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FIRST ANNUAL REPORT OF

Ad Hoc Committee on Geodynamics to The Federal Council for Science and Technology

PREFACE

The ad hoc Committee on Geodynamics was established upon recognition of the need for an interagency mechanism for the coordination of U.S. Federal activities in the International Geodynamics Project (IGP). At the fall 1973, plenary meeting of the Federal Council for Science and Technology (FCST), the establishment of an ad hoc Committee on the IGP was approved in principle. The Committee was formally established by the chairman of the FCST in a memorandum dated May 21, 1974.

The purpose of the ad hoc Committee is to ensure the planning and coordination of Federal activities in the IGP and related matters. The Committee fosters studies and investigations considered appropriate to the IGP and annually reviews the Federal geodynamics programs and budget. It also serves as the focal point for liaison with the U.S. Geodynamics Committee of the National Academy of Sciences, and with other outside bodies concerned with the IGP.

Since its inception, the ad hoc Committee has met a total of fourteen times. The first meeting was on August 29, 1974 and the most recent meeting on June 17, 1976.

The present membership of the Committee is as follows:

Member	*Alternate*	*Organization*
A.P. Crary, chairman		National Science Foundation
Dallas Peck, vice-chairman	Richard S. Fiske	Department of the Interior
Gordon Lill	George Younger	Department of Commerce
Carl Romney	William J. Best Fernand P. dePercin John G. Heacock	Department of Defense
Robert G. Morris		Department of State
George A. Kolstad	Jerry Harbour	Energy Research and Development Administration
Francis L. Williams	Edward A. Flinn Joseph W. Siry	National Aeronautics and and Space Administration
	Observers	
	Robert D. Lanza	Department of Health, Education and Welfare
	Arthur J. Zeizel	Department of Housing and Urban Development
	Jack W. Keely	Environmental Protection Agency
	David Katcher	National Advisory Committee on Oceans and Atmosphere

Executive Secretary: Hugh W. Albers, National Science Foundation

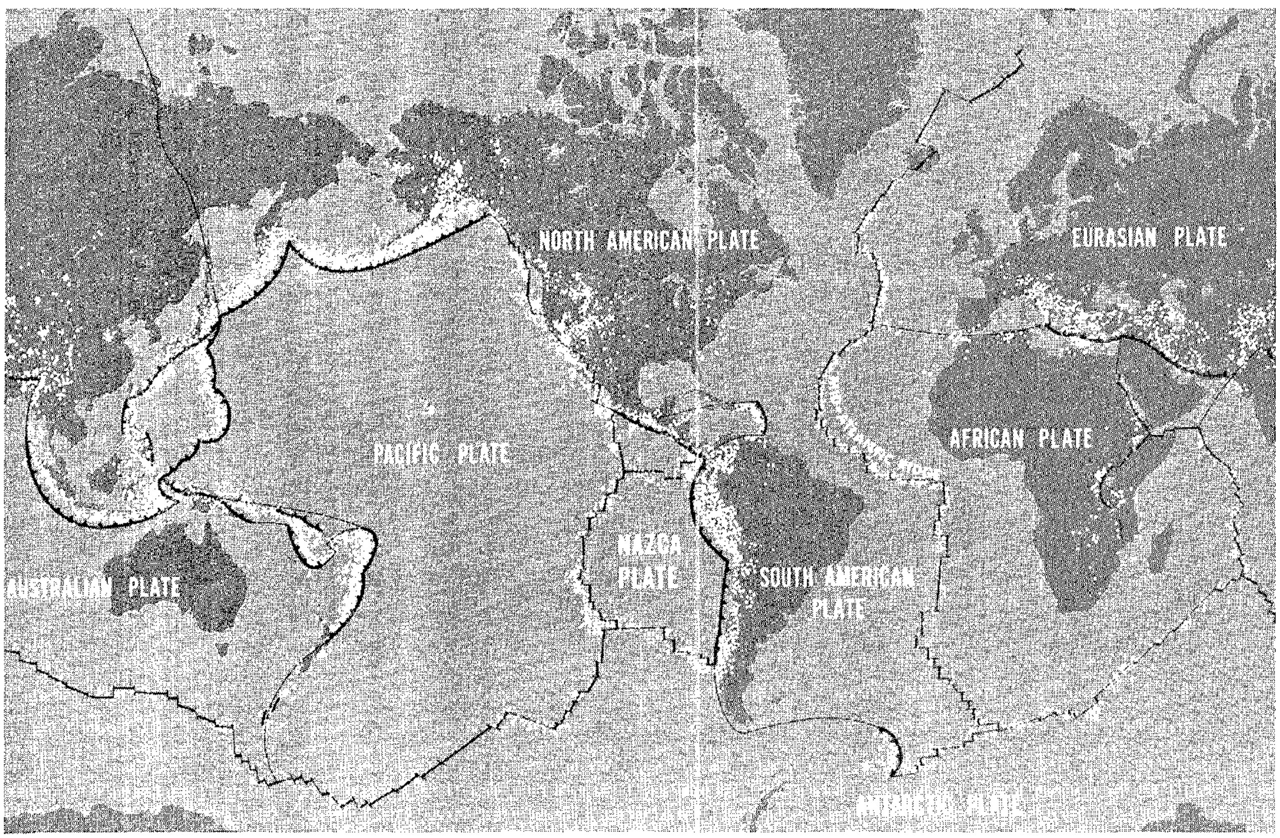
First Annual Report on Federal Activities in Geodynamics

CONTENTS

BACKGROUND OF GEODYNAMICS

The Earth Sciences are undergoing a period of rapid advance, the result of a simplifying theory that has unified geologic thinking and provided a new framework for interpretation of observational and experimental data. The major initial contributions to the new concept came from marine geology and geophysics, and seismology. These observations led to the theory that has become known as plate tectonics, centering on the concept that the earth's outer shell, consisting of the crust and upper part of the mantle, is made up of a small number of very large semi-rigid plates that move relative to one another. The plate tectonics theory differs from continental drift theory in that the plate boundaries seldom coincide with continental boundaries.

Stated very briefly, the plate tectonics concept holds that new crust is constantly being generated along mid-ocean ridges; hot molten material rises from the underlying mantle, cools, and is forced aside by new molten material coming from the depths. The plates are in constant movement, the principal direction being at right angles to and away from the center of the mid-ocean ridges. On the opposite sides, the plates collide to form mountains, or one plate



Map showing the plate structure of the Earth. At subduction zones (heavy dark curves) such as the deep trenches ringing the Pacific, the leading edges of the plates plunge downward to be consumed in the mantle. The mid ocean ridges are shown by the dark segmented lines. Along them the mantle wells up and solidifies as the ocean floor spreads. Plates rub edge to edge along transform faults (thin curved lines). The dots mark the location of earthquakes that have been recorded during the last 20 years.

edge may be drawn below another at the deep sea trenches in what is called a subduction zone. Thus, along their boundaries, the plates either move parallel to one another, move apart (as at spreading centers) or converge (as at subduction zones). According to today's model, the present spreading cycle started about 200 million years ago, at which time the continents were essentially one land mass that split apart along what is now the mid-Atlantic ridge. Since then the continents have been moving apart at about two centimeters a year.

The plate tectonic concept has enormous promise in explaining the origin of earthquakes, volcanoes, faulting, and mountain building with resulting implications for natural disasters, energy resources, and the emplacement of economically valuable concentrations of minerals and hydrocarbons. The general recognition of the potential impact of this "revolution in earth sciences" led to the concept of an intensive international program to study the basic mechanism of earth deformation—the International Geodynamics Project (IGP).

The IGP is an international program of research on the dynamic processes that affect and have affected the earth. A major goal of the IGP is to delineate the internal forces that cause the horizontal motion of the plates, as well as the vertical movements of large parts of the plates, and ultimately to understand the mechanisms that give rise to these forces.

The IGP is coordinated by the Interunion Commission on Geodynamics (ICG) established by the International Council of Scientific Unions (ICSU) at the request of the International Union of Geodesy and Geophysics (IUGG) and the International Union of Geological Sciences (IUGS), with the provision for active participation of all interested ICSU unions and committees. There are now 52 countries participating in the IGP with the realization that the plate tectonic model is a global one, and that a coordinated effort among all parties involved will achieve greater and more rapid progress than isolated individual efforts.

SOCIETAL BENEFITS FROM GEODYNAMICS STUDIES

Man's safety from natural hazards and man's prosperity are closely linked to his understanding of large-scale geodynamic processes occurring at or beneath the earth's surface. Earthquakes; volcanoes; concentrations of hydrocarbons, minerals, and geothermal heat; and mountain ranges are all manifestations of such geodynamic or tectonic processes. It has been known for some time that tectonic activity on a global scale is concentrated in very narrow zones but no rationale for the concentration of a number of seemingly unrelated phenomena was available until the advent of plate tectonics. Now the majority of the narrow zones of tectonic activity are regarded simply as the network of plate boundaries covering the surface of the earth.

Earthquakes

Almost 90 percent of the world's earthquakes occur along these boundaries. Two such zones cross the United States. One extends from the Gulf of California to Cape Mendocino (north of San Francisco) and includes the sites of the 1906 San Francisco and the 1971 San Fernando earthquakes.

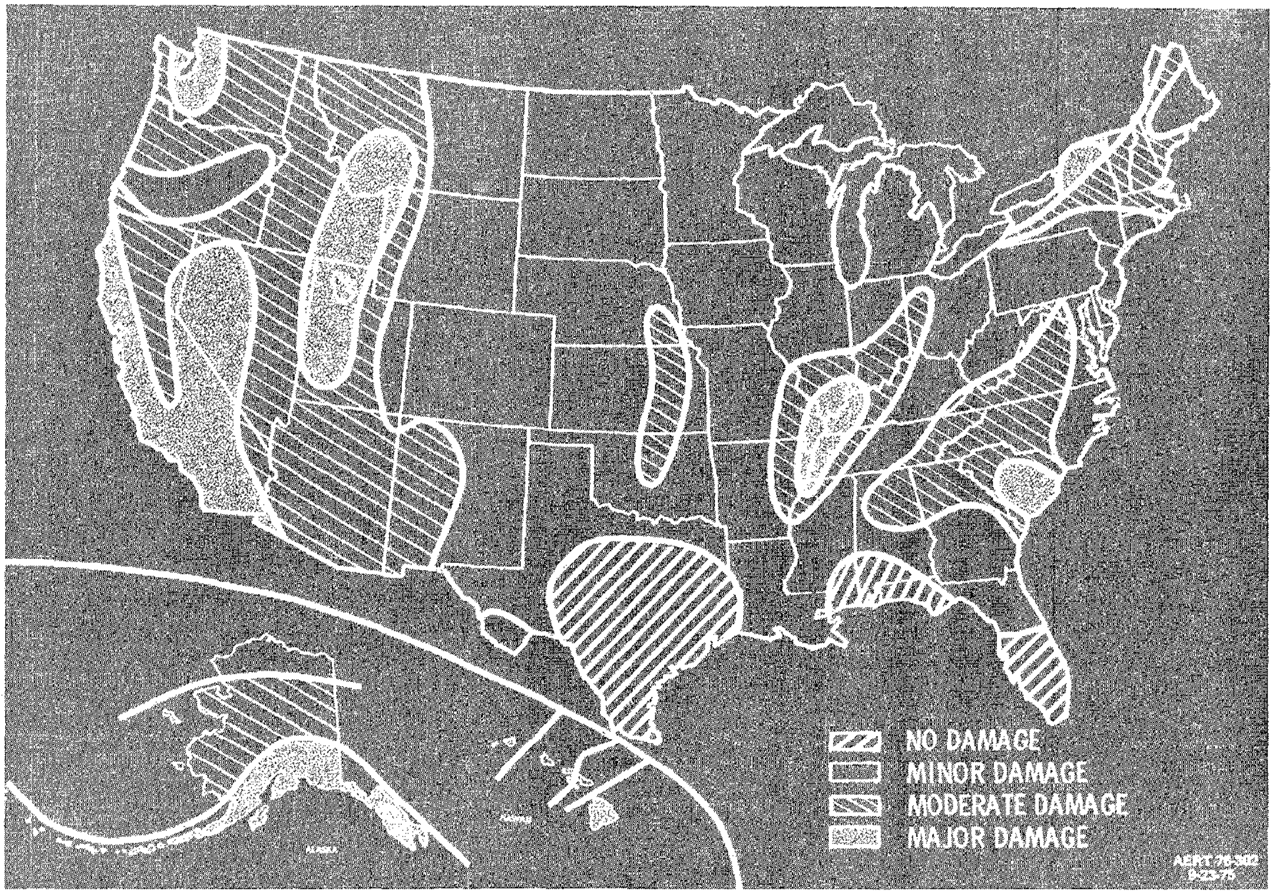
The second zone extends from southeastern Alaska through the Aleutian island chain and includes the Aleutian trench, which is the site of many deep focus earthquakes. On land this zone includes the site of the large earthquake near Anchorage in 1964. Many of the narrow earthquake zones cross densely populated regions, e.g., the Pacific Coast of the United States, Japan, and areas bordering on the Mediterranean Sea. Some 500 million people are exposed to personal danger and damage to personal property in these seismic risk areas. Perhaps more than any other geophysical hazard, major earthquakes are likely to produce almost complete social disruption in modern urban areas. The vital technologies of a city both above and below ground may be shattered. To compound the problem, earthquakes may trigger secondary events such as fires, tsunamis, landslides, or floods, which commonly cause more damage and loss of life than the earthquakes themselves.

The possibility of predicting and, to some extent, controlling earthquakes, has been greatly enhanced by the plate tectonics concept. But, in order to achieve such capabilities, a better understanding is needed of the mechanics of earthquakes and of the forces responsible for the stress accumulations. The dynamics of the plate motions is a crucial factor.

Certainly, a better understanding of the mechanisms behind crustal movement and the state of stress in the interiors of plates is essential before we can venture any effort at earthquake control. Results of several recent experiments at the Rocky Mountain Arsenal and at Rangely, Colorado have indicated that minor earthquake activity can be initiated by pumping fluid under pressure down a borehole so that it relieves the stress at depth on a pre-existing fault. The activity can be stopped by withdrawing the fluid. This limited experience suggests the possibility of control on a large active fault zone such as the San Andreas. Once the details of the stress distribution at depth and the mechanism of movement along the fault are reasonably well understood, a program of control by fluid injection might be achieved whereby the stored strain energy on the fault is released by inducing a number of small and relatively harmless earthquakes.

A better understanding of the detailed mechanisms of crustal movements in fault zones would also be of great value in predicting ground motion from anticipated earthquakes at potential construction sites near or remote from the fault zones. Decisions of great societal and economic importance should be based on such predictions, e.g. the siting of nuclear reactors, oil pipelines, aqueducts, dams and reservoirs, hospitals, and public transit systems.

Although most major earthquakes are along plate boundaries, the interiors of plates are not immune. In the North American Plate there have been major earthquakes in the vicinity of Boston, Massachusetts (1755); at New Madrid, Missouri in the central Mississippi Valley (1811 and 1812); at Charleston, South Carolina (1886); and at Hebgen Lake, Montana (1959). Indeed, most of

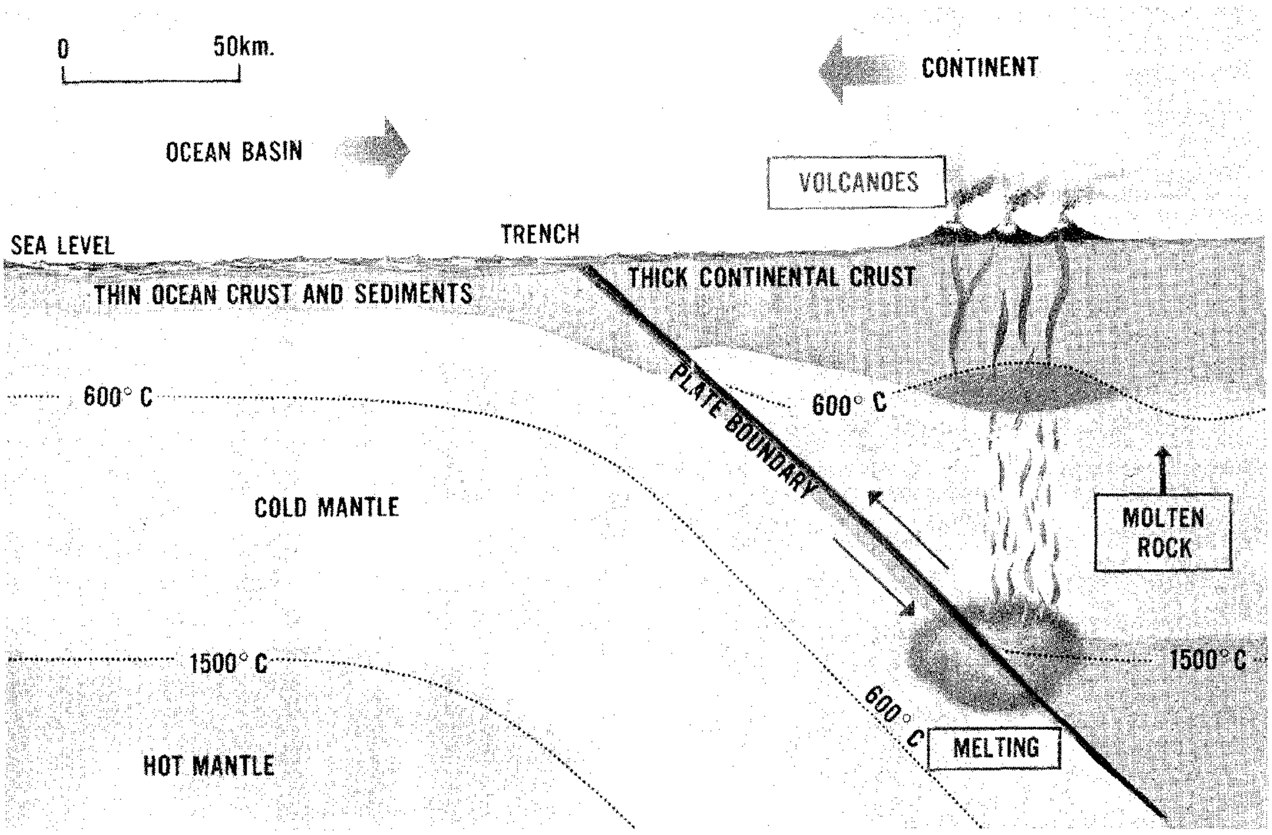


Seismic Risk Map of the United States
Areas of earthquake damage in historic times. Note that of the several areas of major damage only coastal California is associated with one of the plate boundaries.

the U.S. has some risk of seismic disturbance. The so-called intraplate earthquakes pose special problems to be addressed by geodynamics research because their relationship to the horizontal movements of the plates is not obvious. Although intraplate earthquakes are rarer than earthquakes on plate boundaries, the long term risk, in terms of property damage and loss of life, is comparable. This is because the crust in the interiors of most plates is much more uniform and homogeneous than at the boundaries. Thus it is a more efficient propagator of earthquake disturbances and a given magnitude intraplate earthquake will usually have a much larger area of high intensity and damage than one of equal strength along a plate boundary.

Volcanoes

Volcanic activity is a surface manifestation of deep seated geodynamic processes. Its impact on man involves not only potential hazard but also potential benefit. The hazard of volcanic eruptions is of real concern; some 200,000 people have been killed by volcanoes in the past 500 years. Specific hazards include lava flows, pyroclastic flows, ash falls, volcanic mudflows, and floods, as well as a number of volcanically generated events such as tsunamis, forest fires, and debris avalanches and landslides. Volcanic hazard is significant in three major areas of the United States: Hawaii, the Cascade Range of the Pacific Northwest, and Alaska. The potential for loss in terms of property damage, injury and loss of life, and social disruption appears to be increasing because of significant population growth and urbanization in all three major hazard areas. The development of energy resources in Alaska and the Pacific Northwest is magnifying the loss potential.



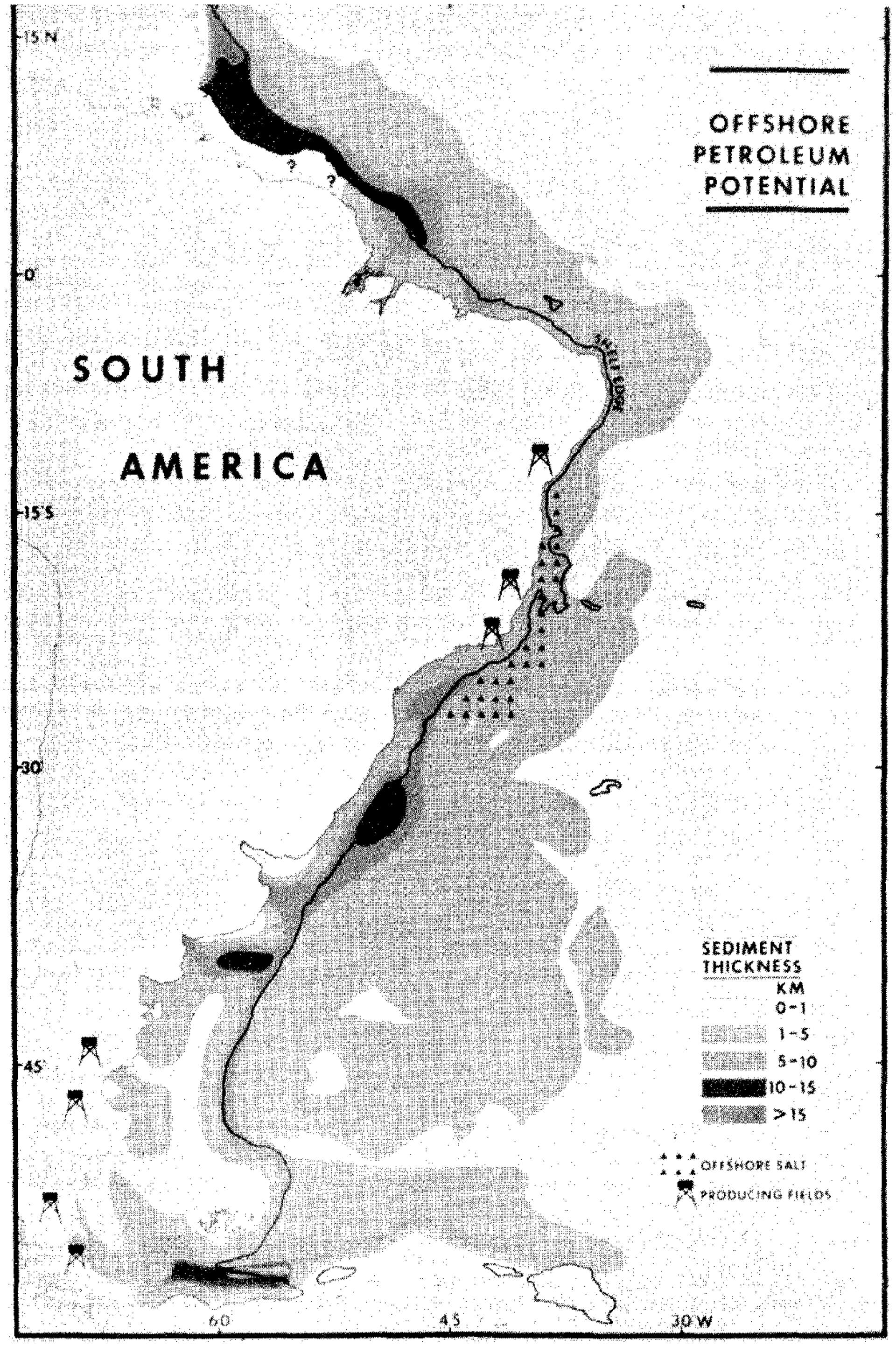
Volcanoes and Plate Boundaries
A schematic cross section of a convergent plate boundary. As the oceanic plate moves from left to right, it is forced under the continental plate. When the upper part of the oceanic plate reaches to about the 1500° isotherm partial melting occurs and the magma rises to form volcanic mountains at the surface. Volcanoes are also characteristic of the spreading centers or divergent plate boundaries.

As with earthquakes, volcanic activity is most common in the tectonic zones that characterize the plate boundaries. A better understanding of the geodynamic processes involved at plate boundaries is a necessary precursor to a better understanding of a volcanic system, and any hoped for eruption prediction.

Volcanoes contribute to man's well being in several ways. Soils derived from volcanic material are extremely fertile. Volcanic emissions of rock and gas are sources of pumice, ammonia, boric acid, and carbon dioxide. The thermal energy of volcanoes is being put to more and more use. Many homes in Iceland are heated by hot water tapped from volcanic springs. Geothermal steam associated with sites of recent volcanism is being exploited as a source of electricity in New Zealand, Italy, the United States, Mexico, Japan, and the U.S.S.R.

Natural Resources

Recent shortages and embargoes have highlighted the need to understand the natural processes that have produced petroleum, coal, metals, and other earth resources, such as geothermal heat, that are essential to the Nation's technology. Plate tectonics is clearly related to the formation of oil and mineral deposits. The formation of oil and gas reservoirs appears to have been determined to a large extent by the history of plate movements over the past 200 million years. For example, long-term vertical movements, which are related to geodynamic processes at depth, have resulted in sediment-filled basin troughs that are important sources of hydrocarbons. Almost nothing is known about the forces that cause these vertical movements, despite their great economic significance. A

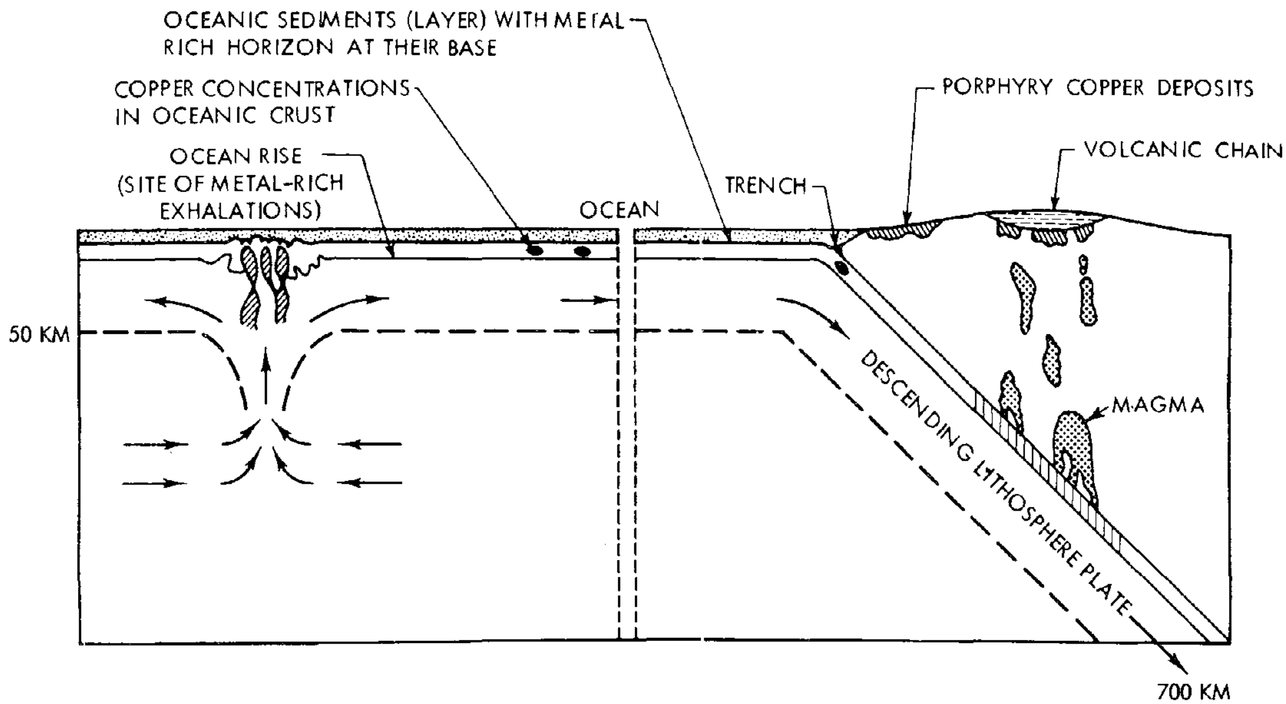


The Offshore Petroleum Potential of South America
Along the east coast of South America are elongated basins filled with sediments that may range back to the time when South America and Africa split apart. These basins are a prime target in the search for oil and natural gas.

better understanding of such forces could improve our techniques for petroleum exploration. The total amount expended by U.S. companies for petroleum exploration is about $4 billion per year. A modest increase of 1 percent in the efficiency of this effort, through better understanding of basic geodynamic processes, would amount to some $40 million per year.

It is equally true that mineral deposits are not randomly distributed, but are related to past and present tectonic zones. The type of ore present and where it is located depends principally on tectonic history of the zone. A particularly clear example is the copper sulfide deposits on the island of Cyprus. The copper sulfide ore occurs in a distinctive sequence of rocks, called an ophiolite sequence, which is now thought to be a largely unaltered piece of oceanic crust thrust up when Cyprus was formed. The minerals it contains are thus characteristic of those formed at mid-ocean ridges. Most of the mineral deposits with easily recognizable surface features have been found. Future success in mineral exploration will require a sophisticated approach that includes an understanding of the relationship between mineral deposits and the underlying geodynamic phenomena responsible for their origin.

Geothermal heat as a natural resource has been exploited for centuries in areas of easily identified surface manifestations such as steam vents, hot springs, and geysers. However, the broader picture of the flow of matter and energy within the earth is one of the principal goals of the International Geodynamics Project. An understanding of deeper patterns of heat distribution, with little or no surface expression, will also be essential to the exploration and development of geothermal resources in the next two decades. The plate tectonics concept and knowledge of the physics of flow of fluids through permeable rocks will be valuable guides to these exploration and development efforts.



A Possible Model for Porphyry Copper Ores
Magmas rising at the ocean spreading center (divergent plate boundaries) give off hydrothermal solutions rich in copper, iron, and other transition metals. These precipitate and are incorporated into the basalt sediments just above the lavas. When these metal-rich sediments are later forced down in a subduction zone at a convergent plate boundary, and are partially melted (as shown in the previous illustration also) the copper is again reconverted and migrates upward in hydrothermal solution to form large ore deposits like those of the Andes Mountains.

HISTORY OF THE INTERNATIONAL GEODYNAMICS PROJECT

Rapid developments that resulted in new concepts of global tectonics were taking place in the earth sciences in the early and middle 1960's. These advances took place during the period of the International Upper Mantle Project—a discipline oriented program directed primarily at understanding the structure of the earth's interior. The exciting new concepts that emerged—sea floor spreading and plate tectonics—caught the fancy of scientists all over the world. It was inevitable that means to exploit these fruitful theories would be actively explored.

The beginnings of the International Geodynamics Project (IGP) can be traced to an informal meeting of the Geophysics Research Board (GRB) of the National Academy of Sciences in March 1968. The Chairman, Merle Tuve, advocated an international effort, with the hypothesis of sea floor spreading as the focus, which would have a revolutionary impact on almost all earth science disciplines.[1] These ideas were approved by the Council of the AGU in April 1968 who directed that they be transmitted to the International Union of Geodesy and Geophysics (IUGG). Later in the same month, the GRB adopted a similar resolution urging that IUGG and the International Union of Geological Sciences (IUGS) take prompt action to organize a program under ICSU sponsorship.

The GRB initiated correspondence with the two relevant international unions, IUGG & IUGS. Both reacted favorably to the proposal and initiated discussions of it at their executive committee meetings in the summer of 1968. The two committees reached agreement on final wording and transmitted the proposal to the General Assembly of ICSU in the latter part of September 1968. ICSU accepted the proposal in principle but requested the unions to prepare a more detailed statement of the nature of the proposed program. The unions then appointed an *ad hoc* committee to be chaired by Prof. Charles L. Drake, composed of three members nominated by each of the unions. The committee held two meetings—in Paris (February 1969) and in London (May 1969), and produced a document entitled *Report of the Ad Hoc Committee on the Long-Range Program of Solid Earth Studies.*

This report, calling for a program entitled, "The Geodynamics Project" was the subject of an informal meeting convened in Madrid in September 1969 during the General Assembly of the International Association of Seismology and Physics of the Earth's Interior (IASPEI)—International Association of Geomagnetism and Aeronomy (IAGA), which was held to give the officers of the unions a chance to discuss the proposed program with a representative group of interested scientists. The report, which authorized the creation of an interunion Commission on the Geodynamics Project (ICG), was accepted by the Executive Committee of ICSU in October 1969. ICG was to consist initially of a bureau of seven, a president agreed to by the two unions and three nominees each from the two unions. Membership of the bureau was approved by the officers of ICSU in February 1970. It held its first meeting in Flagstaff, Arizona, July 1970.

The recommendations and constitution of the ICG were approved by the General Assembly of ICSU in September 1970, following which ICSU called upon the countries to develop programs of participation in the Geodynamics Project. Ten working groups of the ICG were established by the bureau at its meeting in London in 1971 and implemented at the IUGG General Assembly in Moscow in August 1971. These working groups are problem-oriented; some deal with regional problems, some with global problems. Most of these working groups have been very active in developing plans and symposia. They have prepared a series of frontier reports that are intended to assess progress to date in their respective problem areas and to indicate the most fruitful direction for future research during the remainder of the Geodynamics Project.

The ICG has met annually since its initial meeting in July 1970 as follows: Leiden Netherlands, March 1971; Moscow, August 1971; Montreal, August 1972; Lima, Peru, August 1973, Zurich, August 1974; Grenoble, France, August 1975. At each of the meetings, beginning in 1972, there have been several symposia co-sponsored

[1] Transactions of the American Geophysical Union, Vol. 49, No. 6, June 1968.

by the Geodynamics Commission. The largest number of such symposia took place at the meeting in Grenoble in August 1975. In keeping with the constitution of the Commission, there has been a regular rotation of membership of the officers of the Commission. The President in 1970 through 1975 was Prof. Charles L. Drake who was also the Chairman of the U.S. Geodynamics Committee. The new President is Professor Anton Hales of Australian National University, Canberra. There have been three General Secretaries: Xavier Le Pichon, 1970-1972, Frances Delany, 1972-1975, R.D. Russell, 1976 onwards.

The U.S. Geodynamics Committee of the National Academy of Sciences began its work early in 1970. The results of the Committee's initial thinking were published in the *Transactions of the American Geophysical Union*, May 1971. After preparation of its initial document, the U.S. Geodynamics Committee called upon 14 working groups involving some 170 scientists drawn from the academic community, government, and industry to assist in developing recommendations for the program; sent drafts for comment to correspondents (designated by the department chairmen) in more than 100 geoscience departments throughout the United States; consulted with those Federal agencies most likely to be interested in participating in the program; and received strong endorsement for the direction of its planning from 9 major geoscience societies. The result of these deliberations was the issuance in 1973 of a major report, *U.S. Program for the Geodynamics Project: Scope and Objectives*.

The geodynamics of the Americas plate is naturally a principal focal point of the U.S. program. Thus, a significant step was the organization of a meeting of Chairmen of Geodynamics Committees of the countries of the western hemisphere in Brazil, March 1973. Other meetings sponsored or co-sponsored by the geodynamics commission closely related to the Americas plate were: Buenos Aires, Argentina, October 1970; Flagstaff, Arizona, July 1970; Montreal, Canada, August 1972; Lima, Peru, August 1973; Mexico City, June 1973; Santiago, Chile, September 1974; Reykjavik, Iceland, July 1974; Vancouver, Canada, August 1975; Sao Paulo, Brazil, October 1975.

The following time period for the IGP was recommended at the meeting of the Chairmen of Geodynamics Committees of the Americas in March 1973 and was approved by the ICG and by ICSU in September of 1973: 1971-1973 as the period of planning and initiation; 1974-1979 as the period of active research programs.

WHY IGP IS TIMELY

International programs such as IGP, that are sponsored by one or more of the 17 discipline-oriented Unions of the International Council of Scientific Unions (ICSU) and approved by the governing council of ICSU, usually have several common characteristics. These include: (1) the global character of the science (for example the magnetosphere) that usually requires real-time observations and coordination of many nations with similar data-gathering techniques, (2) recent major discoveries in the sciences (as the plate tectonics theory) or in the observing techniques (for example satellite monitoring) that represent new opportunities for participants, and (3) major societal needs that would benefit from new scientific or technical knowledge (for example water resources research).

An international program provides, at the cost of many man-years of scientific planning and the organization of many symposia and workshops, cooperation between larger and smaller nations, the timely sharing of significant results, the elimination of costly duplication of major field efforts, and the establishment of data centers where specifics of the results of field projects are widely distributed. International programs are also a means of increasing the scientific manpower that is marshalled to a scientific discipline and providing for the identification of major obstacles to the progress of the subdisciplines.

Two specific reasons for the timeliness of the IGP are (1) international concerns of the future depletion of many of the earth's nonrenewable material resources: the hydrocarbons and minerals, and the concomitant need for better information on geothermal heat as an independent source of energy; and (2) the political problems dependent on an equitable international solution within the United Nations and the Law-of-the-Sea conferences.

The plate tectonics theory provided the first major breakthrough as a working hypothesis for the horizontal movements of the earth's crust and the sources and sinks of the crust and upper mantle material. It offers some rationale for the specific locations of petroleum fields, the concentration of ore bodies, and of geothermal heat sources. The study of geodynamics provides a major source of the basic information needed for the optimum exploration of these earth resources.

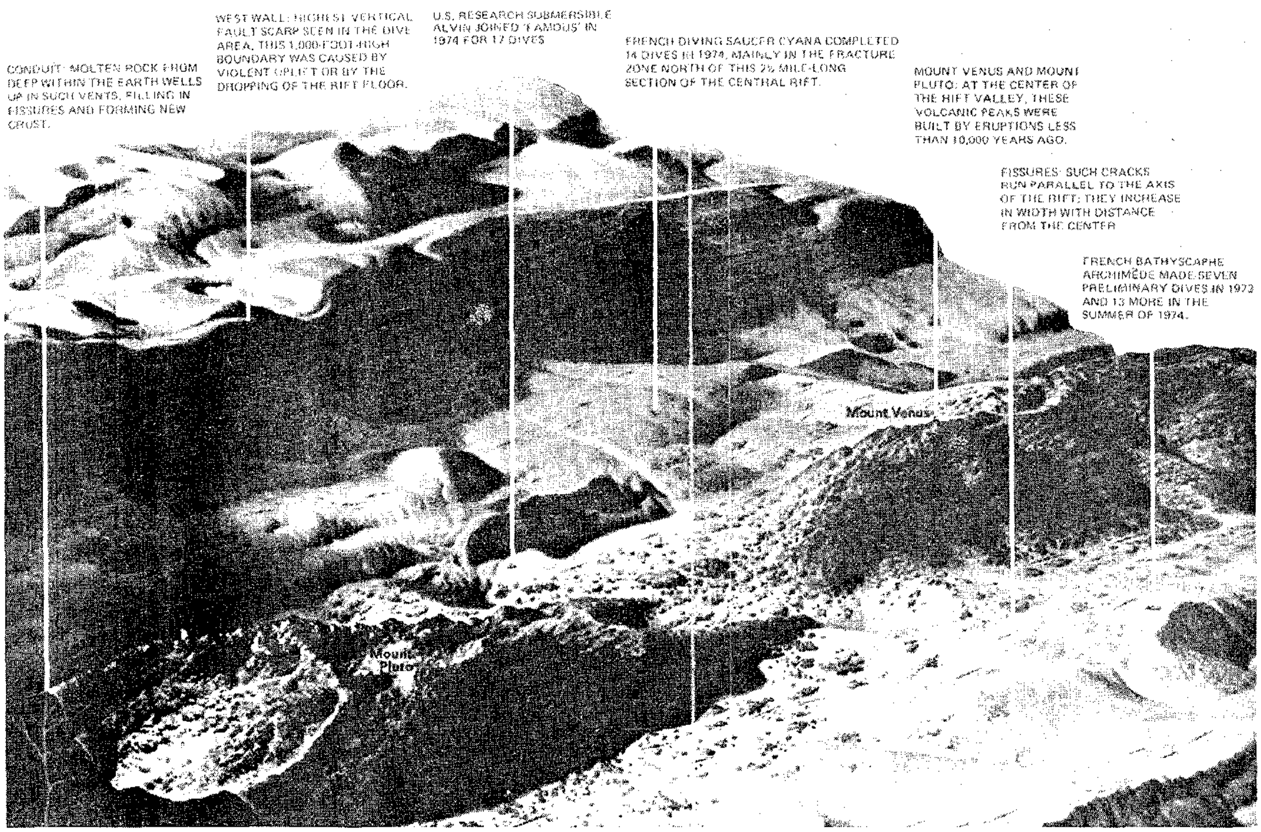
The plate tectonics theory would undoubtedly have been delayed for a number of years were it not for the pioneering work of a relatively few dedicated scientists who studied the characteristics of the oceanic crust: the detailed ocean floor bathymetry, the character of the ocean sediments, and the geophysical parameters of the oceanic crust. A decade or two ago, the oceans had few political boundaries outside the 3-mile zone, but today, with the growing realization of the importance of the oceans as a source for many of man's future requirements, the "ownership" of ocean areas has become a major political problem for the United Nations. Regardless of the outcome of the Law-of-the-Sea conferences, scientific exploration of a major part of the world's oceans will depend largely on international cooperation and goodwill between nations. This cooperation can be best initiated and extended by participation in international programs, such as the International Geodynamics Program, whose objectives have long-term mutual benefits.

QUESTIONS FOR GEODYNAMICS TO ANSWER

Plate tectonics is a very attractive and persuasive hypothesis as a base for geodynamics studies because it apparently explains many of the earth's major features and molds them into a single picture. Yet it is still barely a dozen years old, and many gaps and discrepancies need to be explored before we either give it full credence or replace it with a more-encompassing hypothesis. Among the important problems now needing attention and answers are (a) the nature of processes that act on the plates, both the plate margins and the interiors, (b) the history of spreading and plate movement, and (c) the nature of the driving forces.

Nature of processes

Of the different plate boundaries, the diverging type, i.e. the mid ocean ridges where new crust is formed, are probably the best understood. Yet even these have knowledge gaps. Much of what we are learning about these zones continues to come from standard oceanographic cruises, but much new information is being obtained from the use of more sophisticated and expensive tools such as deeply towed instrument packages, ocean-bottom seismometers, and research submersibles. The recently completed field experiments of Project FAMOUS (French-



Topographic Model of the FAMOUS Area
A model of the area of the Mid-Atlantic Ridge where the French-American Mid-Ocean Undersea Study (FAMOUS) project took place. Many surveying techniques, including observations from deep manned submersibles, were used to produce this model and label its features.

American Mid-Ocean Undersea Study) are good examples. In this project, volcanic and tectonic processes associated with an active spreading center have been directly observed from manned submersibles. Despite these recent advances, there are still significant unexplained geological, geochemical, and geophysical variations that exist along the axes of the mid-ocean ridges. These variations must be accounted for in any comprehensive model of plate tectonics.

Converging plate boundaries are much more complex. When the colliding plates both carry continents near their leading margins, complex structures such as the Himalayas, subparallel mountain ranges, and elevated plateaus are formed. When the convergence is between oceanic crust and continental crust, the oceanic crust is usually subducted with the formation of a deep trench and an island arc system. These are complicated geological structures and the

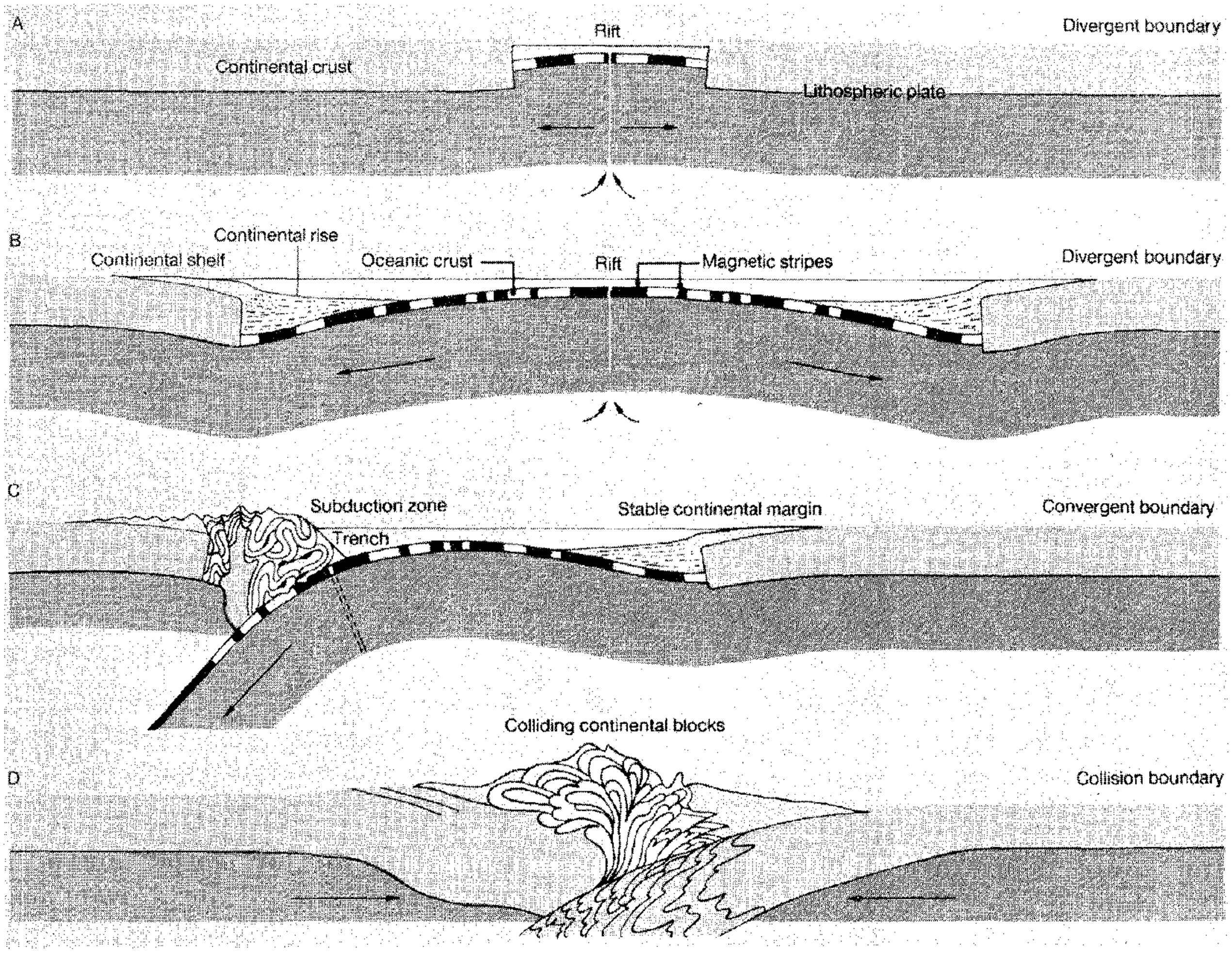


Plate Boundaries
A&B—Divergent Boundary
Magma rises along a rift or spreading center, cools, and is forced aside by new magma coming from below. The rift may split continental crust (A), or oceanic crust (B).
C&D—Convergent Boundary
C. At the zone of convergence one plate is of oceanic crust, the other (on the left) is continental. A subduction zone, trench, and volcanic and folded mountain chain are developed.
D. Both plates carry continental blocks. As these collide, the structures, both in the subduction zone and in the mountains become exceedingly complex. Great nappe folds such as those of the Alps are common.

primary process taking place, underthrusting, occurs at such great depth that it is difficult to measure. A better understanding of converging plate boundaries is very important, for these are the zones of volcanic and earthquake activity with their far-reaching effects on the population.

As noted elsewhere, not all deformation takes place at the plate boundaries. Important deformations, either large scale faulting or warping, can and do occur in the interiors of plates. One record of large vertical movements is the thick sedimentary sequences of subsided basins where most oil and gas deposits are found. Other vertical deformations, often accompanied by volcanism, are found in such areas as the Colorado and Himalayan plateaus and in many of the continental shields. Nor are large vertical movements restricted to continental crust; deep ocean areas within plates have also undergone such deformation (e.g., the sediment-filled depressions beneath the continental rises of eastern North America and the deep sea floor east of Florida).

Vertical movements, both in the interior of plates and at their boundaries, control the occurrence and distribution of many economically valuable mineral deposits. These deposits of igneous and metamorphic origin require a history of subsidence and subsequent vertical uplift to make them accessible for exploitation.

The plate tectonics model in its present form more readily explains horizontal than vertical movement. Perhaps vertical movement will be found to be caused by other dynamic processes operating independently of those that are now causing the horizontal movements. Nevertheless, if the plate tectonics model is to have general validity it must be able to explain all major crustal movements, oceanic and continental, vertical and horizontal.

History of spreading

For a full understanding of how the earth behaves as a system, it is crucial to establish whether plate tectonics has been an integral part of the dynamic history of the earth from the beginning or whether it has appeared during some later stage of the planet's history. The current spreading cycle can only be extrapolated back about 200 million years, when the continents as we now know them were joined together in one large land mass, called Pangaea. As no part of the oceanic crust is older than this, evidence for prior plate movement will have to be sought on the continents; the criteria for recognizing old plate boundaries on land are not yet fully developed. Perhaps one of the best indicators is the location of the mineral rich greenstone belts, volcanic rocks resembling those of modern island arcs. Such greenstone belts are found in Canada, Australia, South Africa, and other areas of very old crust. If these old greenstone belts are indeed relics of ancient island arc subduction systems they constitute evidence of plate tectonic activity prior to the breakup of Pangaea. This is not a universally accepted hypothesis however, and much more work needs to be done.

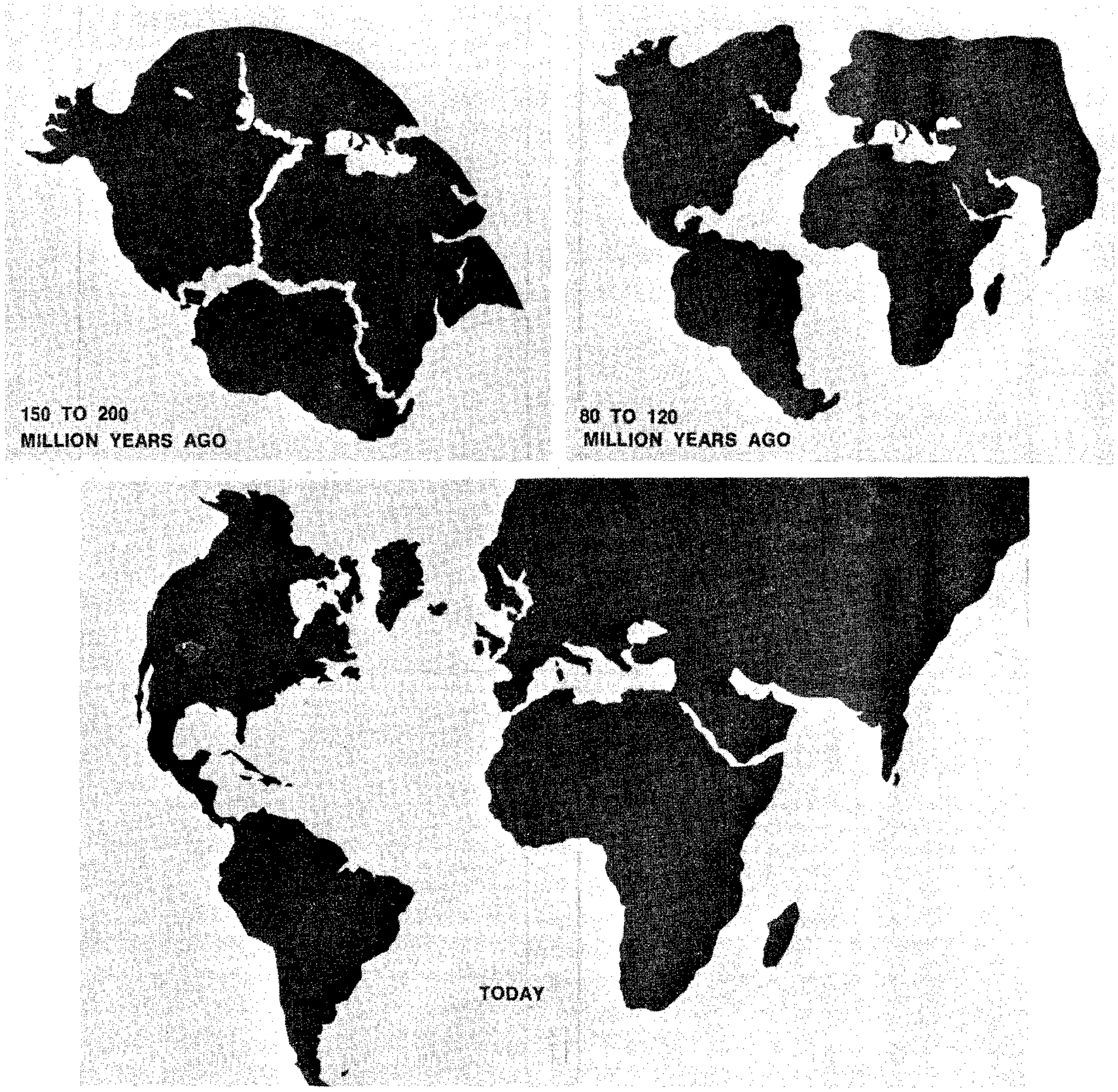
Driving force

The most fundamental problem to be addressed by the IGP is the question of the driving mechanism that keeps the plates in motion. This driving mechanism is the source of the forces involved in all the horizontal and vertical motions we observe in the lithosphere and until we establish its nature a complete description of the geodynamic processes within a planet is beyond our capabilities. There are several promising lines of research to be pursued.

It is generally agreed that the interior of the earth has unstable zones. Three kinds of instability important for a general theory of geodynamics are: density inversions, fusion, and solid-solid phase transformations. The theoretical boundary-value problems associated with these zones of instabilities will be formidable and will require quantum mechanics and lattice theory to explain the nature of fusion and the nature of solid-solid phase transformations.

In the laboratory, tests of representative mantle mineral assemblages at very high pressures and temperatures are needed to determine shear velocities in the vicinity of phase transformations and the creep properties of the assemblages—a measure of the relative fluidity of the mantle. The volume capacity of present day laboratory test facilities must be increased to determine these properties.

When phase transformations are incorporated in a geodynamic theory it is important to know the time scale of the transformation and to know the energy exchange involved. Experimental work on the kinetics of phase transition is just beginning. There may be phase transitions in the earth that are important to geodynamics but



The Drift of Continents
The disposition of the continental crust on the surface of the world during the present spreading cycle. About 200 million years ago the continents, which were at that time joined together in the supercontinent Pangaea, began to split and drift apart. A principal split was along the rift zone that today forms the Mid-Atlantic Ridge. The spreading continues and today's picture is but one frame in a long motion picture.

proceed so slowly in the laboratory that they are unobservable.

Temperature is probably the most important parameter controlling the dynamics of motion in the earth's interior. The interior of the earth is essentially a heat engine, involving heat transfer by large-scale transport of matter, that provides the power to drive the plates. Heat from phase transformations of mantle material and heat from radioactive decay may cause thermal instabilities that would influence the driving forces.

Surface heat flow measurements are not a sensitive indicator of temperature at depth because a major part of the anomalous surface heat flow can be explained in terms of heat transported laterally away from the ocean spreading centers. Seismic shear-wave velocities depend on the temperature and so can be used as an indirect indicator of the thermal state of the earth's interior. More laboratory work must be done to determine equations of state, including the shear properties of matter under temperature and pressure, especially near the melting point.

A number of explicit suggestions have been made for the driving forces, such as convection cells, mantle plumes, gravity sliding from the mid-ocean ridges, and gravity pulling plates down at trenches. Much of the work being done on these explicit mechanisms is theoretical. More constraints from geological evidence are needed that can be placed on mantle motions—such as the patterns of volcanic activity, the distribution of trace elements, and distribution of mantle-type rocks on the earth's surface.

In summary, a few of the important questions to be answered during the International Geodynamics Project by increased effort in the research areas mentioned above are:

1. What is the state of stress in the boundary areas of the plates that manifests itself in the horizontal movements that we are beginning to understand?

2. What is the state of stress in the plate interiors resulting in vertical movements still not understood?

3. What dynamic system operating in the earth's interior is producing these stresses?

4. What are the past locations of the earth's rotation axis relative to the main plates of the lithosphere and the location of these plates relative to each other?

5. Does plate tectonics represent a new and unique episode in the earth's history or has it been an integral part of the dynamic history of the earth from the beginning?

RESUME OF FEDERAL ACTIVITIES IN IGP

In order to obtain a reasonable estimate of the amount of funds presently being allocated for geodynamics-related activities within the U.S. Federal Government, it was first necessary to adopt a set of definitions of geodynamics acceptable to the Committee so that figures from the various agencies will fall within comparable guidelines. The definitions adopted by the *ad hoc* committee were taken primarily from the NAS report *U.S. Program for the Geodynamics Project*. These are divided into two separate categories—those activities concerned generally with the interior parts of the earth: the lower crust, mantle and core, and those which involve the lithospheric plates. The descriptions are included as Appendix I.

Part I, The Internal Processes and Properties, is divided into four parts: Dynamical Models, Geophysical Observations of Internal Processes, Physical and Chemical Properties of Minerals and Mineral Assemblages, and Geological Constraints. This part includes research on the pattern of mantle motion, energy sources within the earth that are responsible for mantle motion, temperature fields, geothermal history of the earth, motions and dimensions of the interior of the plates, the method of plate coupling to the mantle, the phase and mineralogical changes taking place in the interior of the earth, melting phase changes, and the generalized equation of state. Most of these activities are either laboratory studies of selected material, data from various geophysical measurements, and geological character of mantle material found near the surface through volcanic activities or surface erosion.

Part II, Boundaries, Movements, and Structure of Lithospheric Plates, is rather straight forward. A considerable amount of data on boundaries comes from marine studies, and many plate movements are derived from recent magnetic lineations found near the spreading centers, or from independent observations of motions using extraterrestrial sources as references, or studies of recent fault displacements. This category also involves the remeasurements of major networks of control stations in the U.S. The past movement of plates depends to a large extent on paleomagnetic measurements and extension of the history of magnetic reversal, and geological inferences of fault motions. A final category includes the accretions and composition of the plates, such as the characteristics of material added at the margins.

On page 22 is shown a table of agency expenditures in FY 1974, 75 and 76 by the various categories of geodynamics defined above. The two agencies most responsible for geodynamics expenditures are the U.S. Geological Survey and the National Science Foundation with $26.7M and $21.1M for FY 1976, respectively. At a lower level are the composite figures for the four contributing offices of DOD $7.9M, followed by NASA $6.1M, ERDA $4.0M and Commerce $3.0M. For the major programs involved with large logistic components, which are only partially geodynamics related such as NASA's satellite studies, NSF's Ocean Sediment Coring Program, and NOAA's network for horizontal and vertical control, an estimated fraction of the cost related to geodynamics has been made.

Inasmuch as the figures for FY 74 are actual allocations, while those for FY 75 and FY 76 are estimates, the increase shown for the 75 and 76 figures over 74 may be somewhat in error. Most of the increases are within the USGS, and relate to their relatively new responsibilities in earthquake research. Several years of actual figures would be needed to get a reliable estimate of increased funding to geodynamics.

The brief description of agency activities by the geodynamics categories, outlined below, is supplemented by a more extensive description of the work by agencies, Appendix II. The geodynamics activities consist largely of the individual efforts of many scientists. These are in-house activities for some agencies, such as the USGS, and at the universities and other nonprofit institutions, as in the NSF. Major single programs are relatively few and occur mainly where agency mission work is closely related to geodynamics objectives, such as NASA's satellite studies and NOAA's vertical control networks.

Federal Agency* Activities in IGP

Figures with Agency titles refer to FY 76 Estimates.

I. Internal Properties and Processes

A. Dynamical Models

AFGL (120K)—Obtain more accurate models for the gravitational field by better theories and more precise measurements. Predict the response of the earth model to dynamic and static loading of the crust.

ERDA (105K)—Modeling of geologic processes directed at understanding the emplacement of plutons and the thermal state of their environments.

NSF (271K)—Modeling studies of the earth's core and convective motions in the earth's mantle and at the crust-mantle boundary.

USGS (1,090K)—Studies of dynamic modeling of precursor phenomena as part of the Earthquake Hazards Reduction Program—Computer modeling of fault displacements to achieve an understanding of fault mechanisms and related effects—Modeling of selected well-known geothermal systems to study the mechanism by which water and heat are transferred in geothermal systems within the crust.

B. Geophysical Observations of Internal Processes

DOC (630K)—Trans-Atlantic Geotraverse (TAG), an intensive geophysical investigation of a corridor about 285 km. wide from Cape Hatteras to Mauritania to study the structure of continental margins, axial processes of the mid-Atlantic Ridge, and evolution of oceanic crust.

ARPA (220K)—From seismic events, study properties of the crust and upper mantle underlying the Aleutian Island region, mid-Atlantic Ridge, western U.S., central Asia, Iran, and the Arctic Basin.

ONR (923K)—Marine gravity studies of short- and long-term wave anomalies by investigating gravitational effects of primary tectonic features of the ocean floor—Seismic and electrical studies of crust and upper mantle characteristics.

ERDA (885K)—Investigate physical and chemical state of the earth's upper mantle by studying specimens derived from the mantle or analogous synthetic materials—Determination of geothermal gradients and thermal conductivity from drill holes to obtain heat flow—Evaluation of aeromagnetic data to determine depth to Curie point.

NASA (2,900K)—From existing knowledge of lunar motions, support investigations of earth's rotation and polar motion—More precise description of the earth's gravity field from measurements of ocean topography taken by GEOS-3.

NSF (3,495K)—Earthquake seismology for study of internal processes—Geothermal studies—Seismic studies of internal characteristics by controlled explosives—Experiments with the ocean bottom seismograph for earthquake monitoring—Research on telluric, magnetotelluric, electro-magnetic induction, and electrical resistivity methods for crustal and mantle properties—Marine gravity observations from oceanographic vessels.

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*DOC—Dept. of Commerce
AFGL—Air Force Geophysics Laboratory
ARPA—Advanced Research Projects Agency (DOD)
NAVOCEANO—Navy Oceanographic Office
ERDA—Energy Research & Development Administration
ONR—Office of Naval Research
NASA—National Aeronautics & Space Administration
NSF—National Science Foundation
USGS—U.S. Geological Survey (DOI)

USGS (8,550K)—Microearthquake studies with dense arrays of short-period seismographs for three-dimensional mapping of active fault zones—Refraction seismic surveys to determine structural elements of the crust and upper mantle—Information on thermal regime of earth's crust and upper mantle through heat flow measurements—Analysis of thermal infrared images over broad areas for surface indications of heat flow—Magnetic and gravity surveys to identify zones of anomalous magnetization and density in the crust and upper mantle—Detection of zones of anomalous conductivity in the subsurface by various electrical and electromagnetic techniques—Investigations of the deep structure of the continental shelf and slope by continental geophysical surface merged with marine geophysical research—Distribution of magnetization and electrical conductivity within the earth by orbiting satellite magnetometers which record broad wave-length anomalies—Studies of variations of hydrodynamic processes operating in the earth's core by micropulsation data.

C. Physical and Chemical Properties of Minerals and Mineral Assemblages

DOC (126K)—High pressure studies include calibration of pressure scales, continued work on an ultra-high pressure cell, and extension of the pressure scale.

ONR (95K)—Physical properties of the solid earth by electric resistivity of minerals at elevated pressures and temperatures—Effects of microfractures on physical properties of rocks.

ERDA (1,301K)—Construction of test facility at LBL to test rock samples to 400°C. and 1,000 bars—Use of explosive shock waves and static high pressure devices at LASL to extend high P-T ultrasonic and equation of state studies—High P-T phase equilibria studies of individual pure mineral phases—Physical and chemical properties of silicate melts—Static deformation of minerals and rocks to permit accurate prediction of response of the earth's crust to stress—Rock mechanics computer code development.

NSF (2,423K)—Investigations of sonic velocity, flow measurements, development of microcracks, shear strength and electric properties of rocks under high P-T by ultrasonics, shock and static compression—Use of high P-T equipment for geochemical studies such as equilibrium and mass transfer among minerals and aqueous solutions, the diffusion kinetics of trace elements, mineral crystal chemistry, and thermodynamics of ionic interactions.

USGS (1,650K)—Measurement of the physical properties of rock-forming minerals to determine how the thermal and stress histories of minerals affect their properties—Igneous petrology directed toward understanding magmatic systems—Phase equilibria studies of multicomponent systems—Thermodynamic properties of selected minerals—Research in isotopic geochemistry, including light stable isotopes and radiogenic isotopes—Neutron activation studies—Mechanical, electric, and thermal properties of rock samples to 1,000°C and 10 kilobars.

D. Geological Constraints

ERDA (965K)—Field studies of igneous terrains at LASL to understand the implacements of magmas from depth—The dynamics and thermal problems associated with pluton emplacement and volcanic eruptions by field studies of the Rio Grand rift, the andesite volcanoes of the Cascades of northern California and field studies of active volcanoes—Studies of lava, volcanic rocks, and xenoliths from kimberlite pipes and andesites—Observational and analytical geochemistry and petrology.

NSF (3,899K)—Geology, geochemistry and geochronology of volcanic rocks from several geographic areas, and of the mantle and deep crustal rocks exposed at the surface—Studies of the basalts obtained from the OSCP and rocks recovered from the Mid-Atlantic Ridge in the FAMOUS Experiment—Studies of the geochemistry, petrogenesis, and geochronology of Antarctic rocks from the Dry Valley Drilling Project.

USGS (5,000K)—Petrologic and structural studies of volcanic, sedimentary, and plutonic rocks to determine tectonic history of the western margin of the North American plate—Studies of volcanic rocks and associated plutons in the San Juan and Absarka Mountains and in central Idaho to determine the chemistry of the igneous rocks erupted through the North American plate—Detailed studies of ankaramites in Hawaii, caldera deposits in New Mexico, and basalts in the Pacific Northwest to estimate the depths of phenocryst formation and crystallization history in large volumes of silicic melt—Studies at the Hawaiian Volcano Observatory of the generation and movement of magmas—Studies in Alaska of island arc volcanic rocks and of ophiolite complexes indicative of subduction along the margins of the North American plate—Studies in southwest Oregon to determine how podiform chromite-bearing ultramafic and mafic bodies were scraped off the oceanic plate and juxtaposed on the North American plate.

II. Boundaries, Movements and Structure of Lithospheric Plates

A. Present Plate Boundaries

ARPA (150K)—Study of seismicity of Mid-Atlantic Ridge—Relation of seismicity and tectonics in the Indus Suture zone—Characterization of source properties of earthquakes in the case of continent-to-continent collision to aid in the mapping of present plate dimensions.

NAVOCEANO (1,325K)—Detailed geophysical survey of the Galapagos Spreading Ridge—Studies of the Mid-Atlantic Ridge with near-bottom recording magnetometers—Aeromagnetic surveys in the Arctic Ocean for details on the Lomonosov Ridge—Geophysical survey of the Indian Ocean—Continued studies of the Cayman Trough Spreading Center of the Caribbean Plate.

ONR (930K)—Geological and geophysical investigations of the dynamics of the northwestern borders of the Pacific Plate—Structure and tectonics of the Bay of Bengal and western Sundra Arc in the Indian Ocean—Structure and interaction of the Cocos and surrounding plates—Structure and seismicity of the Juan de Fuca Plate.

ERDA (470K)—Operation of a seismic network in the Shumagin Islands near the tip of the Alaskan Peninsula, and a large aperture seismic array in the eastern Aleutian arc east of Unalaska Island.

NSF (3,349K)—Geophysical studies of the boundaries and structures of the Nazca Plate, the eastern and southeastern parts of the Asian Plate and the western part of the Pacific Plate—Studies of the tectonic evaluation of the South Kenya Rift zone—Detailed study of the Mid-Atlantic Ridge—Seismic measurements with Ocean Bottom Seismometer.

USGS (1,510K)—Operation of the Worldwide Network of Standard Seismographs, 116 stations in 69 countries, an essential source for seismological data used in locating earthquakes—Studies of topography and geology of mid-Atlantic Ridge in the region southwest of the Azores Islands with deep submersible craft.

B. Present Motion of Plates

DOC (1,295K)—Establish, maintain and adjust horizontal and vertical geodetic control networks over the U.S., including a special Great Lakes and Mississippi Valley leveling program in cooperation with the Geodetic Survey of Canada—Establish horizontal and vertical networks across the San Andreas fault between Los Angeles and San Francisco—Operation of the zenith tube measurements of polar motion at Gaithersburg, Maryland, where such motions have been observed over the past 75 years—Maintain a gravity base network across the U.S.

ARPA (1,100K)—Studies of anomalous characteristics and causes of moderate to large earthquakes in the normally aseismic area of eastern U.S. by an integration of all available data including sea level changes—Earthquake focal mechanisms for thrust faults.

ERDA (250K)—Electrical resistivity measurements to detect changes due to tectonism within the San Andreas Fault zone.

NASA (3,200K)—Tectonic Plate Motion project will provide measurements of precise motions between defined points, using both laser tracking and very long baseline interferometry—The Lunar Ranging Experiment will utilize existing knowledge of lunar motions and continuing range measurements to support investigations on plate motion—The Geodynamic Experimental Ocean Satellite (GEOS-3) project will provide, through measurement of ocean topography, an improvement in the description of the earth's gravity field, and in the variations of solid earth geometry—The Laser Geodynamic Satellite (LAGEOS) project will provide the capability of accurate measurements of earth's crustal motion.

NSF (172K)—Response of the earth to late Quaternary ice melting—Earth tide studies—Application of atomic clock interferometry—Geophysical applications of long baseline interferometry.

USGS (1,480K)—Geodimeter surveys for horizontal movements and level surveys for vertical movements are used to determine elastic strain accumulation and strike-slip along faults and to detect premonitory strains—Study of sea level measurements for possible use in determining crustal uplift or subsidence—Investigations of seismomagnetic effects along western United States fault zones as an indirect means of monitoring crustal stress.

C. Plate Boundaries and Rates of Movement During the Past

ONR (920K)—Study of marine magnetic anomalies of ocean basins, including triple junction of anomalies in south Atlantic and Indian Oceans—Regional magnetic field of Arctic Basin—Paleo-magnetic studies of sediment cores.

NSF (4,757K)—Studies of cores obtained from the OSCP—Paleomagnetic projects dealing with past plate movements—Geological and geophysical studies in areas of plate boundaries—Studies of sediment cores taken from the *Eltanin* and from the Dry Valley Drilling Project in Antarctica—Geological studies in the Antarctic Mountains and the Antarctic Peninsula—Gravity, heat flow, and magnetic measurements in the continental margin of West Africa and eastern South America in order to construct the various stages of the opening of the South Atlantic.

USGS (780K)—Refinement of geomagnetic reversal times from radiometrically dated volcanic and plutonic rocks—Study of decrease in amplitude of magnetic anomaly stripes with increasing distance from the spreading axis—Research in geochronology, including investigation of the $^{40}Ar/^{39}Ar$ age spectrum dating technique—Study of use of thermoluminescence as a dating tool for young volcanic rocks.

D. Plate Accretion, Composition and Structure

DOC (452K)—Measure sedimentary processes on the continental margin sediment transport system in the mid-Atlantic Bight and measure temporal changes of the sediment substrate.

ONR (652K)—Geological and Geophysical investigations of interior features of the Pacific Plate: Hawaiian Ridge, Emperor Sea Mount, and Hess Rise—Properties of Layer 2, defined seismically as the upper one or two kilometers of the crystalline oceanic crust, including thickness, velocity structure, topography, and magnetic properties.

NSF (3,242K)—Geological and geophysical investigations of the East Atlantic continental margin—Geophysical study of continental margin of Argentina and Brazil—Sedimentary history of ocean basins from studies of the cores from the Ocean Sediment Coring Program—Structural development of the Southern Cordilleran orogen—Geological history of continental accretion on Kodiak Island—Tectonics, evaluation and crustal composition of the western Indian Ocean ridge systems—petrochemical and geochemical evolution of the central North Atlantic—science program of mid-Atlantic Ridge, Project FAMOUS—Marine geology and geophysics of the Sunda Arc—Geology of the Lassiter Coast, Antarctica—Geological investigations in the Pensacola Mountains, Antarctica—The structure and tectonic history of the northern limb of the Scotia Arc.

USGS (6,600K)—Locate recently-active fault strands within the San Andreas system and determine tectonic history along the active plate margin—Analysis of intense folding and faulting in the Salton Trough northward to the Mendocino Fracture Zone to determine the location, direction and magnitude of displacements—Geologic and Geophysical studies of the Oregon and Washington continental margin—Detailed mapping of active surface faults along coastal Alaska—Study of the Tertiary and Quaternary geology and biostratigraphy of the coastal region, the continental shelf and the offshore islands of western Alaska to determine the rates of past and on-going coastal deformation—Synthesis and compilation of geologic information on the Colorado Plateau to determine why this region escaped the deformations that affected the Basin and Range Province to the west and the Rocky Mountains to the east.

Fiscal Summary of Geodynamics-Related Programs in Federal Government
FY 74, FY 75, FY 76

(In thousands of dollars)

	FY	DOC*	AFGL	ARPA	NAVO-CEANO	ONR	ERDA	NASA	NSF	USGS	TOTAL
I. Internal Properties & Processes											
A. Dynamical Models	74		78			45	43		231	1,069	1,466
	75		105			60	95		239	1,079	1,578
	76		120			50	105		271	1,090	1,636
B. Geophysical Observations of Internal Processes	74	600	25	265	35	1,123	253	2,100	2,939	5,015	12,455
	75	165	25	170	20	1,078	540	2,200	3,236	8,496	16,030
	76	630	50	220	10	923	885	2,900	3,495	8,550	17,763
C. Physical & Chemical Properties of Minerals & Mineral Assemblages	74	130				91	795		2,006	1,349	4,371
	75	126				74	1,131		2,141	1,559	5,031
	76	126				95	1,301		2,423	1,650	5,595
D. Geological Constraints	74				10	95	593		5,115	4,588	10,401
	75				7	30	765		6,814	4,901	12,517
	76				5	——	965		3,899	5,000	9,869
II. Boundaries, Movements, & Structure of Lithospheric Plates											
A. Present Plate Boundaries	74	108		145	228	950	300		3,386	1,169	6,286
	75	350		145	258	510	365		3,416	1,486	6,530
	76	10		150	1,325	930	470		3,349	1,510	7,744
B. Present Motion of Plates	74	1,321		362	36		18	1,800	197	1,110	5,004
	75	1,197		715	15		125	3,500	178	1,450	7,370
	76	1,295		1,100	——		250	3,200	172	1,480	7,757
C. Plate Boundaries and Rates of Movement During the Past	74				20	1,050	6		3,056	546	5,128
	75				30	770	25		4,096	750	5,671
	76				30	920	25		4,757	780	6,512
D. Plate Accretion, Composition & Structure	74	680	40		——	865			2,644	5,639	9,968
	75	610	60		——	800			2,631	6,444	10,654
	76	452	60		57	652			3,242	6,600	11,163
TOTAL	74	3,199	143	772	329	4,219	2,008	3,900	20,024	20,485	55,079
	75	2,838	190	1,030	330	3,322	3,046	5,700	22,751	26,165	65,372
	76	2,973	230	1,470	1,427	3,570	4,001	6,100	21,608	26,660	68,039

* DOC Data Center (FY 74-$360K; FY 75 $390K; FY 76 $460K) not included in the DOC column but are added in the TOTAL column. Future reports will contain data center funding of other agencies.

INTERNATIONAL PARTICIPATION

Fifty-two countries have indicated their participation in the International Geodynamics Project. The first 46 countries in the following list have established national committees for the project. The last six have nominated national correspondents.

*Argentina	Israel
*Australia	Italy
*Austria	*Japan
Belgium	Korea
Bolivia	*Mexico
Botswana	*Netherlands
*Brazil	New Zealand
*Canada	Nigeria
Central American Regional Committee	Norway
Chile	Poland
*Colombia	*South Africa
*Czechoslovakia	*Spain
Denmark	*Sweden
*D.R.G.	*Switzerland
Equador	*Taiwan
*F.R.G.	*Turkey
*Finland	*United Kingdom
*France	*U.S.S.R.
Ghana	*U.S.A.
Greece	Venezuela
Hungary	Yugoslavia
*Iceland	Cuba
*India	Indonesia
Iran	Pakistan
Ireland	Philippines
	Rhodesia
	Thailand

Participating countries were requested to prepare reports on their national activities in Geodynamics for the IUGG General Assembly in Grenoble in 1975. Reports were received from 25 countries (marked by asterisks in the above list), and others will be available in the near future.

The reports indicated a high degree of activity in many participating countries with interesting and relevant scientific results. The reports do not, in general, contain fiscal information. Spain, however, did report a specific allocation for the Geodynamics Project at an annual level of $231,000 (plus significant logistic support from the Spanish navy) for a program concentrating on the geodynamics of the Western Betic-Mediterranean Range, the Canarian Archipelago, and the Iberian Plateau. The studies included deep seismic profiling. Similarly, Sweden reported a grant of $230,000 per year from the Swedish Research Council for two principal projects of an international and interdisciplinary character; (1) the Caledonian Research Project, and (2) study of post-glacial earth movements.

Although fiscal data is not given, it is apparent from the reports of such countries as France, Federal Republic of Germany, Japan, U.S.S.R., and others that expensive world-wide field programs have been undertaken under the *aegis* of the program. The French, in addition to the well-known FAMOUS project, have active programs in the Pacific Ocean, the Andes Mountains, the Caribbean Sea, the Mediterranean Sea, and the Alps Mountains. The Federal Republic of Germany has put special emphasis on the Rhinegraben, the European plate, the Alps Mts., Mediterranean Sea, Red Sea, Afar Triangle, Indian Ocean, Iceland, South Africa and Latin America. The Japanese have devoted 14 research cruises to the investigation of the movement and structure of the ocean floor of the Western Pacific and have similarly allocated large-scale and expensive logistic support to a second program emphasizing studies of the movement and structure of island arcs. The USSR has similar large scale expeditions, not only in the Soviet Union, but in Africa, Iceland and elsewhere.

Many countries have not received special funding for the IGP but have successfully put together meaningful programs by reprogramming and redirecting existing resources. The Canadian 3rd report, for example, indicates significant progress in 5 interdisciplinary areas; (1) global dynamics, (2) short term motions, (3) crustal evolution, (4) Phanerozoic fold belts and adjacent oceans, and (5) the Canadian shield. Current activities are broadly distributed among various Federal and provincial government agencies, universities, and mining and petroleum exploration companies.

Other countries, having limited resources, have inaugurated good programs by means of international cooperation. Two examples are

Mexico and Colombia both of which have emphasized cooperative programs with U.S. universities and institutions. The Mexican program includes work in the Gulf of Mexico and the Cocos Plate, a network of 8 seismic stations around the Gulf of California, 360 km. long seismic refraction profile, heat flow studies, and geodetic studies. Similarly, the Colombians have concentrated on seismic refraction studies of the continental margin, oceanographic studies, and magnetotelluric studies.

Most countries have tailored their programs to the study of important geodynamic problems that can be uniquely studied within their own borders or because of relevant experimental and theoretical research practiced in those countries. The G.D.R. presented a broad program encompassed within two complex subjects; (1) development of a geodynamic model of the tectonosphere in Central Europe, and (2) investigation of the driving mechanism of geodynamic processes. They presented a bibliography of some 360 titles. The Turkish program is mainly focussed on geological studies related to plate tectonics of the eastern Mediterrannean, seismological studies with emphasis on the N. Anatolian Fault, together with regional gravity, magnetic and paleomagnetic work. Iceland's program is concerned with 3 areas; (1) the active volcanic zones, (2) the plateau basalt area adjacent to the active volcanic zones, and (3) general studies of Iceland and the shelf regions. Geological, aeromagnetic, and gravity maps are complete or nearly complete. Heat flow, magnetotelluric, and seismic studies are underway. Scientists from several other nations have been working in Iceland in cooperation with Icelandic scientists. The Geodynamics Program has provided considerable stimulus to geophysical and geological research in Austria focused on the Austrian area of the Alpine belt. The Finnish program is concentrated heavily on repeated geodetic and gravity measurements to study crustal movements in Lapland and the Fennoscandian land uplift, although work is also underway in aeromagnetics, magnetic surveys, paleomagnetism, and seismology.

The Czechoslovakian program concentrates on eight projects; regional studies in the West Carpathians and the Bohemian Massif, together with more traditional studies of the physical parameters and structure of the crust and mantle in Czechoslovakia by deep seismic soundings and heat flow, the physical properties of rocks under high pressures and temperatures, geochemistry of mobile zones, secular variation of gravity and earth tides, recent crustal movements, geomagnetism and paleomagnetism.

APPENDIX I

Description of Geodynamics Studies

I. Internal Properties and Processes

A. Dynamical Models

Construction of dynamical models of the processes in the mantle that can explain plate tectonics observations, the thermal history and gravity fields, the origin of the earth's magnetic field, and their possible relation to planetary motions.

B. Geophysical Observations of Internal Processes

Seismic, gravimetric, geodetic, geomagnetic and heat flow measurements as applied to studies of the structure and dynamics of downgoing slabs, spreading centers, transform faults, and plate interiors. Gravimetric and seismic studies of heterogeneities in the asthenosphere. Applicable seismic studies of the deep internal structure of the earth. Calculation of temperature distribution by electrical conductivity studies and seismic mapping of phase transitions.

C. Physical and Chemical Properties of Minerals and Mineral Assemblages

Ultrasonic and shock measurements on earth materials, rheological behavior of earth materials at high pressures and temperatures, equations of state, kinetics of phase transformations, process of magma generation, partitioning of trace elements under controlled conditions of temperature and pressures, thermal and electrical conductivity of rocks at high pressures and temperatures.

D. Geological Constraints

Geological, petrological and geochemical studies that provide constraints on models of: 1) magmatic differentiation, 2) physiochemical conditions of deep crustal processes, and 3) mechanisms by which mantle-derived rocks reach the surface. Includes trace element and isotopic studies of upper mantle rocks brought to the surface as xenoliths in lavas, kimberlite pipes, diapiric emplacements, and through obduction of ophiolite suites. Petrological study of blueschists and related rocks representative of subducted material altered at depth but now exposed in melanges and other areas that may be fossil plate sutures. Investigation of modern volcanoes as a basis for inferring internal dynamic processes, internal reservoir conditions, and mass flux and energy balance of the volcanic process.

II. Boundaries, Movements, and Structure of Lithospheric Plates

A. Present Plate Boundaries

Mapping of the horizontal and vertical dimensions of present plates, with special attention to the subplates in island arc regions. Detailed seismic and geodetic studies of plates presently being broken up. Variations in lithospheric thickness and the properties of the low velocity zone, on land and at sea, with particular attention to high resolution continuous seismic reflection profiling.

B. Present Motion of Plates

The direction and velocity of present plate movements by geodetic measurements along active faults, the direct measurement of vertical displacements on land and at sea, the development of satellite geodesy and radio telescope interferometry, internal plate deformation, relative direction of plate movement by earthquake focal mechanisms, orientation of sea floor fracture zones.

C. Plate Boundaries and Rates of Movement During the Past

Paleomagnetic investigations of unsampled plates, mapping of sea floor fracture zones by depth soundings, time scale of geomagnetic reversals, pole positions for the Paleozoic, pole positions for the Precambrian, fine structure of the magnetic field, magnetism of sea basalt.

D. Plate Accretion, Composition and Structure

Geochemistry and mineralogy of crustal material added to plate margins and intraplate areas; nature of geological structures, especially at convergent plate boundaries and at transcurrent sutures within or at plate boundaries; vertical movement of plates as determined by geological means; relation of geological structures to dynamics of plate movement.

APPENDIX II

Details of Federal Agency Activities in Geodynamics Related Programs

Department of Commerce

In the Department of Commerce, studies related to geodynamics are carried out principally in the National Oceanic and Atmospheric Administration (NOAA) through its National Ocean Survey (NOS), National Geodetic Survey (NGS), Environmental Research Laboratories (ERL) and Environmental Data Services (EDS). The National Geophysical Data Service of EDS provides a wide range of information in seismology, marine geology and geophysics, and geomagnetism and operates the World Data Center A for Solid Earth Geophysics. Geophysical information is regularly exchanged between this World Data Center and other similar centers in the USSR, Europe, and Japan.

Several geodynamics-related projects are also carried out at the Bureau of Standards.

I. Internal Properties and Processes

B. Geophysical Observations of Internal Processes

The Trans-Atlantic Geotraverse (TAG) is an intensive geological, geophysical and geochemical investigation of a corridor about 3° (285 kms.) wide across the Central North Atlantic Ocean from Cape Hatteras in the United States to Mauritania in northwest Africa.

The TAG project has four main objectives: the structure and development of the continental margins of eastern North America and northwestern Africa, axial processes of the mid-Atlantic Ridge between 25° and 28° North latitude, the structural evolution of the oceanic crust from the mid-Atlantic Ridge to the continental margins, and the establishment of a standard crustal section within the TAG corridor across the entire central North Atlantic Ocean.

C. Physical and Chemical Properties of Minerals and Mineral Assemblages

At the National Bureau of Standards, high pressure studies include the calibration of pressure scales using the ruby fluorescent method, continued work on an ultra high-pressure cell, extension of the pressure scale, and some experimental studies involving behavior of materials at high pressure.

II. Boundaries, Movements, and Structures of Lithospheric Plates

A. Present Plate Boundaries

Mineralization processes in the rift valley of the mid-Atlantic Ridge and adjacent fracture zones are studied using samples obtained from the French-American Mid-Ocean Undersea Study (FAMOUS).

B. Present Motion in Plates

The National Geodetic Survey is responsible for the establishment, maintenance, and adjustment of the horizontal and vertical geodetic control networks over the United States. These basic networks are currently being adjusted, the work scheduled for completion in the 1980's. A special Great Lakes leveling program is currently nearing completion, with its objectives the determination of the relationship of the National Great Lakes Datum to Mean Sea Level, in cooperation with the Geodetic Survey of Canada.

This survey also passes through the Adirondack Mountains where evidence of continued upheaval has been detected. Similarly, a loop to be completed soon in the Mississippi Valley will provide data for recent crustal movement in the Great Lakes area.

Horizontal and vertical networks have been established across the San Andreas Fault at intervals between Los Angeles and San Francisco. These are re-measured as time and funds permit, though re-measurement would immediately follow any major earthquakes in the area.

A potentially valuable source of information for plate tectonics is obtained by zenith tube measurements of polar motion at Gaithersburg, Maryland and Ukiah, California where these motions have been observed over the past 75 years. Although newer methods of polar motion observations have shown a potential of higher accuracy, the question of continuity with past information requires a review of these methods.

The National Geodetic Survey also maintains a gravity base network across the U.S. and planned reobservations will provide information on secular gravity changes that are closely related to elevation changes.

D. Plate Accretion, Composition and Structure

A long term program is underway to measure sedimentary processes on the continental margin sediment transport system in the mid-Atlantic Bight, and to develop a conceptual model of this system. In FY 76 the temporal variability of the sediment substrate will be determined by measuring changes in the distribution of its physical and chemical characteristics with time. The velocity profile of the boundary layer will be determined immediately above the substrate surface to provide a basis for quantifying the transfer of storm-driven energy from the water column to the sediments.

Air Force

The Air Force supports, through its Air Force Geophysics Laboratory, a wide range of geodetic and geophysical studies for precise position location, earth size and shape determination, measurements and modeling of the gravity field, and geophysical earth motions. Many of these mission-oriented research programs are closely related to the objectives of the IGP.

Improved knowledge of the earth's properties and more accurate models for the gravitational field will be obtained by the development of better basic theories, improved instrumentation for more precise measurements, and the formulation of mathematical techniques for the combination of large amounts of heteorogeneous data from multiple sources. Basic studies are underway of propagating earth motions and theoretical investigations to explain the nature of long-period and aperiodic crustal motions. Theoretical investigations are directed toward predicting the response of the earth model to dynamic and static loading of the crust. In FY 76 the North American and European continental geoids will be calculated from combinations of gravimetric and satellite data and the geoid over the North Atlantic will be obtained from satellite altimetry data.

Advanced Research Project Agency

The Advanced Research Projects Agency (ARPA) conducts two research programs that contribute to the objectives of the IGP. The Seismic Verification Research Program is concerned primarily with the problem of unidentified seismic events that may arise from peculiarities in the generation of seismic waves by certain earthquakes, distortion of seismic waveforms caused by propagation through heterogeneous portions of the crust and mantle, or inability to detect seismic waves at high enough signal-to-noise ratio to obtain information diagnostic of the source. The Geodesy and Gravity Research Program is concerned with improved methods for the rapid acquisition of precise geodetic and gravity data capable of providing improvements in regional gravity models.

I. Internal Properties and Processes

B. Geophysical Observations of Internal Processes

Special attention is being given to structural properties of the crust and upper mantle as well as lateral inhomogeneities in the mantle underlying the Aleutian Island region, mid-Atlantic Ridge, western U.S., Kamchatka and Kurile Islands, Tibet, and the Arctic Basin.

II. Boundaries, Movements, and Structure of Lithospheric Plates

A. Present Plate Boundaries

Studies involving the determination of seismic sources, the regionalization of source parameters, and the characterization of source properties of earthquakes at the plate boundaries, in particular for the case of continent-to-continent collision, are being conducted to aid in the mapping of the horizontal and vertical dimensions of present plates.

B. Present Motion of Plates

The anomalous characteristics and cause of moderate to large earthquakes (intraplate earthquakes) occurring in a normally aseismic area (Eastern U.S.) are being investigated by integrating all available seismological, geodetic, geomorphological and geologic evidence, and measurements of sea level changes. In addition, an integrated field measurement program using a variety of broadband instruments is being conducted in the seismically active Bear Valley region of California (strike-slip fault region) in an effort to more clearly define the spatial and temporal nature of the source displacement function and resultant spectra of signals from earthquakes in the body wave magnitude range 3.5 to 4.5.

Navy

In order to understand its operating environment more effectively, the Navy supports geological and geophysical research on the characteristics of the seafloor sediments and underlying rock layers. Laboratory and field research on the physical properties of minerals and rocks are also supported to improve surface-based geophysical techniques for inferring the physical properties of deep crustal layers. Many of these mission-oriented programs have a close connection with the objectives of the International Geodynamics Project. This research is supported through two programs of the Office of Naval Research: Marine Geology and Geophysics (MGG-ONR), and Earth Physics (EP-ONR) and through activities of the U.S. Naval Oceanographic Office (NAVOCEANO).

I. Internal Properties and Processes

Marine gravity studies are focused upon the problem of determining the geologic source of the short (kilometers) and medium (hundreds of kilometers) wavelength gravity anomalies. These studies include the investigation of the gravitational effects of primary tectonic features of the ocean floor, such as ocean ridges, trenches, island chains, seamount chains, fracture zones, and marginal basins (MGG-ONR).

Research on the physical properties of the solid earth are supported on an interdisciplinary basis. These include electrical measurements of crustal/upper mantle resistivity-depth distributions; seismic studies of crustal/upper mantle seismic velocity distributions, Q, Poisson's Ratio, seismic velocity transitions and stress distributions; electrical resistivity of minerals at elevated pressures and temperatures; effect of microfractures on physical properties of rocks; and measurements of thermal gradients and electrical resistivity of crustal rocks to infer internal crustal heat distribution (EP-ONR).

In part of the Canary Basin, all available seismic reflection data have been compiled and reduced, and are being analyzed in order to determine the physiography of the acoustic basement surface. Studies of basaltic rocks dredged along the spreading axis north and south of Iceland are focused on the anomalous geochemical changes that occur in these basalts along the Reykjanes Ridge (NAVOCEANO).

II. Boundaries, Movements, and Structure of Lithospheric Plates

A number of discreet geological and geophysical investigations are supported in the northwest Pacific. An objective of the program is to examine the dynamics of an old part of the Pacific plate. Included in the plate interior are the Hawaiian Ridge, Emperor Seamounts, Hess Rise, and the Hokkaido Rise with the Kuril Island Arc, Bonin Island Arc, and Okhotsk Basin at the margins (MGG-ONR).

Better knowledge of the physical, magnetic, and chemical properties of the upper one or two kms. of the crystalline oceanic crust (layer 2) should lead to improved understanding of the dynamics of ocean basin formation. Specific tasks are examining the thickness and velocity structure, topography, and magnetic properties (MGG-ONR).

Two aspects of marine magnetics are being examined. The first is the delineation of the amplitude and configuration of the residual magnetic anomalies of the world's ocean basins and their relations to ocean floor structure. Particular emphasis is directed towards the triple junction anomalies in the South Atlantic and Indian Ocean, the Mesozoic anomaly patterns in the western Pacific, and the regional field of the Arctic Basin. The second aspect is an improved definition of the magnetic time scale through improved analysis and stacking techniques, as well as paleomagnetic studies of sediment cores (MGG-ONR).

Specific regional studies include examination of the geologic history, structure, and tectonics of the Bay of Bengal and Western Sunda Arc in the Indian Ocean; the structure and interaction of the Cocos and surrounding lithospheric plates; and the structure and seismicity of parts of the Juan de Fuca plate (MGG-ONR).

Near-shore magnetic data collected in the northwest Pacific Philippines region are under analysis. A geophysical/acoustic study will be made on seamounts in the western Pacific, to include seismic reflection data, cores and rock dredges, and wide-angle reflection/refraction measurements at selected sites. A geophysical survey has been carried out along the Galapagos Spreading Ridge both east and west of the Galapagos Islands (NAVOCEANO).

Recent studies of the mid-Atlantic Ridge using a near-bottom recording magnometer has revealed the fine structure of the earth's magnetic polarity for the first 3.5 million years and similar studies on other sections are planned. A cooperative geophysical investigation of the mid-Atlantic Ridge south of Iceland with Germany and Iceland is presently underway. Similar studies of magnetic data in the vicinity of Cayman Trough will provide data for further refinement of past rates of movements between the Americas. Caribbean geological and geophysical atlas is presently in progress (NAVOCEANO).

Recent aeromagnetic surveys in the Arctic Ocean have now covered about one-third of the Eurasia Basin, confirming a separation of the Lomonosov Ridge from Eurasia about 60 million years ago. Continuation of this aeromagnetic survey is planned for the next several years (NAVOCEANO).

An extensive acoustic/geophysical/oceanographic survey of the Indian Ocean is planned in FY 76 to include seismic reflection profiles, 3.5 kHz high resolution profiles, 12 kHz bathymetry, magnetic and gravity data. Sediment cores and wide angle reflection/refraction measurements will be taken at selected locations (NAVOCEANO).

Energy Research and Development Administration

The Energy Research and Development Administration (ERDA) consolidates activities related to research and development on the various sources of energy from fossil, nuclear, solar, geothermal, and other energy sources. A considerable amount of this research is geodynamics-related, carried out primarily in ERDA's laboratories: The Los Alamos Scientific Laboratory (LASL), the Lawrence Berkeley Laboratory (LBL), and the Lawrence Livermore Laboratory (LLL). In addition, ERDA supports geodynamics-related research projects through a few university grants or contracts.

I. Internal Properties and Processes

A. Dynamic Modeling

At LASL, modeling of geologic processes include theoretical, numerical and simulation studies directed at understanding the emplacement of plutons and the thermal state of their environments, the eruption mechanism of volcanoes, computer simulation of the chemistry of hydrothermal alteration, heat flow, and heat and mass transfer in the earth's interior.

B. Geophysical Observations of Internal Processes

In a major program focused on magmatic processes at LASL, data are obtained through field and laboratory studies of the chemical and physical state of the earth's upper mantle by studying rock specimens (xenoliths and host basalts) derived from the mantle and analogous synthetic material. This program includes high pressure-temperature experimental geophysics, thermal and electrical conductivities, thermal evolution and convection in the earth's interior by numerical-theoretical methods, fracture propagation, laboratory and *in situ* rock mechanics.

In a planned field experiment by LBL in northern Nevada, a pattern of drill holes 100-200 meters deep will encompass the Battle Mountains regions of high heat flow. Geothermal gradients and thermal conductivity will be determined to obtain heat flow. In another LBL project, an attempt will be made to evaluate aeromagnetic data to determine depth to the Curie point. Geothermal activity due to large thermally anomalous masses in the crust, such as young plutons, is likely to be associated with shallow Curie-point isotherms.

C. Physical and Chemical Properties and Mineral Assemblages

The construction of a physical properties test facility is planned at LBL in FY 76 to test rock samples at varying temperatures and pressures to 400°C and 1,000 bars, respectively. Thermal, electric, and sonic properties of rock-fluid, systems would be measured.

At LASL experimental programs are carried out in geophysics and rock mechanics using both explosive shock waves and static high pressure devices. These programs are directed at the high P-T properties of silicates, oxides, and metals with the principal objective the determination of the composition of the earth's mantle and core. Research on melting phenomena and solution geochemistry currently underway will be expanded to include more rock systems and high P-T studies of phase equilibria of individual pure mineral phases, mineral assemblages, including volatile bearing systems, and the physical and thermochemical properties of silicate melts. Investigations of mineral assemblages in mantle-derived xenoliths with electronprobe are in progress.

The LLL is also involved in a wide range of experiments on the static deformation and shock properties of minerals and rocks to permit accurate predictions of the response of the earth's crust to various types of stress and loading. A research program is in progress to improve understanding of the response of geological media to mechanical stimuli such as explosions or *in situ* stress. Rock behavior on a microscopic (grain size) scale will be modeled, and results verified by experimental work on well-characterized ceramic synthetic rocks. With the help of statistical theory, modeling will then be extended to the larger scale of joints, faults, and other inhomogeneities that exist in the field. Also at LLL numerical modeling of both small scale and field experiments will be conducted for pre-experiment design and post-experiment analysis. In an iterative manner, these should provide a basis for advancing understanding and improving predictive capability.

D. Geological Constraints

Field studies at LASL related to volcanism or plutonic processes provide data in the form of structural relationships, detailed studies of petrochemistry of lavas and xenoliths, and also from physical observations such as spectroscopy of volcanic gases. These activities include field studies of igneous terranes directed at the understanding of such igneous processes as the emplacement of magmas from depth, the dynamics of thermal problems associated with pluton emplacement and volcanic eruptions, and their relationship to tectonic features such as plate interactions. Included are field studies of the Rio Grande rift and its associated volcanics—both basalt and caldera complexes, andesite volcanoes of the Cascades of northern California, and field studies of active volcanoes. Methods include movies, high-speed and time-lapse photography, spectroscopy and interferometry for gas and light isotope analysis, geodesy by optical and laser methods, seismology, aerial photography and remote sensing, air, gas and particulate sampling at low and very high altitude by aircraft, shallow borehole geophysics, and petrological studies of lava, volcanic rocks and xenoliths from kimberlite pipes and andesites.

Laboratory studies at LASL on rock and mineral samples provide major, trace elements, and isotopic data obtained with the goal of establishing the temperature, pressure, and time of formation of the material. From this information, combined with careful field mapping, a sample can be placed in its historical context and its physical or chemical history established.

At LBL the distribution of trace, major, and radiogenic-heat-producing elements in Mesozoic instrusive rocks, and Tertiary and Quaternary igneous rocks, on east-west traverses across the Great Basin will be examined. Radiogenic heat production will be determined, and interelement ratios compared which may indicate the presence of, and depth to, plates of oceanic crust that foundered beneath over-riding continental plates.

II. Boundaries, Movements, and Structure of Lithospheric Plates

Under a cooperative arrangement between two universities, seismic data are analyzed from a network of short period telemetered seismic stations in the Shumagin Islands near the tip of the Alaskan Peninsula, and from a large aperture seismic array in the eastern Aleutian arc east of Unalaska Island. This is part of a seismic tectonic study of the active Pacific-North American plate boundary in the eastern Aleutian arc.

At LASL the present state of activity of both the Rio Grande rift zone and the Jemez caldera are monitored by geophysical observations and a regional seismic network to provide data on a major continental rift feature and the unusual volcanism associated with major rift zone processes. The Rio Grande rift is relatively young and may be a major rift zone in an incipient stage of formation.

Possible topical studies would include: borehole geophysics and core studies along the Rio Grande rift using LASL's 300-m drill rig, the core studies to include petrological, geochemical, and physical properties; regional seismicity using LASL's seismic net; regional geodesy using three-color laser geodimeters, tilt and long baseline precision leveling; and deep seismic reflection profiling (University consortium).

At LBL a study is underway to detect changes in electrical resistivity that might be caused by tectonics within the San Andreas Fault system.

National Aeronautics and Space Administration

The NASA Earth and Ocean Physics Applications Program, through satellite and lunar observation techniques, contributes to the major IGP elements concerned with geophysical observations of internal processes, and present motions of lithospheric plates and the earth's pole. The NASA projects involved are the Tectonic Plate Motion, Measurements Systems and Forecasting Techniques, Experimental Data Analysis, the Lunar Ranging Experiment (LURE) and the Three Satellite Systems, the Geodynamic Experimental Ocean Satellite (GEOS-C), the Laser Geodynamic Satellite (LAGEOS) and the Ocean Dynamics Satellite (SEASAT-A).

The objective of the Tectonic Plate Motion project is to utilize existing capabilities to measure precise motions between defined points, using both laser tracking and very long baseline interferometry.

Measurements Systems and Forecasting Techniques activities involve the planning and implementation of scientific and technical research and other supporting activities in universities, nonprofit and industrial organizations, NASA centers, and other Government agencies.

Experiment Data Analysis provides for the analysis and synthesis of data obtained in EOPAP investigations, e.g. the processing, evaluation, and analysis of data taken during GEOS-3, Skylab, Apollo-Soyuz Test Project, etc.

The Lunar Ranging Experiment will utilize existing knowledge of lunar motions and continuing range measurements to the lunar retroreflectors to support investigations on earth rotation, polar motion and plate motions. The range measurements will be acquired at fixed stations located at the University of Texas McDonald Observatory and the University of Hawaii Maui Laser Ranging Observatory.

The Geodynamic Experimental Ocean Satellite (GEOS-3) presently orbiting project has the objective of demonstrating a much improved altimeter that cannot only measure the topography of the earth's oceans to an accuracy of approximately 30 cm, but that can also measure the wave height (or sea state). The measurements of the ocean topography will provide the capability to make a more precise mathematical description of the earth's gravity field and improve the measurements of the variations in solid earth geometry and other geophysical areas.

The Laser Geodynamic Satellite (LAGEOS) project, launched in 1976, with its very dense spherical satellite covered with laser reflectors, has the objective of providing the capability to make very accurate measurements of the earth's crustal motions (tectonic plate movement, fault motions, polar wobble and rotation rate).

The first Ocean Dynamics Satellite (SEASAT-A) due for launching in 1977 has as its objective the demonstration on a global scale of an integrated monitoring and data gathering capability for a wide range of physical ocean characteristics, including wave height, shape, and direction, the location and motion of currents, global circulation patterns, ocean surface, wind speed and direction and the ocean geoid (topography of the oceans).

National Science Foundation

The National Science Foundation (NSF), forbidden by its charter to conduct research or operate research laboratories, supports scientific research and programs to strengthen scientific research potential through grants and contracts. Most of the thousands of awards made annually are to nonprofit organizations—principally U.S. universities and colleges. Traditionally, NSF has supported basic research through unsolicited proposals by individuals, although in recent years there have been an increasing number of requests for major projects involving a great many scientists, often from consortia of universities.

The grants or contracts made that are geodynamics-related fall in both the large and small categories. The Ocean Sediment Coring Program is an example of a project involving a major facility, the *Glomar Challenger* drilling vessel. However, most of NSF funds, and nearly all of the awards, are for small projects of one or two scientists.

In FY 74, NSF awarded 243 grants or contracts that were geodynamics-related to 78 universities and other nonprofit organizations. The ten major organizations that contributed most to geodynamics through NSF support were Columbia University, the University of California at San Diego (including Scripps Institution of Oceanography), Battelle N.W., Woods Hole Oceanographic Institution, University of Hawaii, MIT, University of Washington, Harvard University, California Institute of Technology, and Stanford University. Although this list may change each year since grants are for only 1 or 2 years, most of the universities noted above will be among the leading contenders. In FY 75 Cornell University received a large award for their deep seismic sounding efforts, while work by Battelle for geodynamics information at Maryville, Montana decreased. On the whole, it is the universities with major facilities that figure most prominently in geodynamic investigations. Since there is a constant change in proposals received, it is impossible to predict an exact future categorization, even though total budget figures are available. Information supplied in this report indicates what is expected in FY 76, although FY 74 figures are the latest that have been documented.

The NSF supports geodynamics-related projects in several offices, as follows: the Earth Science Project Support in the Division of Earth Sciences: Geophysics, Geochemistry, and Geology; the Ocean Sediment Coring Program in the Division of Earth Sciences; the Submarine Geology and Geophysics Program (SG&G) in the Oceanography Section of the Division of Oceanography; the Seabed Assessment Program in the International Decade of Ocean Exploration of the Division of Oceanography; the Polar Earth Sciences Program in the Office of Polar Programs; and the Advanced Geothermal Energy Research and Technology Program (AGERT) in the Division of Advanced Energy Research and Technology. Other offices that also provide some of the facilities and logistics for the research projects are the Office of Oceanographic Facilities and Support of the Division of Oceanography, for oceanographic research ship support, and the Earthquake Engineering Program of the Division of Advanced Environmental Research and Technology for the national strong-motion seismic network.

I. Internal Properties and Processes

A. Dynamic Models

Within the Geophysics Program, about half a dozen grants are normally made per year for modeling studies of the dynamics of the earth's core, geodynamo, and on convective motion in the earth's mantle and at the crust-mantle boundary.

B. Geophysical Observations of Internal Processes

A major effort by about 50 individual grants is being made by university scientists to study internal processes by geophysical methods. These efforts come from various offices throughout the National Science Foundation that deal with geodynamics-related programs, but are most heavily concentrated in Geophysics, SG&G, and in AGERT. The principal tool for the geophysics studies is earthquake seismology, and in most of these studies, heavy reliance is put on the records of the World Wide Standardized Seismograph Network, with about 20 grants and nearly $.90M total. Geothermal studies are carried out mostly in AGERT in the search for methods of locating sources of energy within the earth. Seismic studies of internal characteristics by the use of controlled explosives or mechanical sources account for nearly $.50M in about 10 separate university grants. A few universities are experimenting with the Ocean Bottom Seismograph (OBS) in an effort to obtain more detailed information on the ocean sediments, as well as a new input to earthquake monitoring. A major award in this category, which is now developing, is concerned with the fine structure of the crust and upper mantle in which continuous seismic reflection techniques used in petroleum exploration seismology can be extended to deeper structures in the earth. If seismic discontinuities can be mapped in the lower crust and upper mantle, a great deal of information can be obtained on the evolution of the continental crust from the primitive mantle and on very deep-seated control of surface features. Research on telluric, magnetotelluric, electromagnetic induction, and electrical resistivity methods are increasing and in FY 1974 about $200,000 was spent on such projects. A few gravity studies are sponsored through the Geophysics Program on continental work and gravity measurements at sea were carried out routinely on a few of the oceanographic vessels. Most of the studies above are concerned with the continental U.S. and Hawaii, but several studies were carried out in Mexico, Iceland, and in Southeast Asia.

C. Physical and Chemical Properties of Minerals and Mineral Assemblages

These studies by the NSF can be divided into two or three general groups adding up to about 40 awards totalling almost $2 million. The support by the Geophysics Program is heavily oriented towards the investigation of sonic velocity, flow measurements, development of microcracks, shear strength and electric properties of rocks, particularly the ultrabasic rocks most likely to have originated in the lower crust and upper mantle under high pressure and high temperature. Considerable development work in the past few years has gone into methods of obtaining high temperatures and high pressures. These include ultrasonics and shock compression, as well as static compression, and the advancement has been made at relatively few of the major universities. In the Geochemistry Program, in many cases using high-temperature, high-pressure equipment, 15 to 20 studies involving about $.90M are concerned with a large variety of geochemical problems such as equilibrium and mass transfer among minerals and aqueous solutions, the diffusion kinetics of trace elements, mineral crystal chemistry, thermodynamics of ionic interactions, rate and mechanism of exsolution in minerals, and the measurements of ion-pair formation constants. The IDOE office funded a few projects in which samples recovered from the mid-Atlantic Ridge were analyzed.

D. Geological Constraints

This area of geodynamics-related programs is well represented in NSF with nearly 60 awards totalling between 2.5 and 3.0 million dollars annually. Most of these awards are made in Geochemistry, Geology, Submarine Geology and Geophysics Programs. The Geochemistry Program supports nearly 40 awards varying widely in the topics studied with 6 to 10 on the geology, geochemistry and geochronology of volcanic rocks from several geographic areas, though principally the United States and Mexico. Several mantle or deep crustal rocks that are exposed at the surface in various areas of the world are also studied in these programs. The SG&G Program supports many studies of the basalts obtained from the Ocean Sediment Coring Program, and IDOE supports studies of rocks recovered from submersibles in the FAMOUS Experiment on the Mid-Atlantic Ridge. A few studies of the geochemistry and petrogenesis and geochronology of rocks obtained from the Dry Valley Drilling Project are made under the Office of Polar Programs.

II. Boundaries, Movement, and Structure of the Lithospheric Plates

A. Present Plate Boundaries

The NSF effort in this category, which is about $2 million per year, is largely in the oceanic areas in the SG&G and IDOE Programs. A number of geophysical studies have been made of the boundaries and structure of the Nazca Plate, the eastern and southeastern parts of the Asian Plate, and the western part of the Pacific Plate. The Sunda Arc and the Mid-Atlantic Ridge are also under investigation. Use is made in some of these studies of the relatively new multi-channel marine seismic units, often with high energy air guns, as well as sonabuoys and ocean bottom seismographs. In addition to the seismic work, support has also been provided for major programs involving gravity, heat flow, and magnetic measurements in the continental margin of west Africa and eastern South American in order to construct the various stages of the opening of the South Atlantic. The Geochemistry Program includes isotopic studies of the older geologic history of the southwestern margin of North America and the tectonic evolution of the South Kenya rift zone.

B. Present Motion of Plates

A program with about one-half dozen awards in the Geophysics Program involves the modeling of the response of the earth to late quarternary ice melting, earth tide studies, and applications of atomic clock interferometry. A major program has been initiated on the geophysical application of very long baseline interferometry. This technique has the potential to clarify our concepts of the current nature of plate motion and deformation.

C. Plate Boundaries and Rates of Movements During the Past

In this category the NSF supports about 40 investigations with an estimated total of $2.3 million which includes a sizable portion ($.90M) for the Ocean Sediment Coring Program of Scripps Institution of Oceanography, plus several research studies of cores of OSCP projects that are not part of initial cruise reports. This research on core material is carried out by scientists from many universities and requests are expected to continue to grow. The NSF support of research on these cores, mainly in Submarine Geology and Geophysics, is actually a fairly small percent, about 10-20, of the work on the cores for this program. Other investigators also obtain samples for studies and, although a few of these may be reported to this Committee by other agencies, many samples go to investigators from industry and from universities, both domestic and foreign, where support is not required from the Federal Government. The Ocean Sediment Coring Program is changing somewhat in objectives, as it begins its IPOD phase in late 1975, with concentration on deep crustal drilling and reduced emphasis on paleoenvironmental and ocean margin drilling. Thus, this program will be contributing a greater part of its effort to geodynamics-related projects.

Other investigations in this category are supported through Geophysics, SG&G, and the Office of Polar Programs, and these are about equally divided between paleomagnetic projects dealing with past plate movements and geological and geophysical studies in areas of plate boundaries. The Antarctic Program involves sediments taken from the *Eltanin* and from the Dry Valley Drilling Project, as well as geological studies in the Antarctic Mountains and the Antarctic Peninsula. The *Eltanin*, now operated by the Argentine Government and renamed the *Islas Orcadas*, works in the South Atlantic Ocean in a cooperative study by Argentine and U.S. scientists.

D. Plate Accretion, Composition, and Structure

The NSF support in this category is about $1.5 million in 20 or more grants and contracts, with efforts of the Ocean Sediment Coring Program estimated at about $.30M. A large contribution comes from the International Decade of Ocean Exploration in their projects to provide major support to Woods Hole Oceanographic Institution for the studies of the East Atlantic Continental Margin and to the Lamont-Doherty Geological Observatory of Columbia University for the study of the continental margins of Argentina and Brazil.

U.S. Geological Survey

I. Internal Properties and Processes

A. Dynamical Models

Studies of dynamical models are carried out as part of the Geological Survey's Earthquake Hazards Reduction Program, Geothermal Program, and Geophysical Surveys Program. Recent studies by Survey scientists suggest the reliable prediction of damaging earthquakes may be feasible within a few years for some earthquake-prone areas. Field measurements coupled with laboratory experiments and theoretical studies of precursor phenomena are being carried out by Survey scientists in order to establish a firm physical basis for predicting the time, place and magnitude of earthquakes. This research effort includes the collection and the analysis of data on strain accumulation and release, and the study of the behavior of rocks under physical conditions similar to those encountered in the crust and upper mantle.

Computer modeling of fault displacements is underway to achieve an understanding of fault mechanisms and related effects. These numerical models are used by Survey scientists to develop simulations of vertical and horizontal deformation arising from possible dilatant changes in a fault zone. Both plane-strain and three-dimensional analyses have been applied to problems of source mechanics, earthquake prediction, and earthquake modification.

Survey scientists also study the mechanisms by which water and heat are transferred in geothermal systems within the crust. Conceptual models of selected well-known geothermal systems—based on their known geologic, hydrologic, geochemical and geophysical settings—are being improved by means of shallow drilling to obtain corroborative thermohydrologic data.

Information about the distribution of magnetization and electrical conductivity within the earth is gained by orbiting satellite magnetometers which record broad-wavelength magnetic anomalies plus the small-amplitude fluctuations in the earth's magnetic field (micropulsations) by instruments at land-based geomagnetic observatories.

B. Geophysical Observations of Internal Processes

Numerous geophysical methods are being used by scientists of the U.S. Geological Survey to detect subsurface structures and to describe the dynamics associated with the margins and interior of the North American plate. These methods include microearthquake, refraction and reflection seismic, heat flow, magnetic, gravity, electrical resistivity, electromagnetic, and thermal radiometric studies of the continent, continental shelf, and continental slope.

Microearthquake studies based on dense arrays of short-period seismographs (microseismic nets) permit three-dimensional mapping of active fault zones as well as identification of "locked" sections of known active faults. Recorded microearthquakes are correlated with measured strain patterns in studies of the propagation of strain or slip events throughout the network. Microseismic networks are currently operating in California, Washington, Nevada, Wyoming, Utah, New Mexico, Missouri, Alaska, and Hawaii.

In support of the microseismic studies, refraction seismic surveys are made over broad regions to determine the physical properties, elastic regime, and principal structure elements of the crust and upper mantle.

Heat flow measurements also contribute to an understanding of processes occurring within the earth. Measurements of geothermal gradients in deep wells and mines together with laboratory measurements of thermal conductivity of rocks and radioactive heat production provide information about the thermal regime of the earth's crust and upper mantle.

Surface manifestations of heat flow are detected by analysis of thermal infrared images obtained over broad regions. After deleting solar heating effects from crustal heating effects, the image information is analyzed using thermal inertia and spectral reflectance data obtained in the field. The thermal and reflectance data may be used as indirect measurements of high surface heat flows associated with hydrothermal activity in the crust.

In addition to seismic and heat flow studies, magnetic and gravity surveys are made to identify zones of anomalous magnetization and density in the crust and upper mantle. Magnetic surveys made by air, land vehicle, or on foot are extremely useful in delineating accumulations of serpentine within strands of the San Andreas and related faults; ophiolitic rocks representing ancient oceanic crust, which occur in the California Coast Ranges and Sierra Nevada foothills; and subsurface shapes of plutonic rock massifs such as the Sierra Nevada and Boulder batholiths of western United States;

Magnetic surveying over broad areas is accompanied wherever feasible by regional gravity surveying. The gravity data have proven to be especially useful in major sedimentary basins, low-density plutonic rocks that have been intruded into metamorphic rock complexes, high-density mafic and ultramafic rocks representing crustal and upper mantle sources, and high density relatively nonmagnetic terranes of metamorphic rocks.

Various electrical and electromagnetic techniques such as D.C. resistivity, transient electromagnetic, audio-magnetotelluric, induced polarization, electromagnetic, self-potential, and telluric-current methods are used for detecting zones of anomalous electrical conductivity in the subsurface. These anomalous zones may reflect stratigraphic or structural barriers controlling the distribution of saline ground water or regions of elevated temperature associated with high geothermal potential.

Continental geophysical investigations merge with marine geophysical research at the Atlantic continental margin where marine seismic reflection, seismic refraction, magnetic, and gravity surveys are made to investigate the deep structure of the continental shelf and slope. Current investigations involve structural interpretations and evaluations of the thickness and distribution of sedimentary rocks in the Baltimore Canyon Trough and Georges Bank basins.

C. Physical and Chemical Properties of Minerals and Mineral Assemblages

Because the physical properties and chemical compositions of most rocks and rock-forming magmatic materials cannot be directly measured in their crustal and mantle environments, these properties must be analyzed in the laboratory where physical and chemical conditions can be simulated. Information about the composition, state, temperature, and stress conditions in the earth's interior is obtained in an integrated program of laboratory and field studies in mineralogy, igneous petrology, metamorphic phase petrology, phase equilibria, thermodynamics, isotopic geochemistry, radioelement analysis, neutron activation, and rock mechanics. This program is supported by comprehensive compilations of geochemical and thermodynamic data accessed by digital computer.

Mineralogic research is concerned mainly with precise measurements of the physical properties of rock-forming minerals aimed at determining how the thermal and stress histories of minerals affect their compositions and properties.

Research in igneous petrology is directed toward understanding magmatic systems, with special emphasis on studying the relation of chemical variations to physical properties and to such rate-dependent properties as viscosity, diffusion, and kinetics.

Phase equilibria studies of multicomponent systems, which are fundamental to current research in igneous and metamorphic petrology, are applied to crystal chemistry and physical chemistry data of rock-forming minerals.

Contributing to information obtained by phase petrology and thermodynamic studies is a broad area of research in isotopic geochemistry. This research includes investigations of light stable isotopes, such as carbon, hydrogen, oxygen, and sulfur, and radiogenic isotopes, such as strontium, lead, and intermediate daughter products in the uranium and thorium decay series.

An essential companion to the various studies of the chemical composition of rocks and minerals are investigations of the physical properties of these materials in laboratory experiments that duplicate conditions in the earth's crust and upper mantle. This research in rock mechanics is largely conducted with experimental equipment that simulates conditions at depths of up to 30 kilometers. Mechanical, elastic, and thermal properties of rock samples are currently measured at pressures of up to 10 kilobars (approximately 10,000 atmospheres) and temperatures of up to 1,000°C.

D. Geological Constraints

Geologic constrains on models of plate tectonic evolution and processes are being investigated in a wide variety of geologic settings.

In Washington, Oregon, and California, petrologic and structural studies of volcanic, sedimentary, and plutonic rocks supported by detailed geologic mapping and regional synthesis of large areas of the Cascade, Olympic, and Klamath Mountains are helping unravel the tectonic history of the western margin of the North American Plate and to clarify its interaction with the Nazca and Pacific plates during Mesozoic and Tertiary time.

Both detailed and reconnaissance studies of volcanic rocks and associated plutons of Tertiary age in the San Juan and Absaroka Mountains and in central Idaho are underway to help explain the relation between the chemistry of the igneous rocks erupted through the North American plate and geodynamic processes along the western compressional margin of the plate.

Studies in geochemistry and geophysics are providing constraints to models of properties and processes of plate tectonics through investigations of igneous and metamorphic rocks and of active and dormant volcanoes. Detailed studies of ankaramites in Hawaii, caldera deposits in New Mexico, and basalts in the Pacific Northwest are being made to estimate depths of phenocryst formation and development, physio-chemical processes and crystallization history in large volumes of silicic melt, and the mechanics of extrusion and spreading of prodigious volumes of basalt over vast areas.

Additional studies of the generation and movement of magma are being conducted at the Hawaiian Volcano Observatory, where measurements of deformation at Kilauea Volcano are made and examinations are conducted of old lava flows and of magma in the process of eruption.

All of these investigations of igneous rocks are supplemented by field and laboratory studies of metamorphic rocks that are providing information on load, strain, and fluid pressures during metamorphism as well as means of inferring depths of partial melting.

Consideration of the theory of plate tectonics is an important element of Geological Survey research on mineral resources, because models of ore genesis that explain the relationship of ore-forming processes to other geologic events should improve the capability to predict the presence of useful deposits. The emphasis of present studies in geodynamics as applied to ore deposits is aimed at understanding the origin of important regional structural features and the correlation of the geologic environments of deposits with identifiable parts of the plate tectonic cycle.

Mapping and petrologic studies are showing the existence of island arc volcanic rocks and of ophiolite complexes indicative of subduction and possibly obduction along the margin of the North American plate in late Paleozoic and early Mesozoic time.

Reconnaissance studies in southwest Oregon are aimed at determining how podiform chromite-bearing ultramafic and mafic bodies and related melange units of volcanic rocks from island arcs were scraped off the oceanic plate and juxtaposed on the North American plate in Mesozoic time.

Studies of the base-metal deposits in the Eastern States are concerned with examining evidence that links mineralizing episodes to plate deformation before and during opening of the proto-Atlantic in early Paleozoic time. Some of these deposits provide clues that pulses of mineralization occurred in paleoaquifers whose flow regimes may have been determined by warping during early stages of rifting.

In Puerto Rico, geologic mapping, isotopic dating, and petrologic studies are attempting to establish the relations between the emplacement of porphyry copper deposits, volcanic and plutonic rocks, and the subduction events of Cretaceous to Eocene age.

II. Boundaries, Movements, and Structure of Lithospheric Plates

A. Present Plate Boundaries

The Worldwide Network of Standard Seismographs (known as WWNSS), composed of 31 continuously recording stations in the United States and 85 similarly instrumented cooperative stations in 68 other countries is the most important international seismological effort. This network is the essential source for the seismological data that are used in locating earthquakes, determining focal mechanisms, investigating seismic wave propagation, and developing concepts of global and regional tectonics. The Geological Survey operates 7 seismic observatories in the conterminous United States, Alaska, and Guam and provides equipment maintenance and supplies for the other stations of the WWNSS.

The Geological Survey's National Earthquake Information Service (NEIS) in Golden, Colorado, is responsible for receiving data on potentially damaging earthquakes, rapidly locating such earthquakes, and notifying the proper authorities and the public. NEIS locates as many earthquakes worldwide as can be accurately and rapidly determined with data collected from USGS observatories and seismic stations and from the WWNSS.

USGS scientists are continuing research into the geologic nature of the mid-ocean plate boundaries. A cooperative investigation, the French American Mid-Ocean Underseas Study (FAMOUS), provided a unique opportunity for direct observation of the topography and geology of the Mid-Atlantic Ridge in the region southwest of the Azores Islands. Using deep submersible craft, Geological Survey geologists were able to observe, photograph, and sample across the innermost rift valley of the Ridge.

B. Present Motion of Plates

Precise geodetic techniques—geodimeter surveys for horizontal movements and level surveys for vertical movements—are used to determine elastic strain accumulation and strike-slip along faults and to detect premonitory strains that might be useful for earthquake prediction. Trilateration networks, which are resurveyed annually, are stitched across faults of the San Andreas system, the Nevada seismic zone, the Wasatch fault in Utah, and in the Hebgen Lake area of Montana.

Sea level measurements recorded at automatic tide gages also are being studied for their possible utility in determining crustal uplift or subsidence along tectonically active coast lines. National Ocean Survey tide gage records along the coast of the western United States and Alaska are being analyzed to detect possible tectonically induced trends.

Seismomagnetic effects along western United States fault zones are being investigated as an indirect means of monitoring crustal stress. One aspect of the program has been to search for broad-scale long-period effects with a pair of magnetometers that operate synchronously in a "leap-frog" survey mode.

C. Plate Boundaries and Rates of Movement During the Past

Current paleomagnetic research includes refining the geomagnetic reversal time using radiometrically dated volcanic and plutonic rocks as well as stratigraphically dated sedimentary rocks from the Western and Southwestern United States.

Other major paleomagnetic problems related to interpretations of sea floor spreading rates and apparent polar wandering are the decrease in amplitude of magnetic anomaly stripes with increasing distance away from a spreading axis and fluctuations of the geomagnetic field intensity throughout geologic time. Paleomagnetic and petrologic data from samples of sea floor and sea mount basalt from the Hawaiian-Emperor volcanic chain indicate that the observed decrease in anomaly amplitude away from a spreading center is caused by oxidation of titanomagnetite to cation-deficient titanomaghemite within the basalt.

Recent research in geochronology, important to improving the time framework for interpreting rates of plate motion and tectonic processes, includes investigations of the $^{40}Ar/^{39}Ar$ age spectrum dating technique. This total fusion technique, which can be used on the same materials and nearly the same age range as the conventional technique, has the advantage of using smaller and less homogeneous samples than those used with the conventional technique.

Other research in geochronology is concentrated on the use of thermoluminescence (TL) as a dating tool for very young volcanic rocks. The age range over which the TL method is demonstrated to work using samples independently dated by C^{14} and K-Ar methods is 2,500 to 450,000 years for tholeiitic basalts and 4,500 to 200,000 years for alkalic basalts.

D. Plate Accretion, Composition, and Structure

Much of the Geological Survey's research on the Pacific margin of the Americas Plate is concentrated on the San Andreas Fault zone from the Salton Trough to the Mendocino Fracture zone. Significant efforts are also underway in the vicinity of the Gorda rise and Juan de Fuca Rise and along the Aleutian Trench-Arc system and coastal Alaska. A major objective of this research is locating recently active fault strands within the San Andreas system and the determination of the tectonic history along this active plate margin.

A detailed analysis of the intense folding and faulting in the Salton Trough is underway to determine the tectonic history of the area. These studies should establish or refute the hypothesis of transform faulting and sea-floor spreading in the Salton Trough. From the Salton Trough northward to the Mendocino Fracture zone, the Survey is engaged in detailed mapping of Pre-Tertiary to Recent deposits to determine the location, direction, and magnitude of displacements and the recurrence interval of faulting along the San Andreas, Garlock, Hayward, Concord, Calaveras, Sierra Nevada, Elsinore, and San Jacinto faults.

Geologic and geophysical studies of the Oregon and Washington continental margin are designed to unravel the tectonic history of this part of the Pacific margin and to relate the deformational history to mineral resource accumulation and igneous activity. The unique onshore exposures of oceanic crust provide an excellent opportunity to infer offshore plate boundary geology.

Detailed mapping of active surface faults and the evaluation of geologic evidence for Late Cenozoic faulting is in progress along coastal Alaska. In western Alaska the emphasis is on deciphering the Tertiary and Quaternary geology and biostratigraphy of the coastal region, the continental shelf, and the offshore islands. The objective of this study is to determine and correlate the nature and rates of past and on-going crustal deformation. The stratigraphy and tectonic style of the shelf and slope of the Beaufort-Chukchi sea area are being studied by relating the onshore geology in the Brooks Range thrust belt to the offshore areas, using seismic reflection, magnetic, and gravity profiling. Seabed sampling and heat flow studies are also contributing to a synthesis of the regional tectonic picture.

Since the early 1950's the Geological Survey and other Federal, State, and private institutions have assembled a prodigious amount of geologic information on the Colorado Plateau. The original work, primarily large-scale geologic mapping in support of uranium exploration, is now being synthesized and compiled at 1:250,000 scale for the entire Colorado Plateau. This synthesis of vast amounts of stratigraphic and structural information should provide an integrated data base to help answer the perplexing questions of why and how this plate fragment rose epeirogenically and escaped the intense Laramide and Post-Laramide deformations that affected the Basin and Range Province to the west and the Rocky Mountains to the east.

The geologic features of the sedimentary wedge under the Atlantic margin of the Americas Plate are being determined by shallow (300 meters or less) core drilling. Studies of the paleontology, lithology, mineralogy, and geochemistry of the cores provide a regional picture of the depositional history of the area. This study will provide information about the relationship between crustal tectonic fluctuations and transgressions and regressions of the sea, and provides control for marine geophysical investigations. Geophysical interpretations of the offshore sedimentary section and basement complex are based on seismic reflection and refraction surveys, plus gravity and magnetics data. From these data the geology of the shelf, slope, and rise are studied to identify the structural and tectonic features.