results could be seen immediately. Under the influence of a light breeze the smoke cloud moved sideways as in California and in the eruptions. From the leeward side the cloud at first lowered short, small funnels. Soon they reached the ground, forming the usual tornado.

Unfortunately Dessens' brief paper gives very little data on the characteristics of these fire vortices and tornadoes. The experiments were fantastic. They showed that the vertical vortex, tornado and rotating tornado clouds are phenomena that can be created artificially and then studied.

ASH VORTICES

A vertical hot ash vortex is often formed during volcanic eruptions, especially in the air currents above overheated lava. Wegener (1917, p. 8) gives a number of examples observed in the eruptions of Vesuvius, Santorina and Iceland. Some of the vortices carried volcanic ash and could be referred to as ash vortices.

Wegener gives a short bibliography on the vertical vortex. It starts with such names as Franklin and Grumbol'd and lists diverse and widely distributed vortices. But he did not know about the work of F.A. Batalin.

An ash vortex on the coast of Kunashir Island (Kurile Islands) originated after the eruption of a volcano in northern Japan.

SNOW VORTICES

A snow vortex is formed quite frequently wherever there is an area covered by loose snow. Generally in the winter the snow is boundless in our plains and tundra in the nonforested areas of Canada and Alaska and over the ice sheets of Greenland and Antarctica.

Snow vortices originate in quiet weather on the slopes of Adeli, in Antarctica and are of considerable size, from a few meters to 100 m and more in diameter. While crossing the sea a snow vortex lifts the slush 60–120 m and forms columns of water splash to a height of 1,200 m (Mawson, 1915, p. 111–112).

F.A. Batalin (1854) showed that the snow vortex is not rare in western Europe, in the hilly regions and mountains. In Freiberg a vortex about 60 m in height was observed. Generally the snow vortex occurs in the Alps, particularly in the hotels near the Saint Bernard pass.

The geological significance of the snow vortex is negligible. It only redistributes the dust transported by hurricanes and storms.

WATER VORTICES

The water vortex is not rare on the surface of sea and large lakes. It is similar to the dust vortex and differs only in the sense that the circulating air lifts up not dust but fine drops of water. Generally water vortices are of small size and pass unnoticed. The rare big vortex does not differ from tornadoes and is referred to as a waterspout. The origin of the water vortex is described in the monograph by Humphreys (1929, p. 215).

A typical water vortex was observed in July, 1949, in Washington State, in the lake at Spokane. Suddenly on a hot, sunny day, with a cloudless sky, on the surface of the lake a high, fast-rotating column of water splash originated. It lasted only a few minutes but exhibited considerable strength. Moving to the shore, it lifted a heavy motorboat 4 m in length, carried it a few tens of meters and threw it to the ground, where it shattered into pieces (Severe local storms, 1963).

The water vortex moves from the sea to the land, causing the movement of aquatic organisms into the continent, but this shift is insignificant and considerably less than that by tornadoes. The meteorological dictionary (Huschke, 1959) states that the water vortex is quite widely distributed in tropical and subtropical waters.

AIR VORTICES

The last form of vertical vortex is the one formed by air only; it is known as an air vortex. They are almost invisible and noticed only by the otherwise inexplicable movement of different objects. F.A. Batalin (1854) relates that he and a companion were crossing a bridge across a river. They were walking straight but suddenly something shoved him to one side, to the railing, and his companion to the other side. He explains this as due to the action of an air vortex.

The air vortex is invisible and in this sense it is analogous to the invisible tornado. As such it does not carry anything except air and that in small quantities. The geographical and geological significance is very small.

With this we conclude our essay on tornadoes and vertical vortices—exceptionally peculiar and common puzzling phenomena.

PART IV

GEOLOGICAL ACTIVITY

The geological activity of hurricanes, storms, tornadoes and other strong wind circulations is essentially associated with sedimentation. This relationship is quite varied. Often the mixing of aeolian materials in the deposits is negligible, comprising a small amount of fine particles, but there are cases where the aeolian material leaves quite a thick layer of sand or loess cover.

Often salt transported by the wind has been found in the deposits when accurate chemical analysis was done. The formation of significant deposits of aeolian salt is not rare.

But the most important aspect is not the qualitative features but the worldwide action of the wind. The wind blows everywhere. The hurricanes and storms and the deposits they leave are also encountered almost everywhere.

This exceptionally important worldwide phenomenon as a rule is underestimated by geologists and often altogether ignored. Geologists generally explain phenomena with the help of sea and tectonics. Anything new is immediately related to marine deposits and tectonic movements. In nature, we often encounter continental deposits with marine fauna, transported by the wind. The discontinuities in deposits and marine transgression are not always due to tectonic movement. Rather they are due to the rise and fall of the sea level during hurricanes and storms. It should not be forgotten that such fluctuations often attain great size—20 and even 40 m. If salt and gypsum patches are found in the section by geologists, they often infer the incidence of an arid climate. But actually the salt and gypsum may have been transported by dust storms from hundreds or thousands of kilometers away.

The geological activity of hurricanes, storms and wind, like the other agents of worldwide significance, causes destruction, transportation of destroyed material and formation of new deposits. The destructive activity, mainly deflation, has been studied in great detail and a number of papers are available on it. It is not described in the present book, except for a few cases of abrasion like aeolian activity.

The forms of transportation are briefly described. They have been touched on repeatedly in the preceding part.

The composition of aeolian material is described in great detail. Special attention has been paid to the carbonate and halogen materials and to the peculiar, widely distributed red dust with its organisms.

There follows a short description of the geological destruction caused by the wind. The section concludes with a description of the main widely distributed types of aeolian deposits. They are divided into a number of types, e.g. aeolo-effusive, aeolo-lake, aeolo-watershed and aeolo-depression types.

1
Wind Motion

GENERAL RULES

The motion of wind is a powerful, widely distributed planetary force. It participates in the formation of the majority of deposits in the world.

At first this appears to be a paradox or an absurd statement. How can the gentle flow of wind form large depositions? The answer is simple. First, though the gentle wind is not very significant, the terrible hurricanes, storms and tornadoes have great force. Secondly, the action of the wind is not related only to the air but includes the various agents, primarily water. Wind together with water is a terrible force.

Movement of a body depends on the pressure on it and the pressure is determined by two parameters: the speed and the specific weight of the moving body. The specific weight of air is small and therefore the pressure it causes becomes considerable only when the speed is large. If the air contains dust or water, especially in large quantities, then its specific weight greatly increases. So does the pressure, which can be ten times more.

Actually dirty air with an admixture of large and small particles is involved in all these movements.

In the latter case, the two most important components are water and mineral particles. There are considerable amounts of liquid particles—qualitatively and distribution-wise. Solid particles are also encountered, but in considerably smaller amounts. The classic examples of air polluted by solid particles are sandstorms, haze and smoke. The saturation of air with water particles causes the formation of clouds. The maximum amount of water is contained in cumulonimbus clouds.

In hurricanes, storms and other vertical and horizontal vortices the quantity of water is so great that often it is difficult to state which is more—water or air, especially by weight. The fish carried by tornado clouds to tens of kilometers remain alive for tens of minutes, certainly not in air but in water. In air they would quickly suffocate.

The large-scale destructive activity of hurricanes and tornadoes, which even destroy stone walls, shows that the pressure is caused not only by air but by water, often in enormous quantities.

Often dust storms remove a layer of soil tens of centimeters thick. This is caused not by air but by sand and dust grains contained in the air.

The destructive activity of extraneous particles which saturate the air has not yet received the necessary attention.

In the following section, whenever the destructive and transportation strength of the wind is referred to it means the movement of air containing a considerable amount of liquid and solid admixture. The wind is a mixture of gaseous, liquid and solid particles.

Generally air predominates, but often the quantity of water is very high, e.g. at the site of cloudbursts. During some strong sandstorms the quantities of sand and dust in the air are so great that human beings and animals engulfed by such storms find it difficult to breathe. Sometimes they are badly suffocated and die.

The specific important work carried out combining wind and water is the activity of waves, i.e. abrasion.

MOVEMENT OF LARGE GRAINS AND FRAGMENTS

The movement of large objects is determined primarily by their surface resistance and secondly by their weight. The wind may lift a bridge weighing 100 tons and gently lower it into the water, but it cannot lift a small round boulder.

In the descriptions of hurricanes and tornadoes, a number of cases are cited where heavy objects have been transported relatively short distances if the bodies display a large surface of resistance to the wind. There are numerous examples of tiles and fragments flying through the air but there is no mention of bricks being lifted from the ground.

The transportation of heavy wooden pegs, green coconuts and heavy shells from Haiti to the coast of North America by hurricane Hazel was a unique case. Transportation by this hurricane was 1,500 km. This incident is an exception and therefore its significance is not really clear.

The strongest dust and sandstorms do not even move a considerable amount of stone chips in the deserts. The movement of sand has been studied in great detail. There are several systems that carry sand but there is none that carries stone chips. Numerous explorers, engulfed by storms, describe the sting of flying big-size sand grains but none of them writes about being struck by flying stone chips. There are individual cases of movement of stone chips and rubble and in the mass of aeolian sands small, fine lenses of coarse rubble are found. Generally they are found at the bottom of aeolian sands.

The well known geologist Grabau (1932) realized the significance of the movement of air. In his monograph *The Principles of Stratigraphy* he paid special attention to aeolization—the special name he gave to the activity of the wind. He gives a number of examples in the section on deflation (transportation by wind), when stones the size of a fist were lifted and transported by hurricanes a short distance, as though they had bounced. Such incidents have occurred in the Sahara and Gobi deserts. He describes, with reference to Meine, a rain of small pebbles, 2.5–3.5 cm in diameter. In 1891 pebbles were transported (obviously in a cloud) a distance of 150 km and dropped over France.

A peculiar type of concentration of stone chips is found on the surface of rocky-clayey deserts. The concentration of stone chips is due to their movement and due to the transportation of sand and dust by the wind.

MOVEMENT OF SAND

In the last ten years the movement of sand has been widely studied and a number of works are available on the subject. Many of the legends and myths may be disregarded, but some incidents are still not clear.

The legends about sandstorms speak of unbelievable sand walls moving toward the explorers, who have subsequently disappeared. It has been proved that sandstorms and these terrible sand walls consist of dust (Figs. 69, 71). The myth that enormous quantities of sand are carried from the Sahara to the Atlantic and Europe via the Mediterranean has been disproved.

It has been established that sandy quartz, feldspar and other minerals exhibit a negligible surface of resistance and cannot fly in the air. The main form of movement is big or small bounces.

It is only flakes of mica that are easily engulfed by the wind and fly a great distance along with the dust. Flakes of mica generally accumulate on surfaces of foliation and surfaces of discontinuity. Their mode of transportation has always been debatable. Now it can be said definitely that they are transported by the wind.

The movement of sand grains by bouncing is responsible for a large number of peculiarities of distribution. In addition to a strong wind there should be hard ground on which the grains can bounce. Such ground generally has other sands and therefore the sands are always distributed in continuous, sharply-defined massifs.

Any clay, silt or marshy soil serves as a barrier to the movement of sand because then the sand cannot proceed step by step. Any water barrier retains the sand, which gets concentrated on the bank. Coastal dunes are formed by the wind blowing not only from the sea but also from the land. The wind from the sea transports sand from the beach and the wind from the land brings it back to the beach. The bounce of sand even during a storm does not exceed a few meters. Therefore it cannot overcome a sea or river barrier of greater width than this bounce length.

It may, however, be mentioned that the galloping movement of sands in the formation and distribution of sand massifs has not yet been studied in great detail. All the old concepts are based on the fact that sand flies into the air but this is really not the case. Sand only bounces. The movement of sand has been described on pages 131–134. The main puzzle is the fixed boundaries of the large sand massifs. These hardly change over hundreds of years.

MOVEMENT OF PARTICLES INTERMEDIATE BETWEEN SAND AND DUST

Sand grains of average size bounce a few meters but dust of average size flies tens and hundreds of kilometers freely. The movement of particles of intermediate size, smaller than sand particles of average size and bigger than dust particles, is of special interest. Actually they are fine-grained sand and coarse-grained dust.

Exact observation of the movement of such grains has not been recorded. Either they bounce with the sand mass or fly along with the dust. Theoretically they should bounce like sand grains but their gallop will be longer—tens, hundred or even thousands of meters. The beginning and end of the bounce will be the same as that of sand. In the middle stretch they would fly like dust. It is quite likely that at such times they form what have been referred to by explorers and sailors in the Atlantic as flying sands, sandstorms.

MOVEMENT OF DUST

Dust storms are menacing phenomena and cause enormous loss. They have been studied in great detail and are cited widely in literature. The main data are given on pages113–169. The quantity of transported material has also been calculated. The figure is tens of cubic kilometers for one storm continuing for a few days.

Transportation by dust vortices and tornadoes has been studied relatively little. Each of these formations, even of small size, transports small amounts of dust and therefore does not rate any special attention. But they are repeated many thousands and even millions of times over a long period. The corresponding quantity of material that they transport may be quite large.

The role of transportation of dust by storms and vortices in the formation of lake and marsh deposits, particularly coal and salt, is of special significance.

In coal deposits the mixture of layers of clay with coalbeds by and large betrays the activity of rivers. This is, however, debatable. The enormous swamps that were the site of formation of coal were generally located in wide lowlands covered with thick plant cover. The rivers either skirted these lowlands or crossed them without affecting the plant massifs or disappeared on their fringes. The material transported by the rivers does not reach the large central part of the massive deposits. The dust and clay particles could have been brought here only by the wind particularly by dust storms and vortices.

The transportation of fine-grained material in saline lakes as a rule situated in arid regions, is more significant. In these regions rivers are either absent altogether or dried up. All the fragmented material is carried by storms and vortices. It forms layers of clay. Often fine-grained sandstone formations alternate with layers of pure salt (Nikolaev and Rudenko, 1939).

When the wind is weak or ceases altogether, pure salt is deposited. As soon as storms start the lake receives dust and layers of clay are formed. The periodic repetition of storms gives rise to the alternate layers—the characteristic of lake deposits.

The depositions of lakes and swamps, related to the activity of storms, have been incorporated in the special group of aeolo-lake deposits (see page 538).

MOVEMENT OF HAZE

Dust is transported through the air a distance of thousands of kilometers. But in any case its movement is limited to the tracks of hurricanes and storms. Haze, consisting of fine clay particles, is held in the air in the suspended state and the size and path of movement are not limited. Its distribution is worldwide.

The absolute weight of the clay particles in the haze is negligible but their transportation is not limited and the reserve is infinite. The haze can form a considerable deposit by accumulation over a long period. This deposition is important where other sources of terrigenous material are absent. Such a zone is the surface of the seas and oceans far from land. The clay particles of haze play an important part in the formation of deposits in this zone. This has been repeatedly observed for red deep-water clays (Leuchs, 1932). It has also been noticed in other deposits like diatom silts, etc.

There is no doubt as to the participation of haze in the formation of clay deposits in large lakes and swamps and often it may have an important role. In normal deposits the haze is diffused among other components. It is noticed only when these components are absent or present in negligible amounts.

In conclusion, it can be said that the forms of movement of air and the composition of the moving material are extraordinarily diverse, the quantity of transported material is enormous but we know very little about the process, its manifestation or its results—earlier deposits. There is great scope for thorough and interesting work in this field.

MOVEMENT OF WIND AND WATER

Abrasion

It is generally believed that abrasion is the destruction of the coast by sea waves, breakers. Therefore abrasion is regarded as one of the activities of the sea. This is not precisely correct, though loosely it is true.

As such there is no abrasion due to the sea and this can be seen when the sea is quite calm. Waves are necessary for abrasion and they can be generated only by the wind. The stronger the wind, the greater the abrasion. The greatest strength is attained during major hurricanes.

Abrasion is the joint action of two elements—water and wind—on the earth's surface. Abrasion is inherent in the activities of hurricanes and storms. This fact is generally overlooked.

The destructive activity of the gigantic hurricane and storm waves is a perennial threat. Even the most stable cliff cannot withstand the effect of abrasion. The cliff is washed away meter by meter and disintegrates into the sea in the form of pebbles, sand and silt. There are a number of cities standing on high coasts that face extinction. Some have already disappeared.

All this has happened in recent times, but if we take geological history covering millions of years, then destruction of the order of a few meters becomes kilometers, hundreds of kilometers or even thousands of kilometers. Striking phenomena like the transgression of the sea, etc. come about. It is difficult to overrate its significance.

Abrasion and the related accumulation are described in great detail in the monograph by V.P. Zenkovich—*The Principles of Studies on the Growth of Marine Coasts* (1962). He states that in the process of abrasion the coast is subjected to the impact of breakers of great strength. Therefore the destruction of cliffs is regarded as catastrophic. The large-scale destruction of port structures and coasts by the incidence of breakers is well known. There are numerous examples of this in the reports of oceanography and geomorphology. Fairly complete data have been collected by Matthews (1913) and Johnson (1919). New and interesting material is also given by Bijel and V. Edmondson (1951).

Descriptions of the catastrophic destruction of the coast during violent storms due to the action of waves, though quite common in any bend of the coast, are somewhat rare. However, it is not these catastrophic events but the breaking of the main rocks by waves of various sizes day after day, year in, year out, that is of great significance.

Such a relative appraisal of the activity of storms and ordinary waves requires verification. There is no doubt that the sum total of destruction carried out by waves is greater than the sum of destruction by the normal wind. Storms are repeated more frequently.

Exceptional destruction of old coastlines and the formation of new ones are described in the monograph by V.P. Zenkovich in great detail.

We all know the changeability of the Pre-Caspian. The monotonous, yellowish-gray, smooth, table-like plain stretches hundreds and thousands of kilometers. Fast trains take a considerable time to cross it and all the time they pass through nothing but steppe. Only recently, i.e. tens of thousands years ago only the boundless sea—the Caspian—existed here. Its waves, whipped by storms, formed the great plains.

The Pre-Caspian plains stretched continuously to embrace still bigger areas now occupied by the deserts of Karakoram and Kyzylkum. Study of the deposits which form its base shows that it consists of recently-formed marine deposits. The abrasion by waves formed the desert plains. The flat bottom of the sea changed into a wide alluvial bottom. In these plains the wind that once formed waves in the sea now formed waves of sand and sand hills of enormous size.

The ancient irregular land with well-defined relief was severely transgressed by the sea and the abrasion activity due to the waves caused by hurricanes and storms was also severe.

The uplift changed the sea into land which had already been influenced by abrasion. The enormous rivers intersected its surface. The rivers continuously changed course meandering over the surface of the plains. The rivers transported and deposited enormous quantities of loose fine-grained sandy-alluvial deposits, distributed uniformly over the entire plain. The rich deposition was the manifestation of a thick plant cover. Therefore the activity of hurricanes and storms was relatively weak. These formed a small accumulation of river dunes and enriched the soil with alluvial material.

Then the third, the present epoch started. Due to remote tectonic movement the entire region became a wide depression, with the base of erosion in the Caspian and Aral seas, the Balkhash and the Alakul. The quantities of deposits fell sharply and the entire depression became desert or semidesert. Dust storms became the main factor in the transportation of deposits in place of sea waves and rivers.

The first epoch was dominated by water—the seas; the second, too, was dominated by water—the rivers; but the wind also started playing an important part in the transportation of deposits. In the third epoch the significance of water—the big rivers—became minimal and storms and hurricanes occupied first place.

The same sequence has been noticed in the Sahara. Here the central part of the sea underwent abrasion. The remains of the fauna live even now in the subsurface saline water circulating under the sand. The sea became an alluvial plain on which the villages and cities appeared in course of time. It was only about 2,000 years ago that this plain dried up: the rivers disappeared, excepting the Niger, and the present-day desert came into being.

It is difficult to establish the history of air circulation in these three epochs.

It attained great strength in the first, the marine epoch, weakened in the second, the rainy epoch and new rages in the third, the desert epoch.

Unfortunately, to date there is no science like "historical meteorology" but there is no doubt that soon it will become part of paleogeography.

In the short but authoritative and interesting paper by Steers (1966), a Professor at Cambridge University, the main types of coast of England and Wales are described. Analyzing the conditions of their formations, he divides the coasts into two types—steep and lowland. The first exhibit destruction and the second accumulation. The second type is more widely distributed and at present the area of Great Britain is gradually increasing.

The effects of storms and hurricanes are not considered specifically, but at many places he underlines the great significance of waves accompanying violent storms. In addition to the waves, violent storms form local, short-period channels. These channels are exceptionally powerful and important for the transportation and redistribution of fine-grained sandy and clayey deposits, especially along low-lying coasts.

The storm waves on the coasts of England attain colossal height (12 m), length and force. On the steep coasts the waves swamp the benches and the beach, reaching and damaging the base of the cliffs. The high cliff along the south coast of England with chalk formations is an example. It can be seen in Fig. 221 that in normal weather the cliffs are far from the sea and not damaged by the waves. During violent storms the picture changes drastically. The storm waves cover the sandy beach, the pebble zone, and strike and damage the base of the cliffs. Abrasion is absent during the periods of normal waves but very active during the prevalence of storm waves.

Steers (1966, p. 40) underlines the fact that the sea-coast continuously changes and writes: "In quiet weather these changes are insignificant but the storm washes the entire coast and often carries pebbles and sand . . . Then it exposes the base on which it stands, the platform formed by erosion."

Cliffs isolated from the sea belt of pebble-sand beach are a usual phenomenon, found in many parts of the coast of England and Wales. It is repeatedly cited by Steers and can be seen in the photographs accompanying his work. In all the numerous cases of normal breakers abrasion is absent. It is active, severely so, during hurricanes and storms.

This is, of course, not characteristic of the coasts of England alone. It is observed along all the steep coasts of the world where a beach zone is formed. Normal wind does not cause abrasion along such coasts. It is only during storms that they are damaged, often with great intensity.

The abrasion of steep coasts having beach zones undoubtedly disproves the concept that the destruction of the coast is the work of small waves, acting gradually over a long period. In the case cited above, the abrasion could not have been due to such action.

Abrasion by small waves cannot, however, be overlooked where the cliffs are right over the sea and there is no beach.

Fig. 221. Southeastern coast of England. Cliff of chalk formations. Projection of base contains normal waves but it is covered during storms. Active abrasion by storms (Steers, 1966, Fig. 15).

But it is not clear what is important and significant in these rare cases—the long, slow action of small waves or the catastrophic action of big storms. There are indications that the latter are more significant.

Steers notes that the storm waves striking the coast bring about changes that normal breakers would not have. These changes are quite large in the sandbars, dams, isolated lagoons and coastal swamps of exposed coasts. Even the well-known Chessil bank dam, totally inaccessible to normal breakers, is covered by storm waves of the sea. Then the marine fauna burst into the coastal swamps, covering large areas.

These irruptions are interesting in the sense that they change the saline water deposits to deposits with marine fauna. A typical transgression of limited range shows such a change. These transgressions can be called aeolomarine transgressions. In fossilized condition, it differs from a recent transgression only by the small area of distribution and thickness of deposits.

Many investigators, including Steers, have repeatedly recorded scale changes in the relief and structure of lowlying coasts caused by hurricane and storm waves. Examples are given on page 464. They have been repeatedly observed on the coasts of England.

Another phenomenon observed by Steers is no less important though it has not yet received the necessary attention. The storm wind with its unusual speed not only causes giant waves but also gives rise to large coastal channels. They exhibit limited distribution, corresponding to the width of the zone of action of the storm. They have short life spans and disappear when the storm ceases. Their strength and speed are enormous. They transport a colossal amount of silt, sand and pebbles all along the coast. Storm channels are closely connected with the movement of water accompanying the storm waves but often have another, perpendicular direction.

Storm channels have not been studied and their existence is seen only in the exceptionally large transportation of loose deposits which occurs during storms and hurricanes. Often these transportations are so significant that coastal maps, especially bathymetric maps showing the depths, become obsolete. They have to be drawn again.

Steers writes: "The incoming waves often lift up sand from the sea bottom. If there are channels along the coast at this time part of this sand will be transported to the side as well. In quiet weather this transportation is insignificant but with strong winds and especially with the storms and large waves, a large amount of sand, possibly with coarse materials, is lifted up and transported to the sides by these channels. A considerable amount of material can be transported in this way" (Steers, 1966, p. 42).

A leading specialist like Steers has repeatedly underlined the great significance of hurricanes and storms in the abrasion of seacoasts in his papers (Steers 1953, 1964, 1966). In many cases abrasion occurs only during storms and is absent during quiet weather. These indications deserve serious attention and on the basis of this the present concept of abrasion as involving small, normal waves and wind should be revised.

TRANSGRESSION AND STORMS

Transgression is an important and widely distributed geological phenomenon. Transgression is not possible without abrasion. Abrasion is not possible without storms. Consequently, storms and tornadoes play an important part in transgression.

In geographical and geological literature transgression and abrasion are related to the activity of the sea. This is only partly correct. The sea water alone is not enough. Waves are necessary, i.e. the participation of the wind. It is widely accepted that not simple waves but the waves of storms and hurricanes of catastrophic strength are required.

Transgression is regarded as the result of the prolonged action of small, hardly noticeable phenomena, i.e. an evolutionary process. This, of course, is not true. Transgressions are due to strong, unusually catastrophic phenomena—hurricanes and storms. Only numerous such occurrences could cause transgression, destruction, transportation and deposition of an enormous mass of diverse kinds.

For transgression what is necessary is unusual and catastrophic factors like storms and hurricanes. The abrasion they cause is remarkable. Observations all along the coasts of England showed that abrasion sliced a high cliff by 1.8 m annually and at places by 3.9 m (Steers, 1966, p. 46). These figures have local significance. Generally it is less but it can also be more at times. In an exceptionally detailed work, King (1959, p. 310), gives the maximum figure for abrasion due to storm waves in 1953. At the seaport of Lowestoft these waves cut off the 12 m high cliff formed by glacial sands by 12 m; at the place where the cliff was 2 m high it was cut off by 27 m. These figures are striking in the sense that they are due to the action of one strong storm.

For these loose, steep coasts observations over 25 years (1925–1950) gave average figure of 0.9, 3 and 5 m per year.

Somewhat to the north, on the shores of the North Sea, on the ice formations, abrasion was observed for over 100 years, from 1852 to 1952. The steep coast was cut off at an average rate of 0.3 to 2.75 m at different points. The more common figures were of the order of 1–2 m per year. This gives a figure of 1–2 km in 1,000 years. To penetrate 300 km deep into a continent the corresponding transgression would require 150,000 to 300,000 years for its formation. The period is considerable even on the geological scale. It determines the duration of breaks in the sedimentation, related to the transgression, associated with the duration of abrasion. Stratigraphy, in this sense, gives very little information. An analysis of the duration of transgression yields considerable information.

Unfortunately the range in which these data fluctuate is extremely high. The figures given above are just one possibility. Other figures may be considerably bigger if the formations undergoing abrasion are very massive. Observations on such massifs show that they remain almost undisturbed over many thousand years. Fauna of not less than 20,000 years have been obtained in the rocks constituting the seacoast at Hover, in Wales, in the caves opening onto the sea. During this period the rocks, consisting of lower carboniferous limestones, were practically unscathed.

On the other hand, the sinking of low-lying coasts is considerably enhanced by transgression. The transgression, changing to ingression, is hardly ever accompanied by abrasion. In 100 years, it penetrates deep into the continent by tens of kilometers, especially on the large, wide valleys of rivers.

In the concluding chapter of his monograph King (1959), touching on the significance of abrasion in transgressions, shows that surface erosion also takes place simultaneously with marine abrasion. It is quite likely that in a number of cases the main relief is formed by rivers. The sea is responsible only for the final flattening and smoothening of the peneplane formed by rivers.

This indication probably renders the study of the mechanism of transgression more complicated. This mechanism has not yet been studied in detail but there is no doubt that this complex and many-sided process of abrasion, caused by hurricanes and storms, needs special attention.

2

Composition of Aeolian Material

The composition of aeolian material, in principle, is the same as that of the water deposits. The wind transports: 1) terrigenous fragments, grains and particles; 2) organogenous particles, rock formations and live organisms; 3) halogenous particles; 4) volcanogenous material; 5) cosmic material.

The main features of aeolian deposits are:

1. The widespread prevalence of fine-grained material with grains not more than 1 mm in size. Particles 1 to 10 mm in size are relatively rare and fragments and boulders are altogether absent. The latter are often carried into the aeolian material by landslips and erosion during strong hurricanes.

2. The wide prevalence of terrigenous material. Carbonates and salt are encountered in limited quantities, in secondary deposits, due to the erosion of water deposits. Siliceous particles are very rare and consist of the products of erosion of siliceous rocks and formations, primarily diatoms.

3. Irregular, sloping, fast changing layers are usually absent or appear as fine horizontal layers divided by isolated patches of layers. A layer occupying a large area is rare: it will be very thin. It will be formed during a very violent hurricane or storm.

The rhythmic structure is not very clear and has not been studied in detail. The periodic recurrence of hurricanes and storms must be responsible for the rhythmic structure of the deposits. However, in the widely distributed deposits—aeolian sands and loess—the rhythmic structure is not clear, it is ill-defined and broken.

In large alluvial plains the fine-grained material transported by hurricanes is slowly processed in the flowing water, primarily in rainwater.

In any case, the possibility of the aeolian origin of some fine rhythymic structures of small thickness is not excluded. This problem has been considered by Wegmann (1948).

The erosion, transportation and deposition of sediments transported by the wind are discussed in an original paper by Udden (1894), written 70 years ago. It contains a number of concrete, innovatory ideas for that period and has attracted much attention. His position has since been modified, corrected and accepted: it has become history. He calculated that the wind over the Mississippi valley has the ability to transport 1,000 times more dust than the river.

FOSSIL HAIL AND RAIN

Fossil hail and rain are often found in aeolian deposits. This is quite natural as storms are almost always accompanied by rain and hurricanes and storms by hail.

In the fossilized form the imprints of drops and hail on the soft surface of silt are retained. The imprints are round and the size corresponds to the size of the drop or the hailstone. Generally imprints of small size are retained. Imprints of big hailstones, of the size of an egg, are not known. They would splash after falling on semiliquid silt deposits. Perhaps such imprints exist but we may not be able to distinguish them.

Small circular imprints on the surface of silt formations of continental origin are encountered quite frequently. They have been repeatedly described in the literature. They are generally referred to as raindrops but Long (1963) very pertinently pointed out that the imprints of raindrops should be less defined and of small depth. What we take for imprints of drops are always the imprints of hailstones. He cites an example (Fig. 222) of the imprint of hailstones in the upper Liassic clay, of 2–6 mm size and depth of about 1 mm.

The imprints of hailstones are authentic indications of past storms.

TERRIGENOUS MATERIAL

Particles of all sizes, from a size of 10–1 mm down to fine dust, are encountered in aeolian deposits. Three types of particle predominate: The first—aeolian sands; the second—loess, aeolian dust; the third—red loam. First place, on the basis of quantity and size of the area of distribution, is occupied by aeolian sands. The loess is considerably less developed but in any case its quantity and area of distribution are quite large. Red, gray or yellow loam is quite rare. The ratio of sand to loess formed by the erosion of the alluvial of the Amu-Darya is 2:1. The quantity of sand is double the quantity of loess.

A fact that has not attracted the attention it deserves is the absence or presence in insignificant quantity of an intermediate composition between sand and loess. This fact underlines the sharply defined areas of growth of aeolian sand and loess. They do not overlap and are not even contiguous on the surface. There are many cases of overlapping of loess in alluvial sand but

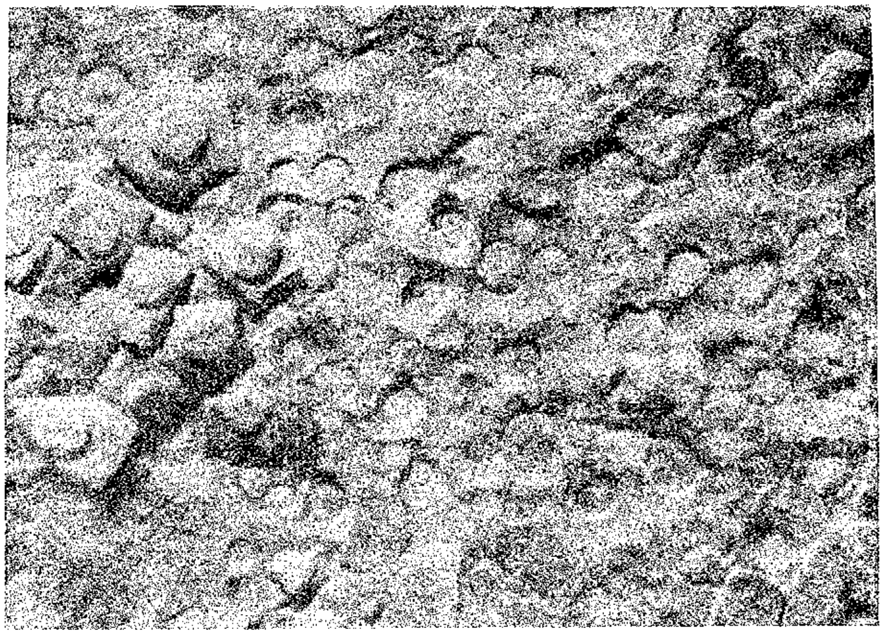

Fig. 222. Imprints of hailstones. Upper Lias of England. Age 160 million years. Diameter of hailstones: 5–6 mm (Long, 1963).

the reverse is not known.

Expressing it in the language of variation statistics, we may say that the quantitative granulometric change in aeolian deposits shows two peaks on the variation curve. One peak is formed by sand, the other by loess (Fig. 223).

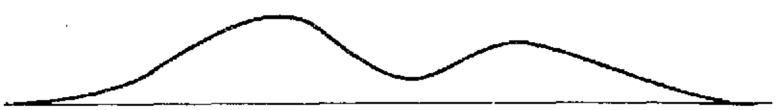

Fig. 223. Variation curve in quantities of grain of aeolian deposits.

On this curve, except for the central low or saddle, the most interesting features are the left- and right-hand ends. The sharp fall in the quantities of particles bigger than sand or finer than loess can be clearly seen.

The left side of the curve generally ends with a grain size of 1–2 mm. This is indicative of weak and strong winds and not of storms or hurricanes. Hurricanes and violent storms freely carry grains and fragments more than 2 mm in size, but in small quantities. This corroborates the small accumulation of gravel, road metal and bigger fragments at the base of sand hills and in the hollows in uneven sands. The maximum size of fragments and boulders is difficult to establish. Hurricanes and tornadoes lift and transport small animals and people, as also large objects like planks and trees, to several hundred meters. All of them are heavy, but at the same time they have a large surface, exposed to the pressure of the wind. During the black storm of 1892, in the Ukraine, tiles weighing 1.5–2.0 kg were transported tens of meters when they were torn off the roofs. It is unlikely that the storm lifted them up from the ground.

Tornadoes easily suck up and lift big planks and iron sheets weighing several kilograms but they may not lift tiles of the same weight as their surface of resistance is aerodynamically very small.

This important phenomenon determines the formation of detritus-clayey, pebbly and rocky deserts. These three types of desert are found in regions of moderate or violent storms which carry off all the loose particles of sand and dust but cannot transport gravel and pebbles. Detritus-clayey deserts occupy an enormous area in the USSR as well as abroad. A photograph of one of them ("reg" in the Sahara) is given in my book *Studies on Facets* (1956, v. II, Fig. 77). It is a boundless plain, completely covered with gravel in a matrix of dense, solid clay. All the fine particles formed by the erosion of this mass are gradually transported by storms.

There are large areas in the Libyan desert covered with a layer of moving pebbles. They are known as "serirs". All the sand and dust are carried away from this place but not the pebbles. Serirs are difficult for all types of transportation. Among our deserts they are hardly found and the alluvials of Amu Darya, Syr Darya, Murgab and other rivers differ in grain size only.

Rocky deserts have horizontal surfaces with rocky formations. The surfaces of the Ustyurt and Zaunguz plateaus are related to such deserts. All the fine-grained products are carried away, leaving behind gravel, rubble and bedrock.

This shows that the grains and rubble more than 2 mm in size are transported in limited quantities by hurricanes and storms. The degree of transportation is also limited. The variation curve should continue to the left, beyond the 1–2 mm gradation, but it will sink to a very low level. Exact data on the level where it would start are not yet available (Sidorenko, 1948).

The other, right-hand end of the variation curve is also interesting since it includes aeolian clay. This is fine particles, carried away by the wind and deposited on the fringe of growth regions of loess. Theoretically the process is clearly understood: in the desert regions the wind erodes alluvial deposits. First sand deposits with occasional pebbles, then dust settles and loess is formed, and later fine loess particles settle, forming aeolian clay. Where loess is formed, the clay zone will not be found and where aeolian clay is found, the loess cannot be seen. This is the situation. The exception is China where the loess zone follows the red clay area.

There is no doubt that river alluvials contain clay particles. They are eroded along with the dust, and transported by the wind beyond the dust particles where they are deposited to form clay beds. These clay deposits have not been distinguished, except in China, from among the present continental deposits surrounding the regions of growth of loess.

In Central Asia, in the deserts of Karakorum, the plains of low-lying regions are occupied by aeolian sand. Farther south the plain is at a higher elevation and the sand changes to detritus-clayey formations of the semi-desert. Still farther on the slopes of the hills and the flat low watersheds are covered with loess. Above the slopes or farther to the south, beyond the watershed, loess should change to aeolian clay but this clay is not well known. Its thickness may have been small, of the order of a few meters, and most likely it is not distinguished from the recent deposits, which are often of considerable thickness.

The opposite picture is found in the People's Republic of China. Here the transportation of dust is from the northwest, from the deserts. Large amounts of dust have been transported. The zone of growth of the loess zone is quite wide and the loess is quite thick at places. The clay particles are numerous and they occupy a wide zone to the south of the loess. A.S. Kes has identified the red clay layers formed by these particles. They have accumulated on the outskirts of the area occupied by loess.

Aeolian clay has been found on the southeast Russian platform in Great Syrt. It has been named "syrt clay". The significant growth of syrt clay is on the western and southwestern slopes of Great Syrt. Here its thickness is 40–50 m. To the west, in the direction of the Volga, the sandy material increases and the clay becomes sand. It is interesting that loess is absent here and the sand, transformed from clay, is basically alluvial. Typical aeolian sand, like loess, is absent.

The syrt clays are of yellow, gray, red or brown color. They do not occur in layers but at places are calcareous and porous and exhibit a columnar structure. The granulometric compositions are characterized by particles 0.1 mm in size and less (55–95%). The content of sandy particles is considerable at the base of the Great Syrt, decreasing up the slope.

The age of the clay is Anthropogene, mostly Holocene.

Ukrainian and southern Russian loess occupy large areas. The outlying areas, especially the northern edge, are covered with aeolian clay. However, pure aeolian clay is not known. It is quite likely that it is mixed with red loam, widely distributed in the central and southern regions of the Russian platform. In its features the red loam is close to syrt clay, especially the variety that differs considerably due to the admixture of sandy material.

If the aeolian clay cannot be traced in the present halogen deposits, it can be ruled out in the older formations. There is no doubt about its existence but to show it in sections is a task for the future.

In his paper (1959) N.I. Mikolaev discusses the origin of loam cover. According to him there are two types of loam. The first—the primary aeolian—develops on the upper part of slopes and in watersheds. It is of relatively small thickness, nonsaline and homogeneous. The second type is on the lowlands. It has localized distribution, large thickness and a sharp lower boundary. It is stratified at places. Its origin is complex.

Dust

Dust is the main material that is transported by the wind, storms and hurricanes. There is no place on earth where there is no wind and therefore no dust. This rates in relation to the other terrigenous particles and determines the significance of the dust storm—its carrier.

The size of the particles is quite limited—10–15 microns—but often dust contains particles of 100 and even 250 microns. The monograph by Fett (1958) gives the following scale, used by soil scientists: coarse-grained dust, 10–250 microns; medium-grained dust, 5–10 microns; fine-grained dust, 1.5–5 microns; silt, 1.5 microns. The very fine dust particles, visible to the naked eyes, give rise to the haze in the sky. Cosmic dust has been described by Dauvillier (1963).

Dust significantly influences people's lives. Therefore the different properties of dust and the effects thereof have been dealt with in numerous works (Obruchev, 1951). The monographs by Blacktin (1934) and Fett (1958) deserve mention. The latter gives a valuable bibliography and contains detailed and interesting material.

Fett divides dust into three main groups: cosmic, ground and cultured dust.

Ground dust is divided into three groups: inorganic, organic and smoke dust. Inorganic dust is further subdivided into continental, volcanic and sea dust. Organic dust is from living animals and plants (the last in turn contains microbes, bacteria and viruses). Cultured dust is due to transports, fires and industry. All these subdivisions are treated in great detail. Special attention is paid to the significance of dust in geophysics, geology, botany, medicine and hygiene, industry, etc.

The origin of loess is considered in great detail in the geological section. Fett has no doubt about the aeolian origin of loess, starting from the total balance and circulation of dust in Nature.

The monograph by Blacktin (1934) was written 25 years ago. The geological portion does not go into great detail, but a number of other problems are considered in detail, especially the properties of dust caused by industrial activity. The general formation of dust in Nature is quite interesting: "The formation and transportation of dust in Nature is an enormous, continuous process taking place on the outer surface of the earth's crust containing oceans and mountains. Therefore the dust forms an intensive and fundamental phenomenon of Nature". There is no doubt about the characteristic role of dust. But we geologists underestimate its significance.

Continental dust is quite important for us since it forms the material for aeolian deposits. V. Fett (1961, p. 36) correctly states that the main source of dust is the desert, but his insistence that the desert dusts are due to the disintegration of rocks is incorrect and requires clarification. The denudation of rocks no doubt yields sand and dust but it is a secondary source.

The main source of aeolian sand and dust is the hologene river deposits, constituting the major portion of our deserts—the Sahara and other major deserts.

Large amounts of dust can be obtained from the erosion of river deposits, especially when the composition of the deposits is glacial clay.

The big rivers, the Amu-Darya and Syr-Darya, by constantly changing course downstream formed the surface of Karakum and Kyzylkum. The source of these rivers is the wide glacial areas of the high mountains, which have increased in size in recent times. The thick glaciers, gouging out their own beds, gave rise to glacial silt which is now changed to dust by storms.

The usual atmospheric dust over London and Washington mainly consists of fine particles of quartz and other minerals. There are many clay particles (loess) too. Here and there one encounters diatoms, spores, pollen and other microorganisms (Kimball and Hand, 1924). Observations and collection of samples were the object of a special aerial survey.

Measurement of the size of the particles of dust showed that the size decreases with altitude. At a height of 3,000 m it is one-fourth that of particles in the lower layers of the atmosphere (Kimball and Hand, 1924).

According to a theory put forward by Humphreys (1913, 1929), the quantity of dust in the atmosphere may become so great and absorb the solar radiation to such an extent that the temperature of the earth may be lowered considerably, thus changing the climate. Humphreys argued that the quantity of dust in the air is considerably enhanced during volcanic eruptions, following each other at short intervals. He even believed that young volcanoes were one of the causes of the ice age.

This assumption has been contradicted by a number of scientists. Among Soviet scientists, the work of M.I. Budyko may be mentioned, which has been developed further.

An interesting classification of the particle high in the atmosphere has been given by El-Fandy: haze, dust, dust storm, sandstorm. Each of these categories is characterized by the particles gradually increasing in size and reducing the visibility. The paper includes a number of tables (El Fandy, 1953).

The explanation that the particles of dust floating in the air are surrounded by hollows or pockets of air, exhibiting humidity and temperature different from the surrounding air, deserves attention (Durst, 1935).

Haze

Haze is the clay and silt particles high in the air. In size they are in the granulometric scale and are next to dust. Whereas for dust the lowest value on the scale is 1 micron, haze mainly consists of particles of sizes less than one micron. A small amount of particles of 1 micron are included in its composition.

The main property of haze is the ability of the particles to float high in the air for a long, practically unlimited time. Haze moves away from a particular locality either due to the air in which it is floating being replaced or due to rain washing it down. In dry, calm weather, haze persists in the air without any perceptible movement.

Haze is a common phenomenon and is often observed in the arid, dry regions. It is a phenomenon that does not affect man. Therefore it has not drawn much attention, nor has substantial work been carried out on this subject. The physical and chemical composition of haze has not yet been studied. The organisms associated with it, the fine spores and pollen, bacteria and viruses, have not yet been studied, though they undoubtedly exist. The haze carries with it bacteria and viruses but how and to what extent is not yet known and these questions need to be answered.

The geological significance of haze is also not known.

Haze occurring at the surface of lakes or on the surface of the land will form silt or clay. Clay is a peculiar formation. It differs from all other formations in a number of ways. It may be just a mechanical mixture displaying a few properties of chemical bonds. It is quite likely that these properties are displayed in the air too.

CARBONATE MATERIAL

Limestone is an important carbonate material. Limestones often occur as dipping beds, characteristic of dunes. Actually these are marine, rarely lake or river dunes. They are formed near the shores of sea, lake and river, i.e. they occur within tens of kilometers of the coast. Such recent deposits in the USSR are not known and quite likely are altogether absent. They are encountered quite frequently in the tropics and subtropics, especially along the coasts fringed by coral reefs. Examples are provided in the well-known monographs by V. Twenkhofel—*Textbook on the Formation of Deposits* (1936) and my own—*Textbook on Facets* (vol. 1, 1955).

The Bermuda Islands have considerable atol reefs. All the deposits in its range are exclusively carbonates. Calcareous sands, particularly colites, are widely distributed. The entire elevated part of the islands, the coastal areas and the cliffs are covered with dense colitic calcareous sands. Such dunes of oolitic limestones are known as "aeolinites". We will use this term hereinafter. The aeolinites of Bermuda have been described by Sayles (1931).

Aeolinites

The work of Evans (1900) remains a valuable work on aeolinites to this day. A typical example of limestone is in Junagarh and in the adjoining areas of the Kathiawar region, situated on the northwestern coast of the Indian subcontinent (Fig. 224). The Girnar range starts to the west of the city and at the base of the range the limestone attains maximum thickness—more than 60 m. Obviously, the range served as an obstacle to the wind transporting particles from the seacoast.

In its external form the limestones display oolitic structure. But typical oolite grains of concentric structure have rarely been found under the microscope. The predominant calcareous components are due to the decomposition of shells whose fragments surround the limestones, giving an external appearance like that of oolites. All the grains can be seen with the naked eye and are cemented to the limestones. The fresh limestone is soft and can be easily cut. It hardens in the air and makes first-class building stone.

The layers of limestone are peculiar. The entire thickness is divided into horizontal surfaces, showing discontinuities in deposition at distances of 0.9–1.2 m from one another. Between these surfaces dipping beds with dips of about 30° can also be found. The dipping beds do not intersect the horizontal surfaces and are found on either side of the surfaces. The dips are toward the east, toward the Girnar ridge.

A study of the fauna carried out by Chapman (1900) showed that shells and other skeletal formations of microforms were altogether absent. Within the oolitic grains particles of shells of pelesipods, gastropods, needles of sea urchins, skeletal formations of calcareous seaweeds, numerous foraminifera, etc. were found. Among the foraminifera the milolins, pulvinulins and nonionins were more common. The polistomels and amfistegens were quite common. The rotalis, trunkatulins and discorobins were quite rare.

Limestones similar to those of Junagarh are found at a number of places in the Kathiawar region (Fig. 224). They differ slightly in lithology. Most of the places are near the coast, but one—Chotila hill—is quite far from the seacoast and situated at a height of 350 m. Some of the points are somewhat to the north, in the Kutch-Mandvi and Pacham regions.

The limestones of Porbander deserve attention. They also show dipping layers with white, granular, pseudo-oolitic structures similar to those of the limestones of Junagarh. The main difference is in the large numbers of foraminifera in the nucleus of the oolites, mainly miliolins, pulvinulins and rotalis. They were named "miliolit". With these indications they were switched to the second group of aeolinites—aeolinites with foraminifera.

The term "miliolit" (from the foraminifera "Miliolin") was used by the English geologist Carter when working on the shores of the Indian Ocean in the middle of the 19th century (1849–1860). He found aeolinite not only in Kathiawar, but also on the coasts of Arabia, in Ras Abu, Ashrin, Marbat and Dofar (Fig. 225). Further, he had word of an analogous formation from an island in the Persian Gulf (Evans, 1900).

Evans (1900) showed that oolitic, calcareous, dipping dunes exist on the

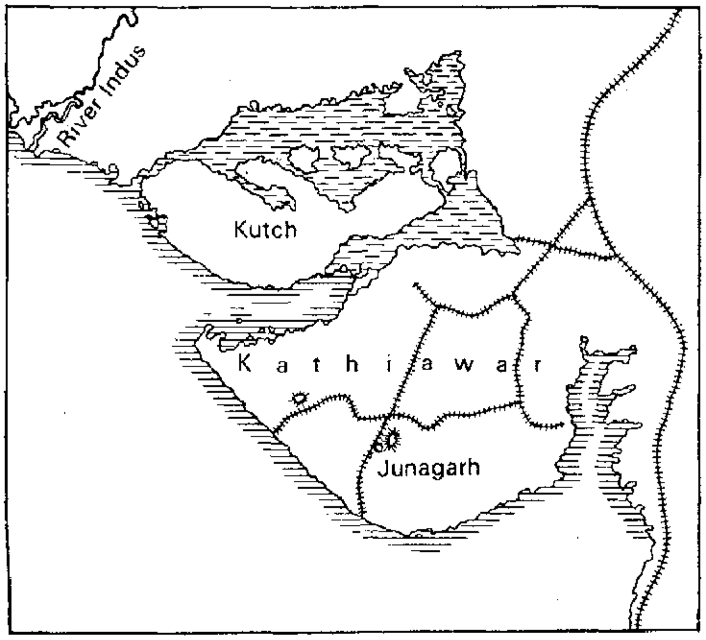

Fig. 224. Map of Kathiawar region, northwestern coast of India (Evans, 1900, Fig. 2).

coast of the Sinai peninsula. Walter also points to their presence in other regions of the Red Sea. Similar formations are found in the Canary Islands and in the St. Helena Islands, off the west coast of Australia. The deposits of the Bahama and Bermuda islands, as well as the deposits on the coasts of Florida and Cuba, are well known. There is no doubt that such deposits occur on the coasts of all islands with coral reefs.

Oliver (1945, 1947) describes the formation of aeolinites on the Mediterranean coast of Egypt. Oolites are formed in the continuous water movement zone of breakers. The strong northwesterly wind carries them to the coast and then the individual oolites move in steps, without going very high in the air. The oolites are clean in shallow water but above them they are mixed with dust, transported by the desert wind—the khamsin. At first the dust is small in amount, but it increases as one goes deeper inland (Fig. 226).

Small humps occur all along the coast. The oolites are transported over this crest and fixed on the silty shores of Lake Marut, situated beyond the hump. Here the mixture of dust goes up to 20–40%, thus forming exceptionally good fertile soil covered with flourishing vegetation.

Such soil will be like aeolinites with a considerable mixture of soil having quartz grains with iron content and red and yellow clay material.

Such aeolinites in the organic world will have a mixed character. There will be numerous marine foraminifera and freshwater diatoms and other forms with siliceous skeletons. Marine varieties with siliceous skeletons are not rare.

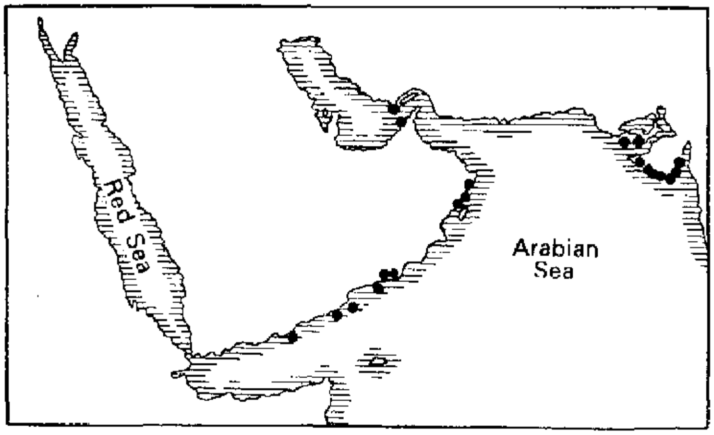

Fig. 225. Map of south Arabian peninsula. Dots show areas of origin of aeolinites (Evans, 1900, Fig. 3).

As such, the area of distribution of oolitic aeolinites is enormous and if the foraminifera and detrital aeolinites described below are added to this its geological significance becomes obvious.

Another variety of aeolinites originates due to the erosion of beaches whose sand mainly consists of foraminifera.

Walter observed how on the shores of the Red Sea, between the coast reefs and the land, the straits settle down with a continuous growth of seaweed in which rich foraminiferous fauna live. The waves throw the shells of foraminifera onto the beach, forming long heaps of snowwhite sand. The sand consists almost of one type of foraminifera in which fairly large shells of orbitolin can be found.

On the east coast of Australia and the adjoining coral islands the sand consists entirely of orbitolin.

Very large quantities of foraminifera live in seaweeds in the shallow water of the reef island Palau. The sand on the beach consists entirely of shells.

The Antiles Islands have sandy beaches consisting mainly of foraminifera. On Saint-Vincent Island, there is a considerable area of deposition to a depth of 12–91 m, and two-thirds of it consists of shells of foraminifera, amfistegin. In Jamaica the calcareous foraminifera are well-developed (150 m).

It is of interest that dunes consisting of one type of shells of foraminifera are found not only in the tropics but also in temperate latitudes. At places on the coast of Ireland dunes consisting of shells of miliolin and trunkatulin are found.

These dunes are described in the work of Evans (1900). They are well-developed on the west coast of Ireland in the region of Galway. The small island Irawall is connected to the main land by a wide isthmus (Fig. 227). Its width is one kilometer and length about 2 kilometers. The entire

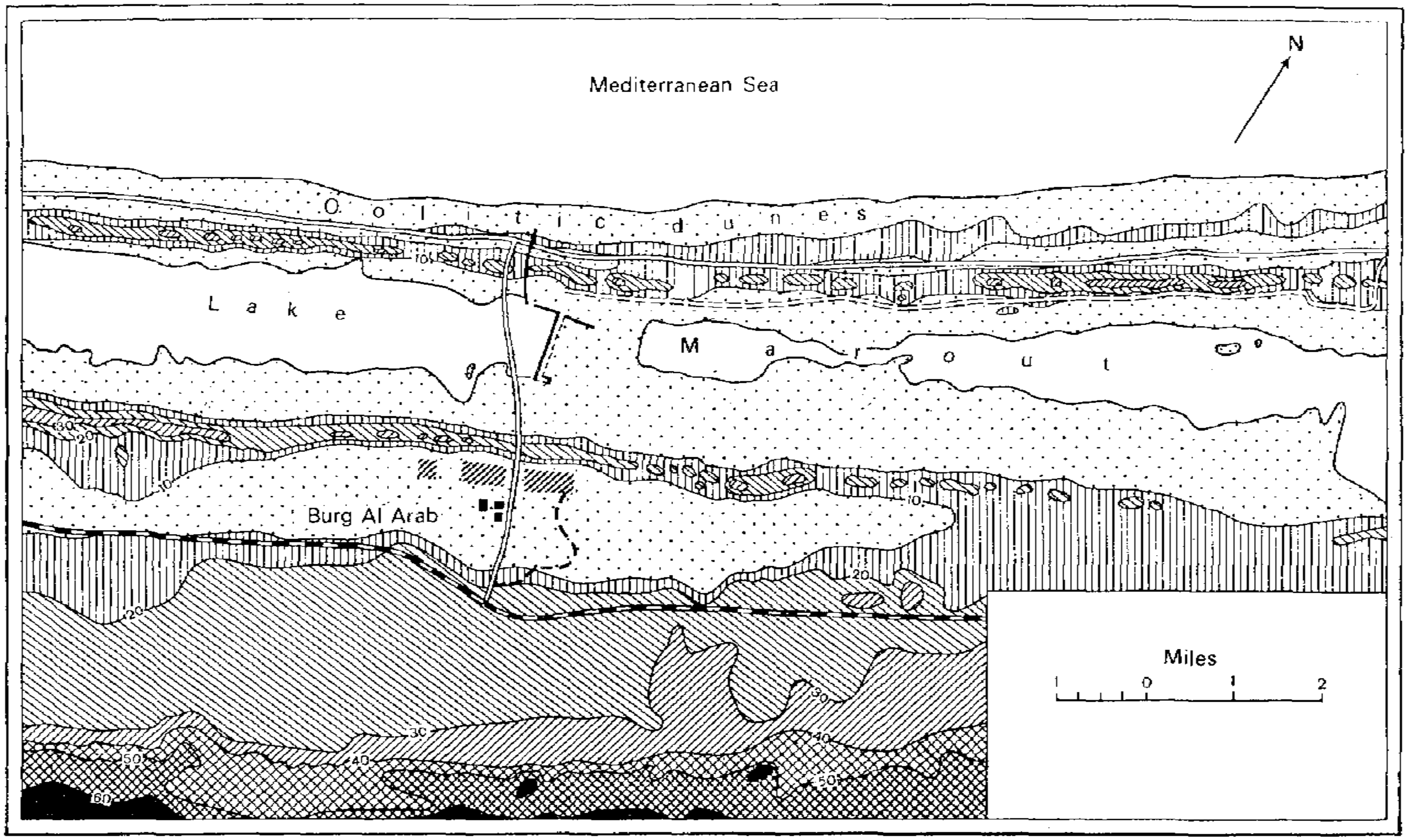

Fig. 226. Region of Lake Maryut west of Alexandria. Mediterranean Sea, south shore. Oolitic dunes on seacost. *White*—end of Lake Maryut (Oliver, 1945, map).

isthmus is covered with low dunes consisting mainly of shells of foraminifera, hemispherical milolin and raised trunkatulin. The winds blowing from the west, from Dogs Bay, blow masses of foraminifera, ostracods and fine fragments of shells onto the coast. During storms the material not only covers the isthmus but is transported to the neighboring bay (Gortin Bay). The foraminifera forming the dunes are not covered by a film of calcite, as in India, and form the foraminifera sand of white color with vague dipping formations. At places pockets of continental gastropods are found. The dunes of Galway are a good example of foraminifera aeolinites formed before our eyes.

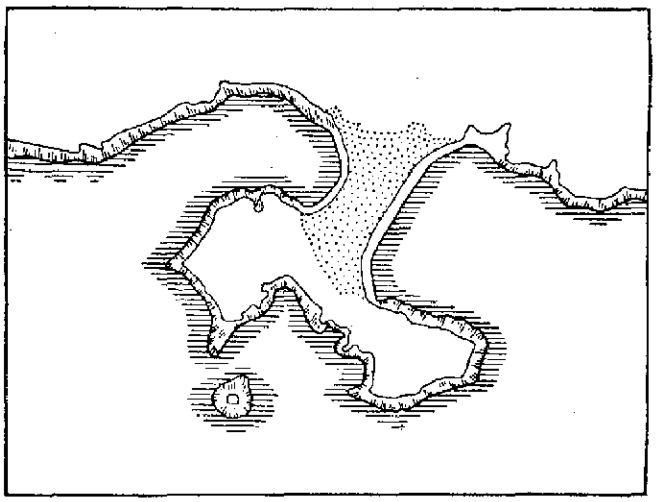

Fig. 227. Map of Galway region, Ireland. Carbonate deposits are shown by dots. 1 cm = 0.64 km (Evans, 1900, Fig. 4).

Recently aeolinites containing economic deposits of chromium have been found on the east coast of New Caledonia on Hugon Island (Avias, 1965; Avias and Coudray, 1965). These are typical dunes containing biogenous detrital limestone with an admixture of mineral particles occurring in the underlying Permian tuffs. They display clear-cut dipping formations and form a number of terraces (Fig. 228). Continental gastropods of Pliestocene age are found here.

Anthropogenous aeolinites have also been found in Australia (Fairbridge, 1950).

These examples by no means exhaust the picture of the various foraminiferous aeolinites. They only show that such occurrences of limestones are not rare. In the past such deposits were not rare either.

If dunes consisting entirely of one type of foraminifera are frequently encountered, then dunes whose sand contains numerous foraminifera but secondary in volume should be encountered more frequently. The main mass of sand contains grains of quartz. If such sands are found in the fossilized form there is no doubt that without hesitation they will be related to shallow marine deposits.

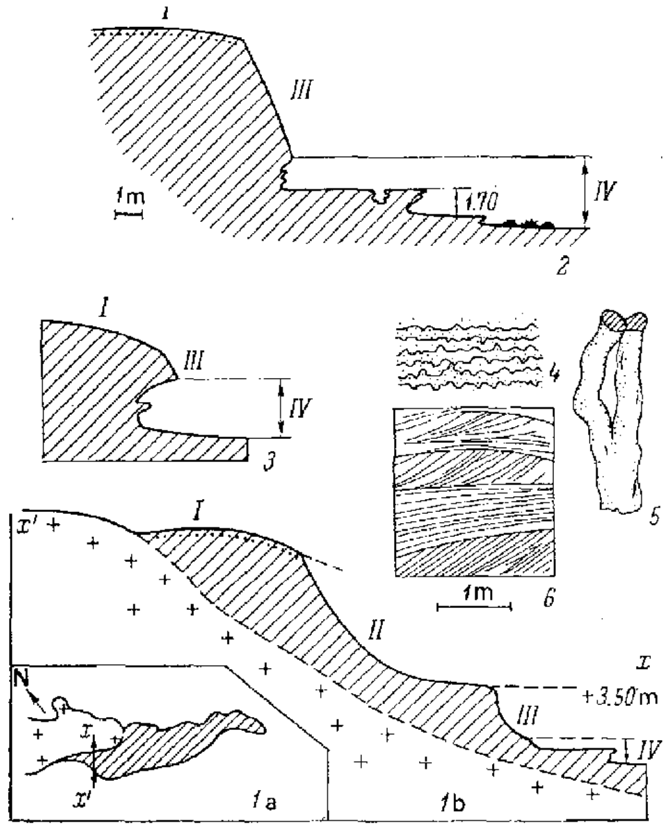

Fig. 228. Aeolinites of New Caledonia (Avias and Coudray, 1965).

1a—map; *1b*—section (*cross*—Permian tuffs, *dashed*—anthropogenous aeolinites—calcarinites—terrace of it); *2*—profile of aeolinites on Izi Island; *3*—calcarinites on Nudke Island; *4*, *6*—layers in aeolinites; *5*—concentrate.

The third variety of aeolinite may be named detrital. It consists of fragments of shells, calcareous waterweeds and other detrital material. They are frequently found, especially on the edge of coral reefs. In temperate climates terrigenous particles in some quantities are mixed with the calcareous grains. Dunes of such mixed composition are found in Eupatori, Batumi and on the shores of the Baltic Sea.

In all cases the fragments or whole shells of pelesipods and gastropods are mixed with detrital material. It is due to this that in the fossilized condition all these aeolinites will be related to shallow marine deposits. They resemble sandy limestone or calcareous sand.

The isolation of aeolinites from the marine deposits of analogous lithology is generally done by the layering. The irregular, distinct dip or indistinct layering of oolites, foraminiferous and detrital limestones is regarded as sufficient sign for dividing the aeolinites. This indication may be supplemented by the relation of the surrounding rocks and retention of skeletal formations. Aeolinites, like all dunes, are essentially found in continental deposits, more frequently in alluvial sands and clays, rarely in lake clays or marshy peats. It cannot be aeolinite if the deposit occurs in a normal marine deposit. It is either marine or alluvial but cannot be aeolian.

Aeolinites can be covered by marine as well as continental deposits, depending on whether the coast has been lowered or raised. Continental deposits are found in not less than three directions over the extension of aeolinites.

The third group of indicators is the retention of skeletal formations. In marine deposits shells are found in live condition as two closed leaves. Such shells do not occur in aeolinites and all the skeletal formations will bear the signs of erosion, transportation and movement by the wind.

The fourth group of indicators is authentic, but unfortunately is rarely encountered. It is the presence of shells in continental molluscs. Evans (1900) in his memorable work showed that on the northwestern coast of the Indian peninsula, in the regions of Kathiawar and Kutch, the dipping oolitic dunes of limestones contain shells of two types of Helix, two types of Buliminus and one form of Cyclotus. The continental Buliminus were found not far from Kutch. Geologists believe that rock containing it cannot be of marine origin because Buliminus is the only large shell found in it. Further, the formations are dipping and so loose and porous that they could not have been formed underwater. The formations consist of fine particles, bound together so loosely that they change to dust under a gentle blow. In composition they are mainly calcareous sand, cemented by the limestones. The formations of Kutch differ from the oolitic dunes of Kathiawar by the large content of sandy material.

Continental gastropods in their present form have been obtained in the aeolinites of New Caledonia (Avias and Coudray, 1965, p. 328).

In all these cases the aeolian carbonate rocks are found at a short distance from the coast. The geologists referring to them as shallow-water or coastal marine deposits, as is generally done, is not essentially incorrect, particularly in paleographic constructions. In any case an error is an error and its elimination will bring out the facts in our research and improve our paleogeographic maps.

Examples of Aeolinites

Aeolian limestones and marls have been encountered repeatedly in fossilized condition. In the USSR the dipping oolitic limestones from the upper Permian Pre-Urals, described by A.V. Habakov, are related to it. They are found in the lower Carboniferous limestones.

The numulitic limestones, occurring around Simphoropole, quite probably are of aeolian, dune origin. They make good building material and many buildings in the city have been built of these stones. The limestone formation is quite thick, irregular or dipping, consisting of one type of shells of numulites.

The other variety of limestones is also of considerable thickness, massive or indistinctly layered in which dipping layers are often well-defined. Generally they are hardly noticeable.

The oolitic limestones are widely distributed in southern England. Evans (1900), analyzing their origin, came to the conclusion that a large part of the limestones is of aquatic origin. However, some varieties display all the signs of aeolian deposits. They are of average thickness, indistinct or dipping, hardly contain shells of marine animals and tortoise eggs have been found in their lower part. It is well known that the tortoise lays eggs in the calcareous sands above sea level, at a distance from the coast. Everything supports Evans' concept and the dipping layers of different aeolinites can be counted.

Aeolinites and Climate

The oolitic grains of which oolitic aeolinites are made are formed only in moving water, saturated or supersaturated with lime. Such water is found under two conditions: in tropical water surrounding coral reefs and in highly saline ponds in arid regions. The oolitic aeolinites, the cores of which consist of foraminifera and fragments of skeletal formations of macroorganisms, are exclusively associated with the coral reefs. The saline ponds require an average annual temperature of the water not below 20°. The oolitic aeolinites show that the temperature of the sea, on whose shores they occur must have been of the same order in the past. In this sense it is as important as coral reefs. Dipping oolitic aeolinites (limestones) are typical of tropical conditions.

Carbonate Material of Distant Transportation

If the aeolian limestones-aeolinites are deposited in the form of a dune not far from the coast, there can also be aeolinites due to long transportation, by many tens and hundreds of kilometers. The only question is how much. Due to the erosion of river alluvial, the quantity of dust material is about one-third. Due to the erosion of sand of the sea beach it is considerably less, because a large part of the dust and clay material is washed away by the sea waves.

The thickness and area of distribution of loess are considerable. The thickness and area of distribution of carbonates of analogous loess should be considerably less. It has not yet been found or, to be precise, not yet identified. The isolation of aeolian sand from loess is not difficult. Isolation of aeolinites formed from carbonate sands from aeolinites in turn formed from carbonate silts is very difficult and often impossible. In carbonate aeolinites the calcareous sand and dust are cemented by limestones. These amalgamate into a continuous mass of limestone and can be distinguished only under the microscope. The problem becomes complicated because each variety of aeolinite has a similar amount of foraminifera. To the naked eye it will appear the same as that of "miliolite".

The difference lies in the fact that the sandy and oolitic aeolinites are deposited nearer to the sea and at lower levels. The dusty aeolinites are formed far from the sea and at higher levels. It is possible that the latter may be related to the "miliolites" obtained in the Kathiawar peninsula, in the Chotila hills, at a height of 300–350 m and at a distance of 150–250 km from the sea (Evans, 1900, p. 566).

The carbonate particles transported deep inland by hurricanes and storms to a distance of hundreds of kilometers, will form a fine layer of limestone and marl. Here and there marine foraminifera will be found in it. The thickness of such a layer will fluctuate from a few millimeters to a few centimeters. They have not been found in the fossilized form. If found, there is a danger that the entire thickness in which they are deposited will be taken as a marine deposit on the basis of the discovery of marine foraminifera.

"At first it was assumed that deep-water silt is analogous to white chalk, but when it was established that the foraminifera of white chalk are of shallow-water origin, this hypothesis was abandoned. The adjoining deposits did not corroborate it. The absence of layering in some parts, the fine grains, the homogeneity and monotony of the depositions gave it a resemblance with loess" (Grabau, 1932, p. 577–578).

Ehrenburg (1849) in his interesting work showed the presence of foraminifera in a number of formations of hurricane dust that he studied. Many of these were in the red dust that accompanied the scirocco in Malta on May 15, 1830, and the hurricane of October 17, 1846, in Lione. In Malta Rotali, Spirolokulin and Textulyari, in Genoa Rotali and Textulyari and moreover Nodozariya (?) were found. A single Textulyari was found in the hurricane dust of 1846 near Vienna and Spirolokulin in the dust of 1847 in the Tyrol. In all these cases the quantity of foraminifera was negligible and did not affect the composition of the deposition.

HALOGEN MATERIAL

Aeolian carbonate materials, especially in the tropics, are encountered quite frequently. Analogous halogenous material is relatively rare. Three types of formations are known.

The first type is related to the far-ranging white salt dust storm, e.g. the storm of April, 1955, in the southeastern European part of the USSR. All of April had been dry, a favorable condition of a dust storm. The meteorological situation gave rise to a recurring strong southeasterly wind, often changing to storm.

The first storm started on April 10 over the Aral-Caspian lowland with abundant lakes. The wind speed attained 15–20 m/sec from the easterly and southeasterly directions. A wind speed of 50–60 kmph was observed to a height of 3 km. The air flow transported dust to the Astrakhan region and Kalmytsk ASSR. A dry haze was recorded at all the meteorological stations on April 11 and 12. In the city of Elist the dust appeared at 6 o'clock in the morning of April 11 and reached its maximum at about 1600 hours. It ceased next day, April 12, at 1700 hours. The windward sides of objects and plants were covered with a film of gray ash 0.1 mm thick. Analysis of the film showed that it was composed of 47.4% soluble salt and 52.6% insoluble precipitate. Of the total quantity of salt sulfates constituted 90.6%, chlorides 7.4% and bicarbonates 2%. According to an approximate calculation, each hectare of soil received 25 kg of sodium sulfate.

The storm recurred with much greater strength on April 18–19. On April 18, in the west of Kazakhstan and in the Astrakhan region the strength of the wind attained 15–20 m/sec and on April 19 even 20–25 m/sec, i.e. almost the strength of a hurricane (30 m/sec and more). The mass of dust that had been lifted moved to the northwest and north, to the central and upper Volga. At noon on April 19 the dust reached the city of Gorky, causing haze with a visibility of 1,000 m. In Volgograd and Saratov the haze was thickest on April 22.

Soon after its onset from the southeast, a dense film of dry surface soil covered objects on the ground, plants and animals. It was highly saline. The thickness of the deposit at Zavolzh was 1–2 mm and at places 2–4 mm. Chemical analysis showed that the deposit contained mostly sodium sulfate, sodium chloride, magnesium salts and also silicon and gypsum. White salt storms had been noticed earlier, but the storms of April 18–22, 1955, attained unusual strength and propagated over more than 500,000 km^2.

Saline dust storms have been observed in the western desert region of the USA. On March 21, 1933, (Harrison, 1933) between the Sierra Nevada and the Rocky Mountains, a white dust storm occurred over the dry salt range. It moved east in the form of a white wall 2,700 m in height. It interrupted air traffic and after three days arrived east of the Rocky Mountains in the form of unusually fine white dust (Fett, 1958, p. 20).

Another duststorm started over the Great Salt lake and, moving east, descended on Wyoming State as a saline downpour. The concentration of salt in the downpour was about 3 tons per square mile. Clothes drenched in the downpour, when dried, were covered with a white encrustation. Many windows were covered with an opaque, dense layer of salt.

Similar salty dust storms originate, of course, over the gigantic saline lands of Central Asia, in Iran, Iraq, Rajasthan (India) and in many other desert regions. But in any case they are much less frequent than the dark yellow dust storms.

The geological activity of the white salt storm is limited. It mainly originates in arid regions with a dry, warm climate and in large lakes and lagoons, covered by loose encrustations consisting of different salts. However, the recurring strong storms or hurricanes necessarily come more or less from one direction.

Such conditions rarely combine and therefore give rise to limited geological activity. The effect is interesting, wherever it occurs. It may give a feeling that the arid region with its saline depositions is distributed many hundred and even thousand kilometers to the north, although this actually is not the case.

Aeolian saline depositions are similar to water deposits but can be distinguished easily by two signs: 1) relatively smaller content of salt, distributed equally over a large area; the salt is of mixed composition; 2) absence of layers or lenses of homogeneous salt, e.g. gypsum or rock salt.

Aqueous salt deposits exhibit localized distribution, following the outlines of lakes or lagoons which behave as tanks of salt. The salt content is high and homogeneous in composition.

Layers of salt, containing some salt—gypsum, rock salt, sodium sulfate, etc. are always present.

The second type of halogeneous material, on the contrary, is related to short transportation and is completely analogous to the oolitic carbonate dunes. The well-known gypsum dunes of Alamogordo in New Mexico State belong to this type. It is such a striking and unique phenomenon that it has been declared a sanctuary—a national park. The enormous hills—snow-white dunes of homogeneous gypsum, glittering in the sun—have their own brilliance and dimension.

They are situated in the central part of a wide, flat valley between the desert hills. The bottom of the valley is of Permian formations which contain patches of gypsum. Gypsum, due to erosion, disintegrates into fine crystals of the size of the sands. They are engulfed by the constantly blowing wind and transported to the border of the saline land, where they are retained (Herrick, 1900).

The area occupied by the gypsum dunes is considerable; the length is about 50 km, the width up to 30 km and the total area about 1,500 km^2. The height of the dunes goes up to 30 m; the average height is 15 m.

In the north gypsum dunes are bordered by sandy rocks. The area occupied by them is insignificant.

The gypsum dunes of Alamogordo, after being declared sanctuary, have been described in three popular articles with exhaustive illustrations (Russel, 1935; Belknap, 1957, 1960). The former expresses the opinion that the main source of the gypsum crystals is the encrustations formed over the gypsum brine, occurring on the valley floor to the south and in between the dunes.

The form of the dune corresponds to the general form of the sand dunes of deserts. Often they are hemispherical sandhills (Fig. 229) over the flat dry beds of lakes. At many places they are irregular massifs with uniform slopes

Fig. 229. Gypsum hills over surface of dry hill, Alamogordo, New Mexico (Belknap, 1957, Fig. 22).

and patches of vegetation (Fig. 230). It is surprising that vegetation can be seen growing on pure gypsum.

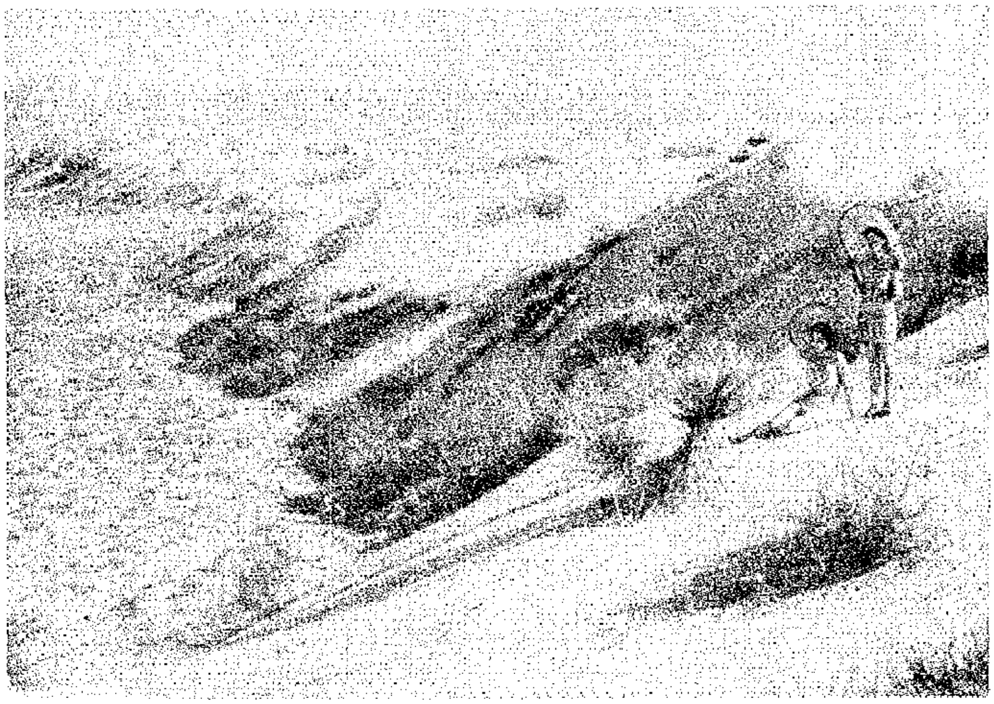

Fig. 230. Gypsum hills with specific plant growth. Alamogordo, New Mexico (Russel, 1935, p. 261).

The purity of this sand is quite interesting. Dust is altogether absent even in violent storms. Only the sands and crystals of gypsum bounce in arcs or simply slide over the surface. Dust storms characterized by quartz sands are absent here.

The quantity of gypsum in the dunes of Alamogordo is enormous but it has not yet been worked out. It is quite remote and its transportation would be costly.

The dazzling, snowwhite dunes are strikingly beautiful against the background of the surrounding dark red and violet mountains. The beauty and the brightness bring 100,000 tourists every year to this sanctuary (Fig. 231).

The third type of transportation of halogenous particles is by wind. This transportation takes place along with sea water. The strong wind, storms and hurricanes over the sea break off the top of the waves, especially the white foamy crests, lift the sea water up and transport it deep into the continents tens, hundreds and even thousand of kilometers away.

In the description of hurricanes, especially of tropical ones, mention has been made of the transportation of sea water inland in such quantities that it accumulates in drops on the windows of houses and destroys vegetation. Such cases are not rare.

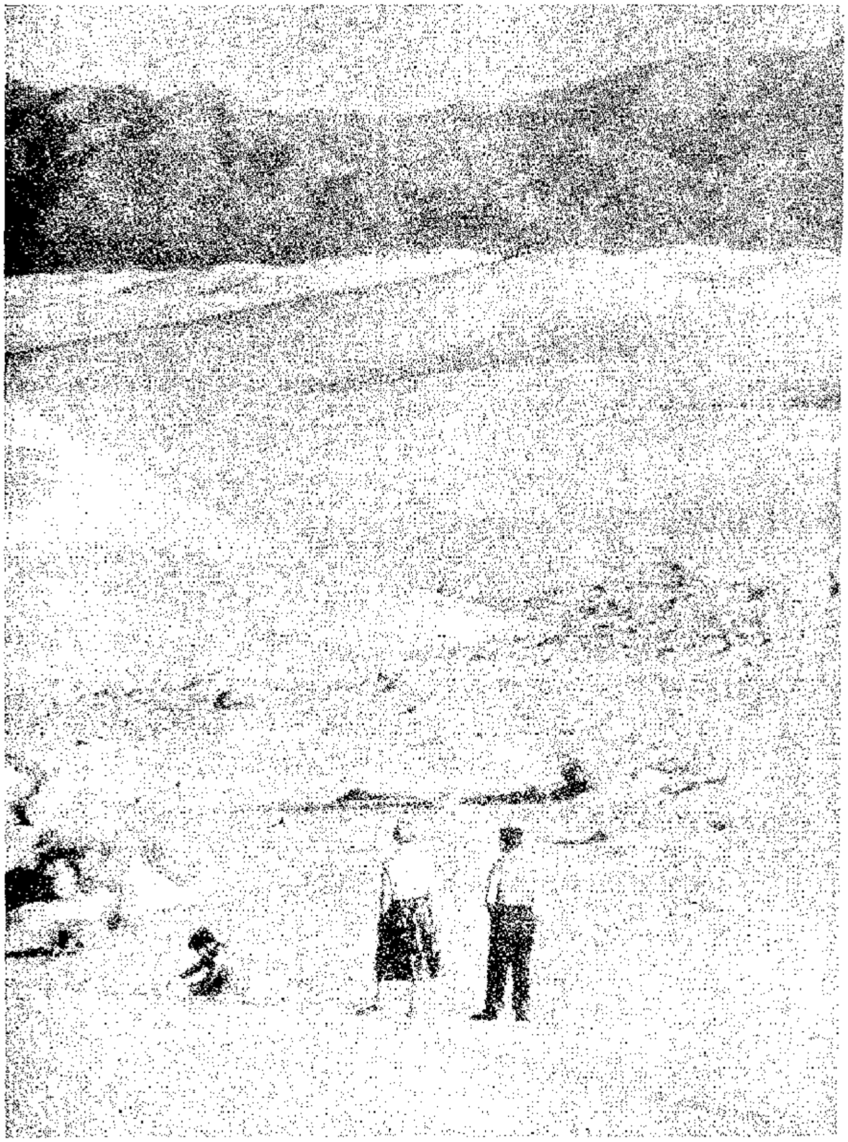

Fig. 231. Gypsum hills against background of hills of Paleozoic formations, Alamogordo, New Mexico (Balknap, 1957).

There are a group of islands called the Pescadores, between Taiwan and the mainland. The 64 islands (of which 21 are inhabited) consist of basalt and coral reefs. Their surface is flat, rocky and low. There are about 100,000 people living on these islands. Every possible place is used for agriculture, though the conditions are quite difficult. Some of the storms, especially the typhoons, irrigate the entire island with sea water, after breaking off the top of the surf. Almost continuous saline rain spoils the crops. The wind is so strong that not a single tree can withstand its force. A few trees grow in pagodas but not above the shielding wall. Each branch protruding above the wall is slowly torn off by the wind as though trimmed by a knife.

The small cultivated plots are surrounded by high, thick stone walls. It is only the walls that protect the plots from the saline drops transported by the storms. Within these shielded zones, groundnut, sweet potatoes, cabbage and other vegetables are grown. "The strong storms regularly affect the plots, the trees and the life of the inhabitants. At times conditions are worsened by the terrible typhoons" (Bristol, 1956).

Figure 232 shows the flat surface of an island with numerous stone walls and the modest plots they shield. The inhabitants are mostly Chinese. The fishing industry is well developed. The island is small, long, narrow and completely exposed to storms and typhoons.

Fig. 232. Pescadores island. Stone walls shield plots from saline splash carried by typhoons (Bristol, 1956).

Marine organisms, mainly macrofauna and microflora, are regularly arried onto the surface of the islands from the sea water. They are so numerous that the recent deposits on the island in fossilized form are taken as marine.

In Japan "the saline wind" or, to be precise, the sea water transported by hurricanes and storms is widely distributed and causes considerable harm. The rice crop in the coastal belt (Fig. 233) suffers worst. Violent storms cause damage to all the crops. The terrible typhoon of September, 1954, destroyed even the trees at places. "Whereas in the city of Akita the foliage of poplars, persimmon and cherry trees largely survived, there were no foliage in the city of Kisakota. The southeasterly wind here has the task of conservation work and it may be added that the splash of sea water transported a considerable mass of sea water to the land" (Okuta Minoru, 1963, p. 169). Even in the village Kamito, 3 km from the sea and situated at a height of 150–200 m, the plants suffered considerable damage. The effect of

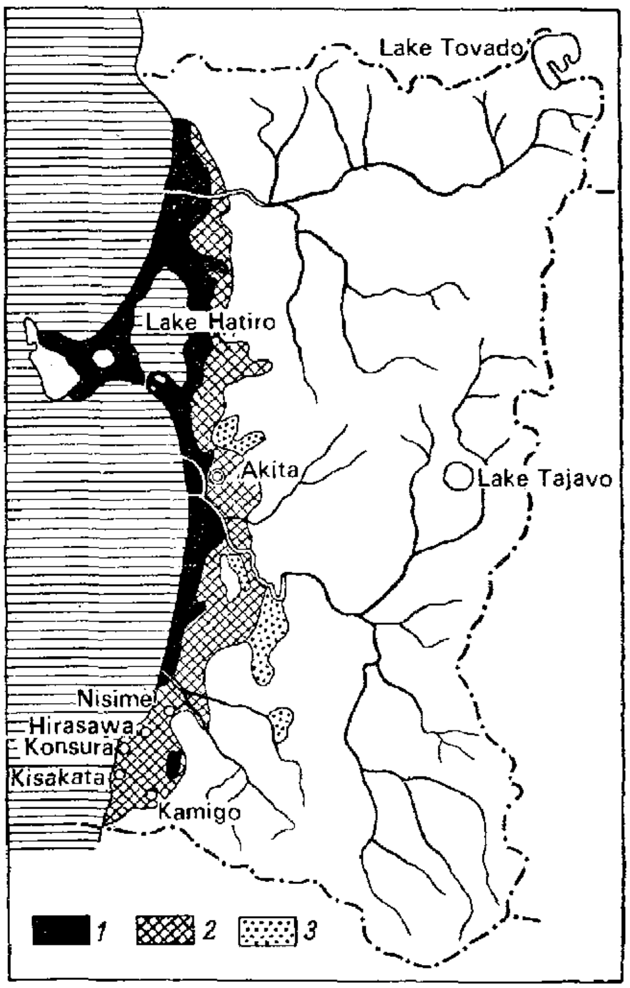

Fig. 233. Loss of vegetation on coast of Japan due to typhoon No. 15 of 1954 (Okuta Minoru, 1963, Fig. 41). *1*—large-scale; *2*—average; *3*—small-scale.

sea water was considerable at a distance of 10–15 km from the sea, in hilly terrain (Fig. 234). There is no doubt that such a mass of sea water, carried inland by a typhoon, contains large quantity of microorganisms. The strength of the wind is so great that the transportation of large shells, even a few centimeters in size, is not ruled out.

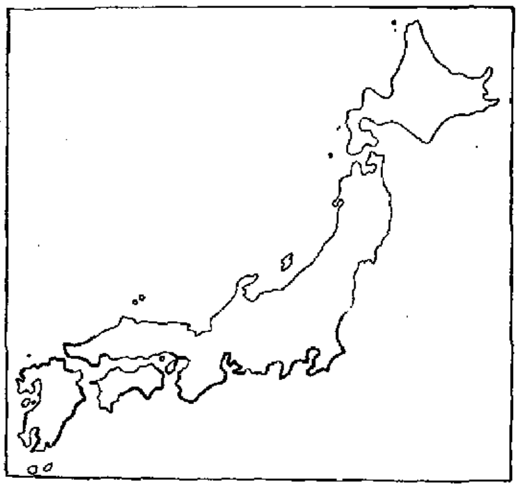

Fig. 234. Loss of rice crops on Japanese coast due to salty wind. Areas affected are shown by thick dark lines (Okuta Minoru, 1963, Fig. 42).

On the west coast of England strong storms carry sea water inland to a distance of 100–120 km and at Bristol to a distance of 160 km.

In the Soviet Union observations on the transportation of sea water were carried out on the south coast of Crimea, in Simeiz. With a wind strength of 10 m/sec and a rough sea of 3–4 points the flow of water splash in the air over the water could be seen with the naked eye. Observations with the help of special films showed that the splash retained its identity to a height of 2.5–3 m and to a distance of 150–200 m from the coast. Farther on or higher up transportation took place in dispersed condition (Dobroklonskii and Vavilov, 1938). It may be added that the coast of Simeiz is steep and shielded by the high walls of Yily.

These data show that the transportation of considerable quantities of sea water by hurricanes and storms to a distance of many tens of kilometers and even 120–150 km is quite common and a widely distributed phenomenon.

The sea water torn from the surface of the sea by the wind transports the microorganisms present on the surface deep inland. The microorganisms are primarily of plankton form, particularly plankton diatoms and foraminifers.

The other widely distributed form of transportation of sea water and salt is in finely-dispersed condition. The salt content of the air is very small and not felt by us. But due to the prolonged and almost continuous transportation of salt it is deposited in such a large quantity in the soil that it enhances the salt content of the ground water. My attention was drawn to this by V.N. Kunin, the great specialist on the hydrogeology of our deserts. He believes that we underestimate and do not understand the phenomenon of the content of salt transported by the wind being high in ground water not only in the deserts, but in many other regions too.

Among Soviet workers the theory of pulverization has been established thoroughly in the works of L.V. Blinov (1947, 1950, 1951). The main sources of the salinity of soil and water, transported by wind along with water and snow, as well as in the form of dust, haze and gases, are in agreement with this theory. Due to the pressure of the wind the salt is pulverized in the soil and water. In his first work L.V. Blinov (1947) gives a bibliography of wind transportation of marine salt and the propagation of salt flux. In 1947–1949 he carried out observations on the wind transportation of sea salt from the Caspian Sea. In his work Blinov (1950) gives many valuable data. In his last work (Blinov, 1951) he gives data on the complete process.

His calculation of the quantity of salt in one cubic meter of air in a wind blowing from the sea to the land is quite interesting and important. The salt content (in finely-dispersed particles) is 0.079 mg/m^3 for a wind with a speed of 6.4 m/sec, 0.223 mg/m^3 at 10.4 m/sec and 0.857 mg/m^3 in a storm wind, i.e. at a speed of 24 m/sec. As such, the figures are not high but for the Caspian Sea this gives a figure of 45,000 tons for 6.4 m/sec, 160,000 tons for 10 m/sec and 700,000 tons for 24 m/sec. These figures are quite substantial. A wind over one kilometer of coastline with a speed of 6.4 m/sec on an average transports 52 tons of salt per day and 19,000 tons per year. According to Eriksson (1958) one kilometer of coastline witnesses the transport of 3,000 tons of salt per year. The figures are comparable.

According to L.V. Blinov's calculations (1951, p. 178–179), the transportation of salt by the wind from the Caspian Sea constitutes about 30% of salt.

The following year L.S. Borishanskii and E.N. Teverovskii (1952) repeated L.V. Blinov's observations and found that due to an error in the formula he used the results were ten times too high. According to their data, with a speed of 6 m/sec, the 1,200 km long coast of the North Caspian Sea is crossed by 2,460 tons of salt per day, 1.3% of the water carried. In L.V. Blinov's case these figures were of the order of 62,400 tons and 30%.

It may be added that the error in L.V. Blinov's computation, if such it is, has no significance. The calculations by L.V. Blinov, L.S. Borishanskii and E.N. Toverovsky and Eriksson are provisionally in agreement. They are correct for a wind speed of 6 m/sec but ignore the action of hurricanes and storms with speeds of 20–30 m/sec and more, when the quantity of transported salt increases tens and even hundreds of times. During quiet weather the transportation of salt completely ceases. A correct calculation can be made only when all the changes of wind speed have been recorded. Now it can only be said that the annual transportation of salt is a few thousand tons for each kilometer of coast. This is a significant figure.

L.V. Blinov (1951, p. 179 and 195) gives the following formula for his calculations: "Seventy percent of the earth's surface is covered by saline sea water, the particles of which are continuously carried away by the wind to the land. We may consider the continuous effect of this transportation as the source of continental salt deposits.

"After considering the ocean as the main source of continental salt deposits, the author of the paper does not and cannot rule out many other phenomena related to the wind transportation of sea salt and its importance in the deposition of highly mobile salts in the soil and ground water".

These postulations are undoubtedly correct for a zone a few hundred kilometers wide adjoining the shores of oceans and seas. They support the observations of Eriksson (1959, 1960) given below. In regions well within land wind transportation of salt from the sea sharply decreases or is even absent. But transportation of salt occurs in a very strong wind from the surface of inland lakes, which are often highly saline, and also from the vast surrounding surface of saline land.

L.V. Blinov's observations and conclusions are very broad and they supplement the work of Eriksson. It is interesting that the latter arrived at the same conclusion independent of the work of L.V. Blinov, which quite likely was unknown to him.

Eriksson (1955) came to the conclusion that the chloride content in the river water and lakes of the Scandinavian peninsula and of the eastern States of North America is due to the transportation of sea salt by wind. He prepared a map of isochlores and it can be clearly seen in the map how the chloride content decreases with the distance from the seacoast.

He believes that the sea salt from which the chlorides arise is found in the air in the form of small hygroscopic particles known as "centers or nucleii of condensation".

Later on Eriksson (1959, 1960) published an authoritative work on the annual circulation of chlorides and sulfur in Nature and its significance for meteorology, geochemistry and soil formation. The work has a good bibliography. In this work he puts forward his views in respect of many parts of the world. He shows that the significant worldwide transportation of sea salt is entirely by wind.

Eriksson's postulation that the enhancement of the chloride content in the rivers north of Tyan Shan, established by P.S. Denisov (1964), is due to the transportation of salt by the wind from the Caspian and even Black Sea is quite interesting. There is no doubt about the transportation of salts to the rivers Tyan Shan by the wind, but the source is the saline land of Aral Sea, the lowlands of the River Chu and the coast of Balkhash. This supports the direction of the main wind, blowing not from the west but from the north.

The large surface of saline land and the shores should be added to the surface of the sea as sources of salt in the atmosphere. The definite significance of this in the formation of white salt dust storms has been described earlier.

The particles of salt present in the air do not concentrate only in the rivers and lakes. They have definite significance in soil formation. Eriksson (1960) mentions that the salt present in the atmosphere was never seriously considered as a factor influencing the composition of the soil, though there are papers that mention the possibility. A study of the composition of peats and plants of neighboring regions of western Sweden showed the effect of the proximity of the sea. The effect of the sea salt on the composition of the soil was similarly established in the coastal regions of New Zealand and Australia.

The effect of the salt present in the atmosphere on the formation of soil is an important and interesting problem which is only now being studied. The average salt content of the air is negligible, but the scale of the atmospheric vortex is so great that negligible amounts, when added up, yield a colossal total. One must remember that the air is always moving. Due to this, the falling salts are fairly quickly replaced by new salts. The quantity of salt in the air is limited by the quantity of salt in all the seas, but this is boundless.

The transportation of sea salt by the normal wind is negligible. Hurricanes and storms with their vortex motion and strong wind speed break off the waves and lift the splash high up into the clouds and then the clouds carry the salt thousands of kilometers. Woodcock (1950) calculated that the tropical hurricanes in the Atlantic Ocean transport 80 times more sea water than the normal wind. He mentions that in individual cases the quantity of the sea water in the air is still larger.

The quantity of water transported by hurricanes is enormous. In Jamaica, as already mentioned (page 220), the rainfall had a total weight of 27 billion tons. The eastern States of North America had a total rainfall of 22.4 billion tons in 1940. According to Woodcock (1950) this is exceeded 100 times or more during hurricanes. Part of the salt is returned to the sea by rivers but a considerable part of it remains in the soil.

Lodge (1955), studying the content of sea water particles during hurricanes over Puerto Rico, came to the conclusion that these particles are sufficient to cause heavy rain. According to him, a similar quantity of sea water is retained in the movement of hurricanes deep into the continents. Lodge carried out aerial observations as well.

Eriksson (1958) gives interesting and important figures on the significance of sea salt transported by the wind in the saline regime of dry, arid regions. Each year, over the shores of the Gulf of Mexico, 3,000 tons of salt are transported for each kilometer of the coast. If the length of the coast is 2,400 km this is 7,200,000 tons of salt every year. Correspondingly, each hectare in the dry regions of Mexico annually receives about 2 kg of salt.

The wide belt, situated immediately to the south of the Sahara is a region of accumulation of sea salt, carried by the wind blowing from the Gulf of Guinea. About 30 kg of salt per hectare per year is deposited with the rain. In the drier regions to the north the quantity of deposition decreases and the quantity of salt decreases to 3 kg per hectare. This is very close to the quantity of salt in Mexico.

In the Kalahari desert, at places near the coast, the quantity of salt is 80 kg per hectare.

In the northwestern Indian peninsula, to the east of the lower course of the Indus, the wide dry region of Rajputana is situated. There is a valley with an area of 5,500 km^2 which contains a salt reserve of 55 million tons (Lake Sambar). The valley is at a height of 300 m and was never connected to the sea and the hills surrounding it are devoid of salt layers. Even 50 years ago, Holland and Christie (1909) stated that the salt deposits of Rajputana have been transported by the monsoons.

Eriksson (1958) supports the point of view of Holland and Christie and furnishes interesting additional data. In three months the monsoon transports deep inside the continent not less than 600,000 tons of salt. This figure is considerably greater than that mentioned earlier.

In Western Australia it has been established that the transportation of salt inside the continent has an important role. Near the seacoast the salt content (chlorides) in the depositions are 100–150 kg and more per hectare. Farther inland this drops to 10–15 kg per hectare but these are also significant figures.

In the Near East the situation is quite interesting. The salts in the Dead Sea have been transported partly by the wind. The same is true of the enormous saline lands in Iran and Iraq. Eriksson believes that even the saline land in the Gobi desert may partly be of aeolian origin.

Study of the transportation of salt by the wind in our dry regions has been conducted by Soviet scientists, specially V.N. Kunin.

Eriksson considers the transportation of salt only in the dissolved condition in the clouds. White dust storms are not mentioned in his work. He showed that the transportation of salt by the wind occurs not only from water, but also in dry condition, in the form of dust. This again underlines the important role of aeolian salts.

The study of aeolian salts has only just started. From the work so far done we already know that halogenous aeolian deposits are not that rare and there is no doubt as to their participation in the formation of a number of saline deposits.

For geochemists this has vast significance. The aeolian salts participate in the geochemical processes everywhere, wherever there is wind. The study of this interaction, the determination of its pattern and size are important problems for geochemists, geologists and soil scientists.

The work carried out at the Central Geophysical Observatory in Leningrad under the guidance of E.S. Selezneva is of great help. The chemical composition of the atmospheric deposits in the European territory of the USSR has been collectively worked out in great detail by V.M. Drozdov, O.P. Petrenchuk, E.S. Selezneva and P.F. Svistov (1964). The Chapter "Geographical change in the composition of atmospheric deposits and intake of matter in unit area", written by E.S. Selezneva is especially important. This chapter contains numerous sketch maps. The distribution of the sulfate ions does not depend on the proximity of the sea but to a great extent is determined by the features of the land. Comparing this distribution map with the map of the annual sulfur input into the soil, one can see that it reaches a maximum in the eastern Ukraine, to the south, in the regions of maximum incidence of dust storms. The total quantity of annual input of sulfur into the soil reaches 20 kg per hectare and even somewhat more. In the remaining areas the isolines of sulfur intake extend mainly in the direction of movement of the cyclones.

A similar situation is observed in the distribution of hydrocarbons and in the intake of calcium by the soil. In these maps the isolines extend to the northeast, independent of the sea, and coincide to a great extent with the region of maximum dust storms. The quantity of calcium reaching the soil is still greater. In the south it is more than 30 kg per hectare per year.

The distribution changes for chloride ions. As has repeatedly been mentioned, it depends on the proximity of the sea. In the maps it can be seen that the maximum content is attained on the shores of the northern sea and on the shores of the Black and Azov seas. The quantity of annual chloride intake by the soil here goes up to 10–15 kg per hectare.

It is interesting that the distribution of sodium differs from the distribution of chloride. If the average concentration of the cations of sodium is distributed in the same way as that of the ions of chlorides, the annual intake in the soil sharply differs. The maximum intake is reached in the central zone of the European territory of the USSR.

The cations of potassium and magnesium are encountered in smaller concentrations. The isolines are again northeasterly in the direction of the cyclones. Potassium is more in the south (0.6–0.9 mg/liter), less in the north (0.2–0.4). Magnesium, like sodium, is in large concentration in the depositions of the central zone of the European part of the USSR—0.3–0.4 mg/liter and at places more in the south. It is less, 0.1–0.2 mg/liter, in the north.

A similar map for the entire territory of the USSR has been prepared by E.S. Selezneva.

Another work by E.S. Selezneva—"Atmospheric aerosol" (1966)—deserves attention. It is a continuation of the work of 1964. Unfortunately very little is said about the composition of the nucleii of condensation. The main focus is on their quantity and distribution. The quantity of matter in the nucleii of condensation is about 107 tons. In the troposphere the quantity of the core of continental deposits is 60%, of marine deposits 35% and of industrial deposits not more than 5%. Near the sea the quantity of chloride is 80% and of sulfates and hydrocarbons 20%. In continental regions it is the reverse—20% and 80% respectively.

SILICEOUS MATERIAL

Siliceous material is not known and quite likely is altogether absent. It may be formed due to the erosion of siliceous rocks, e.g. jasper, or due to the concentration of siliceous skeletal formations. Due to their solid nature and density siliceous materials are not eroded and do not produce the fine products of destruction. Loose rocks of the diatomite types are encountered in large quantities but this cannot give rise to any significant quantity of fine materials for transportation (Cayeux, 1929).

Skeletal formations of living organisms are encountered in large quantities. There are many diatoms and considerably less siliceous sponge. It is possible that in rare cases diatoms get mixed with the aeolian depositions in quantities sufficient for silicification, e.g. dust transported by the Harmatan. Such depositions have not been mentioned in the literature.

Hurricanes and storms transport microscopic skeletal formations of diatoms and needles of siliceous sponge to a great distance, up to 2,000–3,000 km. Ehrenburg (1849) noticed the presence of freshwater diatoms on the sails and decks of ships in the Atlantic Ocean, at a distance of many hundred kilometers from Africa. Such cases do not bring about any error in determining the condition of the formations of marine deposits. There will be sufficient marine fauna of other varieties in them.

Each picture is obtained in the reverse situation where the marine organisms are carried deep inland and retained in the continental deposits generally devoid of other organic remnants. Such continental deposits will be treated as marine, and thus major paleogeographic errors can occur. There are a number of examples where such mistakes have been made. Therefore one marine diatom or needle of sponge cannot be the basis for the establishment of the growth of marine deposits, especially if they are encountered in the layers of possible continental origin.

Generally the aeolian siliceous skeletal formations are mixed with the normal depositions in small quantities and do not make the formations by themselves. There are enormous regions on the surface of the earth's crust where the transportation of terrigenous material in water is actually absent. Such regions are the wide spaces in the oceans, far from the coast. In 1932, Leucks (1932) suggested that an important role is taken by the material transported by the wind in the formation of deep-water red clay. Similarly it may be said that diatoms transported by the wind play an important part in the formation of deep-water diatomic clay.

One region where the transportation of diatoms along with dust occurs in large quantities is clearly seen in the wide dry belt between the Sahara and

Nigeria. In winter, during the dry season, a very strong, dry, dusty wind, often approaching storm strength, blows in this region. This wind is known as the harmatan and blows toward the coast of the Atlantic Ocean, in the region of the islands of Hope and the northern shore of the Gulf of Guinea. Its study (Danckelmann, 1913) showed that the dust it transports has a very high content of diatoms, often up to 95%. This is because the harmatan, starting from the Sahara, blows over the wide belt that it covers in Nigeria carrying an enormous quantity of diatoms. These regions of semidesert and flooded depositions are easily eroded by the harmatan. It is quite likely that the diatoms, often observed in the trade wind dust west of the African coast and studied by Ehrenburg (1849) are transported by the harmatan.

Falling in the Atlantic ring of hurricanes and storms, the diatoms of Nigeria are first carried to the West Indies islands, then to Central America, Mexico and the United States. Some hurricanes even transport them to southern Europe.

The regions of the surface of the land where concentrations of aeolian dust and siliceous skeletal formations of considerable size occur are quite peculiar at places. They are frozen lands, primarily Antarctica and Greenland. The aeolian dust is scattered on the gigantic mass of ice but there is no doubt about the significant mixture of marine material in the ice mass.

At times a periodic concentration of aeolian dust occurs in the regions of winter snow cover. In winter, when the earth is frozen and covered by snow, the accumulation of aquarian terrigenous material ceases but the accumulation of dust goes on continuously over the surface of the snow.

The dust accumulates on the ice covering lakes. Therefore its participation in the formation of the clay belt especially of clay components, may be considerable.

Dust with numerous diatoms from the Sahara is transported not only to the west. The hurricane-force dust wind (khamsin, scirocco) originating in the eastern Sahara and in the region of Lake Chad, blows from south to north. It crosses the Mediterranean Sea and carries dust into south and even central Europe. Generally this dust is red with a considerable content of diatoms and other siliceous organisms. It has been studied and described in detail by Ehrenburg (1849). It is very rarely that a hurricane wind with dust goes to the northeast and reaches the Caucasus and other southern regions of the European part of the USSR. One such storm, which occurred not long ago in 1962, is described by A.D. Zamorsk (1964) (see page 158). The dust it carried was of yellow and red color. It was not studied under the microscope and the quantity of diatoms in it is not known.

In this sense a storm that occurred 100 years ago, in 1849, was exceptionally interesting. The dust was transported from the south in the form of a white, dry cloud, reducing the sunshine considerably. The white dust, at places resembling hoarfrost, fell over an enormous area, the length of which was 1,500 verst and width 400–500 verst. The dust covered the leaves of trees, grass and the surfaces of various objects. The thickness of the layer was equal to the thickness of three sheets of paper. In external appearance it was angular and resembled finely crushed emery. With water it became sticky and colored. Its color changed but in the range of gray and white. It consisted of inorganic matter, mainly clay and limestone. The salt content was very small (Lapshin, 1849).

Samples of this dust, collected in Poltav province, were studied by Ye. I. Eichwald (1849). The dust was white and gray and, most important of all, was siliceous. Examination under the microscope showed that it consisted mainly of broken or whole diatoms. In this, it was similar to the dust brought by the harmatan. Eichwald was surprised at the total absence of flower pollens. He showed that the diatoms were close to the diatoms described by Ehrenburg (1849) three years earlier. Eichwald concluded that the dust was transported from the South Russian steppe. This, of course, was incorrect; Ehrenburg on the basis of the duration of transportation of the dust, seems to be more correct. This confirms the absence of flower dust, a must in April for the southern Russian steppe and the very form of transportation—as a dry cloud. For the dust Ehrenburg studied African origin has been established. It is quite probable that the region of origin of the south Russian siliceous diatomic dust was the same as that of the colored diatomic dust carried by the harmatan in the Gulf of Guinea.

"Junkovsky writes: On April 27, the sunshine was bright, the sky was clear and devoid of even small clouds and there was no wind. Before midday there was no wind and the temperature was 14°. The air suddenly became very thick so that after three hours the sky changed from a bright gray color to a leaden color and the sunshine lost its brightness. The thick air became dull white all around. All the objects were covered by the cloud and nothing was visible at a distance of 1/4 verst.

"This continued next day. In the morning, it was noticed that objects like lids, trees, grass, etc. were covered with a special variety of gray dust which dropped with a slight impact. People returning from the fields had their faces and feet thickly covered with dust. Next day there was rain and the dust disappeared.

"Under the microscope it could be seen that this dust consisted of quartz or fine crushed siliceous shells of aquarian animals, often found in fresh and especially in stagnant water. Nowhere were crushed angular quartz grains or big-size sand noticed. Instead, there were only flat, more or less long, distinct symmetrical pieces, showing that it was derived from the crushed siliceous shells of aquarian animals" (Eichwald, 1849, p. 274).

Such was the original statement made 100 years ago in Pushkin's time, regarding the fall of dust in Poltav province in 1849 and on its composition.

Eichwald was a contemporary of Ehrenburg's and knew his work. This further underlines the sharp difference between the gray diatomic dust and the red quartz dust but there is no doubt about their origin in the Sahara.

Similarly, there is no doubt about the transportation of the diatomic dust to great heights, independent of the calm wind at ground level. All these phenomena give rise to a typical haze. The haze, though caused by dust storms, sharply differs from them.

ORGANIC MATERIAL

Often the vortex motion of air attains a strength sufficient to lift an enormous quantity of organic material into the air and form a "black storm", "black hurricanes", etc. The black, gloomy wall of air, darkening everything around, moves forward inexorably. Everywhere there is a dark downpour. Such dark storms have less impact on people than the terrible red, "blood" storms.

There are two types of black storm. The first is related to the erosion of black soil. The black particles filling the air are dry. The second is the suction of material of marshy peat into the cloud. The moist remnants of plants drop from the cloud along with the rain, giving everything dark coloration.

The black soil storms cause great damage and therefore have been studied in great detail. Lately M.M. Shukov (1964) has given a detailed review of the dark storm of the spring of 1960. It should be noted that each storm has a limited area of distribution, but the dimensions of these areas are considerable. It was more than 1 million square kilometers (Fig. 49) for the April storm of 1960. In this area the speed of the wind was more than 15 m/sec and at places 30 m/sec or more, i.e. the speed of hurricanes. The distribution of wind strength was inhomogeneous and irregular. At places vortices occurred, intensifying the deflation of the soil.

It is due to this that the deflation of the soil is inhomogeneous. In a dry spring, in the absence of ascent, the deflation of exposed, dry, loose soil attains enormous magnitude. Its depth reaches 5–12 cm and even 25 cm at places. According to M.M. Zhukov (1964) about 20–25 cubic kilometers of black soil are transported.

The pattern and distance of transportation are quite interesting. "The large particles, up to 2 mm in diameter, are shifted along the ground a relatively short distance from the place of erosion and accumulate at local barriers in the form of dunes and shafts. The fine materials, from 0.25 to 0.06 mm, are transferred a great distance, but only in the case of dust storms. The fine particles can be transported to great distances" (Zhukov, 1964, p. 16). A turbulent vortex air flow lifted black soil to a height of 1,500–2,000 m in Krasnodar and 2,400 m near Odessa, as observed aerially. In other cases, the dust cloud reached a height of 3–4 km (Kravchenko, 1959). Such dust clouds are transported thousands of kilometers, to Rumania, Poland and even Scandinavia.

Attention is drawn to the hills and ridges formed by the coarse-grained material. From one storm they can reach 4–5 m in height. Actually they are typical dunes, analogous to carbonate dunes, but are constituted of material rich in organic matter. This matter is not retained in fossilized form and the black soil dunes will have the form of the usual medium-grained inclined sand beds.

A storm of the second type occurred on April 14, 1849, in southeastern Ireland. It has been described in the monograph by Ehrenburg (1849). During a violent storm with continuous lightning but no thunder there was a black cloud which made everything dark and unleashed heavy black rain, resembling ink. Ehrenburg called this "ink rain", "silt rain". Analysis showed that the black color was due to a mixture of humus and black plant particles. Volcanic material was absent. Then he noticed many microorganisms of plants and animals of siliceous and calcareous types. Ehrenburg (1849, p. 420) was struck by the fact that rainwater that stood for more than two months contained many live microorganisms. Among them he found Monas viridis and Spirillum undula. The former was in such a large quantity that it gave a green tinge to the water. The presence of shells of foraminifera, rotali and textulyari and numerous fragments thereof is quite interesting.

Ehrenburg (1849, p. 420–421) considers the ink rain of Ireland as analogous to the hurricane dust of red rain. He compares it with the black rain observed in Canada in 1814 and the black hurricane of June 6, 1842, in Kiev.

The origin of the "ink" rain in Ireland remains a paradox. Possibly it was formed due to the lifting of the upper surface of a peat bog, such as are abundant in Ireland, into the cloud.

A peculiar variety of organic dust and rain is exhibited by aeolian dust and rain. They are formed during major droughts accompanied by large-scale forest and peat fires. During these fires, especially the latter, an enormous amount of ash is formed. The storms, not infrequent during droughts, engulf the ashes, lift them into the cloud and transport them hundreds and thousands of kilometers. The ash falls either in the form of dark organic dust or in the form of "ink" rain.

Droughts occur quite frequently. The forest and peat fires accompanying them are generally of colossal dimensions. The ash is carried a great distance and in large quantities. A fine layer of carbon is formed where it settles and such layers are likely to be encountered quite frequently.

RED DUST AND ITS MICROORGANISMS

Work done in the middle of the last century is very much of the past. We have either forgotten it or remember it as a source of science. Actually some of it is such important work that it is still referred to for help and verification.

The work of Murchison and Verneil, *Geology of Russia* in two volumes, the monograph by Kaizerling *Journey to the Pechora Land,* the small but important work by Leopold Von Buch, the monograph by Ehrenburg *Trade*

Wind Dust and Blood Rain, belong to this category.

The monograph by Ehrenburg (1849) was published in 1849 in the 'Proceedings of the Berlin Academy of Sciences'. It runs to 192 pages. The text is accompanied by six tables of small drawings showing hundreds of microorganisms found in hurricane dusts. The work is thorough, authoritative and the result of many years of work. Its importance is all the greater because Ehrenburg was a specialist in the microscopic study of microorganisms. The work was so original and detailed that it is still of considerable importance.

Ehrenburg collected samples of dust from 27 hurricanes and storms. Six of these samples were collected from ships plying the Atlantic Ocean at a distance of a few hundred kilometers from the west coast of Africa. Present-day investigators associate this dust with hurricanes and storms moving from the Sahara into the Atlantic Ocean. Ehrenburg lacking knowledge of the types and characteristics of the Sahara, assumed the dust to be due to transportation from South America. The dust of seven hurricanes, which were referred to as "scirocco", was collected in Lione (especially with various organisms), south Italy (Genoa, Udine), in Calabria and Malta. Five samples of dust were collected after the strong foehn in 1843, in the Tyrol and Salzburg. Dust from the winter dust hurricane of 1848 was collected in Silesia, including Vrotslav (Breslavi) and Austria, including Vienna. Lastly, one sample was from black rain which occurred over southeastern Ireland in 1849.

The composition of the organisms in the dust was divided into 315 components. Of these, 137 were related to *Polygastrica*, 89 to *Phytolitharia*, 19 to *Polythalamia* (*Foraminifera*), 52 to various remnants of plants, generally crushed, 7 to remnants of insects and 11 consisted of inorganic material, microscopic crystals, pieces of pumice stone and quartz grains.

Numerous, diverse *Polygastrica* and *Phytolitharia* exhibit siliceous skeletal formations. Among them marine and freshwater forms are encountered. The marine foraminifera, though relatively few in number, are quite similar. The inflated multichambered rotaliids and textulariids are encountered quite frequently. As has already been mentioned, they participate in the formation of carbonate dunes on the shores of the Indian Ocean and in other regions. The crushed remnants of plants, their fiber, seeds, spores and pollen are encountered quite frequently, but in small quantities. Only in the black rain of 1849 in Ireland, did they form a major part of the precipitation.

The data on the so-called trade wind dust, transported by the wind from Africa to the center of the Atlantic Ocean, where it is distributed over most of the eastern part (Fig. 237), are quite interesting. Here it is mixed with marine deposits over an enormous area, forming marine aeolian deposits. The dust is so voluminous and transported so frequently that for a definite period of the year the air becomes quite dark. Therefore ancient Greeks and

Romans referred to this part of the ocean as the "dark sea" (Mare tenebrum). The Arabs referred to it as the "sea of darkness".

The majority of the samples of trade wind dust were collected by Charles Darwin. Microscopic study, magnifying it 300 times, showed that the main mass of dust consisted of angular grains of quartz, covered with iron encrustations of various tinges of red, yellow and gray color and red clayey mass. They imparted a red color to the dust. Among these, the gray siliceous skeletal formations of diatoms and other organisms were dispersed. In one probe the relatively rare *Textulariid Foraminifera* and its fragments were encountered. Ehrenburg determined a total of 67 varieties. In all six probes the composition was almost the same. Thus he concluded that all the improbable (transported) mass of trade wind dust has one source.

A second group of samples was collected at different points in southern Europe—Lyon, Genoa, Udine, Calabria and Malta. All the samples were taken from the southern foothills of the Alps. They had been transported by the southern hurricanes and storms generally known as Scirocco. At all these points the scirocco dust was also almost the same and quite close to the trade wind dust.

On October 17, 1846, over Lyon, a strong hurricane moved in from the south, accompanied by blood-red rain and a terrible cloud filled with red dust. The dust consisted of silica, calcium carbonate and iron oxide. It showed very fine red grains of quartz and yellowish-red clay particles under the microscope. Among these, skeletal formations of 73 types were distributed: *Polygastrica* 39, *Phytolitharia* 25, *Polythalamia* (*Foraminifera*) 3, crushed particles of plants 5, remnants of insects 1. Among these only 5–8 were marine, particularly *Rotalia, Textularia* and *Nodosaria* (?). The rest were continental freshwater forms. One of them, the diatoms *Eunotia,* was alive. All these 73 forms were European and most of them were either African or Asian. Two forms were of South American origin. Fifty-one forms were from trade wind dust and Scirocco dust of Malta and Genoa.

On May 16, 1846, in Sicily and Genoa, a terrible hurricane-force scirocco struck. It caused large-scale destruction and loss of life and was accompanied by red-yellow dust rain. Examination showed that the coloration was due to iron oxide. Of the total mass, 15 to 30% was organic. The rest was fine grains of quartz, covered with iron encrustations and a yellowish clayey mass.

Chemical analysis gave the following result (percent): siliceous soil 37.13; clayey soil 16.74; iron oxide 7.65; manganese oxide 3.44; calcium carbonate 9.59; clay 1.80; potassium 2.97; natron 1.90; copper oxide 0.25. The calcium carbonate was present due to the shells of foraminifera.

The 46 definite forms were: *Polygastrica* 22, *Phytolitharia* 21, soft parts of plants 3. The forms from other localities were 35. Freshwater forms predominated but some forms were undoubtedly marine. The latter showed the passage of the storm over the seacoast, obviously of Africa.

On May 15, 1830, in Malta, during a strong southeasterly wind (sci-rocco), the air was saturated with red-yellow dust. Samples collected from the sails of ships standing off Guinea island showed the following results under the microscope: siliceous *Polygastrica* 15, siliceous *Phytolitharia* 21, calcareous *Polythalamia* (foraminifera) 7. The latter showed *Rotali, Textularia* and *Spiroloculina.* These could have increased in the air due to the hurricanes off the coast of Africa, as they were found on the sails of the ships standing off the coast of Malta (Fig. 235).

The red Scirocco dust fell not only to the south of the Alps but also over and even to the north of them. On March 31, 1847, the dust fell over the Alps in the form of red snow, and in the Tyrol over a considerable area. The study of samples carried out by Ehrenburg (1849) showed that the composition was similar to that of Scirocco dust. Among the quartz particles and red clay mass, numerous organic remnants, primarily of freshwater organisms, were also found. As usual *Polygastrica* (22) and *Phytolitharia* (28) predominated. There were quite a variety of plant particles (13). There were only two foraminifera (*Miliola*? and *Spiroloculina*?) and one bit of an insect.

The chemical composition of Tyrol dust showed predominance of red sand from the Sahara. Ehrenburg, however, rules out the possibility of a genetic relationship, mainly on the basis of the composition of the microorganisms. The microorganisms of the dust were primarily of freshwater origin. These are absent from the sands of the Sahara. This objection merits attention but it cannot be conclusive. Today there are no freshwater lakes in the Sahara but the quantity and position of the ruins of Roman cities and their irrigation systems show that even in recent times the irrigation of the Sahara, at least in the border zone, was distinctly different. What is a desert today was an irrigated area in the recent past. Erosion now gives rise to a large amount of freshwater forms.

The last group of samples of hurricane dust was from regions situated beyond the Alps, from lower Austria and Silesia. On January 30, 1848, some time after the lunch hour, a horrifying gray cloud appeared to the south of Leibniz. It quickly developed and by evening had changed to a gigantic, grayish-red, slowly moving wall. During the night, terrible hurricane-force winds struck and continued all day on January 31. The hurricane was accompanied by red snow. The direction of the hurricane, while moving over the region of Breslavlya (Wroclaw) was toward the southeast and Austria. Red snow fell in Vienna but the hurricane had already weakened. The quantity of dust giving the red color to the snow was considerable.

The quantity of organisms present in the normal reddish-yellow sandy clay mass was considerable. The usual freshwater siliceous skeletal plant formations (diatoms) predominated. Foraminifera and other marine forms were present but in small quantities (*Textularia*). In spite of the great distance from the Mediterranean Sea and its shores, the composition of organic remnants was almost the same as that in Malta, Genoa, Lyon, Tyrol and, surprisingly, that of the Atlantic Ocean.

Tropical hurricanes originate in the Sahara. While passing over the shores of the Mediterranean Sea or the Atlantic Ocean they suck up an enormous mass of sand and clay material and the microorganisms present in it. The vortex motion continues during the passage over the Mediterranean Sea and ceases over its northern shore, the Alps and southern France. Individual hurricanes cross the Alps and propagate over Lower Austria, Silesia and Bohemia. Irrespective of the place where the dust falls it retains its character along with the organic matter, as has been shown brilliantly by Ehrenburg.

The enormous distribution of similar deposition and similar organic content has great significance for correlating the geological sections. Unfortunately, the formations of layers of negligible thickness are quickly washed away and to locate them in the sections is quite difficult. This is yet to be achieved.

In addition to the description of hurricane dust and its organic content, Ehrenburg carried out a considerable amount of work on the selection of all the well-known cases of fall of hurricane dust in Europe, Asia and Africa for the period starting from the 16th century till his own era. By and large, his data are quite interesting. The first description of "blood" rain accompanying a strong storm is associated with the migration of the Jews from Egypt. Two descriptions are given in Homer's *Iliad*. Numerous descriptions of hurricanes and "blood" rain are given by the creative Roman writers starting from 461 B.C. to the present century. Ehrenburg gives 54 such descriptions relating to the different regions of Italy.

Such, rather more factual, descriptions have been frequently repeated in the first thousand years of the present era. Descriptions such as of enormous black birds, covering the entire sky and carrying burning coal in their beaks, and rivers full of blood advancing toward the banks have been written. Blood-covered bread and other food. Enormous crosses drawn in blood appeared on clothes. The localities where such interesting phenomena occurred are southern England, La-Mansh, south France, Italy, Albania, Constantinople and Syria. The first record of "red" snowfall is from the Tyrol in 869 A.D. The first information on red dust was in Iran: Kazvin, Kufa on the Euphrates, Baghdad and Armenia. In 1120, Liege was struck by a catastrophic hurricane associated with earthquake, "blood" rain and dust.

The first description of the Sea of Darkness to the west of North Africa was given in 1160.

The 16th century is interesting in that events like hurricanes with thunder and "blood" rain were recorded relatively far to the north, e.g. in Britanny, Holland, South Germany, Westphalia, the Dunai valley, Saxonia, Thuringia, Leipzig, Tri and Pomerania. In 1572, in Toruni, stones "weighing up to 10 pounds" dropped from the clouds during a storm with "blood" rain. This is the only case of the fall of such big stones from the clouds. It is probable

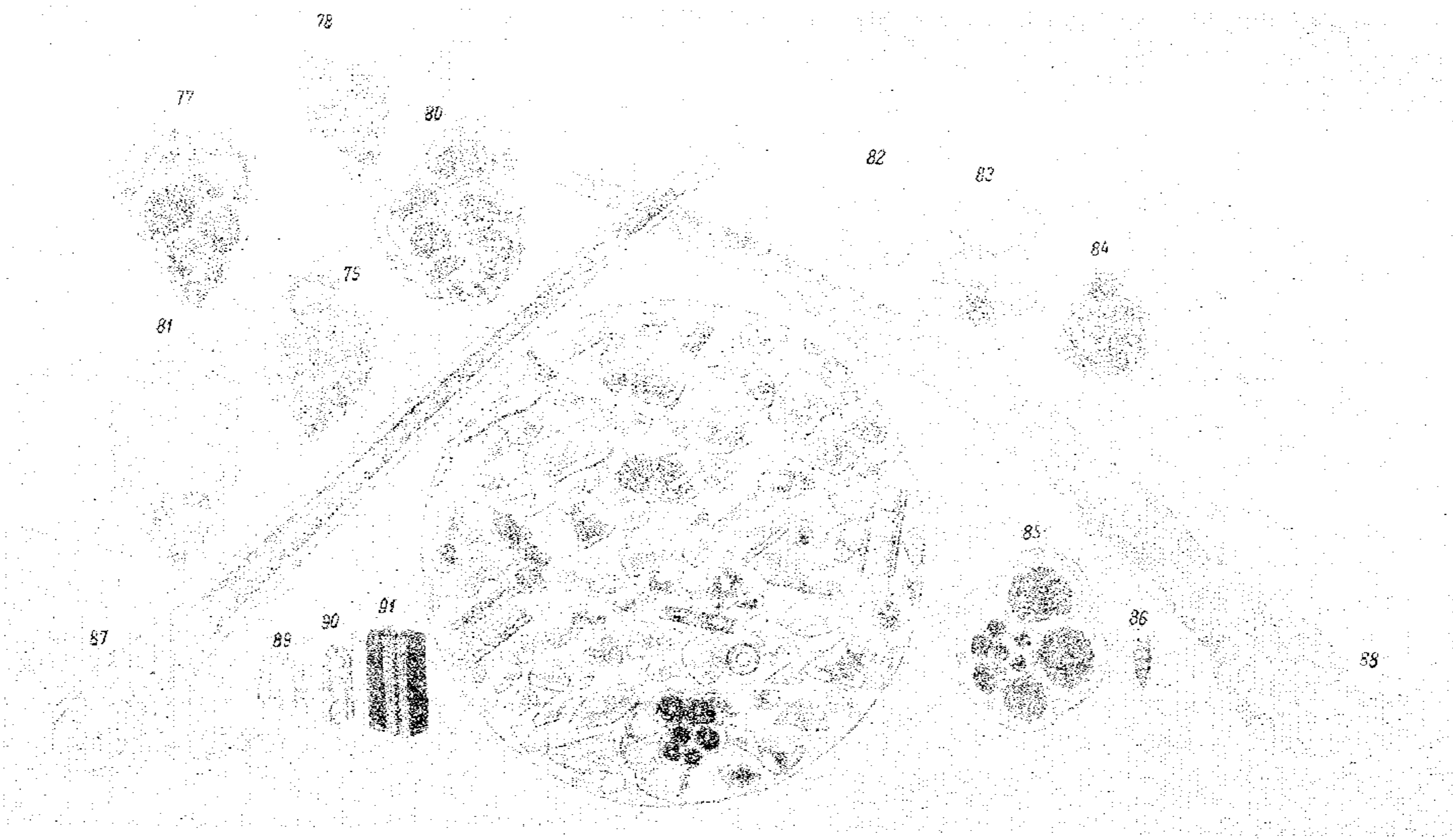

Fig. 235. Red dust collected at port of Malta in 1830. General view of dust after magnification (300 times). Coarse mass displays irregular red grains of quartz. Diatoms are diffused throughout (Ehrenburg, 1849). *Bottom*—Shell of Rotalia; *77–81— Textularia; 82–85*—Rotalia; 86, 87—plants; *88*—insects; *89–91*—crystals.

that they were especially big hailstones; the exceptional suction of stones by a tornado cannot be ruled out. An exaggeration is quite possible.

A dark thunderstorm cloud occurred over Austria, near the border with Hungary in 1618, during the second half of August. From it stones weighing "up to 3 centners" dropped along with "blood" rain. It seems probable that a fairly large amount of fantasy has been added here, to a description of the passage of a tornado.

There are abundant records of "blood" rain during the 17th and 18th centuries but the descriptions are more realistic. The dragons and firebirds almost disappear from the descriptions. The "blood" rain of 1646 in Brussels, which lasted 7–8 hours, is quite interesting. The water had a sour taste and there was red precipitation. In 1680 an enormous black cloud moved over the Red Sea. There was a fire cloud at its edges accompanied by a terrible hurricane which quickly passed by but transported a considerable amount of red sand from the land to the sea. In 1716 a "red" cloud covering the sky moved on L'vov. The L'vov episcope immediately informed the post. In 1755 an unusual hurricane carrying a cloud of red dust, approached Locarno and Lago-Majore. A terrible "blood" rain occurred and continued for three days. There was 23 inches of rain. The water level of the lake rose 15 feet. There was 6 feet of snowfall in the Alps. An approximate calculation showed 100,000 centners of red mass in the Locarno region.

The phenomena mentioned above have been repeated in recent years. New information on red rain over the United States, Baluchistan and Kashgar has been obtained. Fairly detailed data have been obtained for trade wind dust west of North Africa. The article by Charles Darwin on the trade wind red dust was published in 1845 and he showed that its origin was African. Ehrenburg repeated the observations and found that this was not supported by faunal data. Obviously there is a riddle here and his opinion merits further investigation.

No investigation has yet been made in such a fashion. After Ehrenburg not a single specialist has done anything that can be compared with his authoritative work.

The organic content of hurricane dust thus remains completely unstudied. In particular, we do not know anything about the organic matter transported by tropical hurricanes, as described above, which hit the eastern and southern parts of the United States. W. Twenhofel (1936) makes only a passing reference to the origin of the diatoms in hurricane dust. Nothing is known about the organic content of duststorms occurring in the territory of the USSR. It can only be said how ignorant we would have been without Ehrenburg's work.

From the geological point of view the monograph by Ehrenburg provides considerable material. First of all, it establishes that numerous microorganisms are carried thousands of kilometers deep into the continents as part of the hurricane dust. The composition of the transported forms is quite peculiar. It is surprising that among them siliceous freshwater forms predominate. Marine organisms are rare and only a few are found in the siliceous skeletal forms like that of calcareous shells—foraminifera. The latter show striking monotony—only a few families. Among these most frequently *Rotalia*, *Textularia* and *Spiroloculina* are encountered, because their areas of resistance and weights (aerial features) are favorable for transportation. All these forms occur on the African shore of the Mediterranean Sea as they settle on the sails of ships before they touch Europe (in Malta).

In 1872 a new work by Ehrenburg titled *Review of Research since 1847 on Rich Organic Lives Invisible in the Transported Atmosphere,* running to 150 pages and two tables appeared. This book set forth the results of further work carried out over 20 years.

The most surprising thing is that in spite of the long period of research it contained nothing new. All the conclusions reached on the data of the first monograph remained unchanged and were merely supported by new data.

After a brief historical review Ehrenburg gives a description of the new data on the fall of red dust and "blood" rain over the entire world. Incidents after 1847 are enumerated in detail. Their number is 60. Many of them are quite interesting.

The next chapter gives detailed descriptions of seven examples of the fall of red dust in southern Europe and the organisms obtained from them, one case in the Canary Islands, one in Iran (Isfahan), one in Algeria, one in Switzerland and one in Silesia. For comparison, a description of the red volcanic dust of Etna is given. As regards the composition, it differs by the absence of organisms.

The red dust falling on different regions of Europe, was typical "trade wind" hurricane dust of the same origin and same organic content as described earlier.

It is interesting that the composition of the organisms differed with great regularity. As usual, the freshwater forms with siliceous skeletons, primarily diatoms, predominated. There were a few marine forms. Foraminifers were rare but among them the multichambered, inflated *Rotalia* and *Textularia* predominated. Ehrenburg's conclusions were supported by the Swiss scientist Kramer.

SPORES AND POLLEN

The average size of the pollen and spores is the same as that of the dust particles. They generally measure 10 microns, rarely going up to 150–200 microns, and come as small as 1 micron. The aerial size is considerably smaller, since the dust particles mainly consist of quartz and other minerals, considerably heavier than the light capsules of spores and pollen. If the dust can be freely transported hundreds and thousands of kilometers, it is easier to transport spores and pollen. The numerous observations support this.

The monograph by Erdtman (1943, p. 174–186) describes observations carried out on the deck of a ship that sailed from Denmark to New York. Spores and pollen settled all the time and in three cases formed typical spore rain. The definite composition of the spores and pollen showed that the usual distance of transportation is a few hundred kilometers and in two cases figures of 650 km and 1,500 km were obtained.

Study of the peat in the Faeroe Islands showed the presence of spores of plants growing in Norway (580 km), Scotland (420 km) and Iceland (430 km). The spores in the islands of Chetam contained the spores of plants of New Zealand (700 km). Greenland peat included the spores of trees predominant in Labrador (1,000 km or more).

Actually all these observations are superfluous. The transportation of dust to a distance of several thousand kilometers has been proved beyond doubt. The spores and dust exhibit much smaller aerial size than the usual mineral particles of dust. Therefore their transportation to such great distances is beyond doubt. It is yet to be proved and remains to be studied. According to Erdtman (1943) such studies are inconclusive, if not nonexistent. Data on the transportation of pollen and spores by hurricanes and storms are also nonexistent.

The tracks of the West Indies hurricanes show that the African spores and pollen are freely transported to Central and North America and the American varieties are transported to southern and northern Europe. Ehrenburg's (1849) hypothesis as to the presence of South American microorganisms in the red dust that settles in Europe may be correct, after all.

The determination of diatoms and the data on their distribution, as given in the work of Ehrenburg, was examined from the point of view of present-day knowledge by a specialist on diatoms. He believes that the measurement and distribution of material given by Ehrenburg, are supported by recent research. The majority of the diatoms are the cosmopolitan freshwater forms or the forms native to Europe. The marine forms are relatively few. The majority of the forms taken as South American by Ehrenburg, have been established now as cosmopolitan dissemination, but all three types are regarded as South American to this day.

Typical American types are absent if cosmopolitans are not taken into account.

This absence and the presence of South American forms has not yet been completely explained though the transport by hurricanes carrying red dust with these forms from North Africa is beyond doubt.

The composition of foraminifera in the red hurricane dust is the real paradox. It is unusually monotonous and differs sharply from the composition of foraminifera in the upper chalk limestones of the Sahara and the sands on the beaches of North Africa. By and large two groups are generally encountered: forms close to *Rotalia* and forms close to *Textularia*.

Such compositions are displayed only by foraminifera living in the groundwater of the Sahara and the Karakoram deserts. Their presence in the sand and dust of the northern Sahara is quite natural and inevitable. This further supports the view that the main source of the dust carried from Africa to Europe is freshwater, saline water and surface Holocene deposits of the large desert plains of North Africa. They are constantly and regularly eroded by wind and yield an inexhaustive quantity of dust, transported to Europe at a great height.

It is quite interesting that after Ehrenburg, practically no one has studied the microorganisms, especially the foraminifera, in atmospheric dust. The work of Prinz (1908) may be mentioned. He studied the dust falling over Brussels in April, 1906. The dust mainly contained grains of quartz, covered by encrustations of limonite, grains of feldspar, flakes of mica, etc. It was similar to the dust described by Ehrenburg and later on by Meinardus and Herrmann. It is interesting that Prinz obtained grains of gluconite and shells of foraminifera resembling *Rotalia* from the red dust. Unfortunately the foraminifera remained undetected and only their drawings are given. Prinz's data are interesting in that they show that not only red dust but also foraminifera are repeatedly transported to central Europe.

ORGANISMS TRANSPORTED BY THE WINDS

We have considered above the main types of aeolian material transported by the wind: carbonate, siliceous, halogenous, organic. Seemingly the organisms come as a natural part of the organic material. Actually it is not like this. We know that the aeolian deposits consist mainly of terrigenous, carbonate, halogenous, siliceous and organic materials but we do not know how the depositions that consist mainly of organisms come to be transported by the wind. Perhaps it can be said that the "aeolian" organisms are always encountered in a limited quantity, in the form of an admixture in all five types of aeolian deposit. These are not rock-forming material. Very rarely is the quantity significant, e.g. in diatomic dust, transported by the harmatan. But in this case, too, we do not know of the diatoms in harmatan dust.

The transportation of organisms by hurricanes, storms and tornadoes has been dealt with in the respective sections. A brief review here may be sufficient.

Cases of transportation of big animals—elephants, whales and big fish—are not known. Theoretically it is possible but up to a few meters only.

Animals of average size—horses, cows, buffaloes—as well as human beings have been lifted by tornadoes a few and even tens of meters and tranported hundreds of meters and, rarely, 2 or 3 kilometers. The boy Petya Snegirov was transported a distance of about 5 km near Moscow.

Small animals—chickens, dogs, cats—do not rate much attention and their transportation is very rarely recorded. It is, however, clear that they can easily be transported a few kilometers, possibly 10–20 km, by tornadoes.

The transportation of animals capable of flying (birds and insects) within the cavity of hurricanes is remarkable and interesting. The distance of transportation depends on the endurance of the birds or insects in keeping themselves in the air. A cloud of locusts from Africa dropped on a ship in the "eye of the storm" situated at a distance of 2,000 km from the coast. Hundreds of dragon-flies were transported a distance of more than 1,000 km. An analogous figure for birds is also of the order of a thousand kilometers. Along with birds and insects, other organisms, especially the microorganisms, remain hovering in the air for a long time.

The transportation is always in the direction, from south to north, to be precise from the equator to the pole, more or less in a complex curve corresponding to the track of the hurricane (Fig. 47). The direction of transportation has considerable meaning for determining the characteristics of migration.

Small animals not more than 15–20 cm in size and weighing up to 2–3 kg are easily transported from a few tens of kilometers to a few hundreds of kilometers. Their transportation is effected by tornado clouds. Transportation up to 100–150 km has been recorded, but transportation up to 500 km or more is possible, since some tornadoes and tornado clouds cover such distances.

The transportation of individual animals or small numbers of animals goes undetected. It is only when they are transported in large numbers and fish, frogs, crabs, jellyfish, rats, etc. fall along with the rain that they are noticed. Such rains are not rare and on the geological scale, they are common, oft-repeated phenomena.

There is no doubt that hurricanes with their gigantic cloud vortices and strong storms transport large quantities of small animals a few hundred and even thousands of kilometers. All these animals fly individually and their fall goes unnoticed.

There is no doubt that small animals have fallen earlier and they fall even now. When we find the remnants of animals in deposits where they should not normally occur, e.g. marine shells in continental deposits, we shrug our shoulders and say "What does not happen in this world!" and forget about it. Actually we obtain the remnants of animals transported by vortices and hurricanes, tornadoes and tornado clouds.

The transportation of plants occurs in the same fashion as that of animals. Due to their large area of resistance they are easily lifted up and transported a great distance but their fall is never noticed. Only one rain with tree branches is known. In the desert areas attention has been paid to rain with "heavenly semolina". This is stated in the Bible.

In spite of its recurrence, the transportation of microorganisms on a worldwide scale is rare and does not disturb the general picture of the distribution of microorganisms. Such transportation is more the exception than the rule.

There are some other observations regarding microorganisms. Their transportation by the wind is not an exception and as a general rule has greater significance. All over the earth's surface the marine microorganisms are blown deep into the continents, to a distance of hundreds and thousands of kilometers. Transported diatoms have been found in the middle of the Atlantic Ocean. The transportation is in all directions and the difference is only in the quantity and distance of transportation. In the middle latitudes, especially along the tracks of hurricanes and tornadoes, the quantity of transported microorganisms and the duration of the transportation are quite striking.

Without exaggeration it can be said that in such regions the presence of microorganisms in any quantity will not serve paleography. Marine forms will be detected in the continental deposits and freshwater and continental ones in marine deposits. Mixed deposition will be quite common.

The distribution of aeolian microorganisms shows that it is irregular. In one layer they may be more and in another they may be found in lesser quantity. This reflects the periodicity of the strong winds that carry masses of microorganisms. During hurricanes, storms and tornadoes, the formation layers will be full of aeolian microorganisms. During calm weather aeolian microorganisms are either rare or altogether absent.

The rhythmic depositions are accompanied by a rhythmicity of the animals and plants transported by the wind.

3
Geological Destruction

HURRICANES AND EARTHQUAKES

The simultaneous occurrence of earthquakes and hurricanes has been repeatedly recorded. One of the greatest catastrophes of recent times was due to the hurricane of 1923 in Japan and the almost simultaneous earthquake. In Tokyo and Yokahama the hurricane started somewhat earlier than the earthquake. The earthquake of September 1–2, caused fire and damage to buildings. The hurricane changed the fire into a self-perpetuating calamity. Almost 100,000 people died, about 50,000 people were rendered homeless and 105,000 people were injured. Many Japanese seismologists thought that the sudden drop in pressure during the hurricane was one of the factors that gave rise to the earthquake. It has been calculated that a decrease of pressure by 5 cm lowers the load on each square mile by 2 million tons. On the other hand, the hurricane waves 10 feet in height increase the load over a square mile by 9 million tons. An enormous change in pressure on the earth's surface actually can start an earthquake and may be the reason for it.

This significant possibility has not yet received the attention it deserves from seismologists and geologists. Generally, in Central Asia many violent storms and numerous earthquakes occur. It would be interesting to check the relationship between these two, geographically and on the time scale. They do not coincide geographically. The storms strike the plains and the earthquakes occur in the mountains.

The relationship between earthquakes and hurricanes on the shores of the Pacific Ocean has been considered in the monograph by Visher (1925, p. 135–137). He believes that in the unstable seismic regions the hurricanes may trigger an earthquake like the proverbial "last straw on the camel's back." He presents the data and shows that due to the change in the pressure occurring during a hurricane, there is a change in the load of the order of 2–3 million tons on each square mile, occurring over a few hours.

Hurricane tidal waves 2.5 m in height cause a pressure of 7 million tons over 1 square mile. The gigantic waves 10–12 m in height cause much more pressure. Their advance and retreat with the accompanying change of pressure cause changes in the pressure on the inner layers of the earth's surface and this may cause a break in the unstable zone in seismic regions, e.g. in Japan.

Even though the relationship between strong earthquakes and hurricanes is not yet clear, there is no doubt about the relationship between hurricanes and microseisms. Many investigators have worked on it. A brief account is given in the ninth edition of the book *Hurricanes* by Tannehill (1956, p. 273). He writes that a "study of microseisms in the Atlantic and Pacific oceans in relation to hurricanes and typhoons showed that the latter always enhance the amplitude of the microseisms at the nearest seismological stations. The enhancement of amplitude is directly proportional to the size and strength of the hurricane. In some cases the violent storms turn out to be at a great distance, even more than 1,500 miles (2,400 km)." It is not yet clear how hurricanes intensify microseisms and hence correct predictions cannot always be made. In any case, in the United States the effect of microseisms is considered as one of the methods of predicting hurricanes, though of secondary significance.

In the Soviet literature this problem has been discussed by E.F. Savarenskii et al. (1955). They consider the range of cyclones and typhoons to be within a reach of 2,000–3,000 km. Systematic observations are made in a number of countries. They are part of the work of meteorological department. A number of microseismic stations have been established abroad for this purpose and scientists studying this subject held a special session in New York in 1952.

In the USSR observations have been made at two stations—Leningrad and Crimea. They gave good results.

It has been firmly established that microseisms originate due to changes in the atmospheric pressure over the sea and these changes are transferred to the earth's surface through the waves. The standing waves originating in the central part of hurricanes and typhoons are of special significance.

The work of E.F. Savarenskii et al. (1955) has been included in the bibliography.

The relationship between microseisms and tropical hurricanes is considered in the paper by Gilmore (1947) and in the review by Gutenberg and Makilwan (see Defant, 1951a).

FORMATIONS OF UNCONFORMITIES IN SECTIONS

The great strength of hurricanes and the gigantic waves associated with them cause considerable changes in the depositions in the coastal zones of the sea as well as inland. These changes are distributed over large stretches of coast, e.g. the entire Gulf of Mexico, the entire Bay of Bengal. The geological significance of these changes is considerable, though they have not yet been studied well and the geologists have ignored such changes.

There are a number of indications that after strong hurricanes accompanied by large waves the coastal zones, especially the slopes of coastal plains change their character considerably. The outline of the coastline also changes. Sandy patches and islands are replaced by a few meters deep sea water. Closed lagoons and coastal lakes become open gulfs of the sea. Existing gulfs are deepened. Enormous sandbars under the sea disappear and shift to other places. On the contrary, in place of quite deep sea sandbanks and islands are formed. The deep submarine beds of rivers are silted and become too shallow for ship movement. In place of coastal lakes and swamps, dunes of considerable height, consisting of sand with marine fauna, form. The hurricane waves penetrate deep inland and carry sand and silt to a considerable part of the alluvial plain, often into the streets and squares of cities. Coastal coral reefs are washed and overturned. Many such examples can be cited.

Geologically this has only one meaning. On the eroded irregular surface, one deposition will follow the other, often in the opposite direction. In place of silt and peat, marine sand will be deposited. The silts of deep submarine beds give way to sand and pebbles. On the other hand, over an eroded surface of sand, fine-grained and silts with marine fauna are deposited. Over the eroded surface of alluvial, suddenly lenticular sand and clay with marine fauna appear, which are again covered by alluvial deposits. The shallow marine deposits shift considerably more than the deep-seated deposits. The marine deposits are covered by continental deposits and often the continental deposits lie over marine deposits.

In the fossilized condition for the study of their geology all these changes admit of only one explanation; tectonic movement, uplift and submergence, regression and transgression. After hurricanes, in most cases marine deposits due to erosion will be deposited on the continents. In the sections they will appear as typical transgression or ingression. Rarely, i.e. when the dunes shift and close part of the bottom of the gulf, there will be an inverse relationship: the geologists emphatically state that uplift occurred and the marine deposits changed to continental deposits.

Actually, however, there was no tectonic movement. We often run into such conclusion without any basis. All these changes are due to the geological activity of hurricanes and hurricane waves.

UNCONFORMITIES IN CONTINENTAL DEPOSITS

The activity of hurricanes is not confined to the formation of unconformities in the depositions of the coastal zone. Changes in the depositions far from the seacoast, mainly in the river valleys and on the slopes, are due to strong downpours accompanying hurricanes and floods which take place after the downpours. Some figures typical of hurricane downpours have been discussed earlier.

Hurricane Flora, which passed over the islands of Tobago, Haiti and Cuba in October, 1963 (p. 56), was remembered by people for a long time. Flora caused large-scale death and destruction. The hurricane struck Tobago Island on October 1. The wind speed reached 60 m/sec. In a few hours the island was turned into debris. Moving slowly (at a speed of 20 kmph), the hurricane crossed the Carribbean Sea and raged over Haiti Island on October 3. The wind, exceeding a speed of 70 m/sec, overturned heavy loads, moved buildings along with the people in them and wiped all the villages from the face of the earth. Haiti is a mountainous island full of rivers. The downpour accompanying Flora flooded the rivers. The plains of the island with numerous villages were flooded. The water level went up so fast that many inhabitants could not be rescued. In all, about 5,000 people died and 100,000 were rendered homeless.

After passing over Haiti, Flora slowly moved to Cuba and on October 4 came over Orient province in the east of the island. The speed of the wind was 40 m/sec. The terrible downpour caused flash floods. On the evening of October 4 the hurricane reached Olchin town and the floods covered the entire province. The hurricane moved very slowly at a speed of 2 kmph, describing a loop over the island in 90 hours. The speed of the wind, all the time was 50–60 m/sec and the downpour did not cease.

On October 5 Flora moved south and the fertile land was inundated. Many families took refuge in the hills. Changing direction, the hurricane again struck Orient province. All the major cities were cut off. The flood was catastrophic. The river inundated the capital of the province, Santiago de Cuba. Numerous farmers in the villages were cut off and only a few of the inhabitants could be evacuated.

On October 7 Flora turned toward the north. The level of the River Yatiboniko rose 2 meters. The river became so wide that it resembled a sea strait. The level of water in the Tana River rose 4.5 m. The hurricane raged over Camaguay for a few hours and inundated it.

On the morning of October 8 Flora at last moved away from Cuba, having killed thousands of people and caused enormous loss (Tiron, 1964, p. 113–119).

Hurricane downpours often cause landslides. On May 9, 1961, the downpour accompanying a tropical hurricane, caused great landslides in Bakhargung (East Pakistan*). Approximately 450 people died.

On September 15, 1961, typhoon Nancy struck Japan. Osaka, Kyoto and

*Now Bangladesh—Translator.

Kobe suffered from floods. The central regions faced numerous floods, house collapses and landslides.

On September 7–9, 1962, typhoon Emma affected the Primorsky border. The downpour accompanying the typhoon flooded the rivers Suchan, Sudjuke, Daubikhe and Ulakhe and inundated many villages (Tiron, 1964, p. 136).

Tens and hundreds of such examples can be cited. They show that catastrophic flood is a normal feature of tropical hurricanes.

There is considerable geological significance to such floods. They carry large quantities of sandy clay matter, more coarse-grained than the usual river deposits. These coarse-grained deposits will cover diverse deposits—river, lake, continental. Well-defined breaks are formed which will be found over a large part of Cuba. After the floods recede the coarse-grained formations gradually change to fine-grained formations. The well-defined rhythm of deposition over a large area is indicative of this horizon. The recurring hurricane floods repeat this rhythm. Referring to the literature on hurricane floods given in the work of Z.M. Tiron (1964) and Tannehill (1945), we find that in 1960 hurricane Donna inundated Cuba in the same way as Ella did in 1958. In 1954 hurricane Hazel struck Haiti. The overflowing water caused floods and landslides. Due to the landslides, 200 people, and in all about 1,000 people died. The floods on the islands of Puerto-Rico and Jamaica were no less high. Catastrophic floods hit Cuba in 1888, 1844, 1791 and 1768. In 1791 about 3,000 people and in 1768 about 1,000 people died. In between, over a period of 30–40 years, catastrophic floods recurred in Jamaica, Haiti and Puerto-Rico.

Similar large-scale floods, recurring after a few decades, hit different parts of North America lying in the path of tropical hurricanes.

In conclusion, it can be said that the depositional rhythm of the floods is a usual phenomenon among the anthropogenous deposits of these countries. For men, 40 years is a long period, but geologically it is a negligible interval. Geologists to this day do not distinguish the depositional rhythms in sections. Whenever observed, they are associated with tectonic movements.

4
Aeolian Deposits

DEFINITIONS

Aeolian deposit: This is a deposition dominated by aeolian material, e.g. aeolian sands, aeolian lake deposits. The adjective "aeolian" is used in such cases. In addition to the aeolian material, organogenous, river and marine depositions are mixed up. But the distribution is limited.

Mixed aeolian deposit: This is a deposit where the aeolian material is less than the other components, though there is no doubt about its presence. The qualification "aeolo" is used in such cases e.g., aeolomarine, aeololacustrine, aeoloalluvial. The quantity of aeolian material changes considerably. The distribution is extremely wide, on a planetary scale.

GENERAL RULES

The main cause of the formation of aeolian deposits is the wind (from the Greek *aeos*). There is wind wherever there is atmosphere, i.e. over the entire earth's surface. The aeolian deposits, therefore, are also found over the entire earth's surface.

The quantity changes rapidly. It mainly depends on three factors: 1) speed and constancy of the wind; 2) mass of dust and clay particles transported by the wind; 3) mixture of other deposits.

Among the other deposits the most significant is the aquatic deposit. Water, like wind, is also distributed over the entire surface of the earth. As an agent of transportation it is stronger than the wind. It should be noted that all the deposits of halogenous material may be of aquatic origin. All the coarse-grained sands, grains of more than 2–3 mm, are of aquatic origin. In mass the aquatic deposits considerably exceed the aeolian deposits.

Therefore, in places where aquatic and aeolian deposits are formed simultaneously the former is considerably more. Often the aeolian material is dissolved in the mass of the aquatic deposit and cannot be distinguished. Aeolian deposits are also masked by organic and chemical deposits, but to a lesser extent.

The wind predominates at places where the action of the water is weak or is altogether absent and the deposits so formed are known as aeolian. Such areas are: 1) deserts, semiarid areas, steppes where the quantity of aquatic deposits is sharply reduced; 2) plains, wide and sloping watersheds where rain and snow are considerable but the flow and volume of the water current are negligible.

In the deserts the wind speed is high and it causes accumulation of aeolian sands and the formation of colossal massifs. On the borders of the deserts, in the steppe watersheds and plateau-type hills, aeolian loesses and loams are formed.

Aeolian sand, loess and loam always contain an admixture of aquatic, organic and chemical material but this admixture is negligible.

A large volume of literature is available on the aeolian deposits composed of materials transported by the wind, aeolian sand, loess and loam. The main data on them have been given earlier when discussing hurricanes, storms and tornadoes. Now we will discuss the deposits in which the aeolian material is of secondary significance, which are differentiated by the prefix "aeolo".

As already mentioned, the wind is present everywhere. In all deposits an admixture of aeolian material is present. At times the admixture is so small that it is difficult to establish it. At times it is undoubtedly distinct and the prefix "aeolo" can be used without hesitation. The aeolomarine, aeololacustrine, aeoloeffusive, aeolowatershed deposits are widely distributed, occupy large areas and will now be considered. In addition to these, there are aeolofluvial, aeologlacial and many other analogous deposits. These deposits are not widely distributed and have not been studied in detail, so their description must wait for the future.

The main factor determining the origin of aquatic and aeolian depositions is the force of gravity, which has been inappropriately ignored. There is, however, one limitation. It is necessary that such particles be present as can fall down, and that they should be first lifted to a height from which they can fall.

The particles of aquatic deposits are lifted upward as rock formations formed by orogenic tectonic movements.

The particles of aeolian deposits are lifted upward in the form of dust and haze. The wind lifts fine-grained sand to a small height of the order of a few meters. The grading of sand, dust and clay particles and their distribution in aerial precipitation occurs in the floating condition.

Often aeolian materials are washed away, transported downward and deposited by the water currents. A remarkable aquatic deposit, consisting of primary graded aeolian particles, is formed.

AEOLOMARINE DEPOSITS

Aeolomarine deposits are formed in regions of the sea where sand and dust transported by the wind are mixed with the normal marine deposits. These normal marine deposits with the usual marine fauna contain a mixture of aeolian material and continental freshwater organisms.

The quantity of this admixture is not very high and it does not change the marine character of the deposit, but adds a number of features to it. These features can easily be found in recent deposits. It can also be easily established in past deposits, but no one has studied them so far.

The name "aeolomarine" was suggested by me in *Studies on Environment* (1956, p. 285–287), but the transportation of aeolian materials from the Sahara to the Atlantic Ocean was recorded by sailors at least 2,000 years ago. The transportation of dust over the sea is so frequent and involves such large quantities that the darkening of the surroundings is a normal feature.

The Sea of Darkness: This is a region of the accumulation of aeolomarine deposits, quite well known and thoroughly studied, but by no means unique. Aeolomarine deposits are developed along the southern shore on the Mediterranean Sea, where dust storms from the Sahara blowing toward Europe occur. The deposit is developed along the east coast where the dust storms come from Arabia and Asia Minor. An enormous, exceptionally large amount of material is deposited at the bottom of the Red Sea. Here the transportation of terrigenous materials by rivers is negligible and the sandy-clay deposits are almost exclusively of aeolian origin. The considerable transportation of aeolian dust in the Gulf of Persia, especially in its northern part, is mixed with silts transported by the "great rivers". There is no doubt that the aeolian dust transported from the deserts of south Arabia, Iran and Pakistan, in large quantities settles on the bottom of the northern part of the Indian Ocean.

The desert of our Central Asia supplies dust and sand, playing an important part in the deposition in the Caspian Sea, as much as in its northern part (Apollov, 1927) as along the coast of Turkmenia.

Three regions in the Pacific Ocean are known where aeolian dust mixes with the marine deposits. First, there is the sea between northeastern China and Japan where the dust transported from the deserts of Central Asia and loess regions of China settles. Second, there is the Sea of Tasmania between Australia and New Zealand where the dust storms from the deserts of South Australia frequently pass. These storms also pass over the sea to the south of Australia, where the accumulation of aeolomarine deposits is quite probable. The third region is the eastern part of the Pacific Ocean off the coast of the USA.

In all the regions mentioned above, aeolian dust with the inclusion of clay particles settles on the bottom of the open sea. Aeolian sands are not transported that far. The sand flow starting from the surface stops as soon as it reaches the sea. It is due to this that the aeolian sands play a significant part in the formation of coastal dunes and beaches on a number of seacoasts. Mainly it will be those regions where aeolian dust is transported to the sea. Their number increases in regions where winds of average strength constantly blow, e.g. trade winds and monsoon.

The aeolomarine sand of the shores of the Bay of Biscay, where there are frequent strong winds and storms, has been described by Cayeux (1929). A brief account of it is given in my book *Studies on Environment* (1956, p. 287).

Sand dunes consisting of grains of calcite develop on the coasts of India, southern Arabia and Egypt. They are described in the present work, on pages 475–482.

As an example of the range of action of the harmatan the aeolomarine deposit on the west coast of Africa, in the region of the Sea of Darkness (Cape Verde Islands) and to the west of it can be cited. The Sea of Darkness is situated where the Sahara immediately adjoins the Atlantic Ocean (Fig. 237). Here the trade winds and the eastern dust storms (Fig. 67) transport enormous amounts of red dust to the sea. For a long time they have been called "trade wind type".

Samples of this dust were collected by the then young Charles Darwin during his expedition on the ship *Beagle* and were described in the authoritative monograph by Ehrenburg (1849) more than 100 years ago. A brief account of this has been furnished on pages 502–509. To date a few dozen papers have been published, throwing light on the composition, condition of formation and accumulation of aeolian red dust. Most of them are small notes describing individual phenomena. A thorough, authoritative work is yet to be written.

The composition of the dust is normal. Irregular grains of quartz are quite prominent. They have encrustations of red iron oxide. Clay particles, also of yellow-red color, are quite numerous. It is this that gives the dust the red or red-yellow color. Gray siliceous skeletal formations of diatoms, siliceous silty sponge and isolated foraminifera and fragments are also encountered as secondary products (see page 498, 509–511).

The quantity of dust has not been correctly determined. According to Andree (1920, p. 201) 0.4 cm accumulated in 1,000 years. According to him the silt which is generally of white color and 3–4 km in depth receives a tinge of red color here. The figure given by Andree is low. The calculation of the quantity of red dust transported to Europe is more reliable. It is millions of tons for each strong dust storm. Transportation to the Atlantic Ocean undoubtedly is quite considerable.

The distribution of red dust in the ocean has been shown in a number of diagrams, and they are close to one another. The latest is the work of the

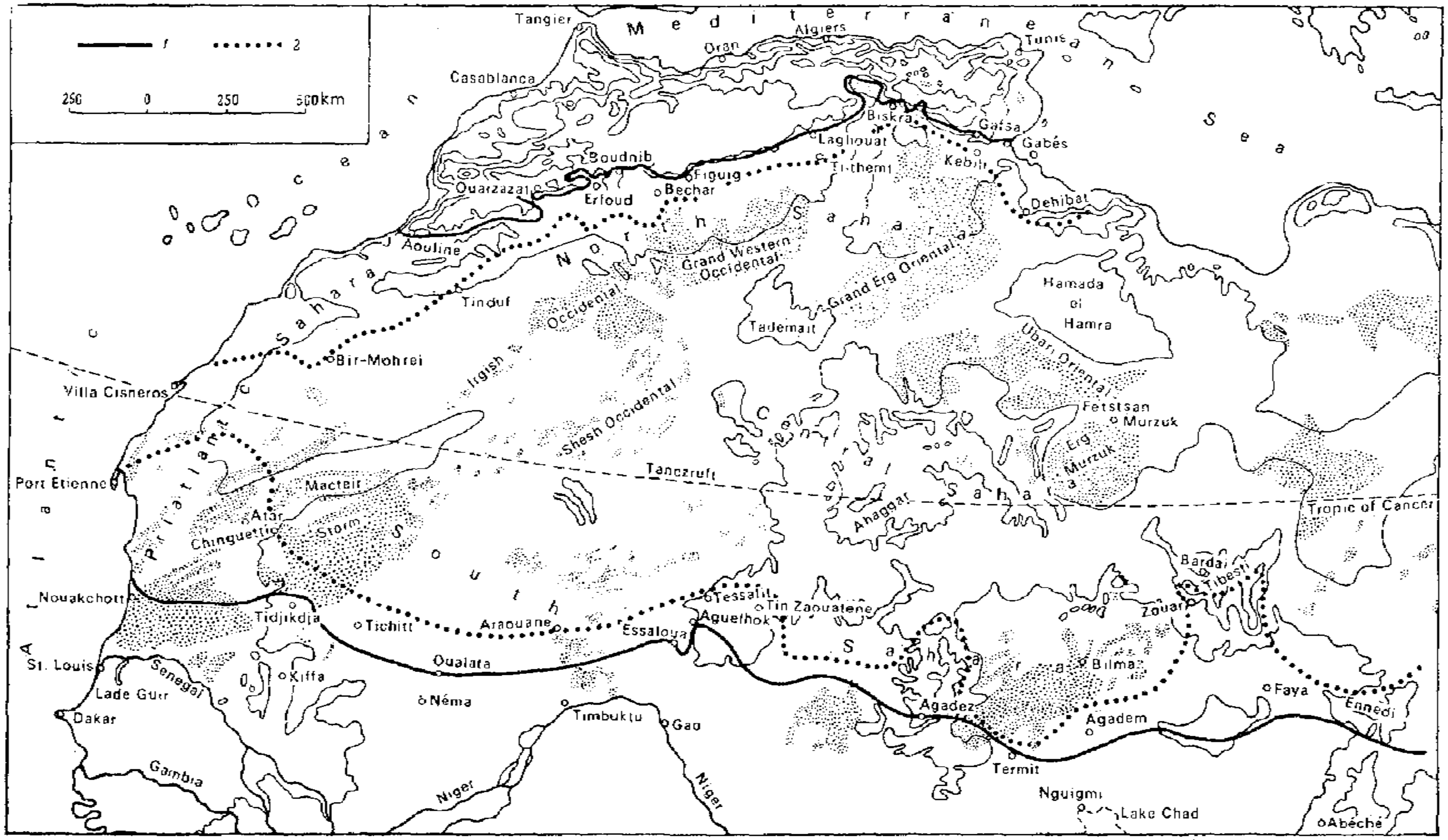

Fig. 236. Boundary of Sahara (Kapo-Rei, 1958, Fig. 1). *1*—boundary of deserts; *2*—boundary of steppe zones.

well-known oceanographer Kuehnen (1950), which is incorporated in *Studies on Environment* (Nalivkin, 1956, p. 286). One can see from it that part of the dust settles far to the west, from the Cape Verde Islands on halfway between Africa and South America. The diameter of the area of deposition of dust is 20°, i.e. half of the diameter of the entire Sahara. The area is enormous but it should be still greater. Kuehnen does not consider the effect of the harmatan.

The harmatan is a dry dust wind, often becoming a dust storm. It moves over the fringe of the Sahara, including upper Nigeria, and transports large amounts of dust to the Atlantic Ocean, to the south of the Cape Verde Islands. This dust is whiter in color than trade wind dust and is often enriched with freshwater diatoms. If the area of distribution is added to the area of distribution of red dust, the map of aeolomarine deposit becomes much more extensive.

Kuehnen's map needs to be modified in the northwest. It should not be closed, since the West Indies hurricanes start from the Sahara or in the region of the Cape Verde Islands and part of the dust is transported far to the northwest, in the direction to the West Indies islands. This fact is brought out in a brief account by Hurd (1922).

According to Dubieff (see Fig. 67) the harmatan has an almost latitudinal direction. In the light of all these circumstances, the map of distribution of aeolomarine deposits should be modified (Fig. 237).

The deposit in the central part of the Atlantic Ocean is described in detail in the monograph by Correns (1937). He notes the significance of aeolian dust in the formation of the deposit but this particular problem is dealt with in two other papers incorporated in the monograph.

One of the papers, by Radczewski (1937), concerns the Cape of Verde Islands and the regions of the Sea of Darkness. It describes the mineralogical composition of the trade wind dust and its significance for sedimentation, on the basis of a study of six samples.

Calcium is predominant and fluctuates from 25 to 40%. Second place is occupied by mica—10–20%. The others are: quartz 10–15%; feldspar 5–15%; iron oxide 5–10%; organic silica 1–3%; a considerable quantity of "aggregates", micaceous clay formation—about 20%; rest 5–10%.

Out of these individual details we will take note of two: first—iron and clay encrustations enveloping the grains of quartz and feldspar (discussed below in detail); second—the presence of calcite formations, similar to coccolite, among the grains. Attention is drawn to the predominance of diatoms in the organic siliceous matter.

The significance of the trade wind in the sedimentation is illustrated by the percentage content of "desert quartz" in the total quartz content. The grains of aeolian quartz are generally less than 55 microns in size. It constitutes 15 to 60%. The figure is generally above 30%. This shows that aeolian dust has an important role in the deposition in the Sea of Darkness. Similar

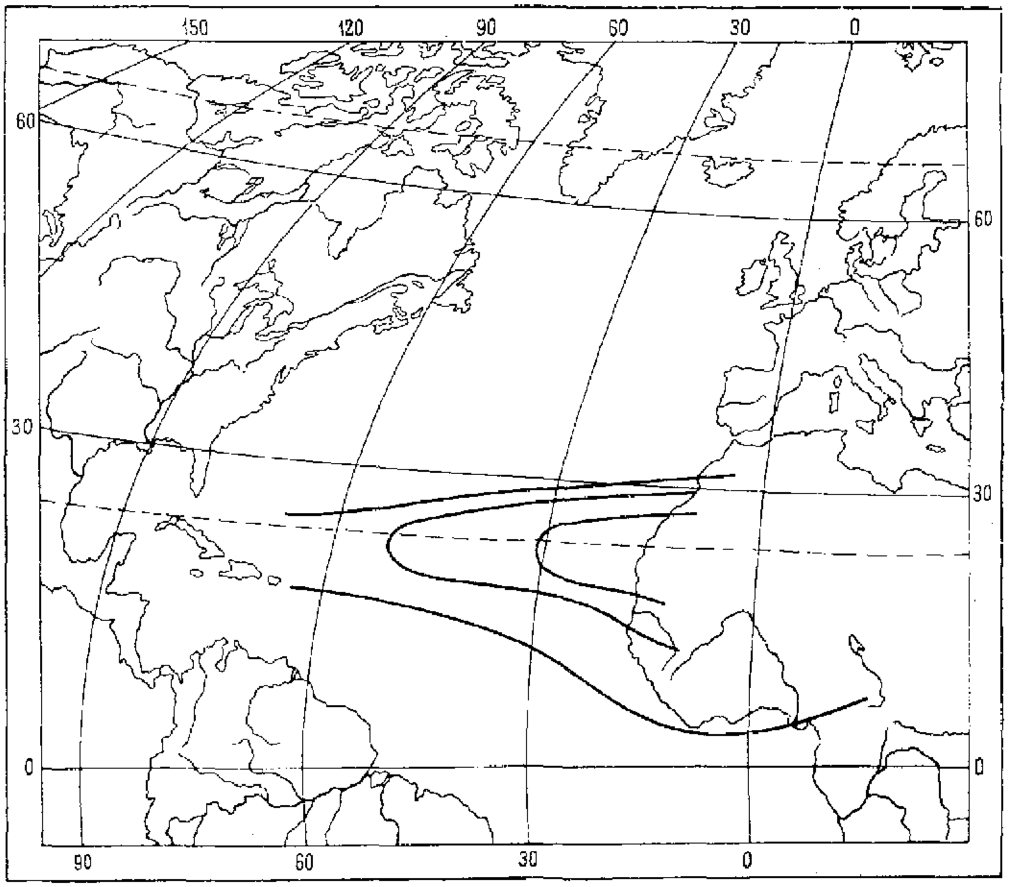

Fig. 237. Atlantic Ocean. Area of deposition of red dust transported from Sahara.

factors undoubtedly operated in the marine deposits of the past, though they have not been studied in detail.

The paper by Leinz (1937) is no less important and interesting than Radczewski's, though it has not received any attention. It considers the mineralogical composition of the deposit on the sea floor off the coast of Guinea and underlines the significance of the harmatan in its formation.

Diatoms and charcoals are widely encountered and exhibit uniform distribution. They are developed all along the north shore of the Gulf of Guinea (Fig. 238) but do not go south of the equator. In the recent planktons of this region marine diatoms are almost absent. Therefore the numerous forms obtained are quite likely of the freshwater type only. They are transported by the harmatan along with the charcoals from the plain and peat fires along the River Niger.

This agrees with Seefried's (1913) and Danckelmann's (1913) data. They studied the dust of the harmatan. Leinz (1937, p. 254–255) analyzed three samples of such dust. Two of them showed a large amount of diatoms and a small amount of charcoal. The third sample (Fernando Po) contained

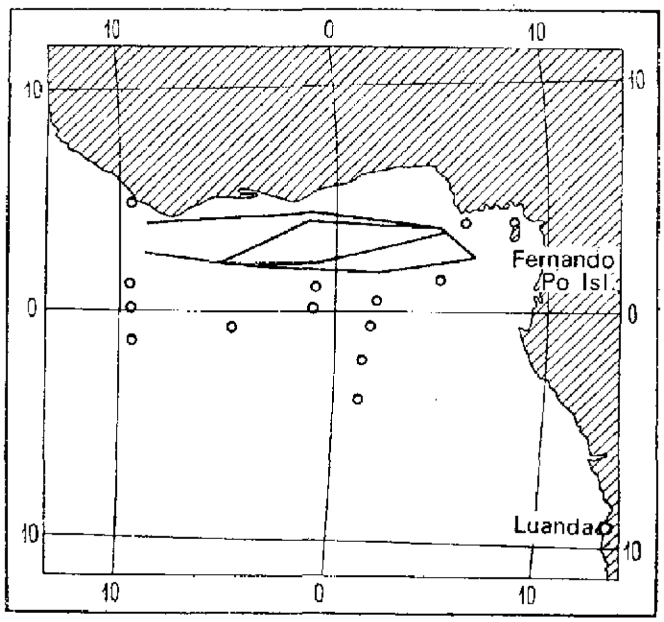

Fig. 238. Gulf of Guinea (Zeinz, 1957, Abb. 96).
Bold line—samples with diatoms; *open circles*—samples without diatoms.

neither diatoms nor charcoal but only mineral particles, primarily quartz, feldspar and calcite. It is quite likely that the sample was of local origin.

Almost all the diatoms and charcoals are from deep-seated silts. They are less in the littoral zone, possibly due to the mixing of terrigenous particles.

Leinz (1937, p. 258–261) believes that the solution of shells of foraminifer silt changes to blue silt. Its mineralogical composition is uniform. Quartz is predominant along with feldspar and mica but clay minerals—kaolin, halluasite and monton orilonite—occupy second place after quartz. At some stations the content goes up to 50 and even 75%. It is possible that they have been transported by the harmatan.

Determination of diatoms in the deposition in relation to the minerals has been done by Leinz (1937, p. 259, Table 51). The calculation gives 5–20% in one sample; for Fernando Po this goes up to 20–40% and for grains of 0.1–0.01 mm it is from 80 to 100%. These are significant figures.

Crust of Deserts

Study of the dust transported from the Sahara to the Atlantic Ocean and Europe showed that its most important feature is the "crust of the desert." All the grains of minerals ascending into the air are covered with fine encrustations of dark red, gray or yellow color. This crust is similar to the "brown desert" and may be referred to as "crust of the desert."

Like the tanned, dark desert encrustation covered by stones and sands, the crust of the desert is extremely stable, solid and often clayey and glittering. It scarcely adds to the action of weak oxidation and cracks found in nature. It scarcely changes over tens of thousands of years, lying under the silt at the bottom of the sea.

The thickness of the crust of the desert is negligible—a fraction of a micron, rarely a few microns. It grows together with the grains of minerals and is inseparable from it.

The composition of the crust has not been studied in detail. It is generally believed that it consists of iron oxide but iron oxide alone may not display such stability and solid character. It is possible that these two properties give rise to the mixture of colloidal silica, which has an important role in the geochemistry of deserts.

The chemical composition of the crust of the desert has not been studied in detail. The most detailed data are given by Radczewski (1937, p. 262, 276). He believes that the red-brown crust consists of Fe_2O_3 and is formed only in the desert. The yellow crust mainly consists of flakes of muscovite and fine FeOOH with a mixture of grains of calcite and flakes of clayey material. It is formed not only in deserts but also at the bottom of the sea. The red crust is developed over quartz, and the yellow over feldspar.

Radczewski believes that the roundness of the grains of quartz generally depends on the envelope of encrustation but the grains are basically irregular.

That the crust of the desert is formed not at the bottom of the ocean but on the surface of the desert is brilliantly demonstrated by the colored photographs of the surface of North Africa. The photographs from satellites clearly show the rose-red coloration of the entire surface of the western Sahara. The photographs taken by the American astronaut in 1965 under the direction of the geologist Lowman, heading the aerial photography work, are still more interesting. They are given in the paper by Lowman (1966). Many of them are exceptionally interesting and important for geologists and geographers. But for us the most important photograph is of the coast of North Africa, including the Sahara and Atlast Mountains, and the adjoining area of the Atlantic Ocean. The entire surface of the Sahara and the adjoining northern mountains have a bright brick-red color, the color of the "crust of the desert". If the entire continent displays such coloration, this color will be transported along with its dust.

In the same photograph a developing tropical hurricane can be clearly seen over the Atlantic Ocean. It is over the Cape Verde Islands. The spiral structure is visible but the "eye of the storm" is not yet formed. It is of interest that the cloud forming the body of the hurricane is also of rose color, though considerably less so than the color of the continent—the Sahara.

There is no doubt that the hurricane started to form over the Sahara and its color is due to the dust lifted from this area.

In recent marine deposits the red crust of the desert consisting of grains of quartz serves as the basis of identification of aeolomarine deposits. The extremely stable crust allows one to conclude that an admixture of grains of quartz from the red crust of the desert in the deposits of the past is sufficient to label them aeolomarine deposits. At the same time this admixture determines the existence of a Sahara-type desert, not far away, within a few hundred kilometers or less. This place is referred to as a "quartz desert" by Radczewski (1937, p. 276).

Loess Dust

Yellow loess dust is transported in large quantities to the sea by the northwesterly wind, often of considerable strength. The quantity of dust is so great that navigation becomes difficult (Hurd, 1922). It is possible that part of the dust is transported by the typhoons coming from a southwesterly direction. Accumulation of fine dust on the surface of the Yellow Sea has been repeatedly recorded. It is quite likely that the name "Yellow Sea" was derived from the yellow dust.

In the literature a yellow dust storm on the shores of the Yellow Sea has not been recorded. The dust is transported by the wind, coming from an altitude of several kilometers and suspended in the air in the form of haze, rarely as a dust cloud. At this height the dust crosses not only the Yellow Sea but also the Sea of Japan, reaching Japan.

Unfortunately, very little is known about the deposition at the bottom of the Yellow Sea.

Brown Dust

The States of Washington and Oregon are situated on the coast of northwestern USA. These two States include a considerable area of desert and semidesert with an inexhaustible source of dust. Often the easterly wind attains storm strength and even hurricane strength. It lifts an enormous quantity of dust in the form of dust storms, blowing far out to sea.

As an example, the dust storm that raged for four days, from April 21 through 24, 1931, can be considered. It transported an incredible amount of dust to the ocean. There was so much dust that visibility became almost nil. Ships moving down the coast moved ahead, as if they were passing through a fog, whistling and ringing bells. Decks were covered with a continuous layer of brown and yellow dust (Cameron, 1931).

There is no doubt that such dust storms recur. They occur in the south, in California, where the jet storm often becomes dusty. Pouring down from the Sierra Nevada Mountains, it transports dust to the south, into Mexico, down the coast of the Californian peninsula and into the Gulf of California.

It is due to this that along the southern half of the west coast of North

America there are regions at the bottom of the Pacific Ocean where the marine deposits constantly mix with aeolian material, primarily in the form of dust and clay particles. The sand from the land does not travel far out to sea but participates in the formation of beach sand.

On the coasts of Africa the particles transported to the bottom are easily distinguished by the red encrustation enveloping them. On the coast of North America the dust transported to the sea is not red but brown. This should be the color of the encrustation on the particles in the deserts. But indications of such particles are not found in the literature on these depositions, which is voluminous.

Caspian Dust

The aeolomarine deposits of the Caspian Sea have been described by B.A. Apollov (1927). In the northern part of the Caspian, to the east of the mouth of the Volga, he placed tubs on special buoys to determine the quantity of dust. Under normal wind conditions, without any storm, the total annual deposition was 0.28 mm, so 28 cm in 100 years. It is a small figure but this figure is considerably enhanced by storms. The dust is of yellow color.

In 1950 M.V. Fedosov (1950) carried out detailed observations. Special observations at the meteorological stations of the Tube-Karagan peninsula showed that the quantity of aeolian material sharply increased during a storm (20 m/sec) and had an important role in the accumulation of the sea bottom deposits. Silicate and carbonate materials predominated. The sand traps, placed at heights of 0.6 and 1.9 m, showed the predominance of fine carbonate sand from the fragments of smashed cockle shells. Such sands were absent at a height of 3 m and only dust with fine remnants of insects and plants was collected.

Fedosov's data on the accumulation of dust on the surface of a glacier in the southern part of the North Caspian are quite interesting. A heap of yellow snow was formed after strong wind conditions (12–14 m/sec). The quantity of dust in the snow was 2.25 g per liter. Particles of 3–10 micron size predominated. Rarely, particles of 20–30 microns and even 50–70 microns were also encountered. The snow was mainly inorganic but there were many spores, pollen and diatoms (*Intushia, Navikula, Haptushina*). Many quartz and clay grains had encrustations of calcite.

The dust of two storms of 1950 and 1951 has been described by S.V. Burevich and M.P. Gudkov (1954). The dust of 1950 was white and salty. It is described in the section "Halogenous material". During the storm, silt particles settled quickly and clay particles gave rise to a "haze" that remained in the air for a few days.

A large amount of carbonate was the characteristic feature: in 1950 111 g/m^2 and in 1951 31 g/m^2. There was 33% silica, 2 to 3% iron oxide and 4 to 8% clay.

The rates of deposition in the north, central and south Caspian Sea are given in the work of S.V. Burevich (1949a). The maximum rates were observed in shallow water, not found in the Gulf of Kaidak nowadays. The figures are 340, 360 and 540 for 1 m of deposition, i.e. 3, 2.8 and 1.8 mm per year. In the conditions of Kaidak, where transportation by river is absent and the strength of the breakers is insignificant, the depositions are mainly of the aeolian type. The maximum rate was observed in Tube-Karagan (580–1600 years), where the observations were carried out by M.V. Fedosov (1950).

The composition of the marine aeolian depositions and partly of the aeolian carbonates has been considered by S.V. Burevich and E.G. Vinogradov (1949). It is shown that the composition of the rocks of the deserts and semideserts of Central Asia includes up to 16.5% carbonates. These carbonates are transported with the wind to the Caspian and deposited along with terrigenous material.

There is no doubt that the aeolian deposits have an important role along the eastern shores of the Caspian and Aral seas, Lake Balkhash and other reservoirs in the desert areas. It is possible to classify the aeololake deposits on the lines of the aeolomarine deposits.

Attention is drawn to the problem of transportation of aeolian sand to the Caspian and other seas, about which little is known. The data given above are mainly related to aeolian dust, silt and clay particles. It is only M.V. Fedosov (1950) showed that at heights of 0.6 and 1.9 m a considerable amount of "pseudosands" can be trapped. It contained carbonate grains derived from crushed cockleshells.

There is no doubt that storms and hurricanes along with the dust of the surface transport a considerable amount of sand to the coast also by the sandy wind flow. This sand falls in the sea and settles off the coast. It gradually augments the land, reducing the area of the sea. Data on the rate of augmentation are not available but the number of strong storms and hurricanes is considerable, the quantity of sand in the deserts is unlimited and there is no doubt about the augmentation of land on the desert side.

It is especially significant in defining the outline of lagoons of the Karaboges type. As such, the aeolian materials predominate in the terrigenous and salt layers of such lagoons.

Past Aeolomarine Deposits

Well-developed as the aeolomarine deposits are in present-day seas, they were no less developed in the past. The main condition for the formation of aeolomarine deposits is the proximity of the sea to a big desert. The storms and hurricanes originate in these deserts, carrying an enormous amount of red and yellow dust to the sea.

Large deserts adjoining the sea have developed repeatedly in the history of the earth. Specifically, a vast red desert was situated in central Europe during the Upper Triassic period. To the south of it, adjoining a warm sea, was the region of growth of thick massifs, situated in the region of what are now the eastern Alps. There is basis to suggest that the red dust from the central European desert was transported to the region of the Alpine reefs.

It is of interest to note that this idea was proposed by the German geologist Leucks 30 years ago. "All the data suggest that the red [clayey-D.N.] layer in the main dolomite contains aeolian material which was deposited on the water and then settled in definite places. Thus short discontinuities in the normal deposits of lime silts originated" (Leucks, 1932, p. 155).

The data are as follows: In a number of regions of the eastern Alps enumerated by Leucks, fine layers of red silt (up to 1 m) were observed in the thick layers of dolomite. The analysis of one sample (in percentages) showed SiC_2—47.5; $(Fe, Al)_2O_3$—36.1; CaO—3.3; MgO—0.5; CO_2—3.2. The particles of quartz and other minerals, going into the composition of the clay. were of small size—0.05 mm and less.

The red clay of the Alps is similar to the red clay at the bottom of the sea between Australia and New Zealand, which contains a considerable amount of aeolian dust transported by storms from the desert of Australia and carried to New Zealand.

Leucks' proposition is quite credible, but has yet to receive support.

The maximum growth of the deserts was attained in the Pre-Cambrian period, and at the beginning of the Paleozoic, Cambrian, Ordovician, Silurian and Devonian periods. During these periods there was no continental higher flora and the entire surface of the continents was desert. Similarly, perennial rivers, lakes and swamps were also absent.

The hurricanes and storms moved freely over the surface of the continents. However, the continents were small compared to the present size.

These storms freely lifted enormous masses of dust into the air. This dust was transported in a direction corresponding to the main direction of movement of the hurricanes and storms. Therefore, in the surrounding seas the aeolian dust was not deposited everywhere but accumulated in definite directions. Where these regions were situated and which clay-carbonate deposits were of aeolomarine type is not yet known.

The very strong storms could give rise to fine layers of red, brown or yellow clay-silt formations whose thickness varied from a few millimeters to a few tens of centimeters. Generally the aeolian dust was mixed with normal marine deposits but could be distinguished by the grains of quartz and feldspar covered with "desert encrustation." The usual size of such grains is from a few tens of microns to a fraction thereof. The discovery of such grains is one of the fascinating tasks of the future.

AEOLOEFFUSIVE DEPOSITS

This name is given mainly to formations of effusive origin which undergo a considerable amount of transportation by the wind. They are deposited without any direct link with volcanoes in different physico-geographical conditions. The marine aeoloeffusive formations occur among the marine deposits and contain marine fauna. The continental aeoloeffusive formations are encountered among the continental deposits. The lake variety contains remnants of freshwater plants and, rarely, of animals. The surface varieties are negligible or in rare cases contain the remnants of bones and shells of land animals. In the lake and swamp facets the imprints of higher plants are not rare. In the extra saline lakes, layers of volcanic material would occur among the salt layers. To date the aeoloeffusive deposits in the fossilized conditions have not been separated from the effusive layers.

Aeoloeffusive deposits are widely distributed among the present deposits. The enormous mass of loose material ejected by many volcanoes is well known. The volcano Tanboro on Sanbaba Island in Indonesia ejected 150 km^3 of material, i.e. the equivalent of 185 Vesuviuses; the volcano Kozegrina in Nicaragua 50 km^3; Katmai in Alaska 20 km^3; Krakatoa in Indonesia 18 km^3; Askya in Iceland 3–4 km^3. The multimeter thickness of volcanic dust ejected by Vesuvius, under which the cities of Pompei and Herculaneum were buried, is well known. When there is a strong wind volcanic dust is carried in a definite direction, settling at a distance of many tens of kilometers from the volcano. In such cases the dust layer loses its link with the centre of eruption and becomes an aeoloeffusive deposit.

The eruption of Krakatoa in 1883 covered an area of 827,000 km^2 with volcanic dust. The fine dust spread as far as western Europe. Deep straits were filled with ash and became unnavigable. An enormous area was covered with aeoloeffusive deposits due to the eruption of the volcano Katmai on June 6, 1912 (*The Eruption of Krakatoa,* 1888; Furneaux, 1964).

Striking examples of the transportation of volcanic ash (dust) to an enormous distance and of aeoloeffusive deposits of considerable thickness are given in the monograph by Blacktin (1934, p. 187–190). With the eruption of Skaptar-Iokull in Iceland (1783) the air was saturated with dust for many weeks and ash settled in Scotland, more than 900 km away, destroying the crops. In the famous eruption of the volcano Mon-Pele in Martinique (1902) the fire cloud, moving with hurricane speed, destroyed the city of Saint Pierre with a population of 30,000 (Fig. 239). Only one citizen, a negro in the jail, survived. The dust covered the bottom of the sea over a large area, forming typical marine aeoloeffusive deposits. A still bigger area at the bottom of the sea was covered by volcanic dust in Japan due to the eruption of the volcano Sakuradzim in 1946.

Interesting data are given in the paper "Volcanic ash fallout" by G.O. Krivolutsk and V.A. Nechaev (1963). It describes the transportation by the

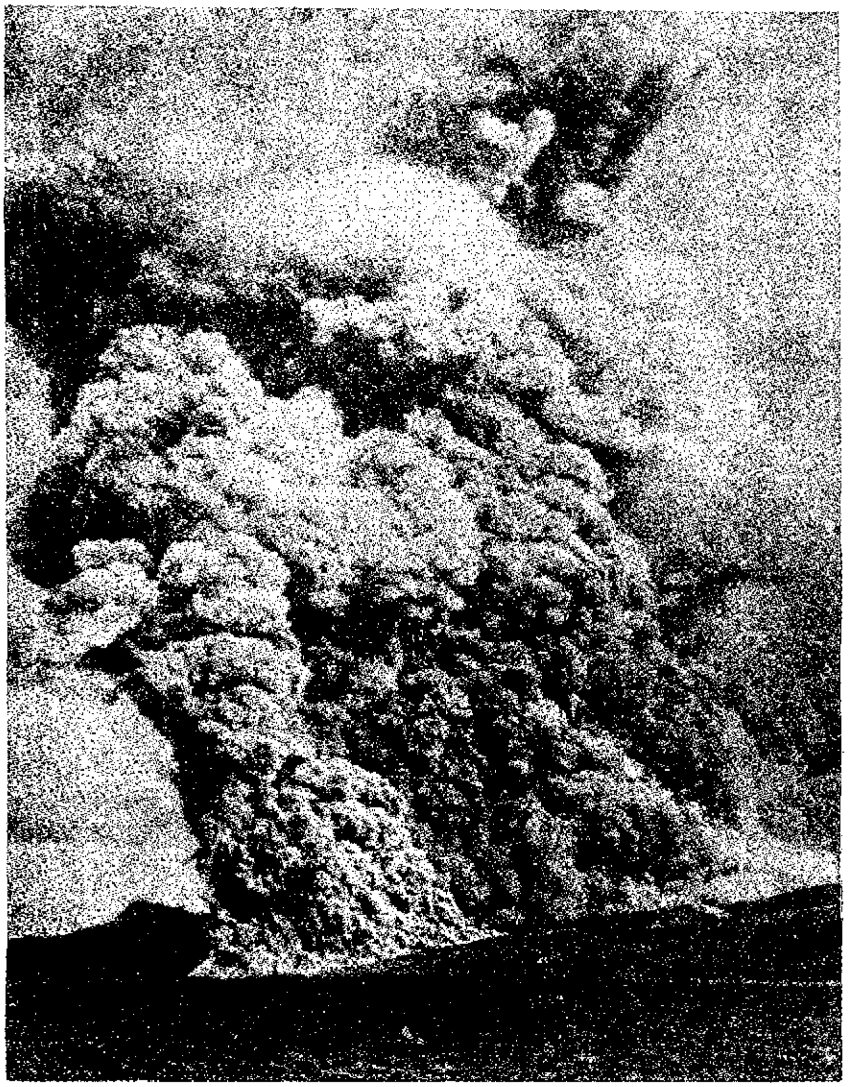

Fig. 239. Volcano Pele. Huge, scorching cloud spreading over sea (Butze, 1955).

wind and the deposition of volcanic ash in the Kurile Islands (Kunashir) after the eruption of the volcano Takashi Dake. An enormous black cloud with a red tinge appeared in the west. It moved slowly. It covered the entire sky and it became dark as in a solar eclipse. The ash vortex whirled over the sea. An enormous quantity of ash fell on the island, killing many insects and even small animals.

It should be remembered that the ash transported by the wind kills not only insects. The examples of Pompei and Herculaneum are vivid in our memories. Recently the volcano Parikutin in South America ejected an enormous quantity of ash. This ash transported by the wind turned the surroundings from a colorful country to a lifeless desert.

Instructive photographs of the eruption of the volcano Bezymyanni in Kamchatka in 1955–1956 are given in the well-known book by G. Tazier, *Volcanoes* (1963). The initial stage of the eruption on October 30, 1955, can be seen in Figure 240. The cloud of volcanic ash is not yet very large, but it can be clearly seen how the strong wind is blowing the cloud of ash in one direction. After five months, on March 30, 1956 the eruptions reached a maximum (Fig. 241). The fantastic cloud was lifted to a height of not less than 20 km. It formed expanding hot gas which carried millions of tons of pulverized exploded material. The strong wind, as usual, carried it in a definite direction.

The books by G. Tazier (1961, 1963) contain a number of photographs showing the enormous size attained by the clouds of the volcanic ash for volcanic eruptions occurring in the relatively recent past.

The aeoloeffusive deposits in fresh condition display one property which is very important in the geological sense. They are easily dissolved in water. The experiments by I.I. Tovarov (1958) showed that the water percolating through fresh pyroclastic material carries away many easily soluble components almost without changing the material.

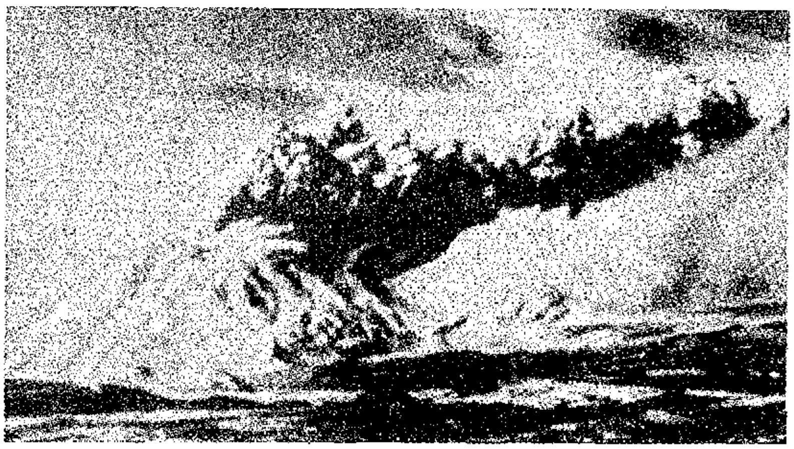

Fig. 240. Volcano Bezymyanni, Kamchatka. Initial eruption of October 30, 1955. Wind carries cloud to one side (Tazier, 1963).

According to him the volcano Bezymyanni erupted 0.8 km^3 of dust and 1.8 km^3 of loose agglomerates in 1955–1956. The burning sand from the explosion covered an area of about 500 km^2. Due to this about 20 million tons of easily soluble materials were transported. They contained 160,000 tons of iron and 100,000 tons of aluminum.

One correction should be made to these data. The orientation of the area occupied by the products of the eruption depended not on the "direction of the eruption" but on the direction of the wind carrying the ash and sand. It is clearly visible in the photograph (Fig. 240) of the initial stage of eruption, where the wind carries the cloud of ash almost parallel to the ground.

Fig. 241. Volcano Bezymyanni, Kamchatka. Maximum eruption on March 30, 1956. Remarkable cloud rose to altitude of 25 km (Tazier, 1963).

The problem of the formation of ore deposits due to the dissolution of aeoloeffusive deposits receives attention in the original work by G.S. Jotsenije (1965). The formation of such deposits takes place at a considerable distance from the volcano, of the order of many tens or even hundreds of kilometers, depending on the quantity of erupted material and the strength and direction of the wind transporting it.

G.S. Dzotsenidze (1965) also studied the formation of volcanic ash and bentonites. He shows that their distribution depends on the direction and strength of the wind.

The authoritative and informative work of E.G. Maleev (1963) considers in detail the numerous facets of volcanoclastic formations. Among the ground facets, deposited in a distant zone and having an allochthonous character, he distinguishes the tiniest group of aeolian facets (Maleev, 1963, p. 152) and divides them into eight seams. Here he considers the volcanic ash of Iceland and Kansas, mixed with the loess deposited over it, as well as the aeolian material mixed with the material of an eruption pipe in South Africa.

This idea of the significance of the wind in the formation of volcanoclastic rock is incorrect and is nothing but a distortion of the facts. Unfortunately, most petrologists go still farther and completely forget that the participation of the wind in the distribution and gradation of volcanic material is considerable.

Boulders and big fragments like volcanic bombs are thrown up into the air and dropped at short distances. Their trajectories are not significantly affected by the wind and they cannot be referred to as aeolian material (Butze, 1955).

Small stone chips and coarse-grained sands are not transported by a wind of average strength or less. After the eruption they also fall near the volcano without changing their trajectory. Such a case, of the eruption of the volcano Maion in Finland, is shown in Fig. 242. It can be seen here that the volcanic clouds have not changed form due to the wind. In the case of the volcanic eruption of Bezymyanni, in 1956, even in the first stage the volcanic cloud was engulfed by a strong wind and stretched out almost parallel to the ground. Such a wind can transport small fragments and sands in a given direction to tens and hundreds of kilometers. Settling on land or at the bottom of the sea, they will form a long area of tuffites and tuffs whose form will correspond to the form of the air current. Such formations should undoubtedly be called aeoloeffusive deposits.

The transportation and deposition of dusty (silty) and clayey (pelitic) volcanic material by the wind, not to speak of storms and hurricanes, have a definite role. The distance of transportation depends on the strength and duration of the wind. Local weak winds will transport material tens and, rarely, a few hundred kilometers, also in a definite direction. Strong storms and hurricanes literally form a powerful and enormous river in the air. For a relatively small width, they have a length of 2,000–3,000 and even 5,000–6,000 kilometers. Volcanic haze is transported to this distance (Kramer, 1950c).

Finally the clayey (pelitic) particles, lifted to a height of more than 12 km, enter the lofty global air current and the duration of transportation is almost unlimited. The clay particles ejected to a great height during the eruption of the volcano Krakatoa in 1883 formed a remarkable cloud, a "haze" which was observed by numerous observatories and circled the earth three times.

On June 12, 1951, the volcano Fogo in the Cape Verde Islands started erupting. The volcano ejected a cloud of ash to a height of 7,500 m. This gigantic mass of ash was subjected to gradation at great heights. The bigger sand and dust particles settled not far from the volcano, mixing with the aeolomarine deposits. The trajectory of the fine particles was quite different. Forming an original cloud of "haze", they traveled along the track of the Atlantic hurricanes. Three days after the eruption the haze had crossed the Atlantic Ocean, and on June 15 it reached the Antilles Islands. On June 18 the haze crossed the Yukatan peninsula. It reached the mouth of the Mississippi on June 20, the Bermuda Islands on the 26th and dissipated over the Atlantic Ocean. The total length of the track was more than 1,200 km. The clay particles forming the haze reduced visibility and produced a film on

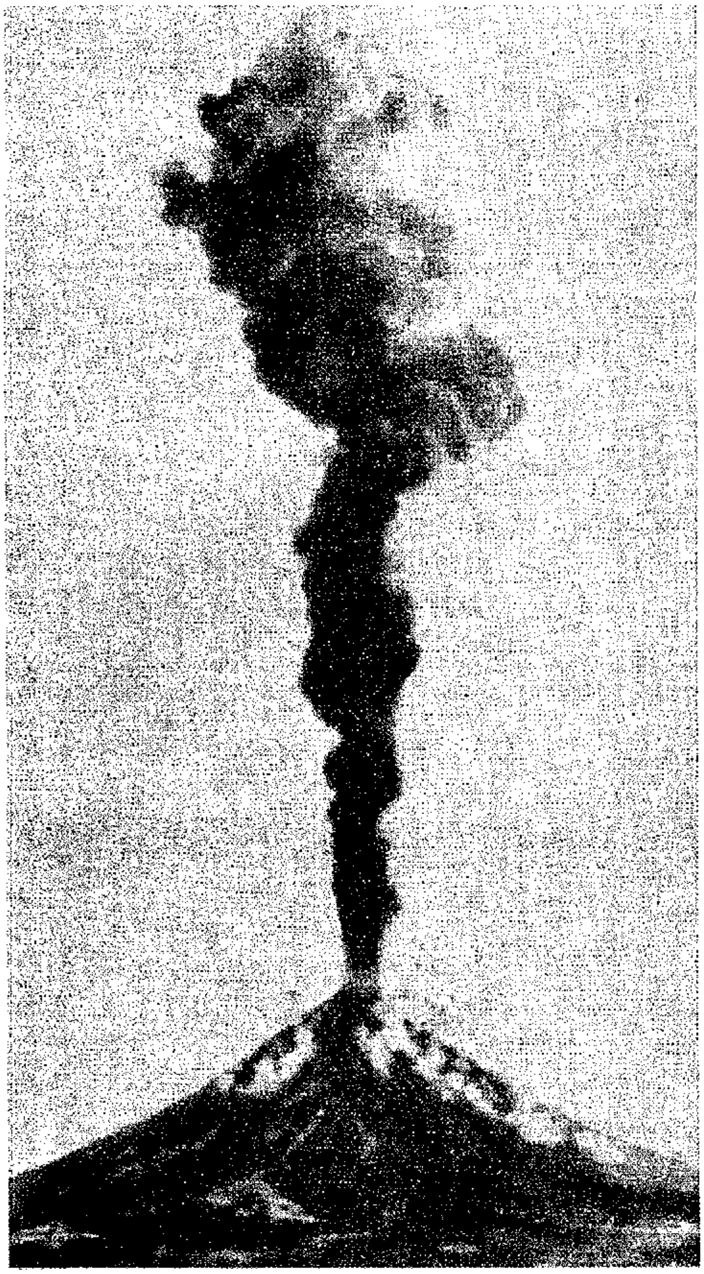

Fig. 242. Powerful ejection from volcano Maion, Philippines (Butze, 1955).

the windshields of airplanes. In the USA examination under the microscope showed that the haze consisted of fine particles of volcanic glass (Brown, 1952).

It is of interest that everywhere the haze moved in clear weather, as if there were no hurricane. The dust was carried to a great height with the speed of the hurricane. It covered the whole long track of 11,200 km up to the Bermuda Islands in 14 days. Hurricanes Donna covered the same track in 15 days in September, 1960. Hurricane Kerry in September, 1957, moved approximately at the same speed and over the same track.

There is no relationship between the gigantic vortex of tropical hurricanes and the accumulation of fine haze, yet it followed the same track at the same speed. The hurricane is a strong vortex motion of air, enveloping the entire atmosphere from the surface of the earth to a height of 12–14 km, having a diameter of many hundred kilometers and destroying everything in its path. The haze is transported almost unnoticed, very high in the sky in clear, bright weather, but the track and speed are the same as the hurricane's.

It should be added that the warm current in the North Atlantic also follows the same track. Obviously, there is some fundamental cause that gives rise to the warm current, the hurricanes and the wind carrying the haze, and the orientation of their paths.

AEOLOLACUSTRINE DEPOSITS

In many lakes sandy-clayey materials are brought by rivers or formed by the action of breakers. There are many other lakes which are devoid of any river flow and have low banks where the action of breakers is negligible. In these lakes the main mass of sand and clay is transported by the wind and a deposition is formed that can be correctly termed an aeololake deposit.

The lakes where such deposits are formed, are divided into three types: freshwater lakes, highly saline lakes and swamps.

They are essentially located in the arid regions, especially in the deserts. Here the quantity of the deposition is negligible, rivers are absent and rain extremely rare. The entire transportation of sandy-clayey materials is carried out by sand- and dust storms. As already mentioned, the small stone chips and sand move over the ground in bounces of not more than 1–2 m. When such materials reach the lake they are deposited on its shore. At any depth in reservoirs only silt-clay materials are deposited. Then this material is deposited over the entire area of the reservoir, forming a homogeneous layer of small thickness, from a few millimeters to a few centimeters.

The storms pass over, the transportation of dust ceases, the surface of deposition becomes dense and plant straws and fine flakes of mica are deposited over it, thus forming the discontinuities of surface and the surface of stratification. A new dust storm brings a new layer in which a surface of stratification is similarly formed. Due to this fine, regular layers develop. They consist of dense, homogeneous fine-grained material, giving a mixture of silt and clay particles.

In freshwater lakes, the entire deposit will be of this silt-clay type. At the shores its growth is gradual but it quickly changes to sand from the rare stone chips. The typical features are the usual freshwater fauna and flora. The distinctive indications of aeolian deposits in freshwater lakes are: 1) fine, regular layers; the thickness of individual layers is quite different, depending on the duration and strength of the dust storm, but generally of the order of a few millimeters to a few centimeters; 2) silt-clay composition predominant with quartz grains and feldspar; 3) limited area of distribution, depending on the size of the lake.

Remarkable examples of aeololake deposits are bituminous layers and diatoms. The first is formed in sapropelic lakes, the second in lakes with massive growth of diatoms. Study of these lakes shows that as a rule they are devoid of water channels. All the silt-clay and sandy materials deposited here are of aeolian origin, transported by storms, and sometimes by hurricanes. These materials mix with the sapropelics and diatoms, forming a thin layer. The latter is formed by strong and prolonged dust storms.

At the moment sapropelic lakes are relatively rare and of small size but in the past, in particular epochs, they were big and widely distributed. In the Upper Jurassic period and in the Lower Chalk series freshwater bituminous layers with fish, insects and other creatures were distributed all over Siberia. They were more widely distributed in Central Asia, in Sin'tszyan. Here, they are related to oil and gas deposits.

Bituminous coal is included in the composition of different carbonaceous layers, underlining the enormous significance of aeolian material in the formation of the latter.

All the coal geologists assume that the ash of coal and lignite is carried by rivers and as such is of aquatic origin. Now this should be reconsidered. Coal ash is a typical aeololake material. It is similarly related to the sapropelic and humus coals.

The saline and highly saline lake deposits consist of layers of chemical depositions, including layers of dolomites and limestones, alternating with layers of silt-clay formations of aeolian origin. The latter differ by their homogeneous composition, small thickness and large area of distribution, often enveloping the entire reservoir.

The stronger and longer the dust storms, the greater the thickness of the silt-clay formations. Small, short-lived storms do not form isolated layers. They only mix the dust particles with the total mass of chemical depositions.

Our salt geologists often think that clay layers in the salt beds are due to the activity of rivers. Actually, in most cases, they are formed not by rivers but by dust storms. Dust storms as a factor in the formation of salt beds deserve very serious attention.

In swamps the entire water area and the adjoining land are completely covered with plant cover, mostly trees of considerable height. It is due to this that the activity of the rivers is negligible, but the enormous mass of aeolian material carried by storms and hurricanes is contained by vegetation and settles in the swamps.

Swamps are distributed everywhere. They occupy large areas in the prepolar region, especially in our tundra. The wide, flat watersheds of Siberia are no less significant. They extend hundreds and thousands of kilometers along the Atlantic coast of North America. Nor should the vast swamps in the wide desert valleys be overlooked.

The dust transported by storms and hurricanes, often in enormous quantities, settles anywhere and everywhere in these regions. In the total absence of transportation by rivers, transportation by the wind has an important role. The aeolian material, settling over a long period, participates considerably in the formation of swampy deposits.

The swampy deposits of the past are the carboniferous formations containing all the coal reserves. The aeolian silt and clay deposits are all very important in their formation. Often we look for rivers in vain to confirm the transportation of large amounts of silt and clay in the coal-bearing formation, forgetting the storms and hurricanes that transport these deposits in larger quantities than rivers could. It is sufficient to remember the calculation given above, according to which the wind carries more dust to the Mississippi valley than the river. What happened in the steppe and desert regions? There is no doubt that storms and hurricanes rage continuously along the Atlantic coast of North America and transport to the coastal swamps greater amounts of dust and sand than the rivers generally skirting or traversing the swamps.

Before concluding this account of aeololake deposits, it may be said that they cover only a negligible part of the entire material. Unfortunately, this material is yet to be studied. The analysis of salt and coal layers, shales and lake deposits does not consider the great role taken by the aeolian processes in their formations.

AEOLOWATERSHED DEPOSITS

In the relief of the earth's surface the watersheds have an important role and occupy a considerable area. The deposits that have developed in them have not been studied in detail and are almost unknown in the fossilized condition.

Lakes and swamps are rarely encountered in watersheds and the main mass of deposits is in the surface subsidence.

The origin of these deposits is extremely interesting, especially for the wide, flat plains of the watershed platforms. It is interesting in that for these watersheds the transportation of deposits to the water is excluded. The water here only moves below already existing deposits. For such depositions the materials are carried only by the wind, especially by hurricanes and dust storms. Therefore it may be taken that deposits in the plains of watersheds are aeolian deposits. They are referred to as "aeolowatershed" deposits.

The fine grains are the typical feature. The wind primarily lifts dust and clay particles to the watersheds. It is only very strong storms and hurricanes that can lift fine-grained sands.

Correspondingly, in the deposits of watersheds fine-grained materials are quite prominent. The wind simultaneously transports dust and clay particles and often sand. Therefore the watershed formations will predominate in loam and loess, as is found in nature.

As a rule the aeolian material more or less changes the soil-forming processes. However, the primary aeolian origin of the deposits of watersheds cannot be doubted.

Exposure of the bedrock whose erosion might have given rise to sandy-clayey material, is either absent or insignificant in the plains of watersheds. The wide, circular, almost flat plains of watersheds stretch over a distance of hundreds or thousands of kilometers. This area of tens of thousands of square kilometers is entirely covered by aeolowatershed deposits.

The picture is remarkable, but it is still more remarkable that geologists do not recognize it and regard aeolowatershed deposits as aquatic deposits. Some geologists go a step farther in fantasy and refer them to marine deposits, though marine fauna are absent and the sea is more than 100 kilometers away. The tendency of excessive emphasis on marine deposits is unfortunately a widely prevalent error.

A remarkable feature of the watershed is the wide elevated plateau. When such a plateau is situated in the path of dust storms its surface becomes a region of accumulation of dust and clay particles, a region of accumulation of aeolian loess and aeolian red loam.

One such well-known plateau is situated in northwestern China. A considerable part of the loess and red loam of the world is to be found in this area.

Another enormous plateau—a region of accumulation of loess—is situated in the western plains of Argentina.

AEOLODEPRESSION DEPOSITS

Whereas aeolowatershed deposits consist primarily of dust and clay particles, aeolodepression deposits, on the contrary, consist of sand particles with little mixture of coarser-grained material.

There are various types of widely distributed depressions over the surface of the earth. They can be divided into three major groups: first—the coasts of oceans and seas; second—the wide river and lake valleys on the banks of rivers and lakes; third—the enormous intracontinental valleys without drainage.

Along the coasts of oceans and seas there are often wide plain regions where the coast has the character of a beach. In such regions there is often a constant strong breeze—the coastal breeze—attaining storm strength. At such places, hurricanes and cyclones often occur. These vortices, storms and hurricanes erode material adjoining the zone of breakers, constituted of sand, dust and clay particles. The sand particles and pebbles are not transported a great distance. The pebbles remain in the zone of the breakers and the sands form coastal dunes. The dunes are formed on the land as well as at the bottom of the sea. The surface dunes retain their form but the submarine dunes are radically changed by the action of marine channels and breakers. It should, however, be remembered that in the adjoining zone of the breakers the sand contains a considerable quantity of grains transported from the land by the wind and these are essentially aeolian material.

Marine coastal dunes are widely distributed. They have been studied and discussed in detail.

The dust and clay particles are carried far and deep inland. Here they are mixed with other deposits and do not form any special deposit that would stand out prominently in the sections.

During very strong storms and hurricanes the quantity of such particles increases so much that they form a whole layer. The thickness of the layer is not great, from a few millimeters to a few centimeters. In individual cases it may be considerably more, up to tens of centimeters or a few meters. This was observed on the exposed clayey coasts during the prolonged dry epoch, giving rise to large quantities of loose silt-clay material.

The fauna of these layers are quite peculiar. Almost exclusively, they consist of marine microorganisms, primarily of foraminifera. Among the latter, the benthic and plankton forms are uniformly present. The number of aeolian layers is considerable and they are more or less widely distributed in all the layers along the entire length of the coastal plains, which are generally of the order of many hundreds or even thousands of kilometers.

Forms other than microorganisms are encountered very rarely. The solitary example is that of the shells that were transported by hurricane Hazel in 1954. They can be very big in size.

If the aeoloplain deposits of the past are to be traced they should primarily be sought in the form of flysch. The detailed work of the Polish geologists, including leading specialists like Prof. Kzenzhkevich, gives exceptionally interesting and important material on the fauna of flysch in Carpathia.

Study of these fauna shows that they display a number of features inherent in the form of aeoloplain deposits. The most important of them are that they generally consist of one type of foraminifera in deep-seated water or coastal areas, due to the absence of other forms. In normal marine deposits this never occurs in such areas. The fauna of nummulitic limestones, at places participating in the composition of flysch, are the fauna of coastal foraminiferous dunes. The menilite bituminous shales very much resemble the aeololake deposits of big sapropelic lagoons. The silt-turbulent types of deposit of flysch are similar to the deposition of big floods caused by hurricane waves.

Here it is not possible to dwell on this problem. It has to be considered in a special work. It may be said that the study of hurricanes and storms and the deposits related to them shows that flysch is a deposit of wide coastal alluvial plains.

River and lake valleys similarly have plain regions with constant strong winds and storms. Here the coastal deposits are eroded and graded. The sand grains form coastal dunes and occupy smaller areas than the sea but generally spread over considerably larger areas. They have been studied in great detail and do not require any additional description.

The dust and clay materials are deposited far from the rivers and lakes where the strength of the wind decreases. Here the layers of loess and loam are formed.

The ratios of the quantity of sand, dust and clay materials in the river valleys are different. Downstream of the big plains rivers the quantity of sand is maximum and here the dunes are best-developed. In the upper part of the valley, on the other hand, dust and clay materials are predominant. Here erosion yields less sand but a considerable amount of silt, stone and clay particles.

It is quite probable that the loess formations and the red and gray loams, so well-developed in the Russian platforms, are due to the erosion of river deposits located near the river and lake valleys. Such an explanation deserves serious attention.

The inner continental depressions yield remarkable geolo-geographic formations which to date have defied thorough explanation. They are absent in Europe. They are of small size in North and South America and of enormous size in Asia, Africa and Australia. Everywhere they are found in arid regions and are absent from humid regions. The rivers flowing in valleys devoid of drainage fill up the depressions with their deposits and are not the reason for their formation. The cause is tectonic movement—the enormous subsidence of blocks invariably accompanied by uplifting of mountains bordering the depression.

The main fact refuting the theory of erosion is the absence of the products of erosion on the fringe of the depression. On the contrary, the main mass of the product of erosion—aeolian sand, consisting of enormous massifs—is not situated on the edge of the depression but at its center. The quantity of loess and loam actually surrounding the depression is many times less than that formation filling the depression, which would have been present before erosion. The volume of the depressions of the Sahara, middle and central Asia is enormous.

Aeolian sands are the best-developed deposit in such depressions. They have been studied in detail and described in numerous works. A large volume of data and conclusions is given above. Often aeololake deposits are encountered in freshwater lakes as well as in salty and marshy lakes. Aeolo-river deposits are formed in the valleys of big rivers crossing the depressions. They are of the normal type and are described above.

The specific characteristics of deserts are shown by the peculiar rubble-clay rocks. They make up the surface of the rubble desert and extend many hundreds of kilometers. Their thicknesses are insignificant as they are formed due to the accumulation of retransported deposits and the removal and erosion of old deposits. The pebbly-clay rocks are of this type, covering a small area only. They occur only in the Sahara and are unknown in the deserts of Asia.

Thus we conclude this account of aeolian deposits. It is obviously not complete and there are a number of other varieties of such deposits. They have not been studied in detail and their description is a task for the future.

Conclusion

Dust storms are distributed all over the world and they often cause large-scale loss to the economy. Therefore there is a large volume of literature available on the subject. It runs to hundreds and maybe thousands of papers if all the languages of the world are taken into account. If the books on the deposits formed by dust storms—aeolian sand, loess, watershed loam—are added, then the quantity of literature is still greater.

The most unexpected thing happens when we go through the unusually rich meteorological literature in all the languages of the world on strong winds and their consequences. Hurricanes and storms have destroyed ships for the last 4,000 years. There have been no catastrophes in the world like those caused by the hurricanes in the Bay of Bengal and the typhoons in the Pacific Ocean, killing many hundred thousand people. Just one hurricane—Donna of August 10–14, 1955, caused loss and destruction of the order of 2 billion dollars. It is not possible to enumerate all the unusual phenomena caused by tornadoes.

Such things have been depicted, recorded and studied in the last 100 years, thoroughly and in great detail. The first data are found in the Egyptian hieroglyphs and Asian cuneiform writings. Interesting and relatively detailed descriptions and even explanations are given in Latin and other ancient languages. The Arabs, Chinese and Indians did not lag behind. Even during the culturally backward period, during the middle ages, the red "blood" rains have been described. Each century, the descriptions have become more numerous. They became more and more detailed and thorough. Their number, like an avalanche, grows steadily and no one knows the total number.

In the last 200 years this avalanche has steadily increased, expanded and become more and more diverse and detailed. The hundreds of works increased to thousands and maybe tens of thousands of monographs, books, papers, notes and references.

Like any other science, the trend in meteorology has been a transition from descriptive, recording work, touching primarily on the main phenomena to generalized, analytical work embracing the entire complex of interrelated phenomena. The most typical development is the greater use of quantitative methods.

The second tendency, characteristic of meteorology, is the increase in the field of narrow specialization, which is quite well-developed now. At the same time, the description of the geological and geographical activities of hurricanes, storms and tornadoes has sharply declined. It is taken to be a familiar initial step. Unfortunately, at times this is far from the reality.

Therefore the very important, essential factual material is contained in the works of the second half of the last century and the first 10 years of the present century. During this period the big reviews and consolidated works have been very few. Mostly the data are found in small, short and often very short descriptions, notes and references. They are quite large in number, in hundreds and thousands. They are scattered in numerous specialist journals. Inevitably, the list of works used has a large number of titles, but often the number of books and notes was very small. The search is laborious and a large number of them contain no important work. The author devoted several years to this quest.

The most complete selection of old and new books and journals is available in the library of the Central Geophysical Observatory in Leningrad (Director E.L. Andronikov). Nowadays it collects through the Moscow Library of the Main Administration of Hydrometeorology. The Moscow library is not bad but the collection for the last 100 years is incomplete.

The nice old library of the Geography Department in Leningrad was of great help to me. A large number of books were obtained from the library of the Geography Institute in Moscow. As usual, the entire geological literature was to be found in the Central Geological Library in Leningrad, the best geological library in the USSR and one of the best in the world.

Inevitably I had recourse to our major libraries: the library of the Academy of Sciences in Leningrad, the Public Library in Leningrad, the V.I. Lenin Library in Moscow, the library of foreign literature in Moscow (Director M.I. Rudomino). But it may sound strange that in spite of the millions of books they keep, the number of monographs and journals, old and new, I did not find all the books I needed. Even our huge libraries do not have all the books, especially foreign ones.

Hurricanes, storms and tornadoes are phenomena that are very difficult to study and observe directly. Books are necessary. Herewith I offer a book with the help of the libraries listed above and with the help of their personnel and directors. This work would have been impossible without their help.

References

A selective bibliography in meteorology. *Weatherwise,* vol. 14, No. 5, 1961, pp. 187–191, 199–205.

A selective bibliography in meteorology. *Weatherwise,* vol. 18, No. 5, 1965, pp. 206–217, 224.

A weather fan. The Tampa bay waterspout. *Weatherwise,* vol. 17, No. 4, 1964, pp. 168, 190.

Abbe, C. Tornado in Cleveland Co, Okla., April 25, 1893, *Monthly Weather Review,* vol. 21, 1893, p. 109.

Abbe, C. The tornado at Little Rock, Ark., October 2, 1894. *Monthly Weather Review,* vol. 22, 1894a, pp. 413–414.

Abbe, C. Remarkable hail. *Monthly Weather Review,* vol. 22, 1894b, p. 215.

Abbe, C. Snow dust. *Monthly Weather Review,* vol. 23, 1895a, pp. 15–19.

Abbe, C. How do rains and winds spread epidemics? *Monthly Weather Review,* vol. 23, 1895b, pp. 295–296.

Abbe, C. Waterspouts in the Great Lakes. *Monthly Weather Review,* vol. 26, 1898, p. 351.

Abbe, C. Dust storms and red rains. *Monthly Weather Review,* vol. 29, 1901, pp. 120–121.

Abbe, C. Tornado at Carbondale, Pa., August 30, 1905. *Monthly Weather Review,* vol. 33, 1905, pp. 400–401.

Abdullah, A.J. Some aspects of the dynamics of tornadoes. *Monthly Weather Review,* vol. 83, 1955, pp. 83–88, Literature.

Abdullah, A.J. The "musical sound" emitted by a tornado. *Monthly Weather Review,* vol. 94, 1966, pp. 213–220.

Abercromby, R. *Weather,* London, 1887, pp. 472.

Aquirre, E.D. Hurricane of the Gulf of Mexico. *Weatherwise,* vol. 16, No. 5, 1963, pp. 223–225, 252.

Akimovich, N.N. Zapylennost' vozdukha vo vremya pyl'nykh bur' na severnom kavkaze (Dust content of air at the time of a dust storm in the North Caucasus). In sb: *Pyl'nye Buri.* Moscow, 1963, pp. 97–100.

Alexander, W.H. Hurricanes. Especially those of Puerto Rico and St. Kitts.

Bull. Weather Bur. United States, vol. 32, 1902, p. 79.

Alexander, W.H. The distribution of thunderstorms in the United States. *Monthly Weather Review,* vol. 52, 1924, pp. 337–343.

Alisov, B.P. Yavlenie bory V vostochnom Kazakhstane (Effect of the bora in East Kazakhstan). *Zhurnal Geogr.* vol. 5, No. 1, 1935, pp. 99–115.

Anapol'skaya, L.E. Rezhim skorosti vetra na territorii SSSR (Wind speed conditions over the territory of the USSR). Leningrad, 1961, pp. 200.

Anderson, F.J. and G.D. Freier. Role of wave motion in a tornado. *Journal of Geophysical Research,* Washington, vol. 70(12), June, 1965, pp. 2781–2784.

Andree, K. Geologie des Meersbodens. Bd. 2. Leipzig, 1920, pp. 201.

Andrus, C.G. Notes on line squalls. *Monthly Weather Rev.,* vol. 7, 1929, pp. 94–96.

Apollov, B.A. Vliyanie elovoi akkumulyatsii na obmelenie severnoi chasti Kaspiiskogo morya (Effect of aeolian accumulation in making the northern part of the Caspian Sea shallow). *Izv. Tesentr. Gidromet Byuro,* No. 7, 1927, pp. 273,

Arabadzhi, V.I. Teoriya atmosfernogo elektrichestva (Theory of atmospheric electricity). *Uch. Zap. Minsk. Univ. Ser. Fiz-mat,* No. 5, 1957, pp. 79–98.

Arakawa, H. Vertical structure of a mature typhoon. *Monthly Weather Review,* vol. 78, 1950, pp. 197–200.

Arakawa, H. Typhoon Vera and its induced storm tide. *Weatherwise,* vol. 13, No. 4, 1960, pp. 150–152.

Arakawa, H. and K. Suda. Analysis of winds, waves and swells over the sea to the east of Japan during the typhoon of September 26, 1935. *Monthly Weather Review,* vol. 81, 1953, pp. 31–37.

Asher, C.D. Windstorm at Independence, Calif., February 12, 1923. *Monthly Weather Review,* vol. 51, 1923, pp. 82–83.

Asp, M.O. Tornadoes in Oklahoma 1875–1949. *Monthly Weather Rev.,* vol. 78, 1950, pp. 23–26.

Astapovich, I.S. Pyl'naya burya nad Tsentralnom Kopet Dagom (Dust storm in Central Kopet Dag). *Priroda,* No. 7, 1955, pp. 98–99.

Avias, J. Sur L'origine du gite de chrome de l'ile Hugon (Nouvelle Caledonie). *Compt. rend.,* fasc. 9, 1965, pp. 301–303.

Avias, J. and Jean-Coudray. Sur la presence d'eolianites en Nouvelle Caledonie. *Compt. rend.,* fasc. 10, 1965, pp. 327–329.

Babichenko, V.N. Pyl'nye buri na Ukraine (Dust storm in the Ukraine). *Tr. Ukr. Gidromet Inst.,* No. 52, pp. 45–62, Literature.

Bagnold, R.A. Libyan sands. London, 1935, pp. 13–351.

Bagnold, R.A. The physics of blown sand and desert dunes. New York, 1941, 265 pp.

Ball, M.M., E.A. Shinn and K.W. Stockman. The geologic effects of hurricane Donna in South Florida. *Journal Geology,* vol. 75, No. 3, 1967, pp. 583–597.

Barabashkina, A.P. and E.A. Leskova Issledovanie taifunov, vykhodyashchikh iz Yaponskogo morya v Primorskii krai (Investigation of typhoons developing in Japanese coastal waters). *Tr. Dal'nevost Gidromet Inst.*, No. 3, 1958, pp. 3–32.

Barakov, P.F. Elovya nanocy i pochvy na razvalinakh Ol'vin (Aeolian overburden and soil in the ruins of Ol'vin). *Pochvovedenie*, No. 4, 1913, pp. 105–122.

Barbour, G.E. Waterspout and tornado within a typhoon area (China). *Monthly Weather Review*, vol. 52, 1924, pp. 106–107.

Bark, L.D. A different-type tornado on June 8, 1966. Manhattan, Kansas. *Weatherwise*, vol. 20, No. 1, 1967, pp. 62–67, 71.

Barnes, F.A. and C.A.M. King. The Lincolnshire coastline and the 1953 storm flood. *Geography*, vol. 38, 1953, pp. 141–160.

Batalin, F.A. Smerchi (The tornadoes). *Vestn. est. Nauk. MOIP*, Nos. 42–46, 1854, pp. 625–632, 653–663, 679–686, 688–702.

Bates, F.C. An aerial observation of a tornado. *Weather Res. Rep.*, vol. 1, Kansas Univ., 1961, 12 pp.

Bates, F.C. An aerial observation of a tornado and its parent cloud. *Weather*, Jan. 1963, pp. 12–18.

Battan, L.J. Radar meteorology. New York, 1959, 161 pp.

Battan, L.J. The nature of violent storms, New York, 1961, 158 pp.

Battan, L.J. Radar observes the weather. New York, 1962, 153 pp.

Battan, L.J. The unclean sky. New York, 1966, 141 pp.

Batyaeva, T.F. and L.S. Minina. Taifuny i uragany 1966g. (Typhoons and hurricanes of 1966). *Priroda*, No. 2, 1967, pp. 64–75.

Becker, R. Die Winde der Erde mit Eigennamen. *Watter u Klima*, Bd. 1, 1948, pp. 358–371

Beebe, R.G. Tornadoes during 1957. *Weatherwise*, vol. 11, No. 1, 1958, pp. 12–15, 37.

Beebe, R.G. Tornadoes during 1958. *Weatherwise*, vol. 12, No. 1, 1959a, pp. 13–15.

Beebe, R.G. Notes on Scottsbluff, Nebraska, tornadoes, 27 June 1955, *Bull. Amer. Met. Soc.*, vol. 40, No. 3, 1959b, pp. 109–116.

Beebe, R.G. The life cycle of the Dallas tornado. *Weather Bur. Unit. Stat.*, Res. Pap., 41, 1960a, pp. 3–52.

Beebe, R.G. Tornadoes during 1959. *Weatherwise*, vol. 13, No. 1, 1960b, pp. 15–17.

Beebe, R.G. Tornadoes during 1960. *Weatherwise*, vol. 14, No. 1, 1961, pp. 16–17, 29.

Belknap, W.N. Jr. New Mexico great white sands. *Nat. Geogr. Mag.*, vol. 112, July 1957, pp. 113–138.

Belknap, W. White sands. In America's wonderlands. Washington, 1960, pp. 249–257.

Belyaevskii, N.A. Novye dannye po geomorfologii i geografii zapadnoi chasti pustyni Takla-Makan (New data on the geomorphology and geography of the western part of the Takla-Makan desert). *Izv. Geogr. Obshch.*, vol. 79, No. 4, 1947, pp. 417–426.

Benevent, E. Bora et mistrel. *Ann. de geogr.*, vol. 39, 1930, pp. 286–289.

Bigelow, F.U. The waterspout seen off Cottage City, Mass., in Vineyard sound, August 19, 1896. *Monthly Weather Rev.*, vol. 34, 1906, pp. 307–315.

Bigelow, G.B. and V.T. Edmondson. Morskie vetrovye volny i priboi (Sea Wind Waves and Breakers). Moscow, 1951, 221 pp.

Billet, H. The tornado of South Wales and West of England, October 27, 1913. *Geophys. Mem. Met. Office,* No. 11, 1914, 16 pp.

Bjerknes, J. Extratropical cyclones. *Comp. Met.*, 1951, pp. 577–598, Literature.

Blacktin, S.C. Dust. London, 1934, 296 pp.

Bleeker, W. and A. Delver. Some new ideas on the formation of windspouts and tornadoes. *Arch. f. Met., Geoph.*, Ser. 4, No. 4, 1951, pp. 220–237.

Blinov, L.V. K voprosu o proiskhozdenii solevogo sostava morskoi vody. II. O proiskhozdenii solevogo sostava vod Kaspiiskogo i Aral'skogo morei (On the problem of the origin of the salt composition of sea water. II. On the origin of the salt content of the water of the Caspian and Aral seas). *Met. i. Gidrol.*, No. 4, 1947, pp. 52–64.

Blinov, L.V. 1950. O postuplenii morskikh solei v atmosferu i o znachenii vetra v solevom balanse kaspiiskogo morya (On the entry of marine salt into the atmosphere and on the significance of the salt balance of the Caspian Sea). *Tr. Inst. Okeanol.*, No. 15, 1950, pp. 67–112 and Literature.

Blinov, L.V. 1951. O vliyanii morya na zasolenie pochv i vod sushi (On the effect of sea on soil salinity and ground water). *Vopr. Geogr.*, sb. 26, 1951, pp. 168–196.

Blumenstock, D.J. Typhoon effects at Jaluit atol in the Marshall Islands. *Nature*, No. 8, 1958, pp. 1267–1269.

Blumenstock, D. The ocean of air. New York, 1959, 457 pp.

Bochet, R. Les tempetes de sable en Oranie. *Met.,* 4th Series, No. 12, 1948, pp. 251–277.

Bonacina, L.C.W. and E. Simmons. Tornadoes across England. *Weather,* March, 1950.

Boswell, P. Modern American Painting. New York, 1939, 166 pp.

Boughner, E.M. Hurricane Hazel. *Weather,* Oct., 1955, pp. 200–205.

Bor'ba s eroziei v raionakh osvoeniya tselennykh i zalezhnykh zemel' (Erosion Control in Regions of Reclamation of Virgin and Fallow Lands). Moscow, 1957, 100 pp.

Borishanskii, L.S. and E.S. Teverovskii 1952. O vynose morskikh solei vetrom na sushu (On the transportation of sea salt to the land by air).

Met. i Gidrol., No. 4, 1952, pp. 31–34.

Bova, N.V. O pyl'nykh buryakh v zavolzhi (On dust storms in Zavolzhe). *Met. i Gidrol.*, No. 12, 1957, pp. 29–31.

Bristol, H. Pescadores, Windswept outposts of Formosa. *Geogr. Mag.*, vol. 109, No. 2, 1956, pp. 265–284.

Bristor, C.L. The great storm of November, 1950. *Weatherwise*, vol. 4, No. 1, 1951, pp. 10–16.

Brooks, C.F. New England snowfall. *Monthly Weather Rev.*, vol. 45, 1917, pp. 371–385.

Brooks, C.F. Effect of winds on the flight of airplanes. *Monthly Weather Review*, vol. 47, 1919, pp. 523–532. Literature.

Brooks, E.M. The tornado-cyclone. *Weatherwise*, vol. 2, No. 2, 1949, pp. 32–33.

Brooks, E.M. Tornadoes. *Comp. Met.*, pp. 673–680, Literature.

Brooks, E.M. Progress in the study of tornadoes during 1954. *Weatherwise*, vol. 8, No. 1, 1955, pp. 20–21.

Brooks, H.B. Rotation of dust devils. *Journ. Met.*, vol. 17, 1960, pp. 85–86.

Brooks, T.R. The tornado of Southern Maryland, November 2, 1920. *Monthly Weather Review*, vol. 54, 1926, p. 462.

Brounov, P.I. Evropeiskie buri predskazaniya ikh (European storms and their prediction). Spb. 1884, 63 pp.

Brounov, P.I. Meteorologiya kak nauka o vetrvykh dvizheniyakh atmosfery (Meteorology: The Science of the Movement of Air in the Atmosphere). Spb. 1897, 33 pp.

Brown, A.H. Men against hurricanes. *Nat. Geogr. Mag.*, vol. 98, 1950, pp. 537–560.

Brown, W.F. Volcanic ash over the Caribbean, June 1951. *Monthly Weather Review*, vol. 80, 1952, pp. 59–62.

Bruevich, S.V. Skorost' obrazovaniya donnykh otlozhenii na Kaspiiskom morem (Formation speed of deposits in the Caspian Sea). *Izv. AN SSSR, Ser. Geogr.*, vol. 13, 1949a, pp. 9–32.

Bruevich, S.V. Skorost' obrazovaniya donnykh otlozhenii v mirovom okeane (Formation speed of deposits in the seas of the world). *Trudy Inst. Okeanol.*, No. 3, 1949b, pp. 90–118, and Literature.

Bruevich, S.V. and E.G. Vinogradova. Osadko obrazovanie v Kaspiiskom morem (Deposition in Caspian Sea). *Tr. Inst. Okeanol.*, No. 3, 1949, pp. 119–156.

Bruevich, S.V. and M.P. Gudkov. Atmosfernaya pyl'nad Kaspsiikom morem (Atmospheric dust over the Caspian Sea). *Izv. AN SSSR, Ser. Geogr.*, No. 4, 1954, pp. 18–27.

Budney, L.J. Unique damage patterns caused by a tornado in dense woodlands. *Weatherwise*, vol. 18, No. 2, 1965, pp. 74–77, 86.

Bugaev, V.A. and V.A. Jorjio. Sinopticheskie proteessy Srednei Azii (Synoptic processes of Central Asia). Tashkent, 1957.

Bugaev, V.A., V.A. Dzhordzhio and V.P. Dubensov. O termicheskom yeffekte pyli pri pyl'nykh i peschanykh buryakh (On the thermic effect of dust in dust- and sandstorms). *Izv. AN SSSR, Ser. Geogr.*, No. 3, 1962, pp. 44–45.

Bundgaard, R.C. The first fly-over of a tropical cyclone. *Weatherwise,* vol. 11, No. 3, 1958, pp. 79–83.

Busk, H.G. Land Waterspouts. *Met. Mag.,* vol. 61, 1927, pp. 289–291.

Butze, A. Lavastorme und Aschenregen. Leipzig, 1955, 244 pp.

Byers, H.R. General meteorology, 2 ed. New York, 1954, 645 pp.

Byers, H.R. Thunderstorms. *Comp. Met.,* 1951, pp. 681–693, Literature.

Byers, H.R. and R.R. Braham. The thunderstorm. Report of the thunderstorm project. Washington, 1949, 287 pp.

C.L.M. A waterspout in the Adirondacks. *Monthly Weather Rev.,* vol. 48, 1920, p. 351.

Cameron, D.C. The great dust storm in Washington and Oregon, April 21–24, 1931. *Monthly Weather Review,* vol. 59, 1931, pp. 195–197.

Capital and Country of Old Cathay. *Nat. Geogr. Mag.,* June, 1933, pl. VIII.

Carlquist, S. Island life. New York, 1965, 451 pp.

Carpenter, F.A. Convectional clouds induced by forest fires. *Monthly Weather Review,* vol. 47, 1919, pp. 143–144.

Carr, P.E. Report on tornado investigation, Smithtown (NSW), August 1964, *Austral. Met. Mag.,* vol. 48, March, 1965, pp. 23–26.

Castelnau, F.L. Pluie des poissons a Singapore. *Compt. rend.,* t. 52, 1861, pp. 880–882.

Cayeux, L. Les roches sedimentaires de France. Roches siliceuses. *Mem. Carte Geol. France,* Paris. 1929, pp. 774.

Chakvetadze, E.A. Nekotorye dannye po nablyudeniyam nad pyl'nymi buryami v priirtyshe' (Some data from the observation of a dust storm over Priirtish). *Pochvovedenie,* No. 2, 1962, pp. 69–77.

Changnon, S.A., Jr. Freak winter snowstorms in Illinois. *Weatherwise,* vol. 17, No. 6, 1964, pp. 272–276.

Changnon, S.A. and R.G. Semonin. A great tornado disaster in retrospect. *Weatherwise,* vol. 19, No. 2, 1966, pp. 56–65.

Chapman, F. Notes on consolidated aeolian sands of Kathiawar. *Quart. Journ. Geol.,* vol. 56, 1900, pp. 584–589.

Chapil, W.S. Dynamics of wind erosion. I. Nature of movement of soil by wind. *Soil Science,* vol. 60, 1945, pp. 305–320; II. Initiation of soil movement, *Soil Sci.,* vol. 60, 1945, pp. 397–411; V. Cumulative intensity of soil drifting across eroding fields. *Soil Sci.,* vol. 61, 1946, pp. 257–263; VI. Sorting of soil material by wind. *Soil Sci.,* vol. 61, 1946, pp. 331–341.

Chizhikov, I.V. Smerchi v Yaroslavskoi oblasti letom 1953 (The tornado in the Yaroslav region during the summer of 1953). *Kraev. Zap. Yarosl. Muzeya,* No. 1, 1956, pp. 67–85.

Choun, H.F. Duststorms in the southwestern plains area. *Monthly Weather*

Rev., vol. 64, 1936, pp. 195–199.
Chzhan Tszun-khu. O genezise i protsesse obrazovaniya lessov raiona Lundun v severo-Zapadnom Kitae (On the genesis and process of formation of loess in the Lundun region of Northwest China). *Tr. Kom. po Izuch. Chetv. Perioda,* No. 14, 1959, pp. 100–112.
Cline, I.M. Relation of changes in storm tides on the coast of the Gulf of Mexico to the center and movement of hurricanes. *Monthly Weather Rev.*, vol. 48, 1920, pp. 127–146.
Cloos, H. Wind und Wuste in Deutschen Namalande. *Neues Jahrab. f. Min.* Bd. 32, 1911, s. 48.
Coe, A.B. How the chinook came in 1896. *Monthly Weather Rev.*, vol. 24, 1896, p. 413.
Cole, H.S. Tornadoes in Arkansas, April 1929. *Monthly Weather Rev.*, vol. 57, 1929, pp. 155–156.
Colton, F.B. The geography of hurricane (New England hurricane of 1938). *Nat. Geogr. Mag.*, vol. 75, 1939, pp. 529–550.
Colton, F.B. Weather flights and works for man. *Nat. Geogr. Mag.*, vol. 84, 1943, pp. 641–670.
Colyer, F.H. Tornado in southern Illinois. *Monthly Weather Rev.*, vol. 41, 1913, p. 384.
Combier, Ch., P. Gaubert and L. Petitjean. Vents de sable et pluies de bone. *Mem. de l'off. Nat. Met. de France,* No. 27, 1937, 135 pp.
Conger, N.B. Report on the tornadoes of May 25 in the State of Michigan. *Monthly Weather Rev.*, vol. 24, 1896, pp. 156.
Correns, C.W. Die Sedimente des Equatorialen Atlantischen Ozeans. *Wiss. Erg. d. dent. Atlant. Exp. "Meteor"*, 1925–1927, Bd. III. Th. 3, 1937, 298 pp.
Cry, G.W. Tropical cyclones of the North Atlantic Ocean. Tracks and frequencies of hurricanes and tropical storms. Techn. Pap., No. 55, Weather Bur. Unit. Stat., 1965, 148 pp., Literature.
Cry, G.W., W.H. Haggard and H.S. White. North Atlantic tropical cyclones. Techn. paper. No. 36, Weather Bur. Unit. Stat., 1959, 214 pp.
Danckelmann, A. Unter der Harmathan phanomen in Togo. *Met. Z.*, Bd., 16, 1899, pp. 289–306.
Danckelmann, A. Die Natur des Harmathanstaubes in Togo. *Met. Z.*, Bd. 30, 1913, p. 448.
Darlington, F.D. Zoogeografiya (Zoogeography). Moscow, 1916, 519 pp.
Dauvillier, A. Cosmic dust. London, 1963, 167 pp.
Davis, W.M. The relation of tornadoes to cyclones. *Amer. Met. Jour.* vol. 1, 1884, pp. 121–127.
Davis, W.M. Elementary meteorology. Boston, 1899, 355 pp.
Davis, W.R. The 1958 hurricane season. *Weatherwise,* vol. 11, No. 1, 1958, pp. 17–19, 36.
Davis, W.R. Hurricane season of 1958. *Weatherwise,* vol. 12, No. 1, 1959,

pp. 16–23.
Defant, F. Compendium of Meteorology. New York, 1951a.
Defant, F. Local winds. *Comp. Met.*, 1951b, pp. 655–672, Literature.
Delpech, L. Sur une trombe a Chartres de Bretagne, 22 mars 1955. *La Met.*, Ser. 4, No. 40, 1955, pp. 317–323.
Delpech, L. Le trombe d'Evreux. *La Met.*, Ser. 4, No. 7, 1962, pp. 273–278.
Denisov, P.S. O borbe s zasukhoi i eroziei pochv v zapadnoi Sibiri (Control of drought and erosion of soil in western Siberia). In sb.: *Zashchita pochv ot yerozii,* Moscow, 1964.
Dessens, J. Man-made tornadoes. *Nature,* vol. 193, No. 4810, 1962, pp. 12–14.
Dessens, H. and J. Desens. Cumulus artificiel sur le Sahara. *Journ. Rech. Atmosphere,* No. 1, 1963, p. 29.
Dickson, D.R. Raw data report and final report (Meteorological analysis of wind velocities of various tornadoes). Oklahoma, *Agric. and Mech. College, Rep.*, 1957, 193 pp.
Dietz, R.S. The explosive birth of Myojin Island. *Nat. Geogr. Mag.*, vol. 105, 1954, pp. 117–128.
Dinwiddie, F.B. Tornadoes near Nags Head, N.C., July 1959. *Monthly Weather Rev.*, vol. 87, 1959a, pp. 346–350.
Dinwiddie, F.B. Waterspout tornado structure and behavior of Nags Head. N.C., August 12, 1959, *Monthly Weather Rev.*, vol. 89, 1961, pp. 20–23.
Disterdick, F.L. Severe sand storm in eastern Wyoming, January 18, 1933. *Monthly Weather Rev.*, vol. 61, 1933, pp. 16–17.
Ditmar, C. Wasserhose in Sudchinesischen Meere. *Ann. D. Hydroger.* Bd. 5, 1877, p. 466.
Dmitriev, D. "Kosmos–122"—Chasovoi pogody (Cosmos–122—Sentinel of weather). *Sovetskaya Rossiya,* September 23, 1966.
Dobroklonskii, S.V. and P.V. Vavilov. K voprosu o vynose solei s bryazgami morskoi vody (On the problem of transportation of salt with splash of sea water). *Izv. AN SSSR, Ser. Geogr.* No. 1, 1938, pp. 25–28.
Dokuchaev, V.V. Osobaya yekspeditsiya (Special Expedition) *Sobr. Soch.*, vol. VI, Moscow, 1951, pp. 137–139.
Doskach, A.G. and A.A. Trushkovskii Pyl'nye buri na ruge Russkoi ravniny (Dust storms in the south Russian plains). In sb.: *Pyl'nye buri,* Moscow, 1963, pp. 50–80.
Doubl-walled waterspouts. *Monthly Weather Rev.*, vol. 51, 1923, p. 209.
Douglas, C.K. The gale of Jan 1953. *Met. Mag.*, vol. 82, 1953, pp. 97–100.
Douglas, M.S. Hurricane. New York, 1958, 393 pp. Literature.
Dove, G.V. Zakon shtormov (Law of Storms). Spb., 1869, 339 pp.
Drozodova, V.M., O.P. Petrenchuk, E.S. Selezneva and P.F. Svistov. Khimicheskii sostav atmosfernykh osadkov na Evropeiskoi territorii SSSR (Chemical Composition of Atmospheric Precipitation in the European Territory of the USSR). Leningrad. 1964, pp. 209 and Literature.

Duane, J.E. The hurricane of September 2, 1935, at Long Key, Florida. *Bull. Amer. Met. Soc.*, vol. 16, 1935, pp. 238–239.

Dubieff, J. Le vent et deplacement du sable au Sahara. *Trav. Inst. Rech. Sahar.*, t-8, 1952, pp. 123–144.

Dubieff, J. Le climat du Sahara, vol. II, pt. IV. Paris, 1959.

Dunn, G.E. Tropical cyclones. *Compt. Met.*, 1951, pp. 887–901, Literature.

Dunn, G.E. Areas of hurricane development. *Monthly Weather Rev.*, vol. 84, 1956, pp. 57–61.

Dunn, G.E. The tropical cyclone problem in East Pakistan. *Monthly Weather Rev.*, vol. 90, 1962, pp. 83–86.

Dunn, G.E. The hurricane season of 1962. *Monthly Weather Rev.*, vol. 91, 1963, pp. 199–207.

Dunn, G.E. The hurricane season of 1963. *Monthly Weather Rev.*, vol. 92, 1964, pp. 128–138.

Dunn, G.E., W.R. Davis and P.L. Moore. Hurricanes of 1958. *Monthly Weather Rev.*, vol. 83, 1955, pp. 315–326.

Dunn, G.E. and B.J. Miller. Atlantic hurricanes: Louisiana. 1960, 326 pp and Literature.

Dunn, G.E. and B.J. Miller. The hurricane season of 1961. *Monthly Weather Rev.*, vol. 90, 1962, pp. 107–119.

Durst, B.A. Dust in the Atmosphere. *Quart. Jour. Met. Soc.*, vol. 61, 1935, pp. 81–88.

Dyubyuk, A.F. Buri i smerchi (Storms and tornadoes). *Priroda,* No. 7, 1957, pp. 80–84.

Dzotsenidze, G.S. Vliyanie vulkanizma na obrazovanie osadkov (Effect of Volcanism on Sedimentation). Moscow, 1965, pp. 155.

Easton, W.H. Underwater effect of hurricane Betsy (1965) on some Bahamian reefs. *Programme 1966 Ann. Met. Geol. soc. Amer.*, 1966, Abstracts, p. 59.

Egorova, V.A. Vliyanie vetrovogo rezhima na solevoi sostav atmosfernykh osadkov severo-vostochnogo poberez'ya Chernogo morya (Effect of wind regime on the composition of salt in the rain of the northeastern shores of the Black Sea). *Tr. Inst. Okeanol.*, No. 53, 1961, pp. 95–111, Literature.

Ehrenberg, C.G. Passat staub und Blutregen. *Abh. d. k. Akad. Wiss.*, Berlin, 1849, 192 pp.

El Fandy, M.G. On the physics of dusty atmosphere. *Quart. Jour. Met. Soc.*, vol. 79, 1953, pp. 284–288.

Eliot, J. Handbook of Cyclonic Storms in the Bay of Bengal. 2 ed. Calcutta, 1900, 310 pp.

Elser, H.L. A desert dust storm strikes El Paso, Texas. *Weatherwise,* vol. 12, No. 2, 1959, pp. 115–116.

Erdtman, D. An Introduction to Pollen Analysis. Copenhagen, 1943, 240 pp.

Erickson, C.O. An incipient hurricane near the West African coast. *Monthly Weather Rev.*, vol. 91, 1963, pp. 61–68.

Eriksson, E. Airborne salts and the chemical composition of river waters. *Tellus*, vol. 7, No. 2, 1955, pp. 243–250.

Eriksson, E. Le climat chimique et les sols salines dans la zone aride, *Rech. zone aride, Climatologie, UNESCO*, 1958, pp. 163–198.

Eriksson, E. The yearly circulation of chloride and sulphur in Nature; meteorological, geochemical and pedological implications. *Tellus*, vol. 11, No. 4, 1959, pp. 375–403, vol. 12, No. 1, 1960, pp. 63–109 and Literature.

Evans, J.W. Mechanically formed limestones from Junagarh (Kathiawar) and other localities. *Quart. Journ. Geol.* vol. 56, 1900, pp. 559–584.

Fairbridge, R.W. The geology and geomorphology of Point Peron, Western Australia. *Jour. Roy. Soc. West. Austr.*, vol. 34, 1950, pp. 34–72.

Farkhauser, J.C. The migration of thunderstorms, *Weatherwise*, vol. 18, No. 2, 1965, pp. 68–73.

Farquharson, J.S. Haboobs and instability in Sudan. *Quart. Jour. Met. Soc.*, vol. 63, No. 271, 1937, pp. 393, 414.

Fassig, O.L. Hurricanes of the West Indies. Bull. No. 10, Weather Bur. Unit. Stat., 1913, 28 pp.

Fassig, O.L. Tropical rains, their duration, frequency and intensity. *Monthly Weather Rev.*, vol. 44, 1916, pp. 329–337.

Fawbush, E. and R.C. Miller. The types of air masses in which North American tornadoes form. *Bull. Amer. Met. Soc.*, vol. 35, 1954, pp. 154–165.

Faye, H. Nouvelle etude sur les tempetes, cyclones, trombes ou tornadoes. Paris, 1897, 142 pp.

Fedorovich, B.A. Rel'ef peskov Azii kak otobrazhenie protsessov tsirkulyatsii atmosfery (Sand relief of Asia as a reflection of the processes of atmospheric circulation). *Probl. Fiz. Geogr.*, No. 13, 1948, Moscow, pp. 91–109.

Fedorovich, B.A. Geograficheskie usloviya rasprostraneniya lessa v Evraziii (Geographical condition of propagation of loess in Eurasia). *Tr. Inst. Geol. Nauk AN Ukr. SSR., ser. Geomorf.*, No. 1, 1951, pp. 106–115.

Fedorovich, B.A. Voprosy proiskhozhdeniya lessa v svyazi s usloviyami ego rasprostraneniya v Evrazii (Problem of origin of loess in relation to its conditions of propagation in Eurasia). *Tr. Inst. Geogr.*, No. 30, 1960, pp. 96–117.

Fedorovich, B.A. Proiskhozhdenie rel'efa pustyni Takla-Makan i voprosy ee osvoeniya (Origin of the relief of Takla-Makan desert and the problem of its development). In sb.: *Kun'-Lun' i Tarim*, Moscow, pp. 28–51.

Fedosov, M.V. Elovaya akkumulyatsiya na Severnom Kaspii (Aeolian accumulation in North Caspian), *DAN SSSR,* 75, No. 6, 1950, pp. 847–849.

Ferrel, W. A Popular Treatise on the Winds. 2 ed. New York. 1890, 505 pp., Literature.

Fett, R.W. Der Atmospharische Staub. Berlin, 1958, 309 pp., Literature.

Fett, R.W. Aspects of hurricane structure. *Monthly Weather Rev.,* vol. 92, 1964, pp. 43–60.

Fett, R.W. Life cycle of tropical cyclone Judy as revealed by *Essa II* and *Nimbus II. Monthly Weather Rev.,* vol. 94, 1966, pp. 605–610.

Fett, V. Atmosfernaya pyl' (Atmospheric Dust). Translated from German, Moscow, 1961, pp. 336, Literature.

Ficker H. Bildung einer Trombe in Gebrige. *Met. Z.*, Bd. 54, 1937, p. 25.

Ficker, H. and P. Rudder. Fohn und Fohnwirkungen. Leipzig, 1848, 114 pp.

Finch, R.H. Fish killed by the cold wave of February 2–4, 1917, in Florida. *Monthly Weather Rev.,* vol. 45, 1917, pp. 171.

Finley, J.P. Report on the tornadoes of May 29 and 30, 1879, in Kansas, Nebraska, *Prof. Paper of the Signal Service,* No. 4, 1881, 116 pp.

Finley, J.P. Report on the character of six hundred tornadoes. *Prof. Paper of the Signal Service,* No. 7, 2 ed., 1884, 29 pp.

Finley, J.P. State tornado charts. *Amer. Met. Journ.*, No. 6, 1890, pp. 13, 62, 121, 158, 249, 318, 350, 399, 504, 563.

Flammarion, C. L'atmosphere. *Meteorologie populaire,* Paris, 1888, 808 pp.

Flawin, J.W. The Denver tornado of May 21, 1952. *Weatherwise,* vol. 5, No. 5, 1952, pp. 106–107.

Fletcher, N.H. The physics of rain clouds. New York, 1962, 386 pp.

Fletcher, R.D. Computation of maximum winds in hurricanes. *Bull. Amer. Met. Soc.*, vol. 36, 1955, pp. 246–250.

Fletcher, R.D., J.R. Smith and R.C. Bundgaard. Superior photographic reconnaissance of tropical cyclones. *Weatherwise,* vol. 14, No. 3, 1961, pp. 103–109.

Flora, S.D. Electrical storms in Western Kansas. *Monthly Weather Rev.,* vol. 40, 1912, p. 895.

Flora, S.D. Electrical storm of March 23, in Kansas. *Monthly Weather Rev.,* vol. 41, 1913, p. 416.

Flora, S.D. Kansas Tornadoes. *Monthly Weather Review,* vol. 47, 1919, pp. 447–448.

Flora, S.D. Tornadoes of the United States. Oklahoma, 1953, 194 pp.

Flora, S.D. Hailstorms of the United States. New York, 1956, 201 pp.

Flowers, E.J. The path of the Kansas-Missouri tornado, May 20, 1957. *Monthly Weather Rev.*, vol. 85, 1957, pp. 205–207.

Frank, N.L. Synoptic case study of tropical cyclogenesis utilising Tiros data. *Monthly Weather Rev.,* vol. 91, 1963, pp. 355–366.

Frank, N.L. The 1963 hurricane season. *Weatherwise,* vol. 17, No. 1, 1964,

pp. 17–23.
Frank, N.L. The 1964 hurricane season. *Weatherwise,* vol. 17, No. 1, 1965, pp. 19–26.
Frankenfield, H.C. The tornado of May 27, 1896, at St. Louis. *Monthly Weather Rev.,* vol. 24, 1896, pp. 77–81.
Frankenfield, H.C. The tornadoes and wind storms of May 25–June 6, 1917. *Monthly Weather Rev.,* vol. 45, 1917, pp. 291–298.
Free, E.C. The movement of soil material by the wind. *Bull. Unit. Stat. Bur. of Soils,* vol. 68, 1917, pp. 125.
Freeman, M.H. Dust storms of the Anglo-Egyptian Sudan. *Met. Reports,* No. 11, Met. Office, 1952, pp. 1–22.
Freeman, O.W. Severe dust storms over Idaho, Washington and Oregon. *Monthly Weather Rev.,* vol. 58, 1930, p. 117.
Fritz, S. Satellite pictures and the origin of hurricane Anna, 1961, *Monthly Weather Rev.,* vol. 90, 1962, pp. 507–513.
Fritz, S. Revised illustrations in "The variable appearance of the earth from satellites". *Monthly Weather Rev.,* vol. 93, 1965, p. 460.
Fritz, S. and H. Wexler. Cloud pictures from satellite *Tiros-I. Monthly Weather Rev.,* vol. 88, 1960, pp. 79–87.
Fruh, J. Ueber die Natur des Staubes vom 21–23 Februar, 1903. *Met. Z.,* Bd. 20, 1903, pp. 173–175.
Fujita, T. Mesoanalysis of Illinois tornadoes of April 9, 1953. *Journ. Met.,* Boston, vol. 15(3), June 1958, pp. 288–296.
Fujita, T. Mother cloud of the Fargo tornadoes of June 20, 1957. *Proc. Ceonfer. on Cumulus Convection,* Washington, 1960a, pp. 175–177.
Fujita, T. A detailed analysis of the Fargo tornadoes of June 20, 1957. Res. Pap. No. 42, Weather Bur. Unit. Stat., 1960b, 67 pp.
Fujita, T. Formation and steering mechanisms of tornado-cyclones and associated hook-echoes. *Monthly Weather Rev.,* vol. 93, 1965, pp. 67–78.
Furneaux, R. Krakatoa. New Jersey, 1964, 224 pp.
Gael', A.G. Velrovaya yeroziya legkikh poch (Wind erosion of light soil). In Sb.: *Bor'ba s yeroziei,* Moscow, 1957, pp. 47–54.
Gael', A.G. and L.F. Smirnova O vetrovoi yerozii legkikh pochv v severnom Kazakhstane (On wind erosion of light soil in North Kazakhstan). In sb.: *Phl'nye buri,* Moscow, 1963, pp. 122–132.
Gaigerov, S.S. Sinopticheskii analiz uslovii vozniknoveniya tornado v S Sh A v 1894 (Synoptic analysis of the conditions in the beginning of a tornado in the USA in 1884). *Met. i Gidrol.,* No. 4, 1939a, pp. 20–31.
Gaigerov, S.S. Shest trombov v tsentralnykh oblastyakh evropeiskoi chasti soyuza i ikh sinopticheskie uslovuya (Six zones in the central region of the European territory of the Soviet Union and their synoptic conditions). *Met. i. Gidrol.,* No. 5, 1939b, pp. 44–54.
Gaisin, Sh.A. and G.I. Lysak. O vetrovoi yerozii pochv v Bashkirri (On

wind erosion of soil in Bashkiria). Ufa. 1958, 22 pp.

Galway, J.G. The Topeka tornado of 8 June, 1966. *Weatherwise,* vol. 19, No. 4, 1966, pp. 144–150.

Garet, R.A. and V.D. Rockney. Tornadoes in Kansas, May 19, 1960. *Monthly Weather Rev.*, vol. 90, 1962, pp. 231–240.

Gedin, Sven. Tarim—Lob Nor—Tibet. Puteshestvie, po Azii, 1899–1902 (Tarim—Lob Nor—Tibet. Journey to Asia, 1899–1902). Spb., 1904, 385 pp.

Gentry, R.C. Wind velocities during hurricanes. *Trans. Amer. Soc., Civil Eng.*, vol. 120, 1945a, 169 pp.

Gentry, R.C. The 1954 hurricane season. *Weatherwise,* vol. 8, No. 1, 1955b, pp. 12–17.

Gentry, R.C. Current hurricane research. *Weatherwise,* vol. 17, No. 4, 1964, pp. 180–185, 189.

Georgii, W. Scirocco Beobachtungen in Palastina. *Metz. Z.*, Bd. 36, 1919, pp. 193–197.

Gerasimov, I.P. Ocherki po fizicheskoi geografii zarubezhnykh stran. Pustynya Gobi (Sketch of the Physical Geography of Foreign Countries. The Gobi Desert). Moscow, 1959a, pp. 63–73.

Garasimov, I.P. Ocherki po fizicheskoi geografii zarubezhnykh stran. Lessy kitaya i ikh proiskhozdenie (Sketch of the Physical Geography of Foreign Countries. Loess of China and Its Origin). Moscow, 1959, pp. 203–216.

Gezekhus, N.A. Atmosfernoe elektrichestvo i vliyanie na nego pyli (Atmospheric electricity and the effect of dust in it). *Izv. Tekhnol. Inst.*, vol. XV, 1903, pp. 65–69.

Gezekhus, N.A. Elektricheskie razryady vo vremya pyl'nykh i snezhnykh bur' (Electrical discharge at the time of dust and snowstorms). *Zap. Geogr. Obshch.* vol. 47, 1911, pp. 389–393.

Gilbert, E.G. and T.M. Walker. Tornado at the Royal Horticultural Society's Garden, *Weather,* June, 1966, pp. 211–214.

Giles, A.W. Tornadoes in Virginia, 1814–1925. *Monthly Weather Rev.*, vol. 55, 1927, pp. 169–175.

Gillmer, T.C. and H.E. Nietsch. Clouds, weather and flight. New York, 1954, 161 pp.

Gilmore, M.H. Tracking ocean storms with the seismograph. *Bull. Amer. Met. Soc.*, 28, No. 2, 1947, pp. 73–86.

Glaser, A.H. Tornado studies. *Met. Abstr.*, vol. 10, No. 2, 1953, 303 pp.

Glawion, H. Ueber einige staublaffe in Arosa in Sommer 1936. *Met. Z.*, bd. 54, 1937, pp. 61–64.

Glazovskaya, M.A. Yelovye melkozemlistye nakopleniya na lednikakh Terskei Alatau (Fine aeolian soil accumulation in the Tersk Alatau glacier). *Tr. Inst. Geogr.*, No. 49, pp. 55–69.

Golyshev, G. and I. Andronov. Kosmicheskaya meteorologiya. Rasskas ob iskustvennom sputnike Zemli "Kosmos-144" (Cosmic meteorology. The story of the artificial earth satellite *Kosmos-144*). *Izvestiya,* March 17, 1967.

Gordon, A.H. Waterspouts, pt. 1, 2. *Marine Observer,* vol. 21 (151) 1951, pp. 47–60; vol. 21 (152), 1952, pp. 87–93.

Grabau, A.W. Principles of stratigraphy. 3 ed. New York, 1932, 1185 pp.

Graham, H.E. A fire-whirlwind of tornadic violence, *Weatherwise,* vol. 5, No. 3, 1952, p. 59.

Graham, H.E. Fire Whirlwinds. *Bull. Amer. Met. Soc.,* vol. 36, 1955, pp. 99–103, Literature.

Gregory, P.H. The Microbiology of the Atmosphere. New York, 1961, 251 pp.

Gribanov, L.N. K poznaniyu chernykh bur' v Kulundinskom stepi (On the knowledge of dark storms in the Kulundin steppe). *Pochvovedenie,* No. 9, 1954, pp. 35–45.

Gruner, H. Ueber das Harmathanphanomen in Togo. *Met. Z.,* Bd. 16, 1899, pp. 289–296.

Gudger, E.W. Rains of fishes. *Nat. Hist.,* vol. 21, 1921, pp. 607–619, Literature.

Gudger, E.W. Rains of fish and frogs. *Nat. Hist.,* vol. 22, 1922, 84 pp.

Gudger, E.W. More rains of fish. *Ann Mag. Nat. Hist.* ser. 10, vol. 3, 1929, pp. 1–26, Literature.

Gusev, A.M. Novorossiiskaya bora (Novorossiisk bora). *Tr. Morsk Gidrofiz, Inst.,* No. 14, 1959, 140 pp., Literature.

Gutman, L.S., Teoreticheskaya Model' smercha (Theoretical model of the tornado). *Izv. AN SSSR, Ser. Geofiz.,* No. 1, 1957, pp. 79–93.

Haggard, W.H. The birthplace of North Atlantic tropical storms. *Monthly Weather Rev.,* vol. 86, 1958, pp. 397–404.

Hale, P.G. Pensacola waterspout of June 14, 1929. *Monthly Weather Rev.,* vol. 57, 1929, pp. 338–339.

Hall, R.S. Inside a Texas tornado. *Weatherwise,* vol. 4, No. 3, 1951, pp. 54–57, 65.

Hall, F. and R.D. Brewer. A sequence of tornado damage patterns. *Monthly Weather Rev.,* vol. 87, 1959, pp. 207–216.

Hardin, H.R. Tornado of May 9, 1918, Pearl Rock to Calmar. Iowa. *Monthly Weather Rev.,* vol. 46, 1918, pp. 230–232.

Hardings, E.T. and W.J. Kotsch. Heavy weather guide Pt. I. Hurricanes. Pt. 2. Typhoons. Annapolis, 1965, 209 pp.

Hardy, W.E. Tornadoes during 1961. *Weatherwise,* vol. 15, No. 1, 1962, pp. 16–19.

Hardy, W.E. Tornadoes during 1962. *Weatherwise,* vol. 16, No. 1, 1963, pp. 22–25, 48.

Hardy, W.E. Tornadoes during 1963. *Weatherwise,* vol. 17, No. 1, 1964, pp. 24–28.

Hardy, W.E. Recent severe storms research. *Weatherwise,* vol. 18, No. 2, 1965a, pp. 61–67.

Hardy, W.E. Tornadoes during 1964. *Weatherwise,* vol. 18, No. 1, 1965b, pp. 26–31.

Hardy, W.E. Tornadoes during 1965. *Weatherwise,* vol. 19, No. 1, 1966, pp. 18–22.

Harris, D.L. Characteristics of the hurricane storm surge. Techn. Pap., No. 48, Weather Bur. Unit. Stat., 1963, 139 pp., Literature.

Harrison, M.C. An unusual Texas dust storm March 24–25, 1963., *Monthly Weather Rev.,* vol. 61, 1933, pp. 113–114.

Harrison, M.C. Dallas tornado 2 April 1957. *Weatherwise,* vol. 10, No. 3, 1957, pp. 90–91.

Haude, W. Ergebnisse der algemeinen meteorologischen Beobachtungen und der Drachenaufstiege an den beiden standlagern bei Ikengung und am Edsen—Gol. 1931–32, Stokholm, 1940, 325 pp.

Hayes, M.O. Hurricanes as geological agents, Texas coast. *Amer. Ass. Petrol. Geol.,* vol. 51, No. 6, 1967, pp. 937–942.

Hayes, M.W. The tornado of October 9, 1913 at Lebanon. Kansas. *Monthly Weather Rev.,* vol. 41, 1913, pp. 1528.

Hazen, U.A. Tornadoes. *Amer. Met. Journ.,* vol. 7, 1890, pp. 205–229.

Hellmann, G. and W. Meinardus Der grosse staubfall vom 9–12 Marz 1901 in Nordafrica, Sud- und Mittel-Europa. *Abh. Preuss. Met. Inst.,* Bd. 2, No. 1, 1901, 93 pp.

Henry, A.J. Tornadoes of April and May 1896. *Monthly Weather Rev.,* vol. 24, 1896, pp. 82–83.

Henry, H. Origine africaine d'un cyclone tropical atlantique. *Ann. Phys. de Globe,* t–6, Aug., 1939, pp. 97–115.

Herrick, C.L. The geology of the white sands of New Mexico. *Journ. Geol.,* No. 8, 1900, pp. 112–127.

Herrmann, E. Die Staubfalle vom 19 bis 23 Februar 1903 uber dem Nordatlantischen Ozean, Gross-britannien und Mittel-Europa. *Ann. Hydrogr.* Bd. 31, H–10, 1903, pp. 425–438, 475–483.

Herrmann, M. Scirocco-Einbruche in Mittel-Europa. *Veroff. d. Geophys. Inst. Univ. Leipz.,* Bd. 4, H. 4, 1929, pp. 181–253.

Hexter, P.L. An observation of arcus and funnel clouds over Chesapeake Bay. *Monthly Weather Rev.,* vol. 90, 1962, pp. 217–224.

Hickman, W.C. Tornadoes of April 15, 1921, in Arkansas and Texas. *Monthly Weather Rev.,* vol. 49, 1921, pp. 194–199.

Hissong, J.E. Whirlwinds at oil-tank fire. *Monthly Weather Rev.,* vol. 54, 1926, pp. 161–163.

Hoecker, W.H. History and measurement of two major Scottsbluff tornadoes of 27 June, 1955. *Bull. Amer. Met. Soc.,* vol. 40, No. 3, 1959, pp. 117–133.

Hoecker, W.H. The dimensional and rotational characteristics of the

tornadoes and their cloud system. The tornadoes at Dallas, 1957, Res. Pap., No. 41, Weather Bur. Unit. Stat., 1960, pp. 53–113.
Hoecker, W.H., Jr. Three dimension pressure pattern of the Dallas tornado and some resultant implications. *Monthly Weather Rev.,* vol. 89, 1961, pp. 533–542.
Hoecker, W.H. and R.C. Beebe. The tornadoes at Dallas, Tex., April 2, 1957, Res. Pap., No. 41, Weather Bur. Unit. Stat., 1960, 175 pp.
Holland, T.H. and W.A. Christie. The origin of the salt deposits of Rajputana. *Geol. Surv. of India,* vol. 38, 1909, pp. 154–186.
Holzman, B. The effect of an atomic bomb explosion on the weather. *Weatherwise,* vol. 4, No. 1, 1951, pp. 3–4, 9.
Hovde, M.R. The Champlin–Anoka, Minnesota, tornado. *Monthly Weather Rev.,* vol. 67, 1939, pp. 176–178.
Hoyt, W.G. and W.B. Langlein. Floods. Princeton, 1955, 469 pp.
Hughes, L.A. On the low-level wind structure of tropical storms. *Journ. Met.,* No. 9, 1952, pp. 422–428.
Humphreys, W.J. Volcanic dust and other factors in the production of climatic changes and their possible relation to ice ages. *Bull. Month. Weather Obs.,* vol. 6, 1913, pp. 1–34.
Humphreys, W.J. The tornado. *Monthly Weather Rev.,* vol. 54, 1926, pp. 501–503.
Humphreys, W.J. Physics of the air. New York, 1929, 654 pp.
Hunter, H.C. The Lorain, Ohio tornado, June 28, 1924. *Monthly Weather Rev.,* vol. 52, 1924, pp. 309–310.
Hurd, W.E. Grasshoppers at sea. *Monthly Weather Review,* vol. 45, 1917, p. 11.
Hurd, W.E. Influence of the wind on the movements of insects. *Monthly Weather Rev.,* vol. 48, 1920, pp. 94–98. Literature.
Hurd, W.E. Dust over the North Atlantic. *Monthly Weather Rev.,* vol. 50, 1922, p. 301.
Hurd, W.E. Waterspouts. *Monthly Weather Rev.,* vol. 56, 1928, pp. 207–211.
Hurd, W.E. Tropical cyclones of the eastern North Pacific Ocean. *Monthly Weather Rev.,* vol. 57, 1929, pp. 43-49.
Hurd, W.E. Some phases of waterspout behaviour. *Weatherwise,* vol. 3, No. 4, 1950, pp. 75–78.
Huschke, R.E. Glossary of meteorology. Boston, 1959, 638 pp.
Ives, R.L. Behaviour of dust devils. *Bull. Amer. Met. Soc.,* vol. 28, 1947, pp. 168–174.
Ives, R.L. Winds of the past. *Weatherwise,* vol. 17, No. 5, 1964, pp. 224–227, 235.
Jacobs, W.C. Aerobiology. *Comp. Met.,* 1951, pp. 1103–1111. Literature.
Jarboe, J.H. The Roskspring, Texas, tornado, April 12, 1927. *Monthly Weather Review,* vol. 55, 1927, pp. 182–183.

Johnson, D.W. Shore processes and shoreline development. New York, 1919, 210 pp.

Jones, H.L. The tornado pulse generator. *Weatherwise,* vol. 18, No. 2, 1965, pp. 78–79, 85.

Jordan, C.L. and Ho Te-chun. Variations in the annual frequency of tropical cyclones, 1886–1958. *Monthly Weather Rev.*, vol. 90, 1962, pp. 157–164.

Jorjio, V.A., M.A. Petrosyants and N.I. Romanov. Klassifikatsiya boltanki samoletov (The classification of bumpy air for airplanes). *Nauchn. Tr. Tashk. Gos. Univ.*, No. 225, 1963, pp. 90–99.

Justice, A.A. Seeing the inside of a tornado. *Monthly Weather Rev.*, vol. 58, 1930, pp. 205–206.

Kalinovskii, K.A. and I.Z. Pinus. Aerologia (Aerology). Moscow, 1951, 454 pp.

Kalstrom, G.W. El Cardonado. *Weatherwise,* vol. 5, No. 5, 1952, pp. 99–103, 110.

Kapitsa, P.L. Priroda Sharovoi molnii (Nature of fireballs). *DAN SSSR,* vol. 101, No. 2, 1955, pp. 245–248.

Kapo-Rei, R. Frantsuzskaya Sakhara (The French Sahara). Moscow, 1958, 496 pp., Literature.

Karetnikova, K.A. Sinopticheskie usloviya vozniknoveniya "afgantsa" i nekotorye osobennosti etogo yavleniya (Synoptic conditions arising from the "Afghan" and some features of this phenomenon). *Zhurn. Geofiz.*, vol. 5, No. 4, 1935, pp. 518–530.

Karetnikova, K.A. Sukhovei, garmsili i "Afgantsy" Srednei Azii (Dry Winds, Garmsili and "Afghan" in Central Asia). Tashkent, 1949, 40 pp.

Karpov, A.I. Pyl' u Saratova (Dust in Saratov). *Met. i. Gidrol.,* No. 3, 1939, p. 92.

Kasterin, N.P., A.K. Timiryazev and T.M. Sviridov. Opytnoe poluchenie vozdushnogo vikhrevogo stdba (Experimentally obtained air vortex column). *Vestn. M Gell,* No. 10, *Ser. Fiz-Mat, i. Ist. Nauk,* 1949, pp. 53–57.

Kenney, N.T. and B.A. Steward. Our changing Atlantic coastline. *Nat. Geogr. Mag.,* vol. 122, No. 6, 1962, pp. 860–887.

Kes', A.S. K voprosu o proiskhozhdenii less severnogo Kitaya (On the problem of the origin of loess in northern China). *Tr. Kom. po Izuch. Chetv. Perioda,* No. 14, 1959, pp. 80–99.

Kes', A.S. Lessy i lessovo-krasnoglinistye porody kak elovo—pochvennye obrazovaniya (Loess and loess red clay rocks and aeolian-soil formations). *Tr. Kom. po Izuch. Chetv. Perioda,* No. 19, 1962, pp. 101–116.

Kes', A.S. Lessovo-krasnoglinistaya formatsyiya i lessovyi rel'ef (Loess red clay formation and Loess relief). Dissertatsiya, Moscow, Inst. Geogr., 1964, 515 pp., Literature.

Keyes, C.R. Midcontinental eolation. *Bull. Geol. Soc. Amer.*, vol. 22, 1911, pp. 187–714.

Keyes, C.R. Competency of wind in land depletion. *Monthly Weather Rev.*, vol. 45, 1917, pp. 57–58.

Khromov, S.P. K dinamicheskoi klimatologii tornado (On the dynamic climatology of the tornado). *Met. i gidrol.*, No. 4, 1939, pp. 13–19.

Khromov, S.P. Meteorologiya i klimatologiya dlya geograficheskikh fakul'tetov (Meteorology and Climatology for Geography Faculties). Leningrad, 1964, 499 pp.

Khromov, S.P. Tropicheskie uragany (Tropical Hurricanes). *Zemlya i Vselennaya,* No. 2, 1966, pp. 20–30.

Khromov, S.P. and L.I. Mamontova. Meteorologicheskii slovar' (Meteorological Dictionary). Leningrad, 1963, 620 pp.

Kimball, H.H. and I.F. Hand. Investigation of the dust content of the atmosphere. *Monthly Weather Rev.*, vol. 52, 1924, pp. 133–139.

Kincer, J.B. Tornado disasters in the southern States, April, 1936. *Monthly Weather Rev.*, vol. 64, 1936, pp. 164–171.

King, C.A.M. Beaches and coasts, London, 1959, 403 pp., Literature.

Kirk, T.H. and D.T.J. Dean. Report on a tornado at Malta, 14 October, 1960. Met. Off., *Geophys. Mem.*, No. 107, 1963, 26 pp.

Kiss, E. Annotated bibliography on satellite meteorology. *Met. Abstr.*, vol. 11, No. 10, 1960, pp. 1683–1729.

Knight, D.C. The science book of meteorology. An introduction to the atmosphere and its phenomena. New York, 1964, 215 pp.

Knox, J.L. The storm Hazel. *Bull. Amer. Met. Soc.,* vol. 36, 1955, pp. 236–246.

Koeppe, C.E. and N.H. Bangs. The climate of China. *Monthly Weather Rev.,* vol. 56, 1928, pp. 1–7.

Kolobkov, N.V. Uragan v Moskve 28 Maya 1937 (Hurricane in Moscow on May 28, 1937). *Met. i Gidrol.*, No. 8, 1937, pp. 89–93.

Kolobkov, N.V. 1951. Grozy i shkvaly (Thunderstorms and Squalls). Moscow-Leningrad, 1951, 349 pp.

Kolobkov, N.V. Vozdushnyi okean i ego zhizn (Pneumatic Ocean and Its Life). Moscow, 1957b, 255 pp.

Kolobkov, N.V. Uragan "Flora" (The hurricane "Flora"). *Priroda,* No. 1, 1964, pp. 91–94.

Konke, G. and A. Bertran Okhrana pochvy (Soil conservation). Translated from English. Moscow, 1962, 344 pp.

Koppen, W. Der Staubfall vom 9 bis 12 Marz 1901 und die Mechanik der atmospharischen wirbel. *Ann. d. Hydrogr.,* Bd. 31, 1903, pp. 45–449.

Korostelev, N.A. Novorosiiskaya bora (Novorossiisk bora). *Zap. Akad. Nauk.*, vol. 15, No. 2, 1904, pp. 1–135.

Koschmieder, H. Die horizontale Trombe von Magdeburg. *Met. Z.,* Bd. 54, 1937a, 340–344 pp.

Koschmieder, H. Ueber Tromben. *Naturwiss.*, Bd. 25, 1927 b, 657 pp.

Koschmieder, H. Ueber Staubsturmen. *Naturwiss.,* Bd. 27, 1939, 113 pp.

Koschmieder, H. Ueber Tromben. *Wissen. Abh. Reichsamt f. Wetterd.*, Bd. 6, No. 3, 1940a, 24 pp.

Koschmieder, H. Ueber Boen. *Wissen. Abh. Reichsamt. f. Wetterd,* Bd. 8, No. 3, 1940b, 55 pp.

Koschmieder, H. Ueber Boen and Tromben. *Naturwiss,* Bd. 1946, pp. 203–211, 235–238.

Koschmieder, H. Zur Trombenbiblung. *Arch. f. Met., Geophys. Ser. A.*, Bd. 4, 1951, pp. 203–219.

Koshinskii, S.D. Bakinskii nord (Baku Nord). Avtoref. diss., Baku, 1959, 13 pp.

Kramer, H.P. Selective annotated bibliography on thunderstorms. *Met. Abstr. a. Bibl.*, vol. 1, 1950a, pp. 517–551.

Kramer, H.P. Selective annotated bibliography on tornadoes. *Met. Abstr. a. Bibl.* vol. 1, 1950b, pp. 307–332.

Kramer, H.P. Selective annotated bibliography on volcanic dust. *Met. Abstr. a. Bibl.*, vol. 1, 1950c, pp. 366–375.

Kramer, S.N. Istoriya nachinaetsya v Shumera (History Begins in Shumer). Moscow, 1965, 256 pp.

Kravchenko, I.V. Solevye Pyl'nye burk (Salt dust storms). *Priroda,* No. 8, 1959, pp. 89–92.

Krebs, M. Staubfall beobachtung im Oberalsass am 22 Februar 1903. *Ann. Hydrogr.*, Bd. 31, 1903, pp. 462–463.

Krivolutskaya, G.O. and V.A. Nachaev. Vulkanicheskii peplopad (Volcanic ashfall). *Priroda,* No. 9, 1963, 126 pp.

Kuenen, P.H. Marine geology. New York, 1950, pp. 210–214.

Kulagin, D.I. Vliyanie pyli v vozdukhe na yelektricheskoe sostoyanie atmosfery (Effect of airborne dust on the electrical condition of the atmosphere). *Tr. Tashk. Geofiz. Obs.*, No. 415, 1950, pp. 71–76.

Lamb, U.H. Tornadoes of May 21, 1950. *Met. Mag.*, London, vol. 79 (939), Sept. 1950, pp. 245–256.

Landsberg, H. Fire storms resulting from bombing conflagrations. *Bull. Amer. Met. Soc.*, vol. 28, No. 2, 1947, p. 72.

Lane, F.W. The Elements Rage. London, 1966, 279 pp.

Lapshin, V.I. O sukhom tumane, byvshem v aprela 1849 g v yuzhnykh guberniyakh srednei polosy Rosii (On the dry cloud during April 1849 in the southern province of the central belt of Russia). *Geogr. Izv.*, 1894, pp. 132–141.

Laughton, C. and V. Heddon. Great storms. London, 1927, 351 pp.

Lawrence, E.N. Fumulus. *Met. Mag.*, vol. 92, 1963, pp. 48–51, Literature.

Lay, O.T. Chicago's greatest snowstorm, March 25–26, 1930, *Monthly Weather Rev.*, vol. 58, 1930, pp. 146–148.

Leinz, V. Die Mineralfacies der Sedimente des Guinea-Beckens. *Wiss. Erg. d. Deutsch. Atl. Exp.*, "Meteor", Bd. III. Th. 3, 1937, pp. 245–262.

Leist, E'. Moskovskii uragan (Moscow hurricane). *Ezhem. Meteor. Byull.*

Glavn. Geofiz. Observe., No. 12, 1904, pp. 1–5.
Letzmann, J. Die trombe von Odenpah am 10 Mai 1920. *Acta et comm. Univ. Dorpatensis,* ser. A., 3, 1922, Miscell., pp. 1–11.
Letzmann, J. Tromben in Ostbaltischen Gebiet. Sitzungber. *Naturf. Ges. Univ. Dorpat,* Bd. 26 (1–4), 1923, 46 pp.
Letzmann, J. Fortschreitende Luftwirbel. *Met. Z.*, Bd. 42, 1925, pp. 42–52.
Letzmann, J. Horizontale Trombe. *Met. Z.*, Bd. 55, 1928, pp. 32–33.
Leuchs, K. Die Bedeutung von Staubsturmen fur die sedimentation. *Centrbl. f. Min.*, Abt. B. No. 3; 1932, pp. 145–156.
Ley, W.C. The Euridice squall. *Symon's Met. Mag.,* vol. 13, 1878, p. 33.
Lipovetskii, V.A. Kamennyi grad (Hailstorm). *Priroda,* No. 3, 1966, p. 128.
Lodge, J.P. A study of sea-salt particles over Puerto Rico. *Journ. Met.*, No. 12, 1955, pp. 493–499.
Long, J.F. Fossil hail prints. *Weather,* Apr., 1963, p. 115.
Lott, G.A. The world record 42 minute Holt, Missouri, rainstorm. *Monthly Weather Rev.,* vol. 82, 1954, pp. 50–59.
Loveland, G.A. Tornadoes in Eastern Nebraska, April 6, 1919. *Monthly Weather Rev.,* vol. 47, 1919, pp. 234–236.
Lowe, A.B. and G.A. McKay. The tornadoes of western Canada. Met. Branch, Dept. of Transp., Ottawa, 1962.
Lowman, P.D. The earth from orbit. *Nat. Geogr. Mag.,* vol. 130, No. 5, 1966, pp. 645–671.
Lyakhov, N.E. Meteorologicheskie usloviya vozniknoveniya i rasprostraneniya pyl'nykh bur' na Severnom Kavkaze vesnoi 1960 (Meteorological condition for the formation and distribution of dust storms in North Caucasus during the spring of 1960). In Sb.: *Pyl'nye buri,* Moscow, 1963, pp. 31–38.
Lyman, J. Oceanography. *Geotimes.* vol. 13, No. 1, 1968, p. 17.
Madat-Zade, A.A. Sil'nye i shtormovye vetry na vostochnom poberezh' severnogo (Strong and stormy wind on the eastern shore of the North Caspian). *Izv. AN Azerb. SSR., Ser. Geol-Geogr.*, No. 3, 1965, pp. 119–124.
Magill, P.L., F.R. Holden, C. Achley and F.C. Swayer. Air pollution handbook. New York, 1956, 720 pp.
Makhon'ko, K.P. Izuchenie perenosa atmosfernoi pyli (Study of transportation of atmospheric dust). *Izv. AN SSR, Ser. Geofiz.*, No. 11, 1960, pp. 1629–1683.
Maleev, E.F. Vulkanoklasticheski gornye poroby (Volcanoclastic Rocks) Moscow, 1963, 168 pp.
Malkin, W. and J.G. Galway. Tornadoes associated with hurricanes. *Monthly Weather Rev.,* vol. 81, 1953, pp. 299–303.
Marshall, P. and E. Kidson. The dust storm of October, 1928. *New Zealand Journ Sci.,* vol. 10 (5), 1929, pp. 291–299.
Martin, R.J. Dust storms of August-December 1936 in the United States.

Monthly Weather Rev., vol. 64, 1963, p. 429.
Martin, R.J. Dust storms of 1938 in the United States. *Monthly Weather Rev.*, vol. 67, 1939, pp. 12–15.
Martonne, E. Traite de geographie physique. Paris. 1913, 922 pp.
Mason, B.J. The Physics of Clouds. Oxford, 1957, 481 pp. Literature.
Matthews, E.K. Coast Erosion and Protection. London, 1913, 147 pp.
Mattice, W.A. Dust storms. November 1933 to May 1934. *Monthly Weather Rev.*, vol. 63, 1935, pp. 53–55.
Mawson, D. The Home of the Blizzard. London, 1934, 438 pp.
McAdie, A.G. A peculiar squall. *Monthly Weather Rev.*, vol. 38, 1910, pp. 1740–1742.
McAtee, W.L. Showers of organic matter. *Monthly Weather Rev.*, vol. 4, 1917, pp. 217–224.
McClurg, R.J. Tornado strikes swiftly-moving train. *Monthly Weather Rev.*, vol. 59, 1931, pp. 198–199.
McCulloch, A.R. Raining fishes. *Austr. Mus. Mag.*, No. 2, 1925, pp. 217–218.
McDonald, W.F. The hurricane of August 31 to September 6, 1935. *Monthly Weather Rev.*, vol. 63, 1935, pp. 269–271.
McIntosh, D.H. Meteorological Glossary. London, 1963, 288 pp.
McKee, E.D. Storm sediments on a Pacific atoll. *Journ. Sed. Petr.*, vol. 29, 1959, p. 354.
Measurement of wind speeds near a tornado funnel. *Monthly Weather Rev.*, vol. 87, 1959, p. 382.
Mikhailov, A. O buryakh (On storms). *Morskoi spori*, No. 3, 1888, Spb., pp. 1–37.
Mikhelson, V. Uragan v Moskve 16 (29) Yunya 1904 (Hurricane in Moscow on 16 (29) June, 1904). *Ezhem. Meteor. Byull. Glavn. Geofiz. Observ.*, No. 12, 1904, pp. 5–14.
Mill, H.R. The Cornish dust fall of January 1902. *Quart. Journ. Met. Soc.*, vol. 28, 1902, pp. 229–252.
Mill, H.R. and R.G.K. Lempfert. The great dust fall of February 1903 and its origin. *Quart. Journ. Met. Soc.*, vol. 30, 1904, pp. 57–91.
Miller, B.I. On the maximum intensity of hurricanes. *Journ. Met.*, vol. 15, 1958a, pp. 185–195.
Miller, B.I. Rainfall rates in Florida hurricanes. *Monthly Weather Rev.*, vol. 86, 1958b, pp. 258–264.
Miller, R.C. Tornado producing synoptic patterns. *Bull. Amer. Met. Soc.*, vol. 40, 1959, pp. 465–472.
Minina, L.S. Vikhrevaya structura oblachnosti po dannym meteorologicheskikh sputnikov (Vortex structure of clouds from weather satellite data). *Met. i. Gidrol.*, No. 1, 1964, pp. 12–22.
Mitchell, C.L. Tornadoes of March 28, 1920, in Illinois. Papers on tornadoes. *Monthly Weather Rev.*, vol. 48, 1920, pp. 191–193.

Mitchell, C.L. West Indian hurricanes and other tropical cyclones of the North Atlantic Ocean. *Monthly Weather Rev.,* Suppl. 24, 1924, pp. 1–47.

Mitchell, C.L. Cyclones and anticyclones of the northern hemisphere, January to April inclusive, 1925. *Monthly Weather Rev.*, vol. 58, 1930, pp. 1–22.

Mahadevan, C. and D.A. Srirama. Effects of high waves on the formation of coastal black sand deposits. *Mem. in Oceanogr.,* Andhra Univ., No. 1, 1954, pp. 57–62.

Molyen, P.A. Okhotnikiza Taifunami (Hunting for Typhoons). Translated from French. Moscow, 1967, 333 pp.

Moore, P.L. The hurricane season of 1957. *Monthly Weather Rev.,* vol. 85, 1957, pp. 401–408.

Moore, P.L. The hurricane season of 1960. *Weatherwise,* vol. 14, No. 1, 1916, pp. 18–23.

Moore, P.L. The 1961 hurricane season. *Weatherwise,* vol. 15, No. 1, 1962, pp. 21–25.

Morgan, J.P., L.G. Nichols and M. Wright. Morphological effects of hurricane Audrey on the Louisiana coast. Techn. Rep. No. 10, Louis. Univ. Coast. Inst., 1958, 33 pp.

Morris, F. The Austin tornado of May 4, 1922. *Monthly Weather Rev.,* vol. 50, 1922, pp. 251–253.

Murzaev, E.M. Geograficheskie osobennosti Kun'lunya (Geographical features of Kunlun). In. sb.: *Kun'lun in Tarim,* Moscow, 1961, pp. 5–27.

Mushketov, I.V. Fizicheskaya geologiya T. II. Denudatsionnye protsessy (Physical Geology v. II. Denudation Processes). Izd. 2, Spb., 1906, pp. 126–146.

Nalivkin, D.V. Uchenie o fastiyakh (Studies on Environments). Izd. AN SSR, Moscow-Leningrad, 1965, 1956, vols. I & II.

Neustrueva, M.V. Nablyudeniya nad atmosferno-pylevymi yavleniyami u g. Osh (Observation of the phenomena of atmospheric dust in the city of Osh). *Izv. Dokuchaevsk. Pochv. Kom.,* No. 4, 1914, pp. 147–181.

Newham, E.V. Hurricanes and tropical revolving storms. *Geophysical Mem.,* vol. 19, 1922, Met. Office Air Ministry, pp. 228–333.

Nezhikhovskii, R.A. Reka Neva (The River Neva), Leningrad, 1955, pp. 92.

Nikitin, N.A. Samum v Irake (Simoon in Iraq). *Priroda,* No. 5, 1961, pp. 64–65.

Nikolaev, N.I. O probleme proiskhozdeniya pokrovnykh suglinkov (On the origin of loam cover). *Izv. AN SSSR, Ser. Geogr.,* No. 4, 1959, pp. 34–35.

Nikolaev, N.I. and E.I. Rudenko. Adsorbtsionnye svoistva pylevykh chastits prinosimykh vetrami v solyanye ozera i vkhodyashchikh v sostav ozernykh ilov (The absorption properties of dust particles transported by the wind to saline lakes and entering into the composition of the lake silts.) *DAN SSSR,* vol. 25, No. 7, 1939, pp. 599–603.

Nordenskiold, A.E. Ueber den grossen staubfall in Schweden und angranzenden Landern am 3 Mai 1892. *Met. Z.*, Bd. 6, 1894, pp. 201–218.

Novorossiiskaya bora (Novorossiisk bora). *Tr. Morsk. Gidrofiz. Inst.,* No. 14, 1959, 140 pp., Literature.

Nowak, F. Zur geologischen Deutung des Staubfalles in Polen in Jahre 1928. *Ann. Soc. Geol. de Pologne,* t-V, 1928, pp. 345–352.

Obruchev, W.A. Loess types and their origin. *Amer. Jour. Sci.,* vol. 243, No. 5, 1945, pp. 256–262.

Obruchev, V.A. Loess kak osobyi vid pochvy, ego genezis is zadachi ego izucheniya (Loess as a special type of soil, its genesis and the problem of its study). *Tr. Pochven. Inst.,* No. 27, 1948, pp. 234–243.

Obruchev, V.A. Rol' i znachenye pyli v prioride (Role and significance of dust in nature). *Izv. AN SSSR, Ser. Geogr.,* No. 3, 1951, pp. 15–27.

Okuta, Minoru. Idet taifun (The Typhoon is Coming). Translated from Japanese, Moscow, 1963, 220 pp.

Oliver, A.R. The Gotheburg, Nebraska, tornadoes, June 24, 1930. *Monthly Weather Rev.,* vol. 59, 1931, pp. 225–229.

Oliver, F.W. Dust storms in Egypt and their relation to the war period, as noted in Margut. 1939–1945. *Geogr. Journ.,* vol. 106, 1945, pp. 26–49, vol. 108, 1947, pp. 221–226.

Orlov, B. Vetry v yugo—vostochnoi chasti Za kaspiiskikh Karakum, po nablyudeniyam v Repeteke (Wind in the southeastern part of the Caspian Karakum from observations in Repetek) *Met. vestn.,* No. 10, 1928, pp. 213–224.

Orlovskii, N.S. Nekotorye dannye o pyl'nykh buryakh Turkmenii (Some data on the dust storms of Turkmenia). *Sb. Rab. Ashkhabadsk. Gidromet. Obs.* No. 3, 1962, pp. 17–42, Literature.

Ostrovskii, I.M. Perenos pyli vo vzveshennom sostoyanii (Transportation of dust in suspended condition). In Sb. *Pyl'nye Buri,* Moscow, 1963, pp. 61–65.

Ota, Y. and S. Sawairis. Tornado in November 1951. *Journ. Met. Res., Tokyo,* vol. 5 (3), 1953, pp. 135–141.

Outram, T.S. Tornadoes of June 6, 1906, in Minnesota and Wisconsin. *Monthly Weather Rev.,* vol. 34, 1906, p. 561.

Ovchinnikov, B.N. Fiziko-geografichskie faktory i rastitelnyi pokrov Tyan'-Shanya (Physico-geographical factors and plant covers in Tyan-Shan). *Izv. Geogr. Obshch.*, vol. 71, No. 8, 1939, pp. 1229–1232.

Palm Sundays tornadoes of 1965. A weather bureau summary. *Weatherwise,* vol. 18, No. 3, 1965, pp. 122–127.

Papers on tornadoes. *Monthly Weather Rev.,* vol. 48, 1920, pp. 191–213.

Parker, R.H. Ecology and distributional patterns of marine macroinvertebrates. Northern Gulf of Mexico. In Recent Sediments. Gulf of Mexico,

Tulsa, Oklahoma, 1960, pp. 302–344.
Paulhaus, J.L.H. Indian Ocean and Taiwan rainfalls set new records. *Monthly Weather Rev.*, vol. 93, 1965, pp. 331–335.
Pearson, A.D. and A.F. Sadowski. Hurricane induced tornadoes and their distribution. *Monthly Weather Rev.*, vol. 93, 1965, pp. 461–464.
Pedelabord, P. Mussony (The Monsoon). Translated from French. Moscow, 1963, 195 pp.
Peryshkin, I.N. Smerch v Belorussii (Tornado in Belorussia). *Met. i Gidrol.*, No. 5, 1963, pp. 29–30.
Peskov, B.E. Nekotorye osobennosti obrazovaniya kuchevo-dozhdevykh oblakov i uslovii poleta vblizi nikh (Some features of cumulonimbus cloud formation and the flying conditions near it). *Met. i Gidrol.*, No. 5, pp. 22–27.
Peterson, O. Ueber die Neigung der Magdeburger Trombe. *Met. Z.*, Bd. 55, 1938, pp. 33–36.
Petrov, M.V. Podviznye peski pustyn', ikh peredvizhenie i formy nakopleniya (Shifting sand of the desert, its movement and form of accumulation). *Izv. Geogr. Obshch.*, vol. 71, No. 8, 1939, pp. 1180–1199.
Petrov, M.P. Podvizhnye peski pustyn' SSSR i borba s nimi (Shifting sands of the deserts of USSR and their control). Moscow, 1950, 454 pp.
Petrov, M.P. O mineralogicheskom i granulometricheskom sostave elovikh peskov Ordosa, vostochnogo Alashanya i doliny srednego techneniya r. Khunkhye (On the mineralogical and granulometric composition of aeolian sands of Ordos, eastern Alashan and the central valley of the river Huan-He). *Vestn. Len. Univ.*, vol. 6, Otd. Geol., No. 1, 1961, pp. 19–31.
Petrov, M.P. Pustyni Tsentralnoi Azii. T.I. Ordos. Alashan', Beishan. (Deserts of Central Asia. V. I., Ordos, Alshan, Beishan). Moscow, 1966, 274 pp. and Literature.
Phillipson, J. A small tornado. *Weather*, Jan., 1963, pp. 30–31.
Pierce, C.H. The meteorological history of the New England hurricane of Sep. 21, 1938. *Monthly Weather Rev.*, vol. 67, 1939, pp. 237–285.
Pinus, N.Z. Sovremennoe sostoyanie voprosa o turbulentsosti svobodnoi atmosfery, vyazyayushchei boltanku samoletov (Current situation of the problem of turbulence in free atmosphere causing bumps in airplanes). *Tr. Tsentr. Aerol. Obs.*, No. 34, 1960, pp. 3–51.
Ponomarev, M.D. Mestnye sil'nye vetry ibe (ebe) v pogranichnoi Jungarii [The local strong wind Ibe (Ebe) in the environs of Junagarh]. *Klim. i Pogoda.* No. 5, 1936, pp. 13–25.
Ponyavin, I.D. Volny tsunami (Seismic Sea Waves). Leningrad, 1965, 110 pp.
Popov, B.M. Prokozhdenie smercha pod Rostovu Yaroslavskoi obl. 24 augusta 1953 (Passage of a tornado over Rostov City in Yaroslav region on August 24, 1953). *Met. i Gidrol.*, No. 3, 1954, pp. 27–30.

Popov, N.I. Smerchi na poberezhie Chernogo morya (The waterspouts near the shores of the Black Sea). *Met. i Gidrol.*, No. 5, 1955, pp. 35–37.

Popruzhenko, S. Materialy po izucheniyu pyl'nogo tumana i peschanykh bur' (v'yugi), gospodstvovavshikh na yugo-zapade Rossii v aprele i mae mestyatsakh 1892 [Materials for the study of the dust cloud and sandstorm (Vyugi) in southwest of Russia in April and May, 1892]. *Tr. Meteor. seti Yugo-Zapada Rossii, v 1892,* No. 4, Odessa. 1893, pp. 54–94.

Pore, A. Ocean surface waves produced by some recent hurricanes. *Monthly Weather Rev.*, vol. 85, 1957, pp. 385–392, Literature.

Prager, M. Sandsturme im golf von Sue. *Ann Hydrogr.*, Jan., 1903, pp. 22–23.

Pratje, O. Staubfalle auf dem mittleren Atlantischen Ozeans. *Cbl. f. Min.*, Abt. B, 1934, pp. 177–182.

Pray, L.C. Hurricane Betsy (1965) and nearshore carbonate sediments of the Florida Keys. Program 1966. *Ann. Met. Geol. Soc. Amer.*, 1966, Abstracts. pp. 168–169.

Przheval'skii, N.M. Tret'e puteshestvie po Tsentral'noi Azii (Third voyage to Central Asia). Spb. 1883, 472 pp.

Price, S. and R.I. Sasaki. Some tornadoes, waterspouts and other funnel clouds of Hawaii. *Monthly Weather Rev.*, vol. 91, 1963, pp. 175–190.

Prinz, W. Analyse de sediments atmospheriques d'avril et de mai 1906. *Ciel et Terre,* t-28, 1908, pp. 437–443.

Prokh, L.Z. Serditye i dobrye vetry (Strong and weak winds). Leningrad, 1961, pp. 151.

Protor, F.W. Horizontal atmospheric rolls. *Monthly Weather Rev.*, vol. 24, 1896, pp. 367–368.

Prosser, N.E. Aerial photographs of a tornado path in Nebraska, May 5, 1964. Tokyo, 1955, 257 pp.

Prosser, N.E. Aerial photographs of a tornado path in Nebraska, May 5, 1964. *Monthly Weather Rev.*, vol. 92, 1964, pp. 593–598.

Pyl'nye buri i ikh predotvrashchenie (Dust storms and their prevention). *Sborn. Akad. Nauk.*, Inst. Geogr., Moscow, 168 pp.

Pyl'nye buri v Manchzhuriii (Dust storms in Manchuria). *Met. Vestn.*, 15, 1965, p. 182.

Rabot, Ch. La tempete du 31 december 1904, dans la Baltique occidentale. *La Geographie,* No. 11, 1905, pp. 32–38.

Radczewski, O.E. Die Mineralfacies der Sedimente des Kapverden—Beckens. *Wiss. Erh. d. Deutsch. Atlant. Exp.*, "Meteor", Bd. III. Th. 3, 1937, pp. 262–277.

Radczewski, O.E. Eolian deposits in marine sediments. *Rec. Marine Sedim.*, 1939, pp. 496–503, Literature.

Radford, J.A. Formation of the Nisby tornado. *Weather,* June, 1966, p. 214.

Rao, P.R.K. and S.N. Sen. Dust-devil at Karachi on 28 February, 1941, *Sci.*

Notes, vol. VIII, No. 100, India Met. Dept., 1942, pp. 167–170.
Reber, C.M. The South Platte Valley tornadoes of June 7, 1953. *Bull. Amer. Met. Soc.,* vol. 35, No. 5, 1954, pp. 191–197.
Redfield, W.C. Whirlwinds excited by fire. *Amer. Journ. Sci.,* vol. 36, No. 1, 1840, p. 1–14.
Reeds, C.A. Storms and storm tracks. *Nat. Hist.,* vol. 28, 1928, pp. 589–604.
Reid, W. The law of storms. London, 1850, 530 pp.
Reinolds, G.W. A common wind damage pattern in relation to the classical tornado. *Bull. Amer. Met. Soc.,* vol. 38, 1957, pp. 1–5.
Remizov, G.A. Tornado pod Moskovi (Tornado near Moscow). *Priroda,* vol. 43, No. 8, 1954, pp. 100–102.
Reye, T. Die Wirbelstume, Tornados und Wettersaulen. Hannover. 1872, 248 pp.
Ride, D.J. Convection from burning cornfields. *Weather,* Aug. 1965, pp. 238–241.
Ril', G. Tropicheskaya meteorologiya (Tropical Meteorology). Moscow, 1963, 381 pp.
Riley, J.A. Sandstorm in Texas. *Monthly Weather Rev.,* vol. 59, 1931, pp. 30–31.
Robinson, A.H.W. The storm surge of 31 Jan–1 Feb. 1953. *Geogr.,* vol. 38, 1953, pp. 134–141.
Romanov, N.N. Pyl'nye buri v srednei Azii (Dust storm in Central Asia). Tashkent, 1961, 198 pp.
Root, C.J. Some outstanding tornadoes. *Monthly Weather Rev.,* vol. 54, 1926, pp. 58–60.
Ross, R.B. and M.D. Blum. Hurricane Audrey, 1957. *Monthly Weather Rev.,* vol. 85, 1957, pp. 221–227.
Rossiter, J.R. The North Sea storm surge of 31 Jan, and Feb. 1, 1953. *Phil. Trans. Roy. Soc.,* vol. A246, 1954, pp. 371–399.
Rossmann, F. Ueber einen Fall elektrischer Feldserregung bei Wustestaubwind. *Wetter und Klime,* No. 1, 1948, pp. 162–164.
Rozenan, N. Obzor pogody po zemnomu sharu za 1967 (Weather review of the world for 1967). *Byull. VMO,* vol. 17, No. 2, 1968, pp. 9–10.
Rue, de la A.E. L'homme et le vent. Paris, 1940, 219 pp.
Rue, A.E. Man and the Winds. New York, 1955, 224 pp.
Russel, C.T. The white sands of Alamogordo. *Nat. Geogr. Mag.,* Aug., 1935, pp. 250–264.
Sadowski, A. Tornadoes associated with hurricane Carla. *Monthly Weather Rev.,* vol. 89, 1961, pp. 514–516.
Sadowski, A. Tornadoes with hurricanes. *Weatherwise,* vol. 19, No. 2, 1966, pp. 71–75.
Saidnazarov, Kh. E'. Vertikal'naya moshchnost' sloev mgly pri pyl'nykh buryakh v Srednei Azii (The vertical thickness of the layer of haze for the

dust storms of Central Asia). *Izv. AN Uzbeksk. SSR., Ser. Fiz-mat.,* No. 4, 1963, pp. 88–93.

Samuel, P., C. Pierce and J.K. McGuire. The squall line and Massachusetts tornadoes of June 9, 1953. *Bull. Amer. Met. Soc.,* vol. 36, No. 3, 1955, pp. 109–122.

Savarenskii, E., T.A. Proskuryakova and V.S. Tsarel'-Sirinuson. O svyazi mezhdu mikroseismicheskimi kolebaniyami i polozheniem tsiklonov nad okeanami (On the relation between microseismic pulsations and the positions of cyclones over oceans). *Met. i. Gidrol.,* No. 6, 1955, pp. 13–18 and Literature.

Sayles, R.W. Bermuda during the Ice Age. *Proc. Amer. Acad. Sci.,* vol. 66, No. 11, 1931, pp. 381–467.

Schamp, H. Die Winde der Erde und ihre Namen. Leipzig, 1964, 94 pp.

Schaubert, H. Ein Sandsturm im sudpersien. *Met. Z.,* Bd. 14, 1897, pp. 189–190.

Schempff, W.H. On Haboob in the Egyptian Sudan. *Bull. Amer. Met. Soc.,* vol. 24, 1943, pp. 371–377.

Schlafli, A. Uber Staubtromben und den "samun" in Unter—Mesopotamien. *Z. d. Osterr. Ges. f. Met.,* Bd. 5, 1870, pp. 469–472.

Schmidt, W. Schlammregan am Alpen-Ostrand am 25 Mai 1935. *Z. f. Angew. Met.,* Bd. 55, No. 1, 1936, pp. 6–11.

Schrock, R.R. Sedimentation and wind action around volcano Parikutin. *Indian Acad. Sci. Proc.,* vol. 55, 1945, pp. 117–120.

Schubert, W.J. On the hurricane tide at Miami. *Monthly Weather Rev.,* vol. 55, 1927, pp. 74–75.

Shuck, A. Die bogenformigen Boen (arched squalls) der passatgrenzen. *Ann. d. Hydrogr.,* Bd. 5, 1877, pp. 132–137.

Schulz, W.A. Jr. and E.L. Hill. Hurricane Hilda, Oct. 1964. *Weatherwise,* vol. 18, No. 4, 1965, pp. 152–161.

Schweder, G. Der Halelsturm des 10 (22) Mai 1872. *Arb. Nat., Var. Z.* Riga, Bd. 5, 1873, 78 pp.

Scott, R.H. Elementary meteorology. London, 1885, 385 pp.

Seefried, A. Untersuchungen uber die Natur der Harmattan trube. *Mitt Deut. Schutzgeb.,* Bd. 26, No. 1, 1913.

Segner, E.P. Estimates of minimum wind forces causing structural damage. The tornadoes at Dallas, 1957. Res. Pap. 41. Weather Bur. Unit. Stat., 1960, pp. 169–175.

Selezneva, E.S. Atmosfernye ayerozoli (Atmospheric Aerosol). Leningrad, 1966, 174 pp. and Literature.

Semmelhack, W. Staubfalle in Nordwesfrikanischen Gabiet des Atlantischen Ozeans. *Ann. d. Hydrogr.,* Bd. 62, 1934, 273 pp.

Seredkina, E.A. Pyl'nye buri v Kazakhstane (Dust storms in Kazakhstan). *Tr. Kazaksk, Gidromet. Inst.,* No. 15, 1960, pp. 54–59.

Sergius, L.A., G.R. Ellis and R.M. Ogden. The Santa-Ana winds of

Southern California. *Weatherwise,* vol. 15, No. 3, 1962, pp. 102–105, 121
Severe local storms. *Amer. Met. Soc. Mont.,* vol. 5, No. 27, 1963, 256 pp.
Shantkhai-Lyubimov, B. K Novorossiiskiibore (On the Novorossiisk bora). *Met. Vestn.,* No. 38, 1928, pp. 17–21.
Shenk, W.E. Analysis of a Caspian Sea vortex. *Monthly Weather Rev.,* vol. 93, 1965, pp. 613–617.
Shipman, T.G. Observing a tornado's life. *Monthly Weather Rev.,* vol. 55, 1927, pp. 183–184.
Shishkin, N.S. Oblaka, Osadki i grozovoe yelektrichestvo (Clouds, Rain and Lightning). Leningrad, 1964, 401 pp. and Literature.
Shoner, R.W. and S. Molansky. Rainfall associated with hurricanes. Nat. Hurr. Res. Project, Rep. No. 3, 1956, 305 pp.
Shostakovich, V.B. Sloistye ilovye otlozheniya i nekotorye voprosy geologii (The layers of silt deposits and some problems of geology). *Izv. Geogr. Obshch.,* vol. 73, No. 3, 1941, pp. 395–405.
Shuliekin, V.V. Vychislenie razmerov voln, vozmozhnykh pri atlanticheskikh uraganakh (Calculation of the size of wave possible in Atlantic hurricanes). *Izv. AN SSR, Ser. Geog.,* No. 7, 1960, pp. 1013–1021.
Sidorenko, A.V. Sostav galek v peschanykh tolshchakh yugo-vostochnykh karakumov (Composition of pebbles in the sandy layer of southeastern Karakum). *DAN SSSR,* vol. 62, No. 31, 1948, pp. 525–527.
Sidorenko, A.V. Elovaya differentisiatsiya veshchestva v pustyne (Aeolian differentiation of matter in deserts). *Izv. AN SSR, Ser. Geogr.,* No. 3, 1956, pp. 3–23.
Siemens, W. Beschreibung ungewohnlich starker elektrischer Erscheinungen auf der Cheops-Pyramide bei Cairo wahrend des Wehens des Chamsin. *Poggen-dorf's Ann. d. Phys. U. Chem.,* Bd. 109, 1860, pp. 355–359.
Sierra wave. *Weather,* May, 1965, p. 162.
Simpson, H.E. Photographs of the Antler, N. Dak, tornado of August 20, 1911. *Monthly Weather Rev.,* vol. 45, 1917, p. 237.
Sinclair, P.C. Some preliminary dust devil measurements. *Monthly Weather Rev.,* vol. 92, 1964, pp. 363–367.
Sinitsyn, V.M. Ordos i Alashan (Ordos and Alashan). Moscow, 1954, 238 pp.
Sinitsyn, V.M. Tsentralnaya Aziya (The Central Asia). Moscow, 1959a, 456 pp.
Sinitsyn, V.M. Mongolo-sibirskii antitsiklon i regional'naya zonal'nost' yelovikh otlozhenii Tsentralnoi Azii (Mongol-Siberian anticyclone and regional zonality of aeolian deposits of Central Asia). *DAN SSSR,* vol. 125, No. 6, 1959b, pp. 1326–1328.
Skeib, G. Orkane uber Antarctica. Leipzig, 1963, 270 pp.
Slamon, L.H. Preliminary report on tornadoes in the United States during 1946. *Monthly Weather Rev.,* vol. 74, 1946, pp. 211–213.

Sloane, E. The book of storms. New York, 1956, 109 pp.

Smith, J.C. The hurricane tornado. *Monthly Weather Rev.*, vol. 93, 1965, pp. 453–459.

Sobolev, S.S. Razvitie erozionnykh protsessov na territorii Evropeiskoi chasti SSSR i borba s nimi (Growth of erosion processes in the European Territory of the USSR and its control. Vols. I & II), 1948, 1960, 248 pp.

Sokolve, K.F. Pyl'naya burya v primor'e (Dust storm at sea). *Met. i Gidrol.*, No. 3, 1957, pp. 45–46.

Sokolov, N.A. Duny, ikh obrazovanie, razvitie i vnutrennee stroenie (Dunes, their formation, growth and internal structure). Spb., 1884, 286 pp.

Sokolovskii, I.L. Lessovye porody zapadnoi chasti USSR (Loess of the Western Part of the Ukr. SSR). Kiev, 1958, 100 pp. and Literature.

Some photographs of tornadoes. *Quart. Journ. Met. Soc.*, April, 1937, 162 pp.

Spohn, H.R. and P.J. Waite. Iowa tornadoes. *Monthly Weather Rev.*, vol. 90, 1962, pp. 398–406.

Staff members, Academia Sinica, Peking. On the general circulation over Eastern Asia. *Tellus*, vol. 9, No. 4, 1957, pp. 432–447.

Stankewitz, L.A., A. Johnson and J.W. Dobry. The Wichita Falls tornado. *Weatherwise*, vol. 17, No. 12, 1964, pp. 80–81, 98.

Starov, D.K. Smerchi na chernom i Azovskom moryakh (Waterspouts in the Black and Azov seas). *Zap. po Gidrogr.*, No. 1, 1935, pp. 56–58.

Stearns, R.D. Dot—Hawaii's third hurricane. *Weatherwise*, vol. 13, No. 4, 1960, pp. 146–149.

Steers, J.A. The sea coast. 3 ed., London, 1953, 276 pp.

Steers, J.A. The coast line of England and Wales. 3 ed., Cambridge, 1964, 750 pp. Literature.

Steers, J.A. The English coast. London, 1966, 192 pp.

Stekol'nikov, I.S. Molniya i grom (Lightning and Thunder). Moscow, 1954, 95 pp.

Stewart, W.P. Thundersqualls in Wisconsin, June 9–10, 1922. *Monthly Weather Rev.*, vol. 50, 1922, pp. 311–312.

Stoddart, D.R. Catastrophic storm effects on the British Honduras reefs and cays. *Nature*, vol. 196, No. 4854, 1962a, pp. 512–515.

Stoddart, D.R. Physiographic studies on the British Honduras reefs and cays. *Geogr. Journ.*, vol. 128, pt., 2, 1962b, pp. 161–173.

Stommel, H.G. The great blizzard of '66. *Weatherwise*, vol. 19, No. 5, 1966, pp. 189–193.

Strong, C.M. The tornado of May 10, 1905, at Synder, Okla. *Monthly Weather Rev.*, vol. 33, 1905, pp. 355–356.

Stuntz, S.C. and E.E. Free. Bibliography of aeolian geology. Bull. 68, Unit. Stat. Dept. Agric.. Bur. of Soils, 1911, pp. 174–263.

Sysoeva, N. Burya na severe 13–17 iyunya 1915 (Storm in the North on June

13–17, 1915). *Met. Vestn.* No. 26, 1916, pp. 38–41.
Tannehill, I.R. Hurricanes. Their nature and history. Princeton, 1945, 275 pp.
Tannehill, I.R. Hurricane Hunters. New York, 1954, 271 pp.
Taziev, G. Vstrechi s d'yavolom (Encounter with the Devil). Translated from French. Moscow, 1961, 102 pp.
Taziev, G. Vulkany (Volcanoes). Translated from French. Moscow, 1963, 117 pp.
Tepper, M. A report on the meteorological satellite program. *Weatherwise,* vol. 14, No. 4, 1961, pp. 131–137.
The eruption of Krakatoa. London, 1888, 494 pp.
The eye of Betsy. *Weatherwise,* vol. 18, No. 5, 1965, pp. 218–219.
Thomas, T.M. Some observations on the Chinook "arch" in Western Alberta and Northwestern Montana. *Monthly Weather Rev.,* vol. 91, 1963, pp. 166–170.
Thorarinson, S. and B. Vonnegut. Whirlwinds produced by the eruption of Surtsey volcano. *Bull. Amer. Met. Soc.,* vol. 45, No. 8, 1964, pp. 440–444, Literature.
Thotonyi, G. Bibliography on tornado analysis and forecasting. *Meteor. abstr. and bibliography,* vol. 10, No. 2, 1959, pp. 175–330.
Tiron, Z.M. Uragany (Hurricanes). Leningrad, 1964, 328 pp.
Tornado et Fergus Falls, Minn., June 22, 1919. *Monthly Weather Rev.,* vol. 47, 1919, pp. 392–393.
Tovarova, I.I. O vynose vodnorastvorimykh veschestv iz piroklastiki vulkana Bezymyannyi (On the transportation of water-soluble matter from the pyroclastic volcano of Bezymyannyi). *Geokhimiya,* No. 7, pp. 686–688.
Townsend, C.H. Two giant tortoises were swept twenty miles by a hurricane. *Bull. N.Y. Zool. Soc.,* vol. 39, 1936, pp. 119–120.
Turovslev, M.M. Vetrovaya i vodnaya yeroziya v Bashkirskoi ASSR (The wind and water erosion in Bashkir Autonomous SSR). In Sb.: *Zashchita pochv ot yeroziya,* Moscow, 1964, pp. 64–72.
Tvenhofel, V.G. Uchenie ob obrazonvanii osadkov (Studies in rain formation). Moscow-Leningrad, 1936, 916 pp.
Twenhofel W. Treatise on sedimentation. Baltimore, 1926, 661 pp.
Typhoon Opal, Tiros V photographs of typhoon Opal. *Weather,* May, 1965, p. 145.
Udden, J.A. Erosion, transportation and sedimentation performed by the atmosphere. *Journ. Geol.,* No. 11, 1894, pp. 318–331.
Udden, J.A. Dust and sand storms in the West. *Popul. Sci., Monthly,* vol. 49, 1896, pp. 655–664.
Udden, J.A. The mechanical composition of wind deposits. Publ. *Augustana Libr.,* No. 1, 1898, p. 65.
UNESCO Symposium on typhoons, Tokyo, 1955. National Hurricane Res.

Project, 1958, pp. 129–150.
Unoki, S. and M. Nakana. Estimation of storm waves caused by typhoon at Gozen Iwa and Goto-hada. *Journ. Ocean. Soc. Tokyo,* vol. 14 (1), 1958, pp. 15–23.
Valentin, J. Der Staubfall von 9 bis 12 Marz 1901. *Sitzungber d. k. Akad. Wiss.,* Wien, Math-Nat, cl, Bd, CVI, IIa, 1902, 50 pp.
Van Tassel, E.L. The North Platte valley tornado outbreak of June 27, 1955. *Monthly Weather Rev.*, vol. 83, 1955, pp. 255–264.
Varney, B.M. A further note on the Lorain, Ohio, tornado of June 28, 1924. *Monthly Weather Rev.* vol. 52, 1924, pp. 396–397.
Verbeek, R.D.M. Krakatua. Batavia, 1885, 567 pp.
Veryard, R.G. Dust Devils. *Met. Mag.*, vol. 69, Dec., 1934, pp. 268–269.
Veryard, R.G. A preliminary study of a tornado at Peshawar. *Sci. Notes,* India Met. Dept., vol. 56, 1935, pp. 109–116.
Visher, S.S. Tropical cyclones in Australia and the South Pacific and Indian oceans. *Monthly Weather Rev.*, vol. 50, 1922a, pp. 288–295.
Visher, S.S. Tropical cyclones in the Northeast Pacific between Hawaii and Mexico. *Monthly Weather Rev.*, vol. 50, 1922b, pp. 295–297.
Visher, S.S. Tropical cyclones of the Pacific. *Bull. B.P. Bishop Mus.*, vol. 20, 1925, 163 pp. Literature.
Visher, S.S. and D. Hodge. Australian hurricanes and related storms. *Bull. Meteor. Branch,* Australia, vol. 16, 1925, 54 pp.
Vize, V. Yu. Novozemel'skaya bora (Bora of Novaya Zemlya). *Izv. Tsentr. Gidromet. Byuro,* No. 5, 1925, pp. 1–56.
Voeikov, A.I. Meteorologicheskie nablyudeniya N.M. Przheval'skogo (Meteorological observations of N.M. Przheval'sky). Spb. 1895, 281 pp.
Volkov, I.N. Nekotorye osobennosti sovremennykh yelovikh protsessov (Some features of contemporary aeolian processes). *Tr. Inst. Geol. i Geofiz., Sibirsk. otd. AN SSSR,* No. 24, 1964, pp. 26–49.
Vonnegut, B. Electrical theory of tornadoes. *Journ. Geoph. Res.,* vol. 65, 1960, pp. 203–212.
Vonnegut, B. and J.R. Meyer. Luminous phenomena accompanying tornadoes. *Weatherwise,* vol. 19, No. 2, 1966, pp. 66–68.
Vonnegut, B. and C.B. Moore. Giant electrical storms. *In Rec. Advan. in atm electric.,* Washington, 1958, pp. 399–411.
Vorob'ev, S.O. Chernye buri na Ukraine (Dark storms in the Ukraine). *Tr. po Sel'skokhoz. Meteor.*, No. 21, 1930, pp. 268–280.
Voznesenskii, A.V. Po povodu pyl'noi buri 26–27 aprelya 1928 (On the dust storm of April 26–27, 1928). *Tr. po Sel'skokhoz. Meteor.*, No. 21, 1930, pp. 281–294.
Voznyachuk, L.N. K voprosu ob opredenlenii severnoi granitsy rasprostraneniya smerchei v Europe i zapadnoi Sibiri (On the problem of determining the northern boundary of propagation of storms in Europe and Western Siberia). *Uchen. Zap. Belorussk. Gos. Univ.*, No. 21, 1954,

Ser. Geol. i Geogr., No. 21, 1954, pp. 87–103 and Literature.
Voznyachuk, L.N. Materialy k izucheniyu smerchei na territorii Belorusii (Materials for the study of tornadoes in the territory of Belorussia). *Uchen. Belorussk. Univ. Ser. Geol. i Geogr.,* No. 21, 1954b, pp. 104–123.
Vysotskii, G.N. Materialy po izucheniyu chernyk bur' v stepyakh Rossii (Materials on the study of dark storms in the steppes of Russia). *Tr. Yeksped. v.v. Dokuchaev,* No. 1, 1894, pp. 31–48.
Wadati, K. and T. Hirono. Storm tides caused by typhoons. Proc. UNESCO Symp., Tokyo, 1954, Tokyo 1955, pp. 31–48 and Literature.
Walz, F.G. Tornado of March 23, 1917, at New Albany, Indiana. *Monthly Weather Rev.,* vol. 45, 1917, pp. 169–171.
Waterspouts in the Strait of Malacca. *Monthly Weather Rev.,* vol. 57, 1929, pp. 249–250.
Weaver, K.F. Tracking America's man in orbit. *Nat. Geogr. Mag.,* vol. 121, No. 2, 1962, pp. 184–218. Literature.
Webster, D.L. The squall cloud in a thunderstorm, a direct observation of its motion. *Monthly Weather Rev.,* vol. 52, 1924, p. 586.
Wegener, A. Wind und Wasserhosen in Europa. *In: Die Wissenschaft,* Bd. 60, Braunschweig, 1917, 301 pp.
Wegmann, C.E. Staubfalle und zyklische Gliederung von Meeressedimenten. Geol. Rundschau, Bd. 36, 1948, pp. 29–31. Literature.
Whittingham, H.E. The Bathhurst bay hurricane and associated storm surge. *Austral. Met. Mag.,* No. 23, Dec., 1958, pp. 14–36.
Widger, W.K. Meteorological satellites. New York, 1960, 280 pp.
Williams, N.R. Development of dust whirls and similar small-scale vortices. *Bull. Amer. Met. Soc.,* vol. 29, No. 3, 1948, pp. 106-116.
Williams, P. Wasatch winds of Northeastern Utah. *Weatherwise,* vol. 5, No. 6, 1952, pp. 130–132.
Williams, W.W. Coastal changes, London, 1960, 220 pp.
Williamson, R.M. Tornado in Davidson county, Tennessee, May 12, 1923. *Monthly Weather Rev.,* vol. 51, 1923, p. 262.
Williamson, R.M. Tornado at Nashville, Tenn., March 14, 1933. *Monthly Weather Rev.,* vol. 61, 1933, pp. 84–85.
Winchell, A.N. The great dustfall of 1920. *Amer. Journ. Sci.,* vol. 48, 1920, pp. 349–364.
Winchell, A.N. and E.R. Miller. The dust fall of March 9, 1918. *Amer. Journ. Sci.,* vol. 46, 1918, pp. 599–609.
Wittschell, L. Die Bedeutung aolischer Boden in Nordafrica nebst einigen Bemerkungen zum Lossproblem. *Pett. Mitt.,* 1928, s—344 ff.
Wittschell, L. Uber sand und staubsturme und ihre Bedeutung fur die Morphologie der Erdoberglache. *Zeit. f. Geomorph,* Bd. 6, H. 1, 1930, pp. 1–18.
Wobus, H.B. Tornado from cumulo-nimbus. *Bull. Amer. Met. Soc.,* vol. 21,

No. 9, 1940, pp. 367–368.

Wolford, L.V. Tornado occurrences in the United States. Techn. Paper. No. 20, Weather Bur. Unit. Stat., 1960, 71 pp.

Wolke, C.H. Nachricht von einer sehr nahe beobachteten Wasserhose. *Gilberts Ann. d. Physics,* Bd. 10, 1802, p. 482.

Wood, P. The story of a typhoon. *Weather,* vol. 25, No. 5, 1965, pp. 146–153.

Woodcock, A.H. Sea salt in tropical storm. *Journ. Met.,* vol. 7, 1950, pp. 397–401.

Yakhontov, G. Buri ozera Baikal (Storm over Lake Baikal). *Zap. AN,* VIII Ser., vol. 19, No. 3, 1906, pp. 1–15.

Yakubov, T.F. Vetrovaya eroziya pochvy i bor'ba s neyu (Soil Erosion by Wind and Its Control). Moscow, 1946, 80 pp.

Yakubov, T.F. Novye dannye po izucheniyu vetrovoi erozii pochv i bor'be s neyu (New data on the study of soil erosion by wind and its control). *Pochvovedenie,* No. 7, 1959, pp. 41–52 and Literature; No. 11, 1959, pp. 65–77.

Yakubov, T.F. Zashchita pochv ot vetrovoi erozii. Obzor Inostrannoi Literatury (Soil conservation against wind erosion. A review of foreign literature). *Pochvovedenie,* No. 8, pp. 84–93. Literature.

Yastrebov, A.E. Sil'nyi shkval v severnom Priural'e (Strong squall in North Ural). *Met. i Gidrol,* No. 2, 1958, pp. 30–33.

Yeikhval'd, Ye. I. Rezul'taty mikroskopicheskikh issledovanii, proizvedennykh nad pyl'yu sukhogo tumana aprelya 1849 (The results of microscopic examination of dry dust cloud in April, 1894). *Geogr. Izv.,* 1849, pp. 274–276.

Yeroziya pochv i bor'ba s neyu (Soil Erosion and Its Control). Moscow, 1957, 680 pp.

Young, F. Tornadoes of March 11, 1917, in Ohio. *Monthly Weather Rev.,* vol. 45, 1917, pp. 117–118.

Yurasova, V.I., A.M. Koshenko and V.A. Bezuglova. Garmsili v Turkmenii (Garmsil in Turkmenia). *Tr. Sredneaz. Gidromet. Inst.,* No. 8, (23), 1963, pp. 109–124.

Zakharov, P.S. Pyl'nye buri (Dust Storms). Leningrad, 1965, 164 pp., Literature.

Zamorskii, A.D. Sluchai okrashennogo snegopada v Rostove-na-Donu (The incidence of colored snowfall in Rostov-on-Don). *Met. i Gidrol.,* No. 6, 1939, pp. 46–50.

Zamorskii, A.D. Osazhdenie solevoi pyli (Fallout of salt dust). *Met. i. Gidrol.,* No. 9, 1952, pp. 25–28.

Zamorskii, A.D. Mezhkontinental'nyi perenos pyli struinymi techeniyami (Intercontinental transportation of dust by jet flow). *Met. i Gidrol.,* No. 4, 1964, pp. 33–35.

Zaschita Pochv ot Yerozii (Control of Soil Erosion). Moscow, 1964, 599 pp.

Zemlyanitskii, L.T. Priroda pyl'nykh bur' i bor'ba s vyduvaniem pochv (The nature of dust storms and control of soil erosion). In Sb.: *Borba s yeroziei,* Moscow, 1957, pp. 55–68.

Zenkovich, V.P. Osnovy ucheniya o razvitiimorskikh beregov (Fundamental studies on the growth of the seacoast). Moscow, 1962, 710 pp. and Literature.

Zhirkov, K.F. O pyl'nykh buryakh v stepyakh zapadnoi Sibiri i Kazakhstana (On the dust storms in the steppes of Western Siberia and Kazakhstan). *Izv. AN SSSR, ser. Geogr.,* No. 6, 1963, pp. 50–55.

Zhukov, M.M. Otsenka yelovogo faktora obrazovaniya lessa v svete izucheniya chernykh bur' (Estimation of the aeolian factor in loess formation in the light of the study of dark storms). *Tr. Inst. Geol. i Geofiz., Sibirsk otd., AN SSSR,* No. 24, 1964, pp. 5–25.

Zurcher and Margolle. Trombes et cyclones. Paris, 1883, 320 pp.

Zvonkov, V.V. Vodnaya i vetrovaya yeroziya zemli (Water and Wind Erosion of Land). Moscow, 1962, 175 pp., Literature.

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200 B.C.	Rain with frogs	Greece	429
689 A.D.	Rain with fish	Saxony	422
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1160	Dust storms, Atlantic Ocean	Western North Africa	506
1164	Storm, incursion by sea	North Sea, coast of Germany	76
1282	Storm, incursion by sea, formation of Zuider-Zee	North Sea, coast of Holland	76
1300	Flood	River Neva	78
1334	Storm, incursion by sea	North Sea, coast of Germany	76
1345	Rain with frogs	Germany	429
1362	Storm, incursion by sea	North Sea, coast of Germany	76
1509	Storm, incursion by sea	,,	76
1541	Flood	River Neva	78
1549	Rain with frogs	Yel'zas	429–430
1555	Rain with fish	Sweden	422
1570	Storm, incursion by sea	North Sea, coast of Germany	76
1572	Storm, blood-red rain	Poland, Torun (Thorn)	506
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1717	Storm, incursion by sea	North Sea, coast of Germany	76
1737	Hurricane, incursion by waves	Gangetic delta (River Hoogly)	68
1755	Hurricane, blood-red rain, red snow	Locarno, Lago-Majore	508
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1809, Jun. 23	Rain with toads	France	429
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1822, Aug.	Rain with toads	France	429
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1833, May 21	Hurricane	Bay of Bengal	68
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1834	Rain with mollusks	USA	421
1834, May 16	Rain with fish	India	424
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1913, Mar. 23	Sandstorm, strong electri-fication	Kansas, USA	182
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1917, Mar. 23	Tornado	New Albany, Indiana, USA	254, 405, 418
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