SOEST TECHNICAL REPORT 94-03

TSUNAMI FACTS

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INTRODUCTION

From 1900 through 1965, a total of 13 significant tsunamis (i.e., those with wave heights $\geq$ 1 meter) produced by distant earthquakes were reported for the Hawaiian Islands (Table 1 and Figure 1). For some of these, amplitudes in excess of 10 m (or 32.8 ft) have been reported with substantial losses of life and property damage. However, from 1965 through 1993, no Pacific-wide tsunamis have struck the Hawaiian Islands. This has led to a false sense of complacency and lack of awareness that may add to the dangers associated with tsunamis, especially for the youth of Hawaii. Since 1965 the population has experienced substantial growth with much of the development in potential tsunami inundation areas. There are now more shoreline recreational areas with more people at risk in these coastal inundation zones. A majority of the people in these areas are the youth of Hawaii. With both parents working, or with single-parent families, many of these children may have no adult supervision. In the event of a destructive tsunami, lack of knowledge could lead to an unnecessary repetition of past tragedies.

Although most of the destruction and loss of life due to tsunamis in Hawaii has been produced by distant earthquakes, 5 locally generated tsunamis with runups $\geq$ 1 meter have been reported from 1900 through 1993 (see Appendix I). Three were the result of earthquakes near the southeastern coast of the Island of Hawaii. One was produced by an earthquake near Hookena along the Kona Coast and another was the result of the slumping of volcanic material which had flowed into the ocean several days earlier near Milolii. Only one locally generated tsunami is reported prior to 1900. This tsunami was also produced by an earthquake near the southeastern coast. Years of occurrence and maximum reported runups in meters are: 1868, 13.7; 1908, 1.2; 1919, 4.3; 1951, 1.2; 1952, 3.0; and 1975, 14.3. The large tsunamis of 1868 and 1975 had significant runups all along the southeastern coast (in excess of 6 meters at several locations). The 1868 tsunami also had reported runups of 3.4 m for Kailua, Kona and 2.7 m for Hilo. The 1975 tsunami had values of 3.3 m for Napoopoo, 2.9 m for Keauhou Bay, 1.8 m for Kailua, Kona, and 2.6 m for Hilo. The data which follows are for the more frequent and devastating tsunamis generated by distant

earthquakes.

This report is intended as a source book for increasing awareness and knowledge of tsunamis. It is hoped that "Tsunami Facts", "What You Should Do", and the "Self-Quiz" contained in this report would be copied and distributed by educators to students in public and private schools throughout the State. We would also hope that these materials would be discussed in the classroom and possibly even be used as a learning tool. The topic of tsunamis can be incorporated into discussions of earthquakes and volcanoes, plate tectonics, sea-floor spreading, ocean waves, earth science, natural hazards (e.g., tsunamis, hurricanes, storms, or flash floods), or the Civil Defense Warning System. Island by island summaries and comparisons are presented to assist educators in personalizing the information for their school and students. This booklet is intended primarily for students at the intermediate or high school level. It may, however, be a useful source of information for teachers of other students, or for the general public. **All of the tables and figures may be freely copied for classroom use or for other educational purposes.**

For interesting discussions and first person testimonies on the devastating and tragic effects of past tsunamis in Hawaii, we recommend Tsunami by Walter Dudley and Min Lee (University of Hawaii Press, 1988). This book is available at most bookstores and local libraries. Other publications which we recommend for increasing tsunami awareness are Tsunami Warning and Tsunamis in Hawaii. Tsunami Warning may be especially appealing to elementary and intermediate school children because of its "comic book" format. It is published by the International Tsunami Information Center (ITIC) in Honolulu. Tsunamis in Hawaii is a poster-sized, color map which shows the source locations, years of origin, maximum runups in the Hawaiian Islands, and tsunami travel times to Honolulu Harbor for many tsunamis from 1819 through 1993. Also shown are runup values throughout the Hawaiian Islands for the 1 April 1946 tsunami, and listings of "What You Should Know" and "What You Should Do." For additional information on the availability of these publications please contact this author, the ITIC, or the University of Hawaii Press.

TABLE 1

Tsunamis Observed in Hawaii from 1900 through 1993 with Runups $\geq$ 1.0 Meter[1]

Year	Earthquake Magnitude[2]	Runup (m)	Runup (ft)	Earthquake Source Location
1901	7.8	1.2	3.9	Vanuatu
1906	8.1	1.8	5.9	Ecuador
1906	8.0	3.6	11.8	Chile
1918	8.0	1.5	4.9	Kurils
1922	8.1	2.1	6.9	Chile
1923	8.1	6.1	20.0	Kamchatka
1933	8.3	3.3	10.8	Japan
1946	7.1	16.4	53.8	Aleutians
1952	8.2	9.1	29.9	Kamchatka
1957	8.1	16.1	52.8	Aleutians
1960	8.5	10.7	35.1	Chile
1964	8.4	4.9	16.1	Alaska
1965	8.2	1.1	3.6	Aleutians

1. When a tsunami strikes a low-lying coastal area which is normally above sea-level, the maximum observed height of the sea-surface is called the amplitude, vertical runup, or just "runup" of the tsunami. It is usually measured relative to mean sea level. The maximum horizontal distance inland that a tsunami penetrates might be thought of as the horizontal component of a tsunami's "runup", but is usually referred to as "inundation".

2. The magnitudes given are surface wave Richter values.

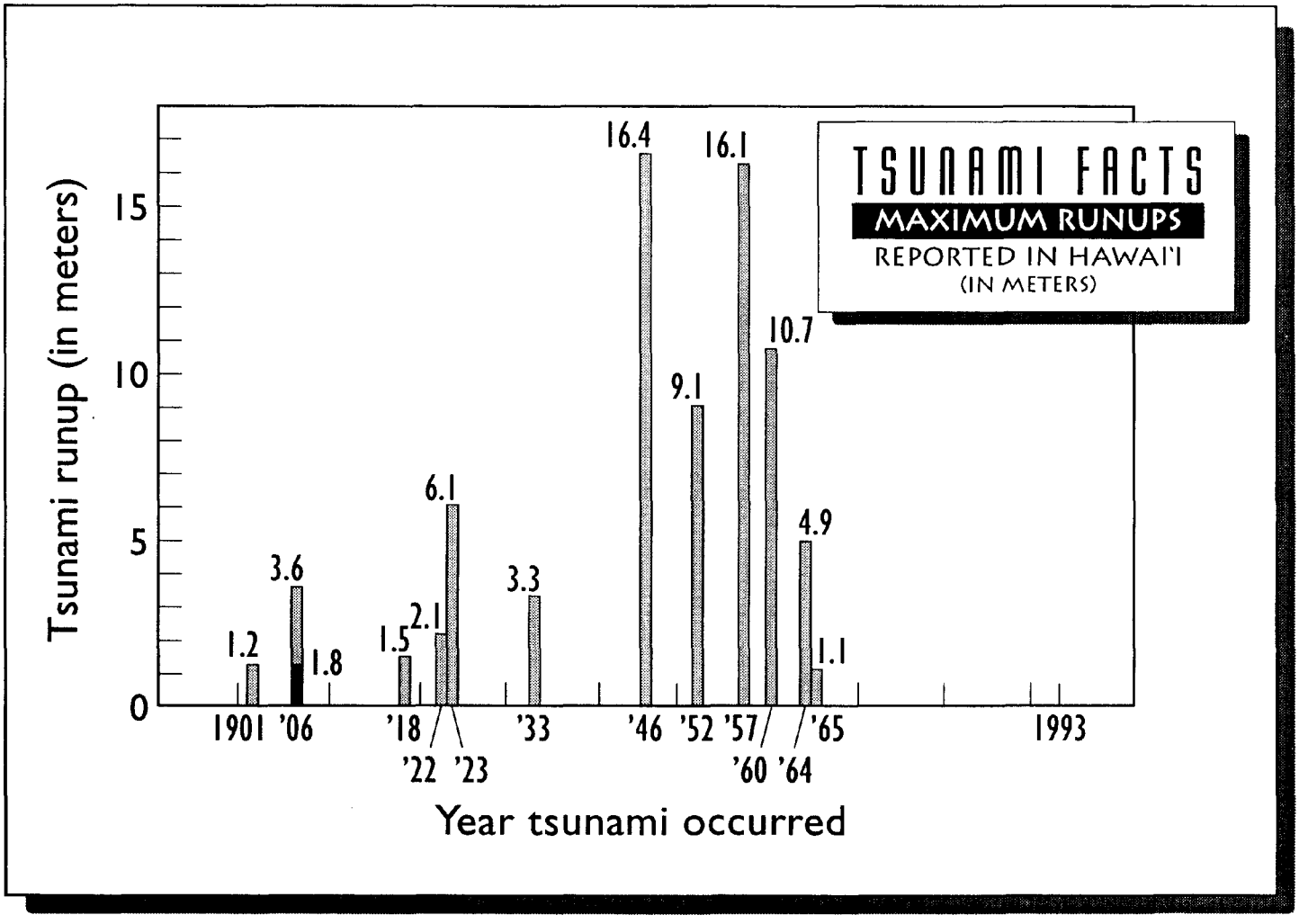

TSUNAMI FACTS
MAXIMUM RUNUPS
REPORTED IN HAWAI'I
(IN METERS)
Tsunami runup (in meters)
0
5
10
15
1.2
3.6
1.8
1.5
2.1
6.1
3.3
16.4
9.1
16.1
10.7
4.9
1.1
1901
'06
'18
'22
'23
'33
'46
'52
'57
'60
'64
'65
1993
Year tsunami occurred

Figure 1a.

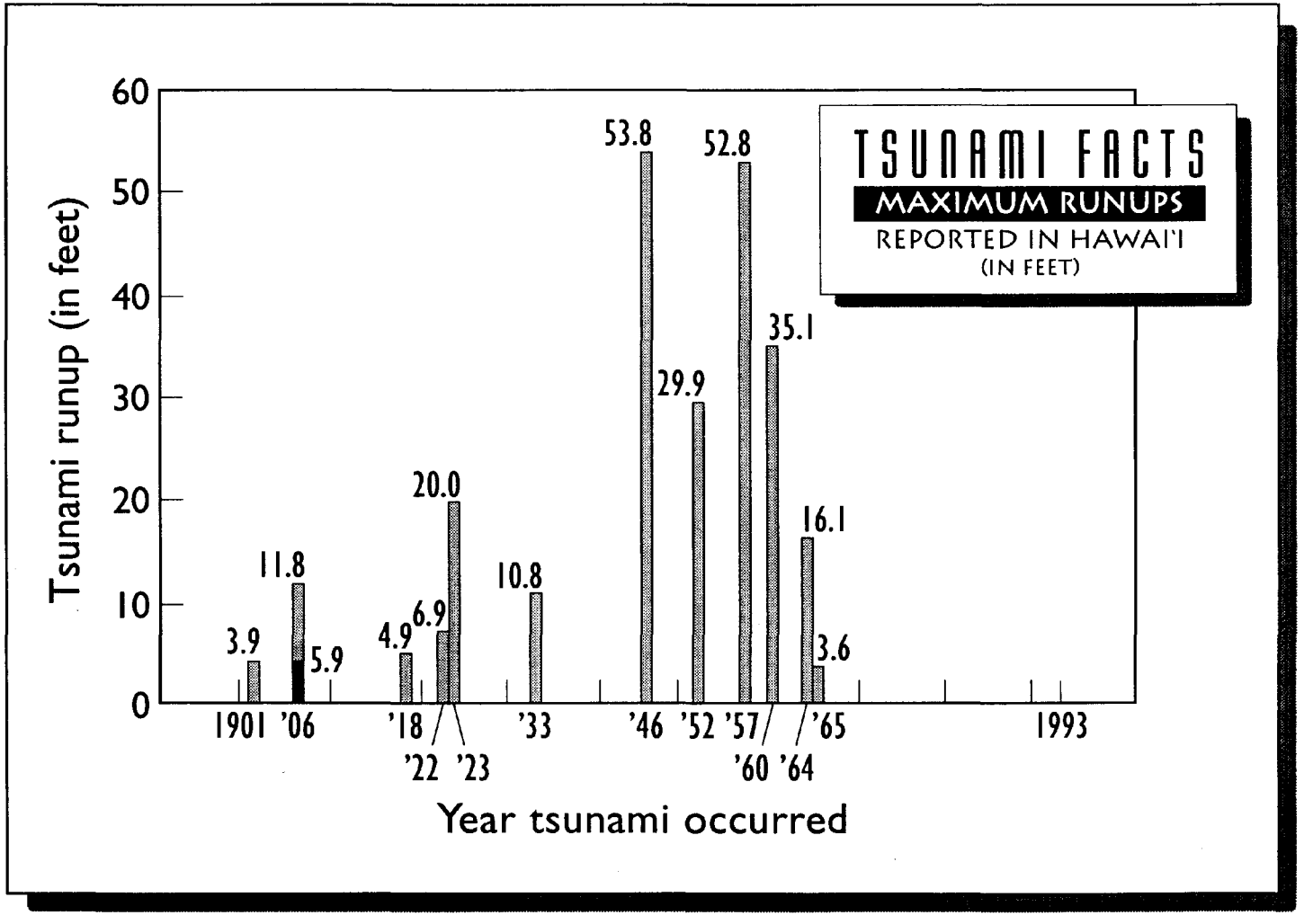

TSUNAMI FACTS
MAXIMUM RUNUPS
REPORTED IN HAWAI'I
(IN FEET)
Tsunami runup (in feet)
0
10
20
30
40
50
60
3.9
11.8
5.9
4.9
6.9
20.0
10.8
53.8
29.9
52.8
35.1
16.1
3.6
1901
'06
'18
'22
'23
'33
'46
'52
'57
'60
'64
'65
1993
Year tsunami occurred

Figure 1b.

The Hawaiian proverb prefacing this report may be found on page 133 in 'Olelo No'eau: Hawaiian Proverbs & Poetical Sayings by Mary Kawena Pukui (Bernice P. Bishop Museum Special Publication No. 71, Bishop Museum Press, Honolulu, Hawai'i, 1983, 351 pp).

Data have been taken from the following sources:

Cox, D. C. and J. Morgan (1977). *Local Tsunamis and Possible Local Tsunamis in Hawaii,* HIG-77-14, Hawaii Inst. of Geophysics, 118 pp.

Lander, J. F., and P. A. Lockridge (1989). United States Tsunamis (including United States possessions) 1690–1988, National Geophysical Data Center, Publication 41-2, Boulder, Colorado, 265 pp.

Pacheco, J. F., and L. R. Sykes (1992). Seismic moment catalog of large, shallow earthquakes, 1900-1989, *Bull. Seismol. Soc. Am.,* **82**, 1306-1349.

Walker, D. A. (1993). *Pacific-Wide Tsunamis Reported in Hawaii from 1819 through 1990: Runups, Magnitudes, Moments, and Implications for Warning Systems*, School of Ocean and Earth Science and Technology Report 93-2, Univ. of Hawaii, 17 pp.

Walker, D. A. (1993). *Recent Evaluations of Parameters Used in Determining Tsunamigenic Potential*, Memorandum to State and County Civil Defense Agencies, dated 10 June 1993, 10 pp.

ISLAND AND COUNTY SUMMARIES OF RUNUPS FOR LARGE TSUNAMIS

Unless otherwise indicated, data are taken from Lander and Lockridge (1989). Excluded are tsunamis originating in the Hawaiian Islands and runups merely reported as "observed" with no assigned values. For a discussion of the term "runup", please refer to Table 1 or the definition given below. Figures with runups in meters and in feet are given. Tables have runup values in meters (1 meter = 3.28 feet).

Runups larger than those indicated in the following tables may have occurred, especially in earlier years, but were not observed or reported due to sparse populations, poor communications, the difficulty of travel into remote coastal areas, or insufficient personnel for comprehensive runup surveys. Locations indicated on runup maps are geographic names closest to the site of actual runup measurements.

Also, runups may not have been originally measured to the nearest tenth of a meter or foot as indicated in the tables or figures. Such apparent accuracy may merely be an artifact of differences in the precision of unit conversons. [For example, the maximum value of 53.8 feet reported for the 1946 tsunami was probably originally reported as 54 feet. Converting to meters using 1 m = 3.3 ft gives 16.4 meters which is the value reported in the scientific literature. Converting back to feet and using the more precise relationship of 1 m = 3.28 ft gives the value of 53.8 ft.]

DEFINITION

Runup—maximum height of the sea-surface in a coastal area which is normally above sea-level. Runup is usually measured relative to mean sea-level. Runup might also be referred to as amplitude or vertical runup. Runup might best be understood by realizing that it is often determined by measuring the height of seaweed in trees. The maximum horizontal distance inland that a tsunami penetrates might be thought of as the horizontal component of a tsunami's runup, but is usually referred to as "**inundation**".

Hawaii. A total of 22 Pacific-wide tsunamis with reported runups $\geq$ 1 meter on the Island of Hawaii have occurred since 1812 (Table 2). Source areas for the earthquakes listed in Table 2 are South America, Kamchatka, the Aleutians, Japan, Tonga, the Kurils, Alaska, and possibly, California. The largest runups ever reported for Hilo were for tsunamis in 1837 (6.0 m; Chile), 1923 (6.1 m; Kamchatka), 1946 (8.1 m; Aleutians), and 1960 (10.7 m; Chile). The largest runups reported at Keauhou on the west coast of Hawaii are for tsunamis in 1896 (5.5 m; Japan), 1933 (3.2 m; Japan), 1946 (4.0 m; Aleutians), 1957 (2.1 m; Aleutians), and 1960 (3.7 m; Chile). Island-wide, the largest and most comprehensive runups are for the 1896, 1933, 1946, 1952, 1957, and 1960 tsunamis (Figs. 2 through 5). The largest runups for the 1964 Alaskan tsunami were 3.0 m at Hilo, 1.0 m at Kawaihae, 1.9 m at Mahukona, and 1.2 m at Waipio Bay. Other than for Japanese tsunamis which have their greatest runups along the western shores, maximum runups for Kamchatka, Aleutian, and Chilean tsunamis are at Hilo or along the Hamakua coast. However, for all of these source locations, significant "wrap-around" effects are observed (e.g.: in Fig. 2 for Japan tsunamis, the runups at Kaiwilahilahi, Hilo, Punaluu, Honuapo, and Kaalualu; in Fig. 3 for Aleutian tsunamis, at Kaimu, Kalapana, Punaluu, Honuapo, South Point, Keauhou, Kailua, and Honokohau; in Fig. 4 for the Kamchatka tsunami, at Hookena and Napoopoo; and in Fig. 5 for the Chilean tsunami at Napoopoo, Keauhou, Kahaluu, and Kawaihae.

Six locally generated tsunamis with runups $\geq$ 1 meter have also been reported for the Island of Hawaii since 1812. These tsunamis have been discussed earlier in this report and their island-wide runup values are plotted in Appendix I.

Table 2.

All Pacific-Wide Tsunamis with Reported Runups $\geq$ 1.0 m

on the Island of Hawaii through 1993

Date	Source Area	Runup (m)	Location
1812 12 21	S. California(?)	3.0	Hookena
1819 04 12	N.C. Chile	2.0	W. Hawaii
1837 11 07	S.C. Chile	6.0	Hilo
1841 05 17	Kamchatka	4.6	Hilo
1868 08 13	N. Chile	4.5 1.8	Hilo Kalapana
1868 10 02	S. Pacific(?)	6.1	Kahaualea
1869 07 24	S. Pacific(?)	8.2	Puna Coast
1872 08 23	Aleutians	1.3	Hilo
1877 05 10	N. Chile	4.2 3.7 0.8 4.5 4.8	Coconut Is. Hilo Kawaihae Kealakekua Bay Waiakea
1896 06 15	Japan	2.4 3.6 3.3 3.6 5.3 3.0 3.0 2.6 5.5 5.3 3.6	Hilo Honuapo Hookena Kaalualu Kaawaloa Kailua Kaiwilahilahi Kawaihae Keauhou Napoopoo Punaluu
1901 08 09	Tonga	1.2 1.2	Hoopuloa Kailua-Kona
1906 01 31	Columbia-Ecuador	1.8	Hilo
1906 08 17	C. Chile	1.5	Hilo
1918 09 07	Kurils	1.5	Hilo
1922 11 11	N.C. Chile	2.1	Hilo
1923 02 03	Kamchatka	6.1	Hilo
1933 03 02	Japan	0.5 3.3 3.0 3.2 2.9	Hilo Kaalualu Kailua-Kona Keauhou Napoopoo

1946 04 01	E. Aleutians	7.5	Coconut Is.
		11.3	Hakalau
		8.1	Hilo
		2.1	Honaunau
		8.5	Honokaa
		8.5	Honokohau
		11.3	Honomu
		4.3	Honuapo
		2.4	Hookena
		3.3	Kailua-Kona
		6.1	Kaimu
		6.1	Kalapana
		3.7	Kawaihae
		7.3	Keaau
		4.0	Keauhou
		9.8	Keokea Pt.
		11.0	Kolekole Stream
		9.1	Laupahoehoe
		4.3	Mahukona
		0.6	Mililii
		2.7	Napoopoo
		10.4	Onomea
		10.7	Papaikou
		8.2	Pepeekeo
		2.7	Pohoiki
		12.0	Pololu Valley
		4.3	Punaluu Bay
		6.1	South Pt.
		6.1	Upolu Pt.
		12.0	Waipio Valley
1952 11 04	Kamchatka	3.2	Coconut Is.
		2.4	Hilo
		1.2	Hookena
		0.6	Kailua
		0.9	Kalapana
		0.6	Kawaihae
		0.9	Keauhou
		1.2	Napoopoo

1957 03 09	C. Aleutians	3.6	Cape Kumukahi
		3.0	Hakalau
		3.9	Hilo
		1.8	Honaunau
		3.0	Honokaa
		3.4	Honomu
		2.1	Honuapo
		2.1	Hookena
		1.5	Kailua-Kona
		3.0	Kaimu
		2.1	Kalapana
		1.5	Kawaihae
		2.4	Keaau
		2.1	Keauhou
		3.0	Laupahoehoe
		2.1	Mahukona
		1.5	Mililii
		2.1	Napoopoo
		5.2	Onomea
		2.7	Papaikou
		3.7	Pepeekeo
		2.1	Pohoiki
		9.8	Pololu Valley
		2.1	Punaluu Bay
		3.0	South Pt.
		2.4	Upolu Pt.
		5.2	Waipio Valley

1960 05 22	S.C. Chile	0.9	Cape Kamukahi
		2.7	Hakalau
		1.5	Halape
		10.7	Hilo
		1.5	Honaunau
		1.8	Honokaa
		3.7	Honomu
		5.2	Honuapo
		2.1	Hookena
		5.2	Kaalualu
		3.0	Kahaluu
		2.4	Kailua-Kona
		4.0	Kaimu
		2.1	Kalapana
		2.7	Kawaihae
		3.7	Keaau
		3.7	Keauhou
		2.1	Laupahoehoe
		1.2	Mahukona
		0.9	Milolii
		4.9	Naapoopoo
		3.4	Onomea
		1.8	Opihikao
		2.7	Papaikou
		1.5	Pepeekeo
		1.8	Pohoiki
		3.4	Pololu Valley
		3.4	Punaluu Bay
		3.7	South Pt.
		2.1	Upolu Pt.
		2.4	Waipio Valley
1964 03 28	Alaska	3.0	Hilo
		1.0	Kawaihae
		0.7	Laupahoehoe
		1.9	Mahukona
		0.6	Puako
		1.2	Waipio Bay

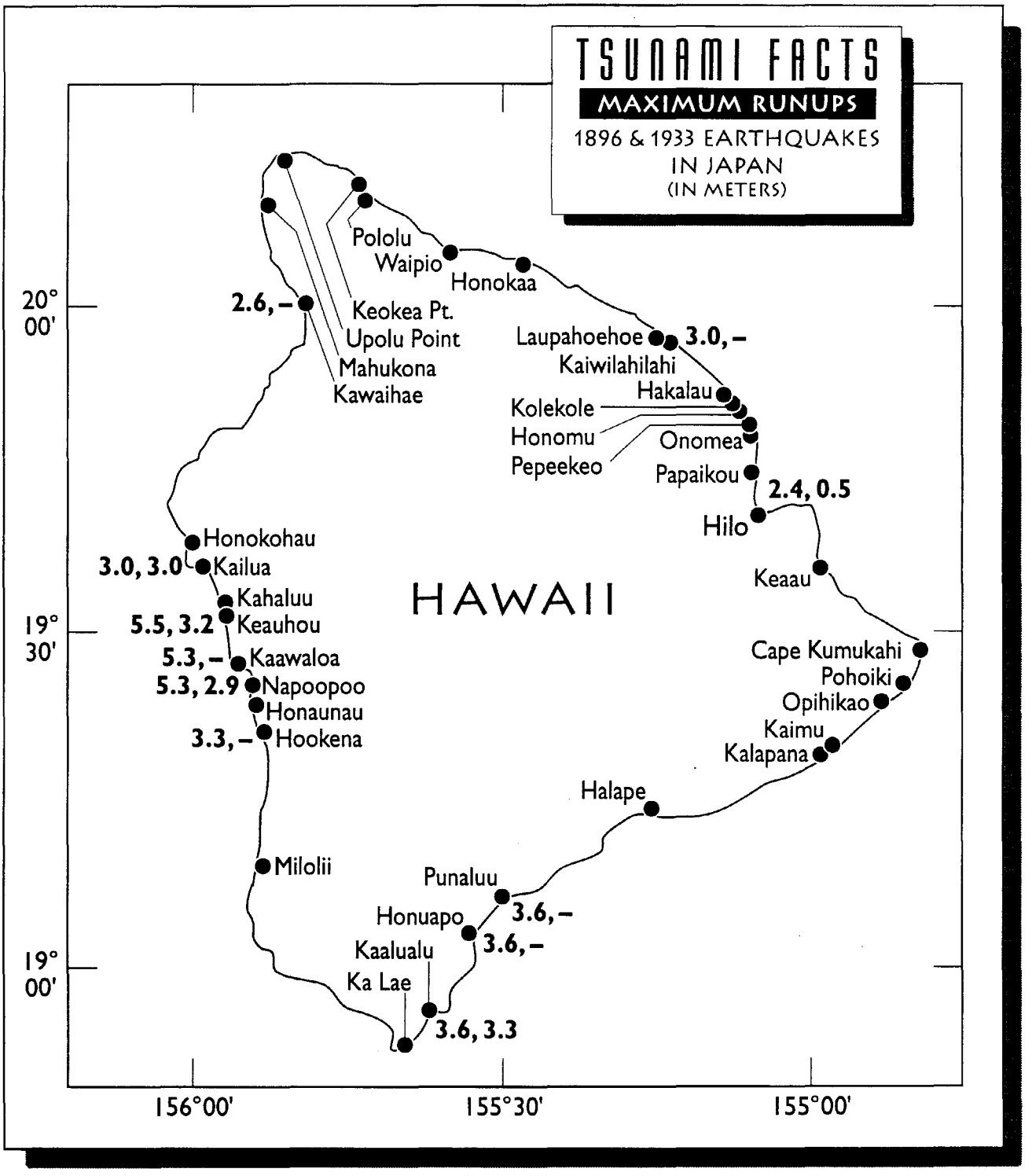

TSUNAMI FACTS
MAXIMUM RUNUPS
1896 & 1933 EARTHQUAKES
IN JAPAN
(IN METERS)
Pololu
Waipio
Honokaa
2.6, –
Keokea Pt.
Upolu Point
Mahukona
Kawaihae
Laupahoehoe
3.0, –
Kaiwilahilahi
Hakalau
Kolekole
Honomu
Pepeekeo
Onomea
Papaikou
2.4, 0.5
Hilo
Honokohau
3.0, 3.0
Kailua
Kahaluu
5.5, 3.2
Keauhou
5.3, –
Kaawaloa
5.3, 2.9
Napoopoo
Honaunau
3.3, –
Hookena
HAWAII
Keaau
Cape Kumukahi
Pohoiki
Opihikao
Kaimu
Kalapana
Halape
Milolii
Punaluu
Honuapo
3.6, –
3.6, –
Kaalualu
Ka Lae
3.6, 3.3
20° 00'
19° 30'
19° 00'
156°00'
155°30'
155°00'

Figure 2a.


TSUNAMI FACTS
MAXIMUM RUNUPS
1896 & 1933 EARTHQUAKES
IN JAPAN
(IN FEET)
HAWAII
Pololu
Waipio
Honokaa
8.5, –
Keokea Pt.
Upolu Point
Mahukona
Kawaihae
Laupahoehoe
9.8, –
Kaiwilahilahi
Hakalau
Kolekole
Honomu
Pepeekeo
Onomea
Papaikou
7.9, 1.6
Hilo
Keaau
Honokohau
9.8, 9.8
Kailua
Kahaluu
18.0, 10.5
Keauhou
17.4, –
Kaawaloa
17.4, 9.5
Napoopoo
Honaunau
10.8, –
Hookena
Cape Kumukahi
Pohoiki
Opihikao
Kaimu
Kalapana
Halape
Milolii
Punaluu
11.8, –
Honuapo
11.8, –
Kaalualu
Ka Lae
11.8, 10.8
20° 00'
19° 30'
19° 00'
156°00'
155°30'
155°00'

Figure 2b.

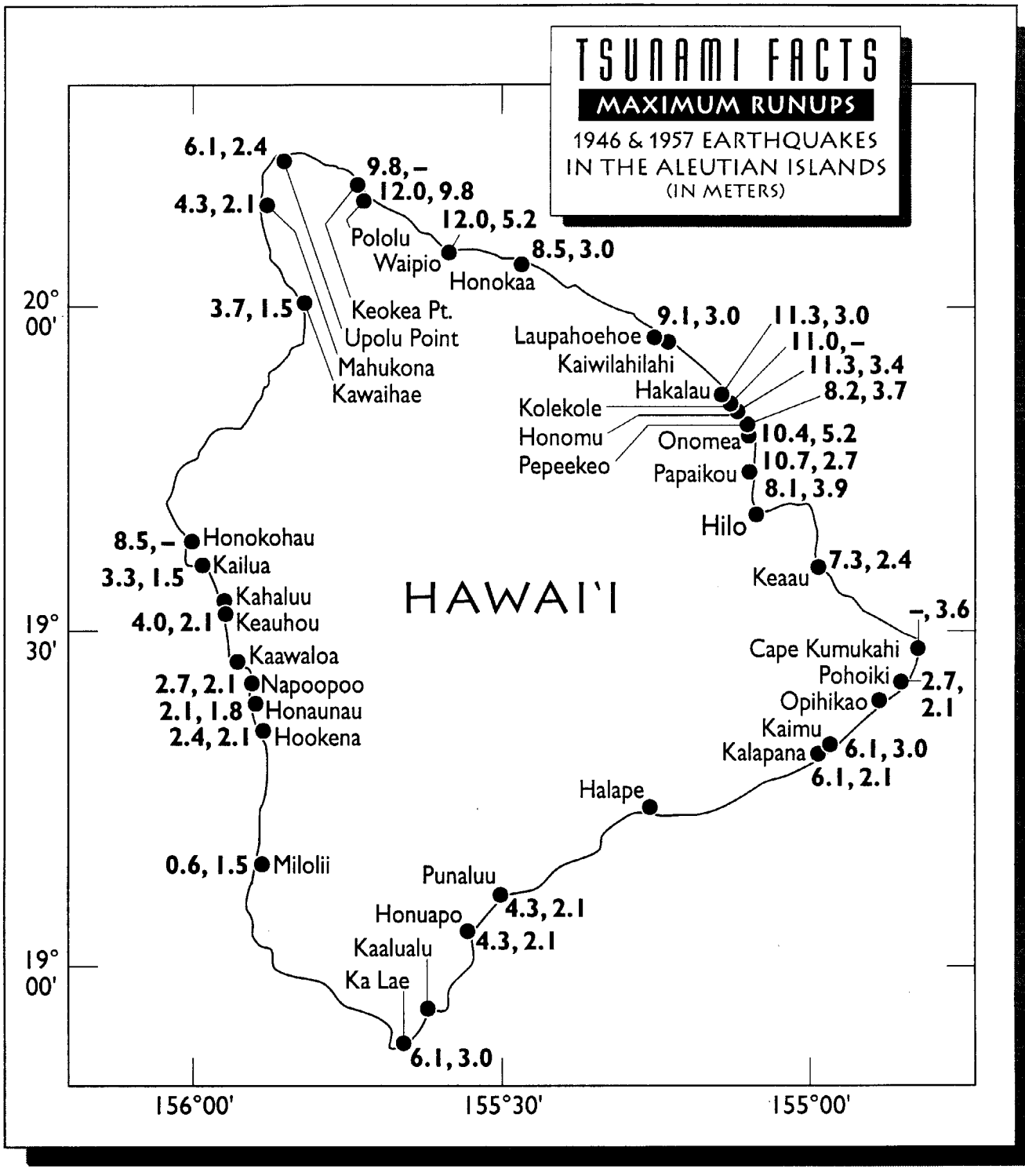

TSUNAMI FACTS
MAXIMUM RUNUPS
1946 & 1957 EARTHQUAKES
IN THE ALEUTIAN ISLANDS
(IN METERS)
HAWAI'I
6.1, 2.4
9.8, –
12.0, 9.8
4.3, 2.1
12.0, 5.2
Pololu
Waipio
8.5, 3.0
Honokaa
20° 00'
3.7, 1.5
Keokea Pt.
Upolu Point
Mahukona
Kawaihae
9.1, 3.0
11.3, 3.0
Laupahoehoe
11.0, –
Kaiwilahilahi
11.3, 3.4
Hakalau
8.2, 3.7
Kolekole
Honomu
Pepeekeo
Onomea
10.4, 5.2
10.7, 2.7
Papaikou
8.1, 3.9
Hilo
8.5, – Honokohau
3.3, 1.5 Kailua
Kahaluu
4.0, 2.1 Keauhou
Kaawaloa
2.7, 2.1 Napoopoo
2.1, 1.8 Honaunau
2.4, 2.1 Hookena
19° 30'
7.3, 2.4
Keaau
–, 3.6
Cape Kumukahi
Pohoiki
2.7, 2.1
Opihikao
Kaimu
Kalapana
6.1, 3.0
6.1, 2.1
Halape
0.6, 1.5 Milolii
Punaluu
4.3, 2.1
Honuapo
4.3, 2.1
Kaalualu
Ka Lae
19° 00'
6.1, 3.0
156°00'
155°30'
155°00'

Figure 3a.


TSUNAMI FACTS
MAXIMUM RUNUPS
1946 & 1957 EARTHQUAKES
IN THE ALEUTIAN ISLANDS
(IN FEET)
HAWAI'I
20.0, 7.9
32.2, –
39.4, 32.2
14.1, 6.9
39.4, 17.1
Pololu
Waipio
27.9, 9.8
Honokaa
20° 00'
12.1, 4.9
Keokea Pt.
Upolu Point
Mahukona
Kawaihae
29.9, 9.8
37.1, 9.8
Laupahoehoe
36.1, –
Kaiwilahilahi
37.1, 11.2
Hakalau
26.9, 12.1
Kolekole
Honomu
Pepeekeo
34.1, 17.1
Onomea
35.1, 8.9
Papaikou
26.6, 12.8
Hilo
27.9, –
Honokohau
Kailua
23.9, 7.9
Keaau
10.8, 4.9
Kahaluu
–, 11.8
19° 30'
13.1, 6.9
Keauhou
Cape Kumukahi
Kaawaloa
Pohoiki
8.9, 6.9
Napoopoo
8.9, 6.9
Opihikao
6.9, 5.9
Honaunau
Kaimu
7.9, 6.9
Hookena
Kalapana
20.0, 9.8
20.0, 6.9
Halape
2.0, 4.9
Milolii
Punaluu
14.1, 6.9
Honuapo
14.1, 6.9
19° 00'
Kaalualu
Ka Lae
20.0, 9.8
156°00'
155°30'
155°00'

Figure 3b.

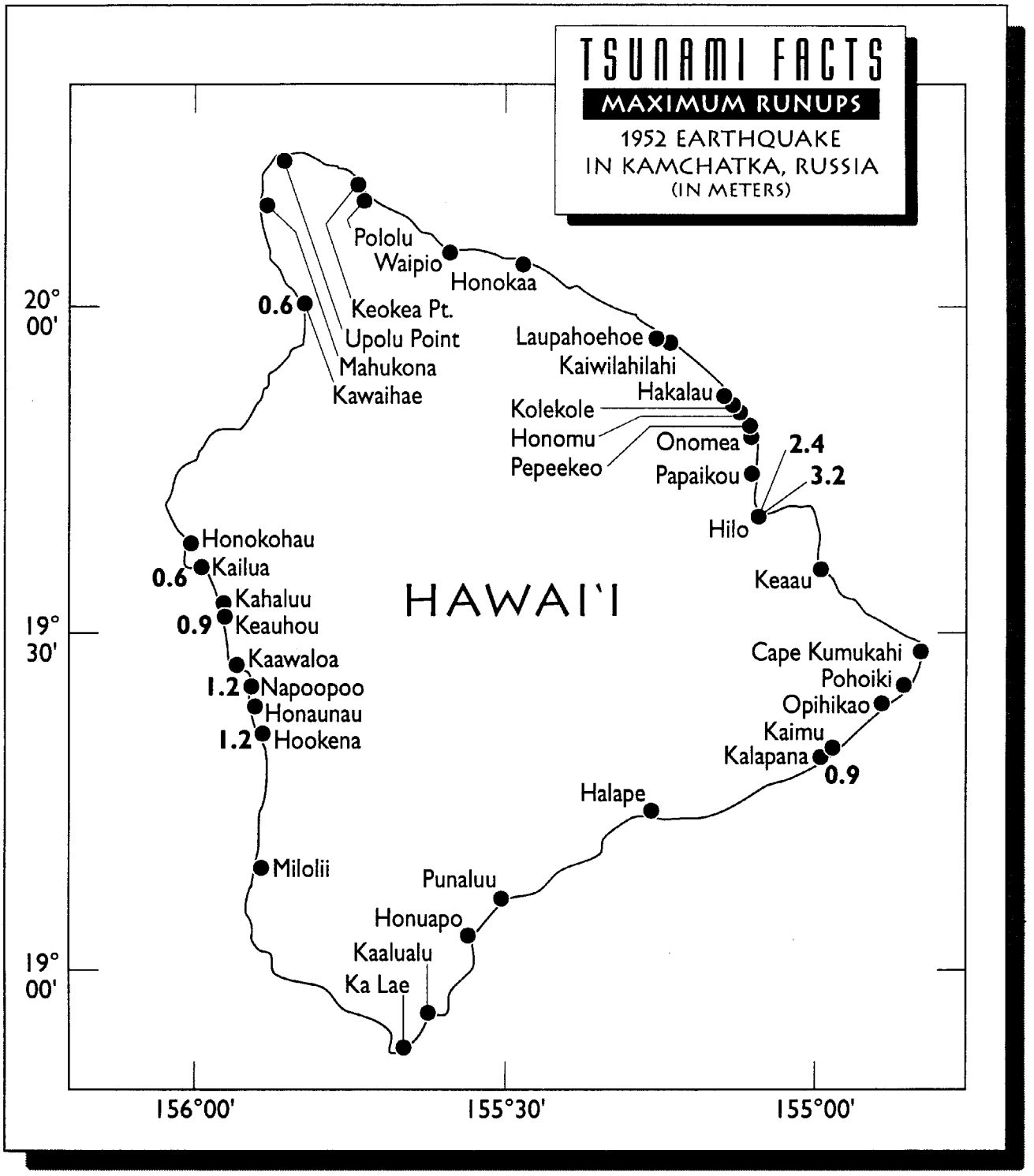

TSUNAMI FACTS
MAXIMUM RUNUPS
1952 EARTHQUAKE
IN KAMCHATKA, RUSSIA
(IN METERS)
Pololu
Waipio
Honokaa
0.6
Keokea Pt.
Upolu Point
Mahukona
Kawaihae
Laupahoehoe
Kaiwilahilahi
Hakalau
Kolekole
Honomu
Pepeekeo
Onomea
2.4
Papaikou
3.2
Hilo
Honokohau
0.6
Kailua
Kahaluu
0.9
Keauhou
Kaawaloa
1.2
Napoopoo
Honaunau
1.2
Hookena
HAWAI'I
Keaau
Cape Kumukahi
Pohoiki
Opihikao
Kaimu
Kalapana
0.9
Halape
Milolii
Punaluu
Honuapo
Kaalualu
Ka Lae
20° 00'
19° 30'
19° 00'
156°00'
155°30'
155°00'

Figure 4a.

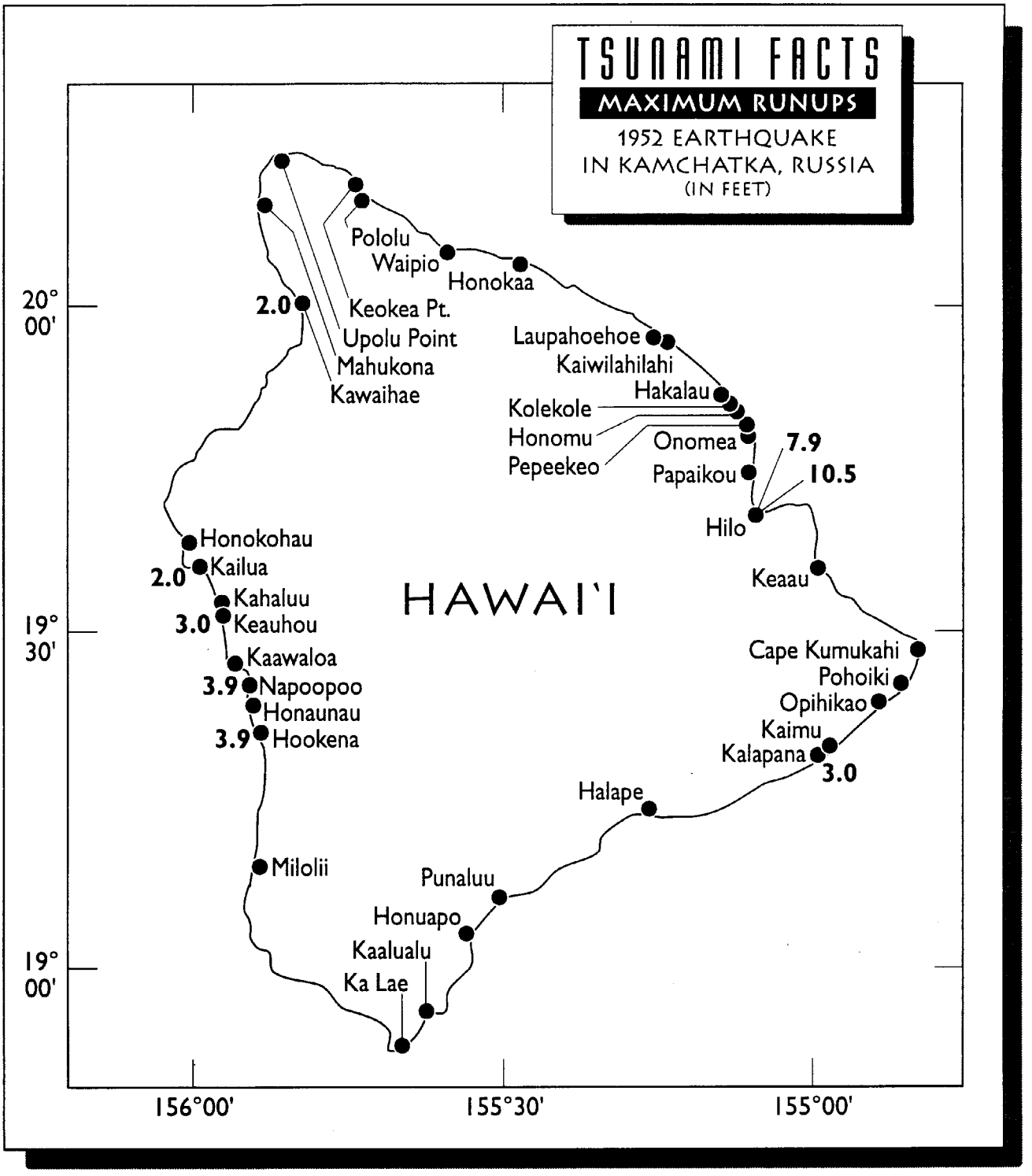

TSUNAMI FACTS
MAXIMUM RUNUPS
1952 EARTHQUAKE
IN KAMCHATKA, RUSSIA
(IN FEET)
Pololu
Waipio
Honokaa
2.0
Keokea Pt.
Upolu Point
Mahukona
Kawaihae
Laupahoehoe
Kaiwilahilahi
Hakalau
Kolekole
Honomu
Pepeekeo
Onomea
7.9
Papaikou
10.5
Hilo
Honokohau
Kailua
2.0
Kahaluu
3.0
Keauhou
HAWAI'I
Keaau
Kaawaloa
3.9
Napoopoo
Honaunau
3.9
Hookena
Cape Kumukahi
Pohoiki
Opihikao
Kaimu
Kalapana
3.0
Halape
Milolii
Punaluu
Honuapo
Kaalualu
Ka Lae
20° 00'
19° 30'
19° 00'
156°00'
155°30'
155°00'

Figure 4b.

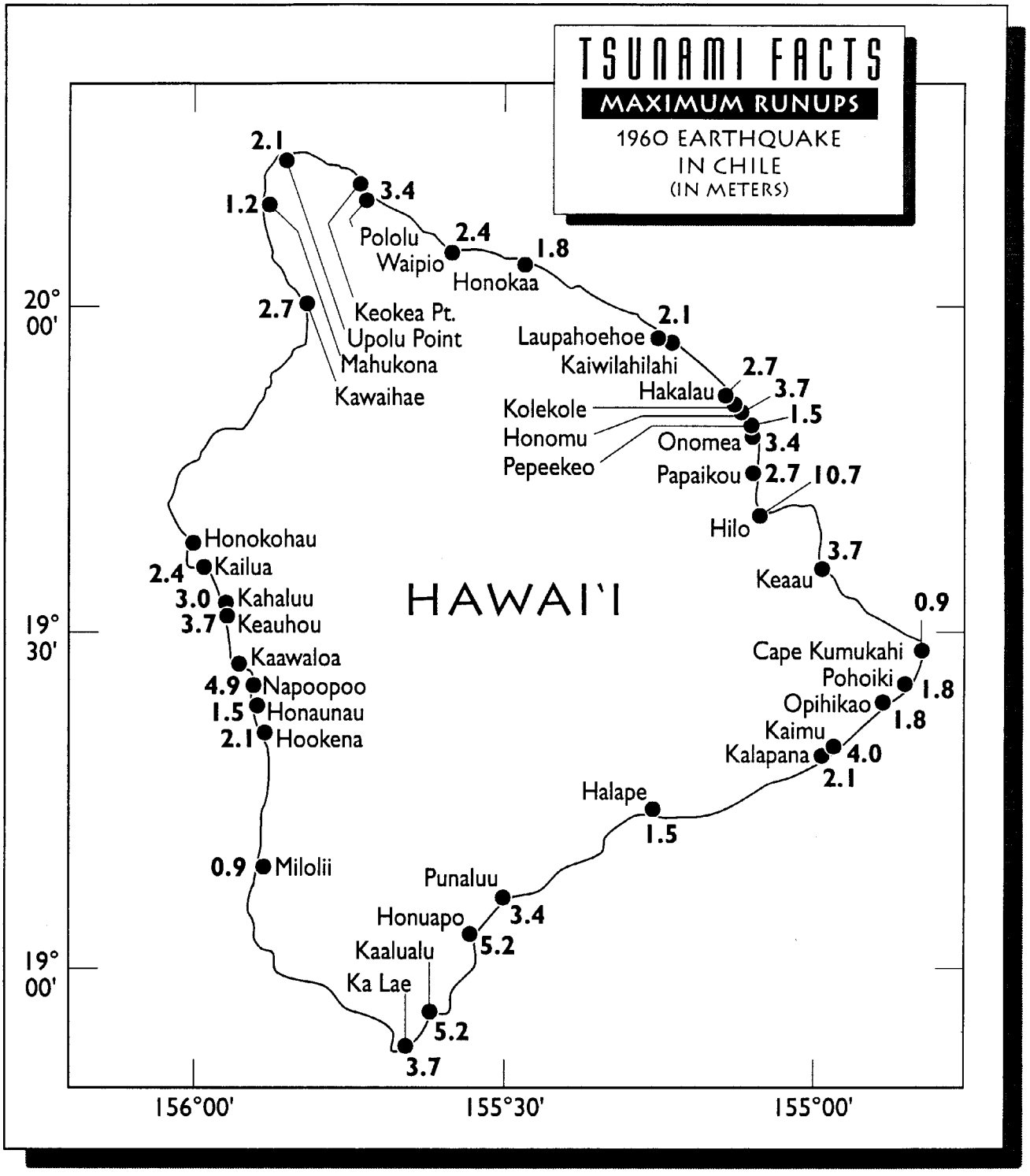

TSUNAMI FACTS
MAXIMUM RUNUPS
1960 EARTHQUAKE
IN CHILE
(IN METERS)
HAWAI'I
2.1
3.4
1.2
Pololu
2.4
Waipio
1.8
Honokaa
20°
00'
2.7
Keokea Pt.
Upolu Point
Mahukona
Kawaihae
2.1
Laupahoehoe
Kaiwilahilahi
2.7
Hakalau
3.7
Kolekole
1.5
Honomu
Onomea
3.4
Pepeekeo
Papaikou
2.7
10.7
Hilo
Honokohau
Kailua
2.4
3.7
Keaau
3.0
Kahaluu
3.7
Keauhou
19°
30'
0.9
Cape Kumukahi
Kaawaloa
Pohoiki
1.8
4.9
Napoopoo
Opihikao
1.8
1.5
Honaunau
Kaimu
2.1
Hookena
Kalapana
4.0
2.1
Halape
1.5
0.9
Milolii
Punaluu
Honuapo
3.4
5.2
19°
00'
Kaalualu
Ka Lae
5.2
3.7
156°00'
155°30'
155°00'

Figure 5a.

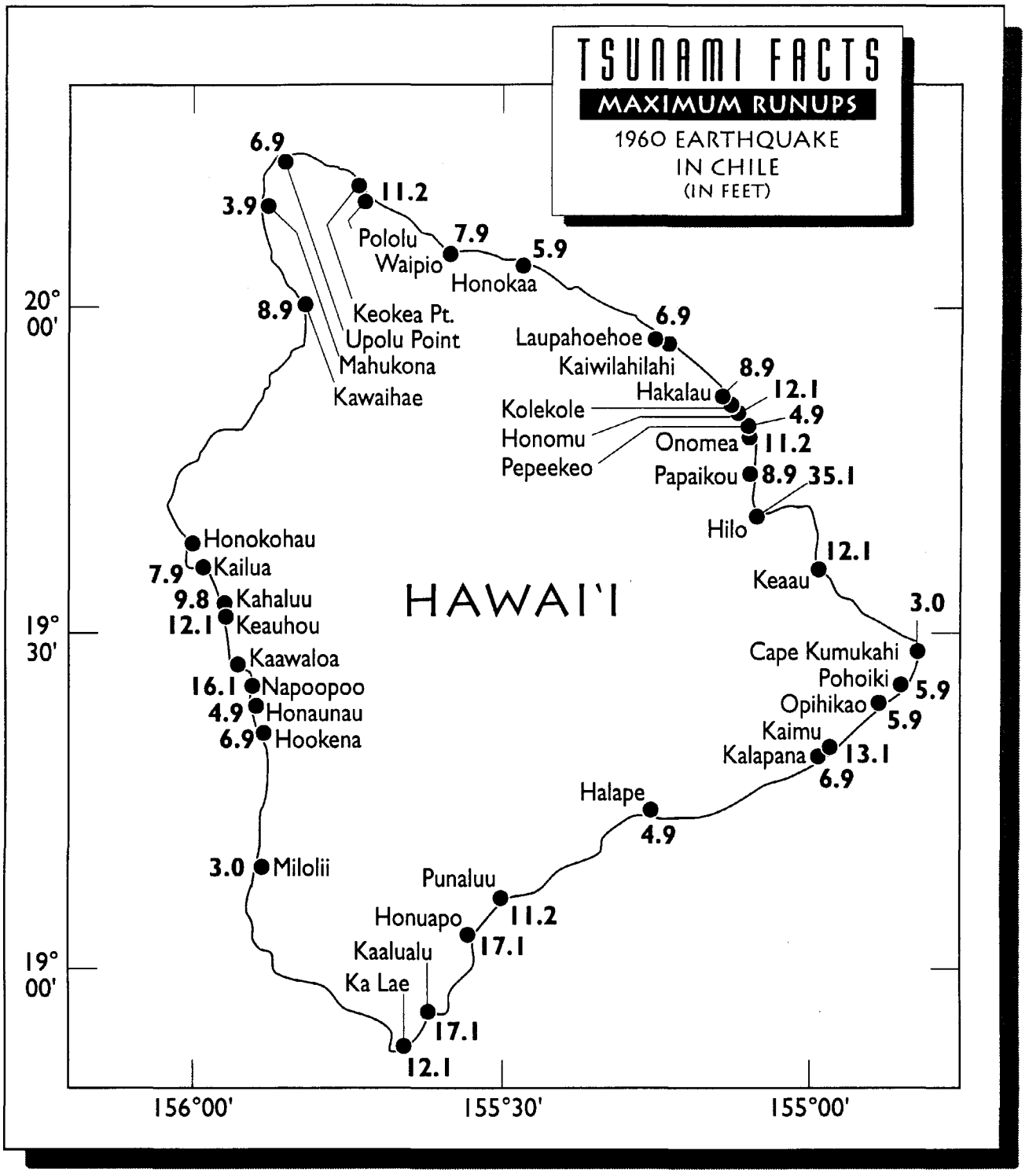

TSUNAMI FACTS
MAXIMUM RUNUPS
1960 EARTHQUAKE
IN CHILE
(IN FEET)
HAWAI'I
6.9
11.2
3.9
Pololu
7.9
Waipio
5.9
Honokaa
20°
00'
8.9
Keokea Pt.
Upolu Point
Mahukona
Kawaihae
6.9
Laupahoehoe
Kaiwilahilahi
8.9
Hakalau
12.1
Kolekole
4.9
Honomu
Onomea
11.2
Pepeekeo
Papaikou
8.9
35.1
Hilo
12.1
Keaau
3.0
Cape Kumukahi
Pohoiki
5.9
Opihikao
5.9
Kaimu
Kalapana
13.1
6.9
Halape
4.9
Punaluu
Honuapo
11.2
17.1
Kaalualu
Ka Lae
17.1
12.1
Honokohau
7.9
Kailua
9.8
Kahaluu
12.1
Keauhou
19°
30'
Kaawaloa
16.1
Napoopoo
4.9
Honaunau
6.9
Hookena
3.0
Milolii
19°
00'
156°00'
155°30'
155°00'

Figure 5b.

Maui. A total of 15 tsunamis with reported runups $\geq$ 1 meter on Maui or Molokai have occurred since 1837 (Table 3). No runup values have been reported from the islands of Lanai or Kahoolawe. Some tsunamis have been reported as "observed" on Lanai. Source regions for the earthquakes in Table 3 are Chile, Kamchatka, Japan, the Aleutians, and Alaska. Runups $\geq$ 3.0 meters were reported for 11 of the 15 earthquakes in Table 3. The largest and most comprehensive runups are for the '46 and '60 tsunamis (Figs. 6 and 7, respectively). Large runups for both of these earthquakes were in the Kahului area with substantial runups also reported on the western shores and especially on the east coast (Hana and Hamoa) for the '46 tsunami. The "wrap-around" effect in the Kahului area for the Chilean tsunami is somewhat similar to observations for Hilo for South American tsunamis. Hilo values, however, may be 2 to 3 times greater than Kahului values.

Table 3.

All Pacific-Wide Tsunamis with Reported Runups $\geq$ 1.0 m

on the Islands of Maui and Molokai through 1993[1]

Date			Source Area	Runup (m)	Location
1837	11	07	S.C. Chile	2.5	Lahaina
1841	05	17	Kamchatka	1.0	Lahaina
1860	12	01	N. Pacific?	2.5 3.6	Kahului Maliko
1868	08	13	N. Chile	1.8 1.2	Kahului Molokai
1869	07	24	S. Pacific?	4.6	Kaupo
1877	05	10	N. Chile	1.5 3.6	Kahului Lahaina
1878	01	20	Aleutians?	3.0 3.0 3.6	Halehaku Honomanu Maliko
1896	06	15	Japan	1.1	Kaanapali
1903	11	29	N. Pacific?	9.1[2] 15.7	Honokohau Kalaupapa, Molokai
1906	08	07	C. Chile	3.6	Maalaea
1923	02	03	Kamchatka	3.5	Kahului
1946	04	01	E. Aleutians	7.0 9.1 4.9 10.0 8.5 2.1 0.6 2.0 6.0 2.7 3.7 8.5 6.1 8.5 16.4	Hamoa Hana Bay Kaanapali Kahakuloa Kahului Kalaupapa, Molokai Kaunakakai, Molokai Lahaina Lower Paia Maalaea Mala Maliko Bay Paukukalo Spreckelsville Waikolu Valley, Molokai
1957	03	09	C. Aleutians	2.8 1.8 3.3	Halawa, Molokai Kahului Maalaea

1960 05 22	S.C. Chile	3.4	Kahului
		2.4	Kihei
		2.1	Lahaina
		3.7	Paia
		4.6	Paukukalo
		3.4	Spreckelsville
1964 03 28	Alaska	3.6	Kahului
		2.8	Lower Paia
		2.5	Maliko Bay

[1]Unless otherwise indicated, locations are on the island of Maui. No runup values from Lanai have been reported for these earthquakes. [2]Runups for this possible tsunami are taken from Cox and Morgan (1977).

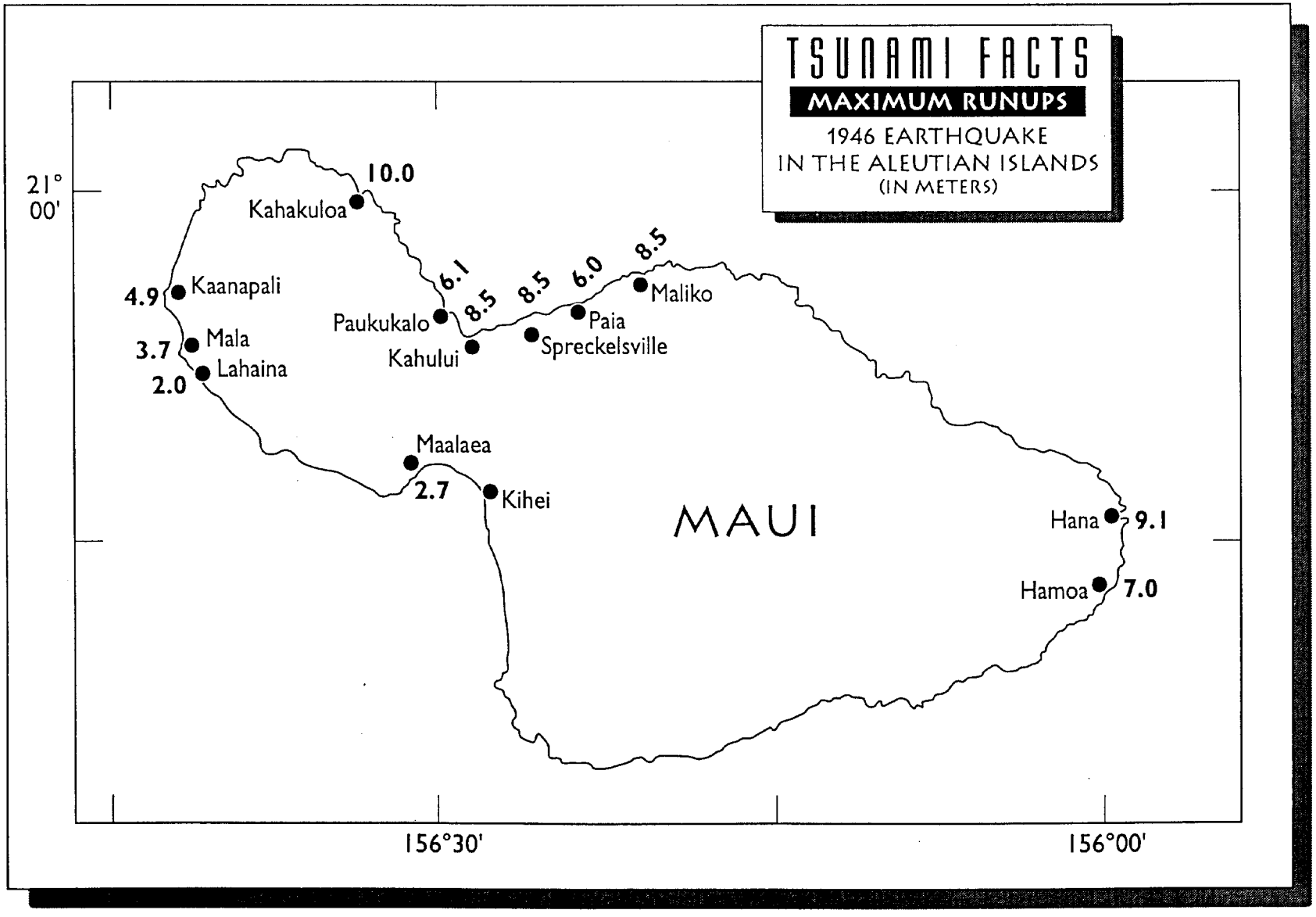

TSUNAMI FACTS
MAXIMUM RUNUPS
1946 EARTHQUAKE
IN THE ALEUTIAN ISLANDS
(IN METERS)
21° 00'
Kahakuloa
10.0
Kaanapali
4.9
Mala
3.7
Lahaina
2.0
Paukukalo
6.1
Kahului
8.5
8.5
6.0
Paia
Spreckelsville
8.5
Maliko
Maalaea
2.7
Kihei
MAUI
Hana
9.1
Hamoa
7.0
156°30'
156°00'

Figure 6a.

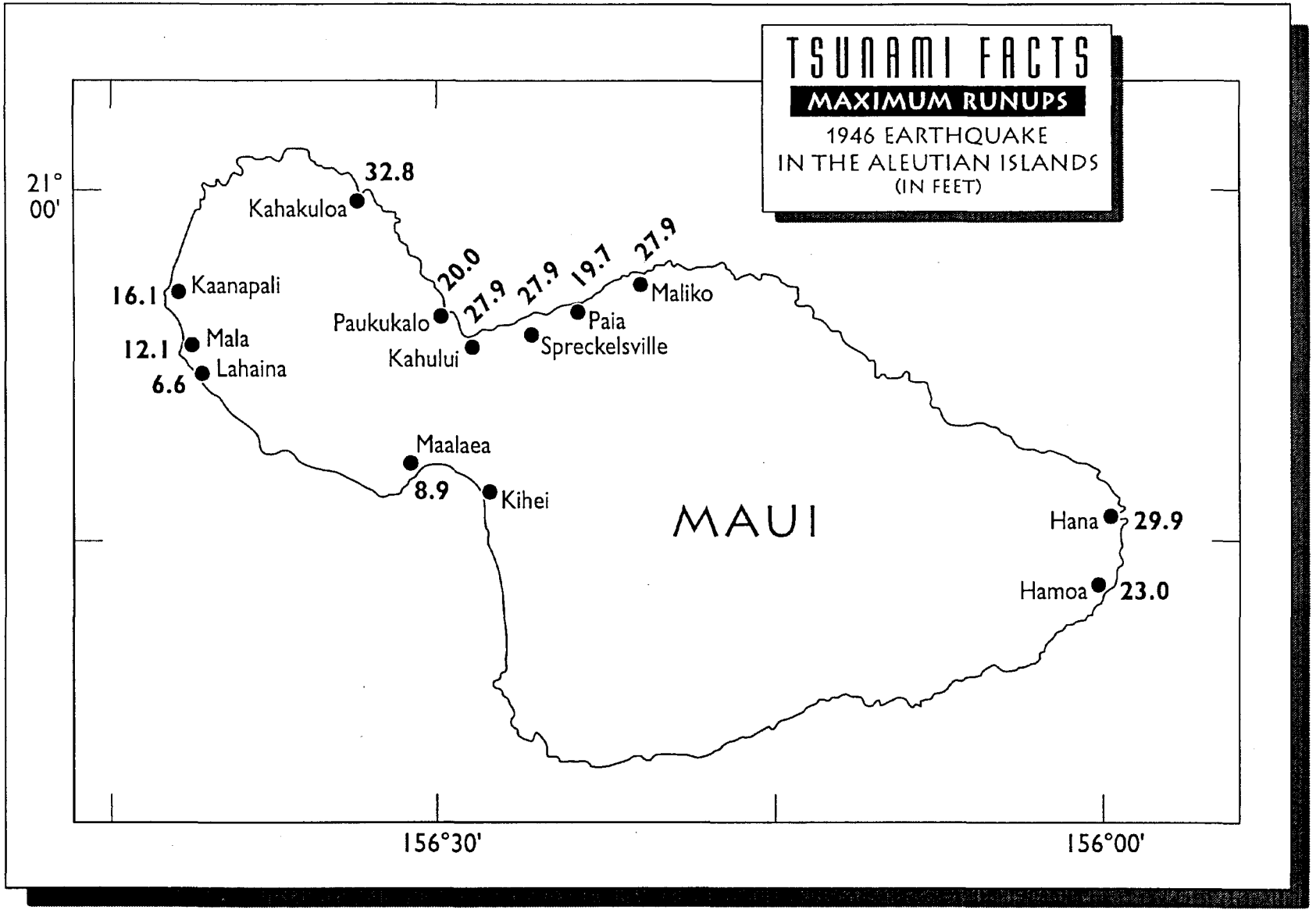

TSUNAMI FACTS
MAXIMUM RUNUPS
1946 EARTHQUAKE
IN THE ALEUTIAN ISLANDS
(IN FEET)
21°
00'
32.8
Kahakuloa
16.1
Kaanapali
12.1
Mala
6.6
Lahaina
20.0
27.9
27.9
19.7
27.9
Maliko
Paukukalo
Paia
Kahului
Spreckelsville
Maalaea
8.9
Kihei
MAUI
Hana
29.9
Hamoa
23.0
156°30'
156°00'

Figure 6b.

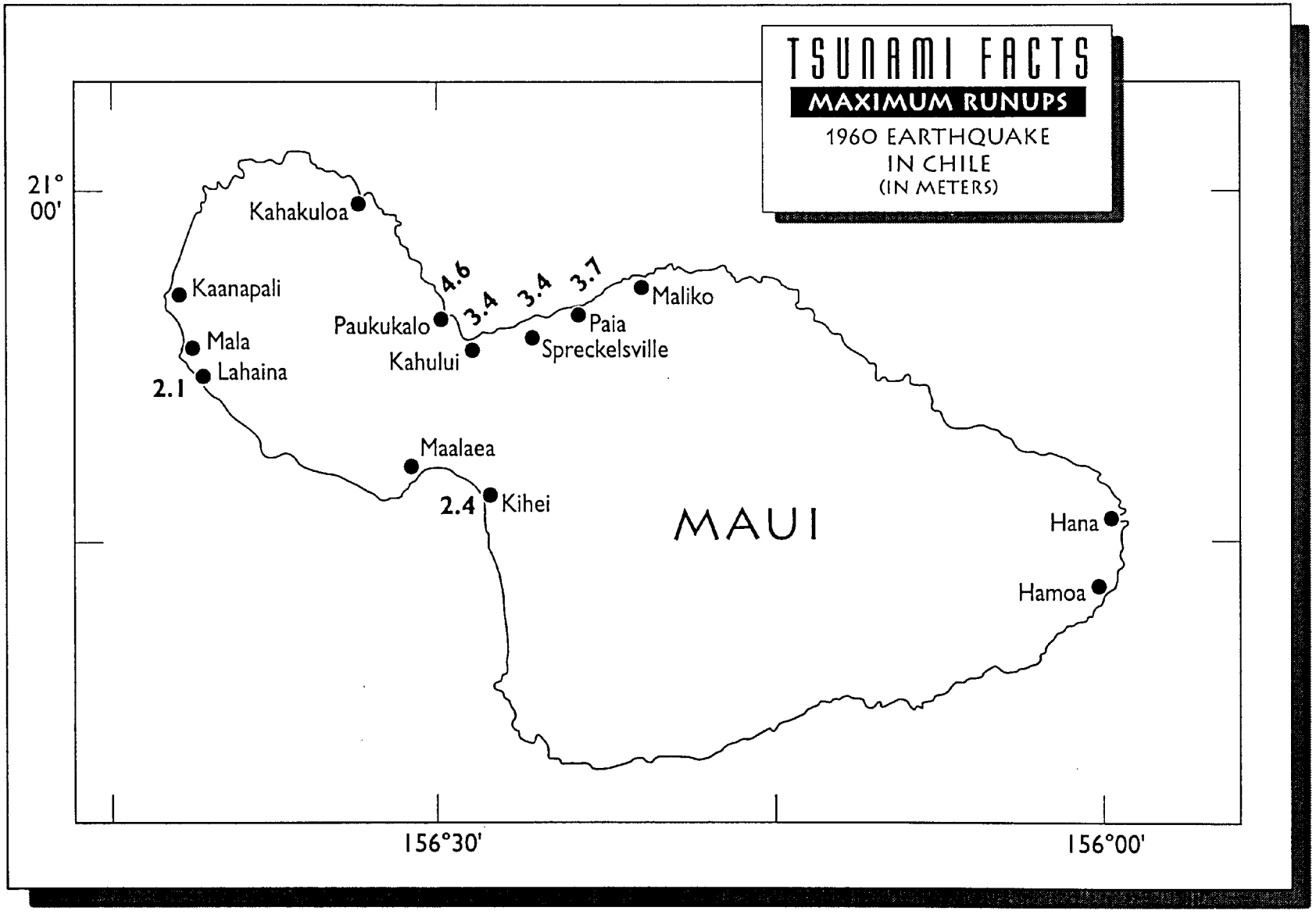

TSUNAMI FACTS
MAXIMUM RUNUPS
1960 EARTHQUAKE
IN CHILE
(IN METERS)
21°
00'
Kahakuloa
Kaanapali
Mala
Lahaina
2.1
Paukukalo
Kahului
4.6
3.4
3.4
3.7
Maliko
Paia
Spreckelsville
Maalaea
2.4
Kihei
MAUI
Hana
Hamoa
156°30'
156°00'

Figure 7a.

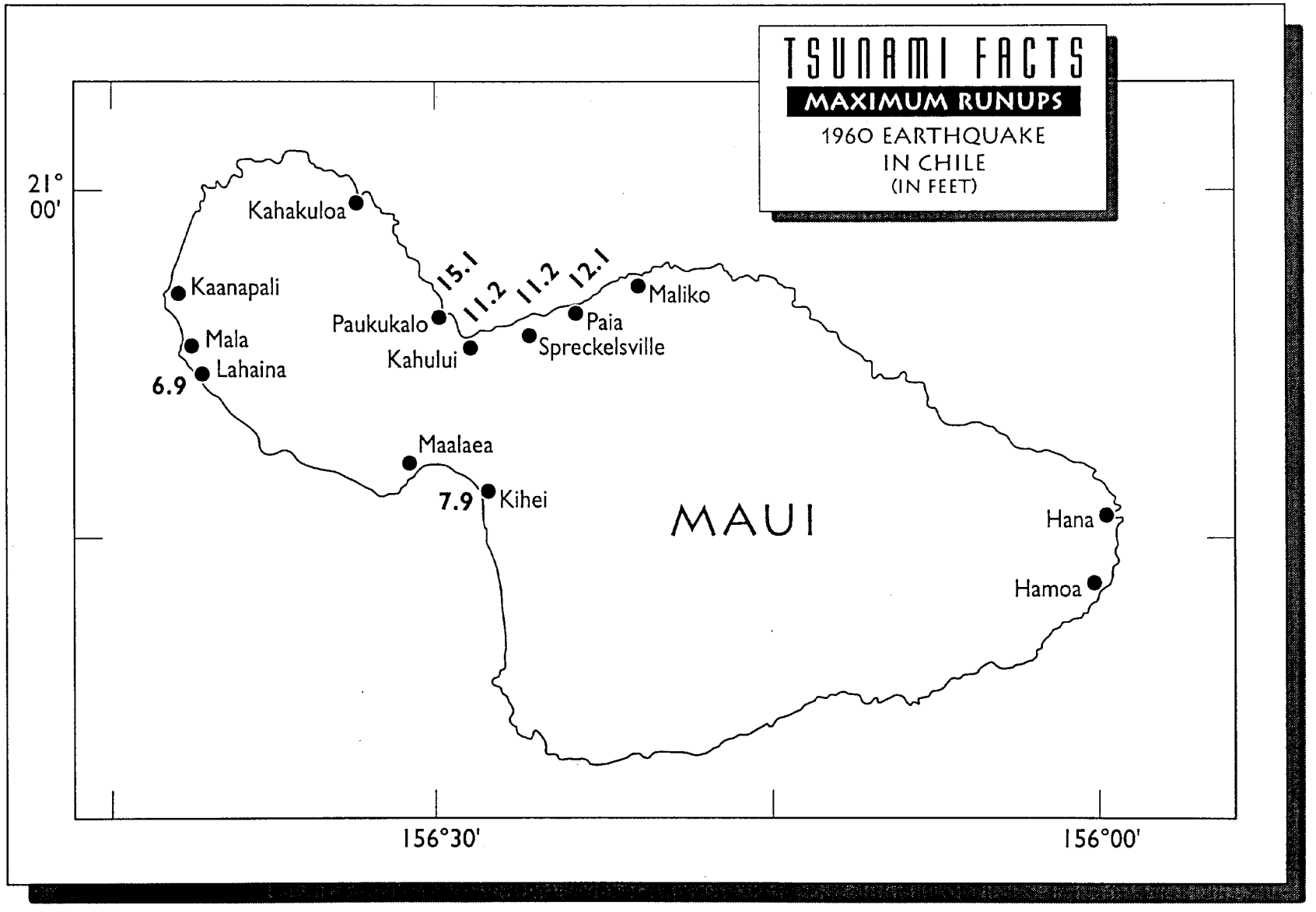

TSUNAMI FACTS
MAXIMUM RUNUPS
1960 EARTHQUAKE
IN CHILE
(IN FEET)
21°
00'
Kahakuloa
Kaanapali
Mala
Lahaina
6.9
Paukukalo
Kahului
15.1
11.2
11.2
12.1
Maliko
Paia
Spreckelsville
Maalaea
7.9
Kihei
MAUI
Hana
Hamoa
156°30'
156°00'

Figure 7b.

Oahu. A total of 11 tsunamis with reported runups $\geq$ 1 meter on Oahu have occurred since 1837 (Table 4). Source regions for the earthquakes listed in Table 4 are Chile, Kamchatka, the Aleutians, and Alaska. Runups $\geq$ 3.0 meters were reported for 7 of the 11 earthquakes in Table 4. The largest runup ever reported for Honolulu is 2.5 m produced by a Chilean earthquake in 1837. Significant values for Honolulu in this century are 1.3 m for the 1952 Kamchatka earthquake and 1.0 m for the 1957 Aleutian earthquake. The only reports from Waikiki are for the '46 and '57 earthquakes (2.7 and 1.5 m, respectively). The largest runups for Oahu are generally along the north shore (Haleiwa, Kaena Point, Kahuku, Waialua, and Waimea Bay; values are as high as 10.9 m). However, "wrap-around" effects are still significant – note the 4.3 m at Waianae and 2.7 m at Waikiki for the '46 tsunami. The largest and most comprehensive island-wide runups are for the '46, '52, '57, and '64 earthquakes (Figs. 8 and 9, respectively). Other than a 4.0 meter runup at some unspecified location on Oahu (possibly at Kuliouou at the southeastern corner of the island, near Hawaii Kai), the only other reports for the 1960 Chile tsunami were for Honolulu and Coconut Island (0.8 and 0.3 m, respectively).

Table 4.

All Pacific-Wide Tsunamis with Reported Runups $\geq$ 1.0 m

on the Island of Oahu through 1993

Date	Source Area	Runup (m)	Location
1837 11 07	S.C. Chile	2.5	Honolulu
1841 05 17	Kamchatka	1.0	Honolulu
1868 08 13	N. Chile	1.6	Honolulu
1877 05 10	N. Chile	1.5	Honolulu
1878 01 20	Aleutians(?)	3.0	Waialua
1923 02 03	Kamchatka	3.7	Haleiwa
		0.9	Honolulu
1946 04 01	E. Aleutians	3.4	Haleiwa
		0.6	Honolulu
		10.9	Kaena Pt.
		2.1	Kahana
		8.2	Kahuku Pt.
		4.5	Kapoho
		5.8	Kawela Bay
		2.1	Lanikai
		11.1	Makapuu Pt.
		6.6	Mokapu Pen.
		3.7	Punaluu
		4.3	Waianae
		2.7	Waikiki
1952 11 04	Kamchatka	1.3	Honolulu
		9.1	Kaena Pt.
		1.2	Kahuku Pt.
		3.0	Makapuu Pt.
		0.2	Pearl Harbor
		5.2	Waialua
1957 03 09	C. Aleutians	5.2	Haleiwa
		1.0	Honolulu
		7.0	Kahuku
		3.9	Waialua
		1.5	Waikiki
1960 05 22	S.C. Chile	0.3	Coconut Is.
		0.8	Honolulu
		4.0	Oahu
1964 03 28	Alaska	0.3	Coconut Is.
		3.1	Haleiwa
		1.2	Hauula
		0.5	Honolulu
		4.6	Kaiaka (Waialua)
		2.4	Puaena Pt.(Haleiwa)
		1.8	Waialee
		4.9	Waimea Bay

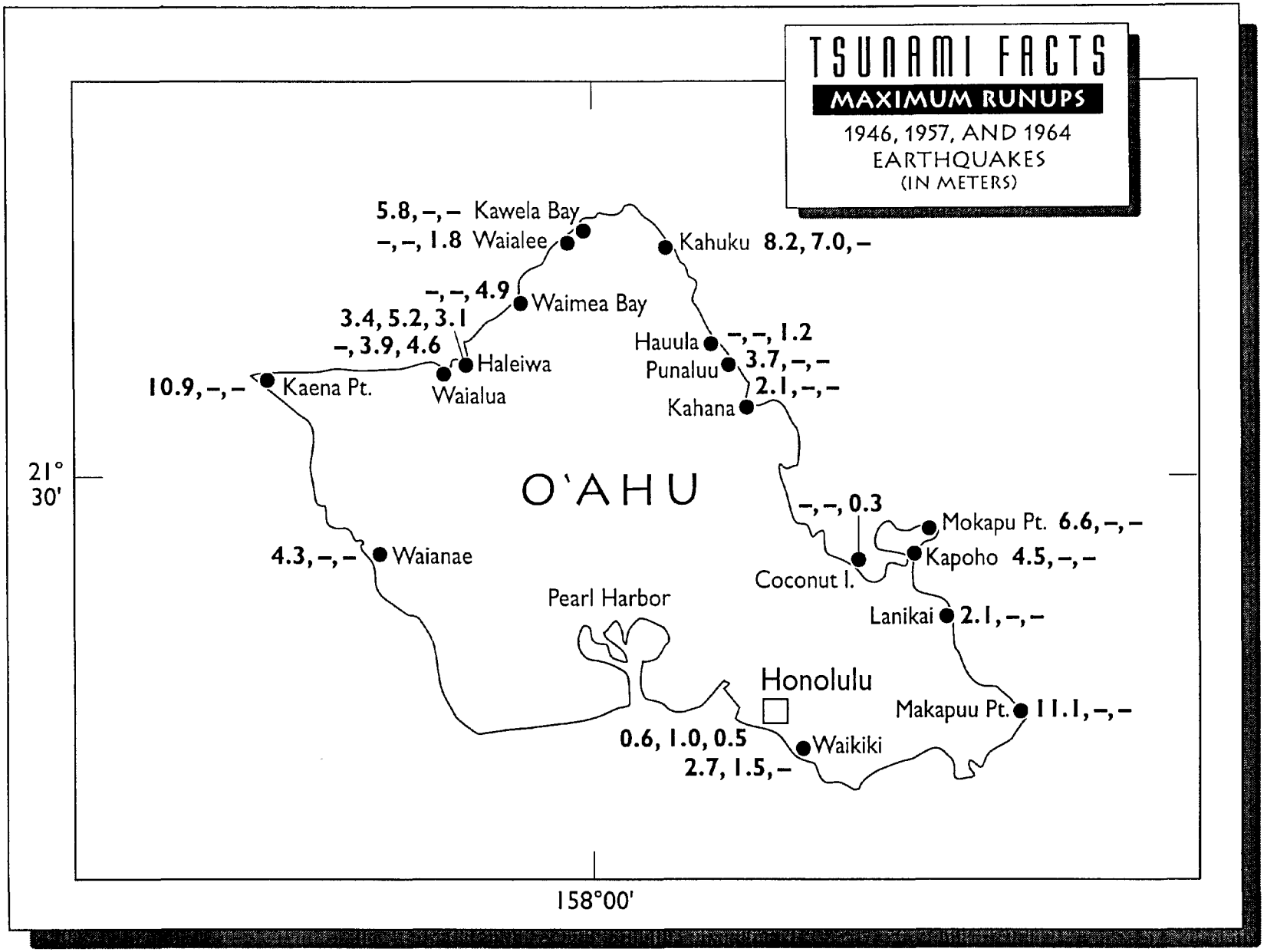

TSUNAMI FACTS
MAXIMUM RUNUPS
1946, 1957, AND 1964
EARTHQUAKES
(IN METERS)
5.8, –, – Kawela Bay
–, –, 1.8 Waialee
Kahuku 8.2, 7.0, –
–, –, 4.9
Waimea Bay
3.4, 5.2, 3.1
–, 3.9, 4.6
Haleiwa
Waialua
10.9, –, – Kaena Pt.
Hauula –, –, 1.2
Punaluu 3.7, –, –
Kahana 2.1, –, –
21° 30'
O'AHU
–, –, 0.3
Mokapu Pt. 6.6, –, –
Kapoho 4.5, –, –
Coconut I.
4.3, –, – Waianae
Pearl Harbor
Lanikai 2.1, –, –
Honolulu
Makapuu Pt. 11.1, –, –
0.6, 1.0, 0.5
2.7, 1.5, –
Waikiki
158°00'

Figure 8a.

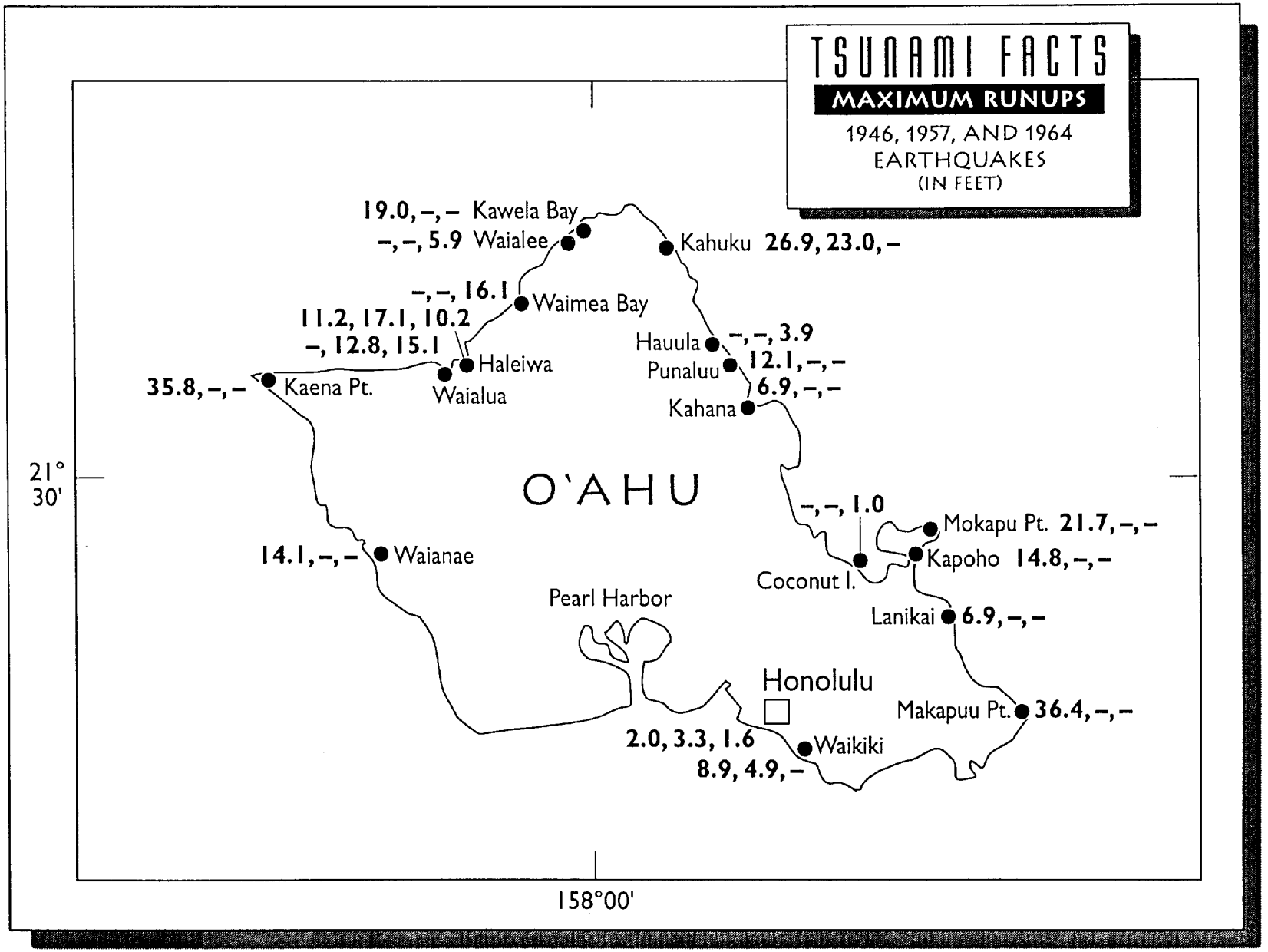

TSUNAMI FACTS
MAXIMUM RUNUPS
1946, 1957, AND 1964
EARTHQUAKES
(IN FEET)
19.0, –, – Kawela Bay
–, –, 5.9 Waialee
Kahuku 26.9, 23.0, –
–, –, 16.1
Waimea Bay
11.2, 17.1, 10.2
–, 12.8, 15.1
Haleiwa
Waialua
35.8, –, – Kaena Pt.
Hauula –, –, 3.9
Punaluu 12.1, –, –
6.9, –, –
Kahana
21° 30'
O'AHU
–, –, 1.0
Mokapu Pt. 21.7, –, –
Kapoho 14.8, –, –
Coconut I.
14.1, –, – Waianae
Pearl Harbor
Lanikai 6.9, –, –
Honolulu
Makapuu Pt. 36.4, –, –
2.0, 3.3, 1.6
Waikiki
8.9, 4.9, –
158°00'

Figure 8b

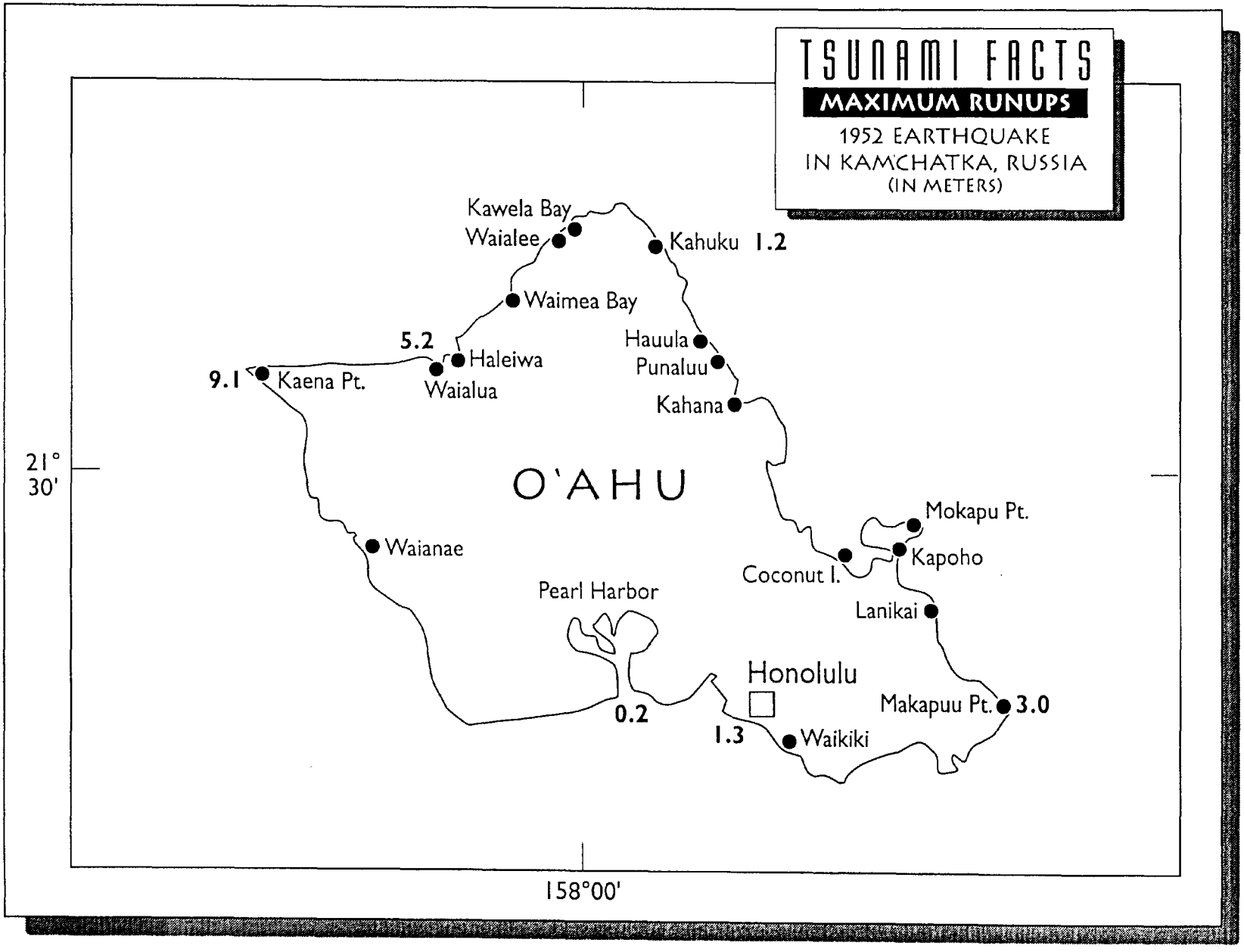

TSUNAMI FACTS
MAXIMUM RUNUPS
1952 EARTHQUAKE
IN KAMCHATKA, RUSSIA
(IN METERS)
Kawela Bay
Waialee
Kahuku 1.2
Waimea Bay
5.2
Haleiwa
Hauula
Punaluu
9.1
Kaena Pt.
Waialua
Kahana
21°
30'
O'AHU
Mokapu Pt.
Waianae
Kapoho
Coconut I.
Pearl Harbor
Lanikai
Honolulu
Makapuu Pt. 3.0
0.2
1.3
Waikiki
158°00'

Figure 9a.

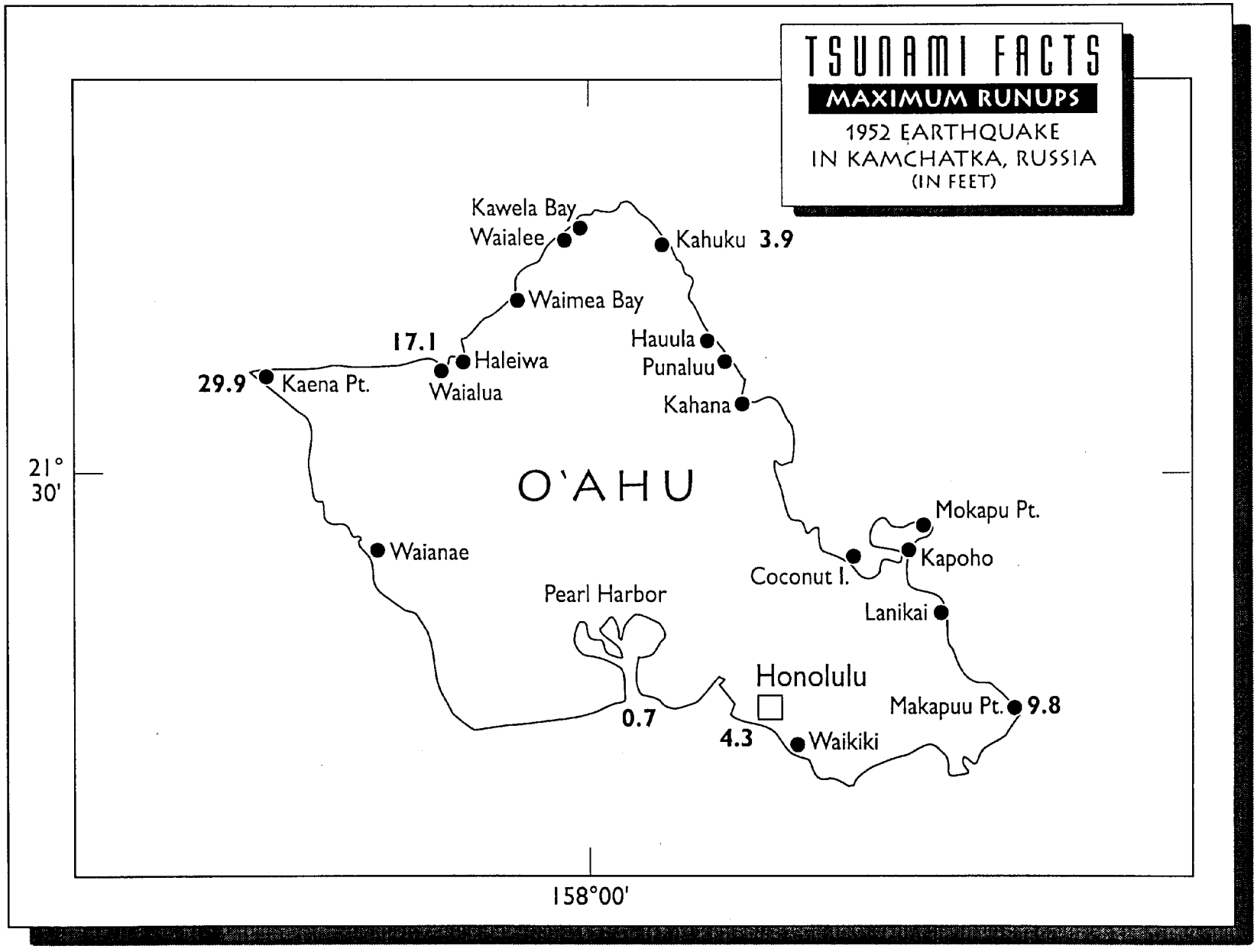

TSUNAMI FACTS
MAXIMUM RUNUPS
1952 EARTHQUAKE
IN KAMCHATKA, RUSSIA
(IN FEET)
Kawela Bay
Waialee
Kahuku 3.9
Waimea Bay
17.1
Haleiwa
Hauula
Punaluu
29.9
Kaena Pt.
Waialua
Kahana
21°
30'
O'AHU
Mokapu Pt.
Waianae
Kapoho
Coconut I.
Pearl Harbor
Lanikai
Honolulu
Makapuu Pt. 9.8
0.7
4.3
Waikiki
158°00'

Figure 9b.

Kauai. A total of 9 tsunamis with reported runups $\geq$ 1 meter on Kauai or Niihau have occurred since 1868 (Table 5). Source regions are Chile, Japan, the Aleutians, Kamchatka, and Alaska. Runups $\geq$ 3.0 meters were reported for five of the nine earthquakes in Table 5. Several tsunamis are reported merely as "observed" prior to 1933 which had significant tsunamis on other Hawaiian Islands. The largest reported runups are for the 1946 and 1957 Aleutian tsunamis (13.7 and 16.1 m, respectively). Also, the '46 and '57 tsunamis are the only tsunamis for which runups were reported from the island of Niihau (6.0 and 3.0 m, respectively). Smaller but still substantial tsunamis were generated by the '52 Kamchatka, '60 Chile, and '64 Alaska earthquakes (3.0, 4.3, and 3.0 m, respectively). Runup values for the '46, '57, and '60 tsunamis are shown in Figures 10 and 11. As might be expected the greatest runups are observed on the northern shores for the Aleutian tsunamis (Fig. 10) and on southern shores for the Chilean tsunami (Fig. 11). However, considerable "wrap around" is indicated by the reported runups for '46 and '60. For the '46 tsunami, the 10.0 m at Pakala Point on the southwest shore is close to the 13.7 m value at Haena on the north shore. For the '60 tsunami, the 4.1 m at Haena is close to the 4.3 m at Wahiawa Bay on the south shore. There were only two reported, adjacent readings for the '52 tsunami which originated northwest of Kauai (Kamchatka).

Table 5.

All Pacific-Wide Tsunamis with Reported Runups ≥ 1.0 m

on the Islands of Kauai and Niihau through 1993

Date	Source Area	Runup (m)	Location
1868 08 13	N. Chile	1.8	Kauai
		0.9	Waimea Bay
1896 06 15	Japan	1.2	Kapaa
		1.5	Kilauea Landing
		1.5	Nawiliwili
1933 03 02	Japan	1.2	Kukuiula
		1.2	Pakala
1946 04 01	E. Aleutians	13.7	Haena
		5.8	Hanalei Bay
		6.7	Kalihiwai Bay
		2.4	Kaumakani
		4.2	Nawiliwili
		6.0	Niihau Island
		10.0	Pakala Point
		2.4	Port Allen
		7.3	Wainiha
		4.2	Waimea Bay
1952 11 04	Kamchatka	0.3	Port Allen
		3.0	Wahiawa Bay
1957 03 09	C. Aleutians	10.4	Haena
		6.1	Kalihiwai
		16.1	Kauai
		3.0	Nawiliwili
		3.0	Niihau Island
		11.6	Wainiha
1960 05 22	S.C. Chile	3.3	Aweoweonui
		0.6	Anini
		4.1	Haena
		2.7	Kaumakani
		3.0	Kekaha
		1.5	Nawiliwili
		3.2	Pakala
		4.3	Wahaiwa Bay
		1.5	Wailua
1964 03 28	Alaska	1.0	Anahola Bay
		3.0	Haena
		1.9	Hanalei
		2.2	Kapaa
		1.0	Moloaa
		0.4	Nawiliwili
		1.3	Wailua
1965 02 04	W. Aleutians	1.1	N. Kauai
		0.3	Nawiliwili

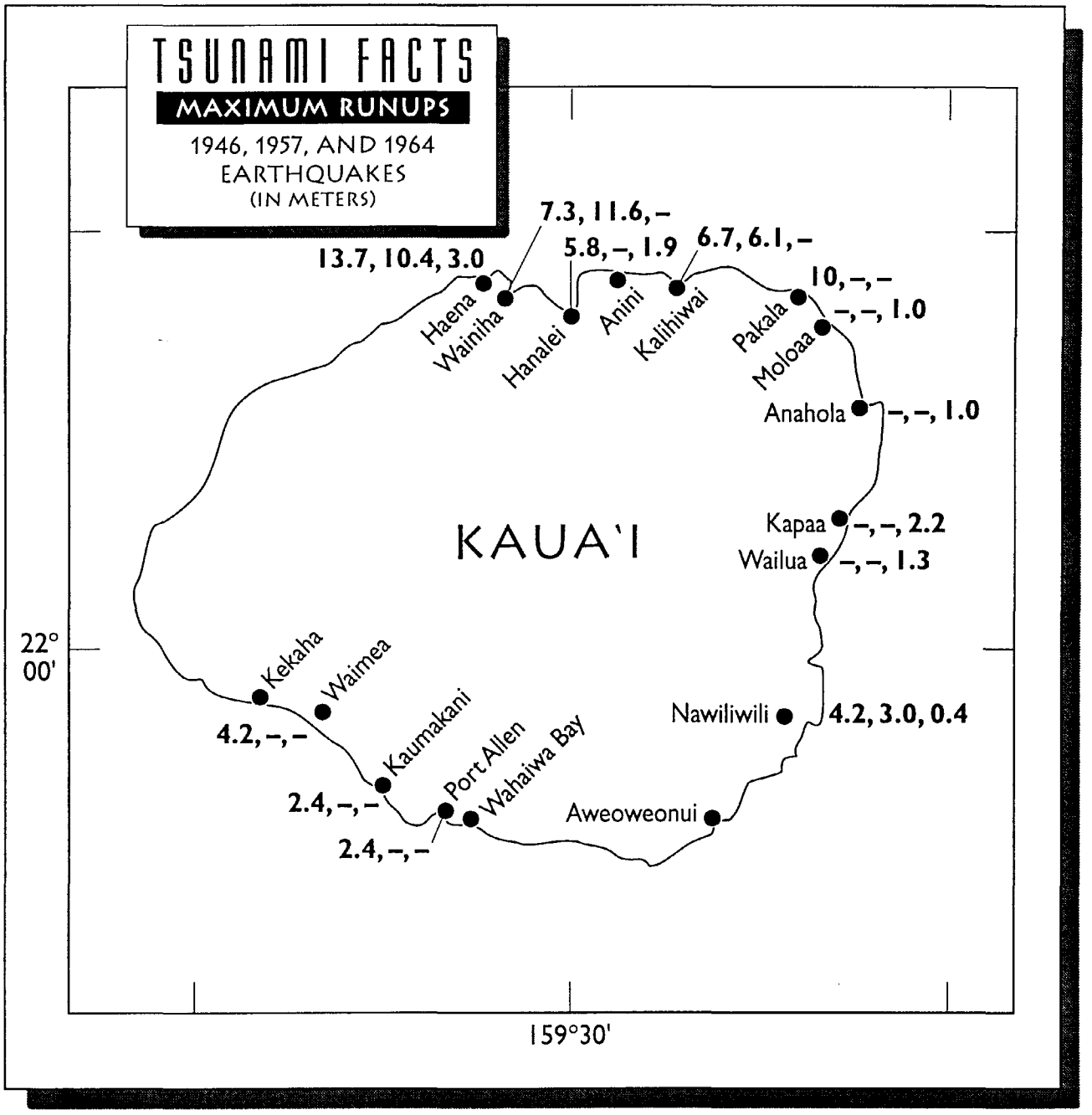

TSUNAMI FACTS
MAXIMUM RUNUPS
1946, 1957, AND 1964
EARTHQUAKES
(IN METERS)
KAUA'I
13.7, 10.4, 3.0
7.3, 11.6, –
5.8, –, 1.9
6.7, 6.1, –
10, –, –
–, –, 1.0
Haena
Wainiha
Hanalei
Anini
Kalihiwai
Pakala
Moloaa
Anahola
–, –, 1.0
Kapaa
–, –, 2.2
Wailua
–, –, 1.3
Nawiliwili
4.2, 3.0, 0.4
Aweoweonui
Kekaha
Waimea
4.2, –, –
Kaumakani
Port Allen
Wahaiwa Bay
2.4, –, –
2.4, –, –
22°
00'
159°30'

Figure 10a.

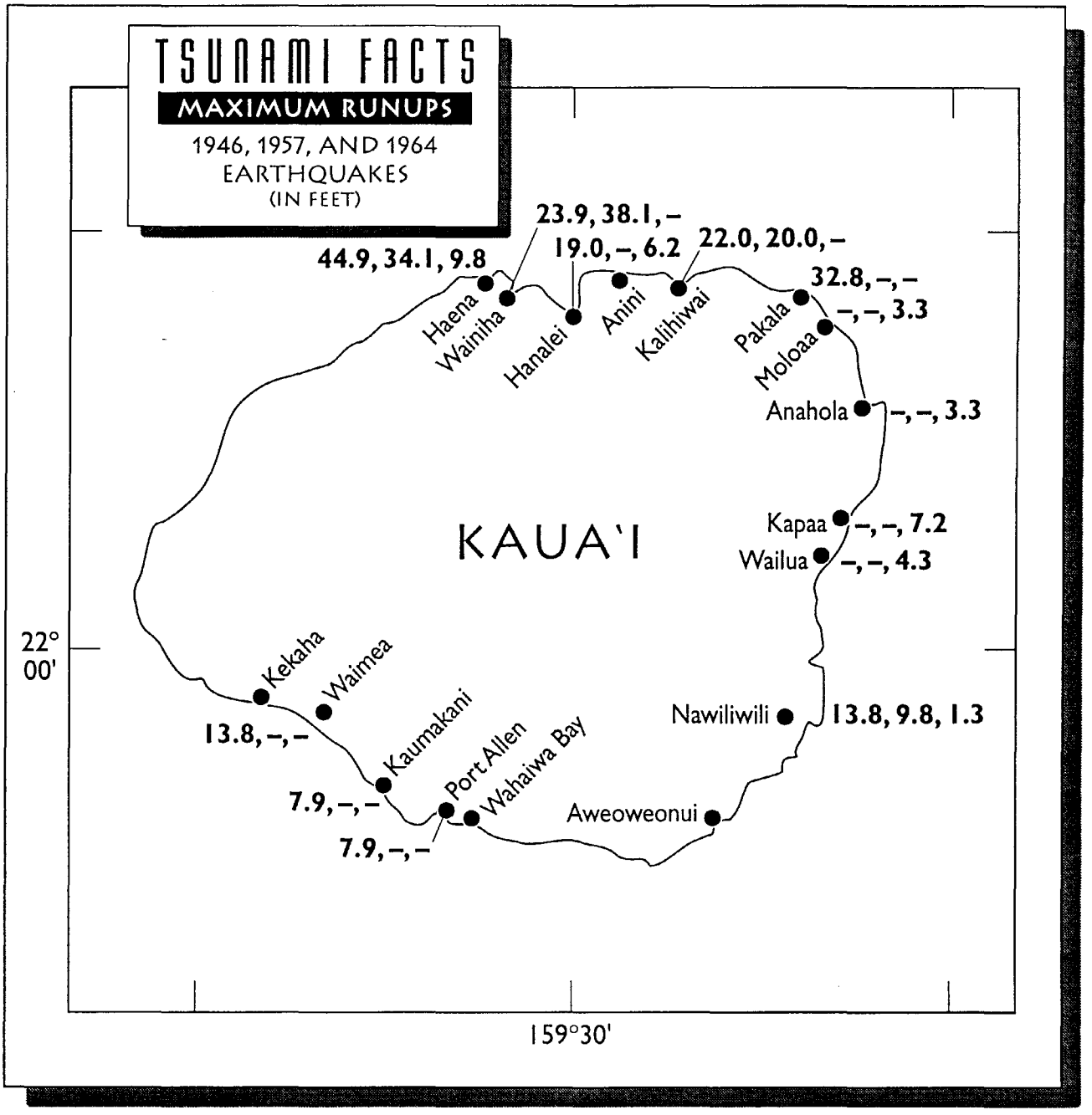

TSUNAMI FACTS
MAXIMUM RUNUPS
1946, 1957, AND 1964
EARTHQUAKES
(IN FEET)
KAUA'I
44.9, 34.1, 9.8
Haena
Wainiha
23.9, 38.1, –
19.0, –, 6.2
Hanalei
Anini
22.0, 20.0, –
Kalihiwai
32.8, –, –
–, –, 3.3
Pakala
Moloaa
Anahola
–, –, 3.3
Kapaa
–, –, 7.2
Wailua
–, –, 4.3
Nawiliwili
13.8, 9.8, 1.3
Aweoweonui
Kekaha
Waimea
13.8, –, –
Kaumakani
7.9, –, –
Port Allen
Wahaiwa Bay
7.9, –, –
22°
00'
159°30'

Figure 10b.

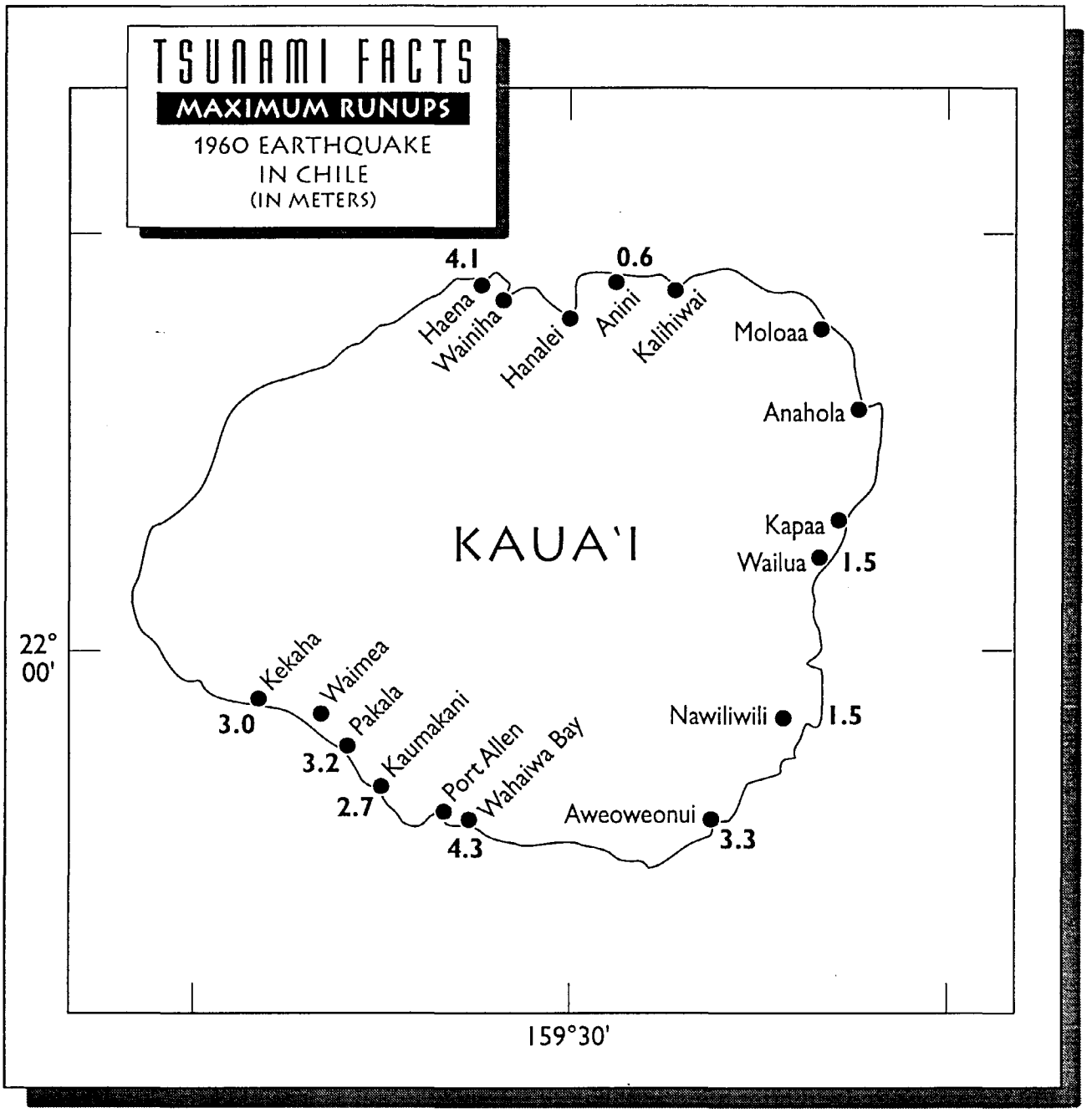

TSUNAMI FACTS
MAXIMUM RUNUPS
1960 EARTHQUAKE
IN CHILE
(IN METERS)
4.1
0.6
Haena
Wainiha
Hanalei
Anini
Kalihiwai
Moloaa
Anahola
KAUA'I
Kapaa
Wailua
1.5
22°
00'
Kekaha
Waimea
3.0
Pakala
3.2
Kaumakani
2.7
Port Allen
Wahaiwa Bay
4.3
Nawiliwili
1.5
Aweoweonui
3.3
159°30'

Figure 11a.

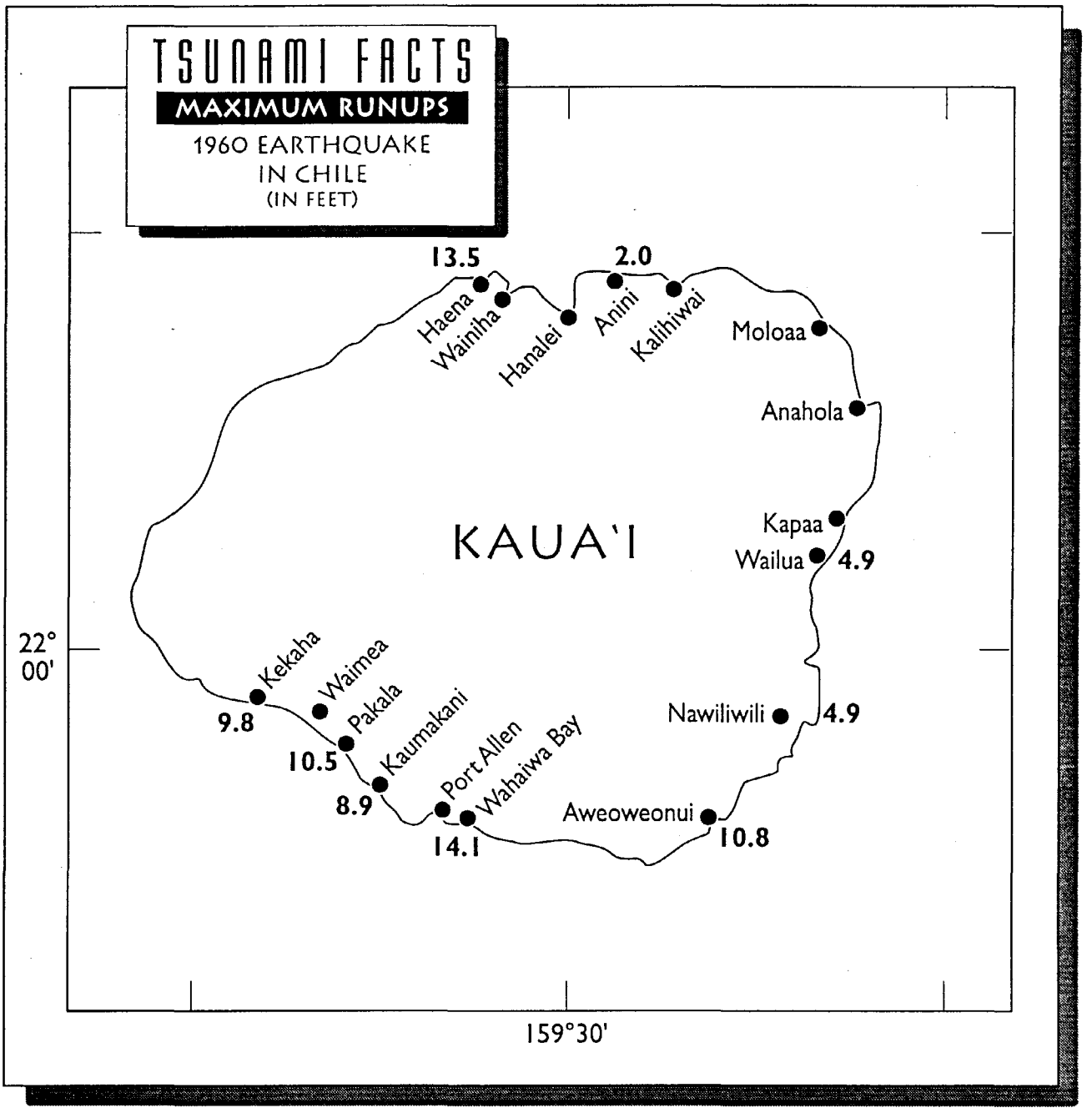

TSUNAMI FACTS
MAXIMUM RUNUPS
1960 EARTHQUAKE
IN CHILE
(IN FEET)
13.5
Haena
Wainiha
Hanalei
2.0
Anini
Kalihiwai
Moloaa
Anahola
KAUA'I
Kapaa
Wailua
4.9
22°
00'
Kekaha
Waimea
9.8
Pakala
10.5
Kaumakani
8.9
Port Allen
Wahaiwa Bay
14.1
Nawiliwili
4.9
Aweoweonui
10.8
159°30'

Figure 11b.

ISLAND BY ISLAND COMPARISONS FOR LARGE TSUNAMIS

Available maximum reported runups on different islands for several large tsunamis (i.e., the six largest from 1900 through 1993) are given in Table 6 and Figures 12 and 13. These data indicate that all islands are susceptible to large tsunamis.

TABLE 6

Maximum Reported Runups on Different Islands for Large Tsunamis[1]

Year	Source area	Hawaii		Maui		Molokai		Oahu		Kauai		Niihau	
		(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)
1923	Kamchatka	6.1	20.0	3.5	11.5	—	—	3.7	12.1	—	—	—	—
1946	E. Aleutians	12.0	39.4	10.0	32.8	16.4	53.8	11.1	36.4	13.7	44.9	6.0	19.7
1952	Kamchatka	3.2	10.5	—	—	—	—	9.1	29.9	3.0	9.8	—	—
1957	C. Aleutians	9.8	32.2	3.3	10.8	2.7	8.9	7.0	23.0	16.1	52.8	3.0	9.8
1960	Chile	10.7	35.1	4.6	15.1	—	—	4.0	13.1	4.3	14.1	—	—
1964	Alaska	3.0	9.8	3.6	11.8	—	—	4.9	16.1	3.0	9.8	—	—

1. Only runups for tsunamis with reported values of 1 meter or more on three or more islands are listed. These are the six largest tsunamis reported in the Hawaiian Islands from 1900 through 1993.

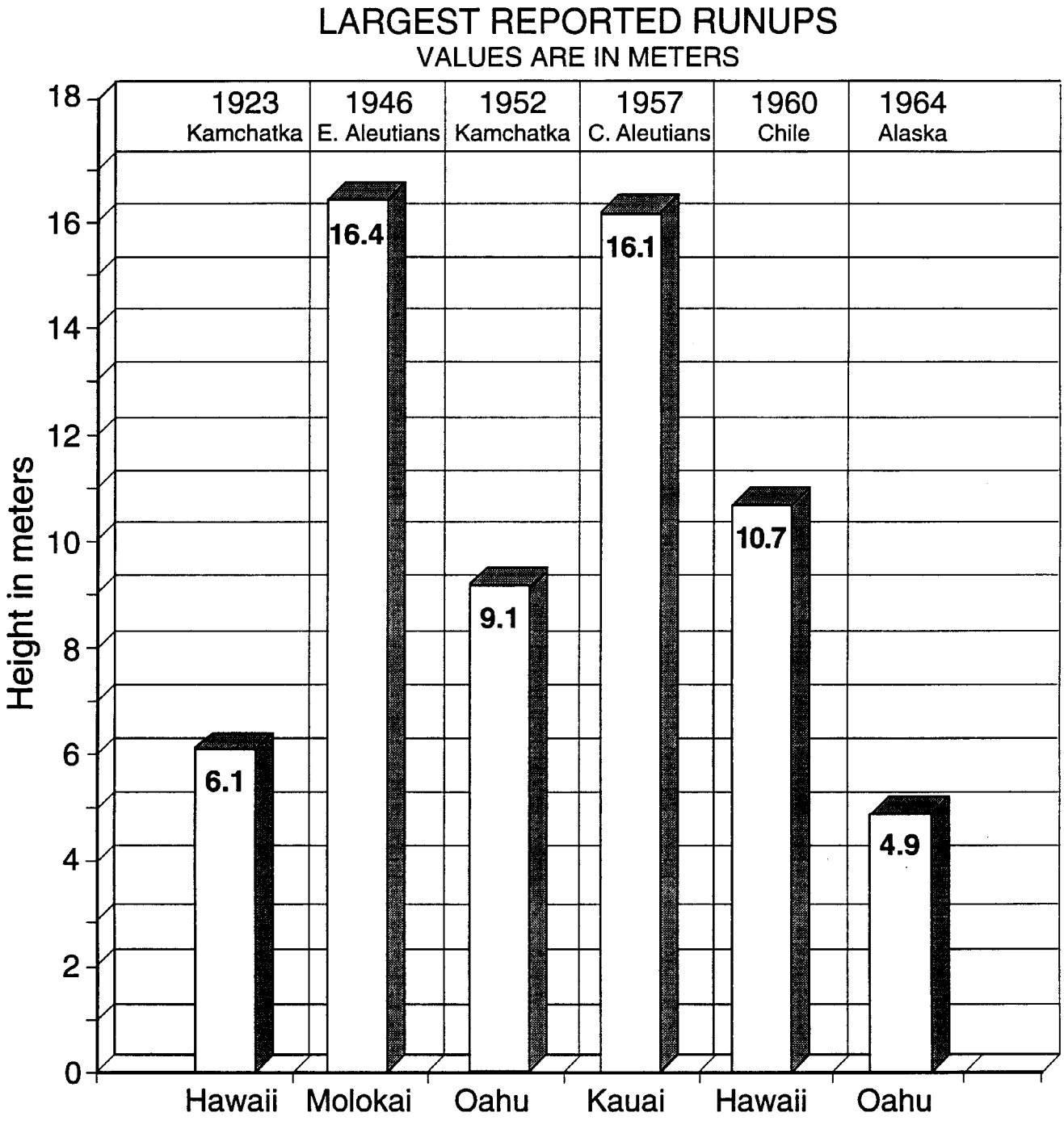

LARGEST REPORTED RUNUPS
VALUES ARE IN METERS
Height in meters
18
16
14
12
10
8
6
4
2
0
1923
Kamchatka
1946
E. Aleutians
1952
Kamchatka
1957
C. Aleutians
1960
Chile
1964
Alaska
6.1
16.4
9.1
16.1
10.7
4.9
Hawaii
Molokai
Oahu
Kauai
Hawaii
Oahu

Figure 12a.

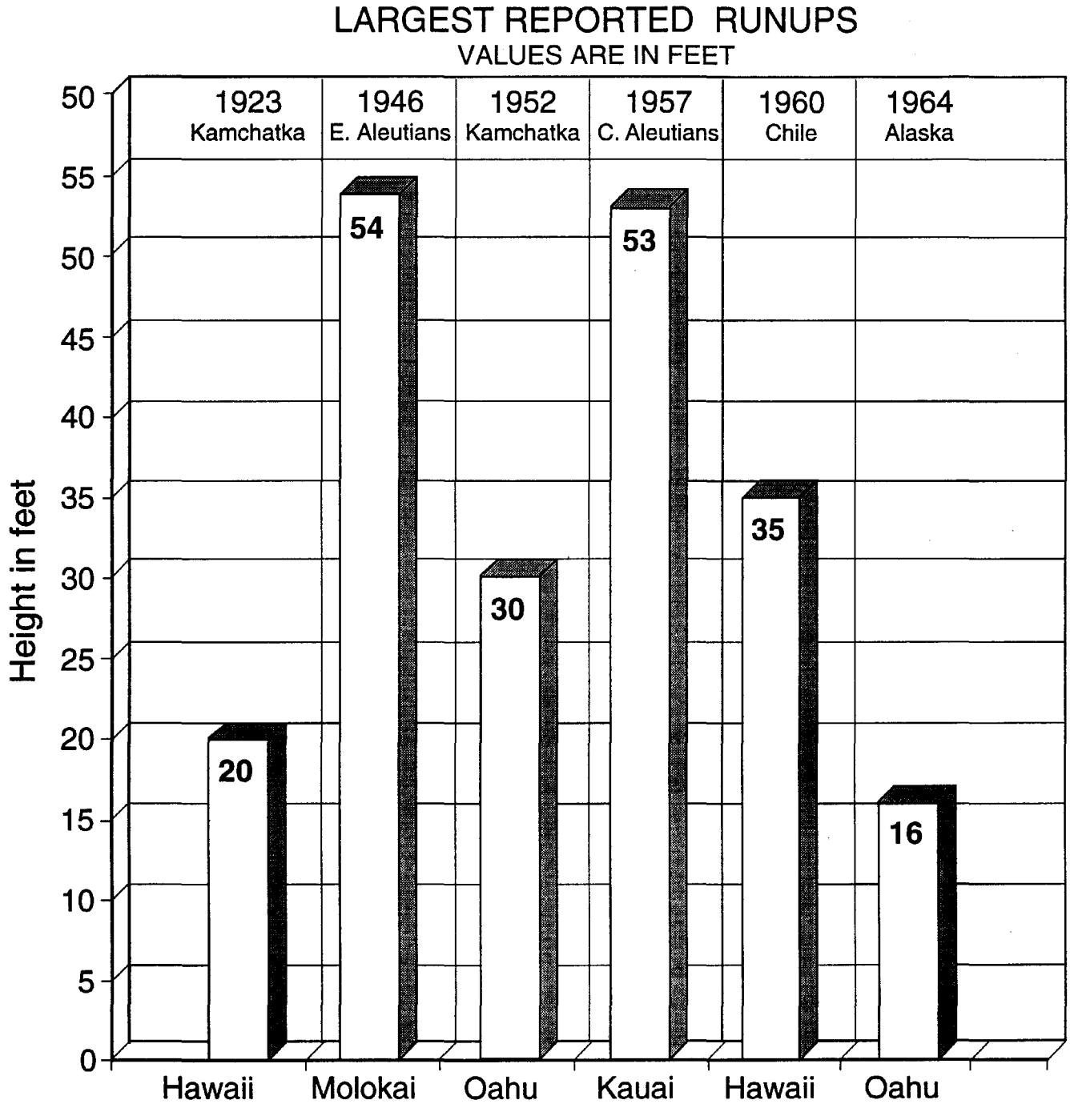

LARGEST REPORTED RUNUPS
VALUES ARE IN FEET
Height in feet
0
5
10
15
20
25
30
35
40
45
50
55
1923
Kamchatka
1946
E. Aleutians
1952
Kamchatka
1957
C. Aleutians
1960
Chile
1964
Alaska
20
54
30
53
35
16
Hawaii
Molokai
Oahu
Kauai
Hawaii
Oahu

Figure 12b.

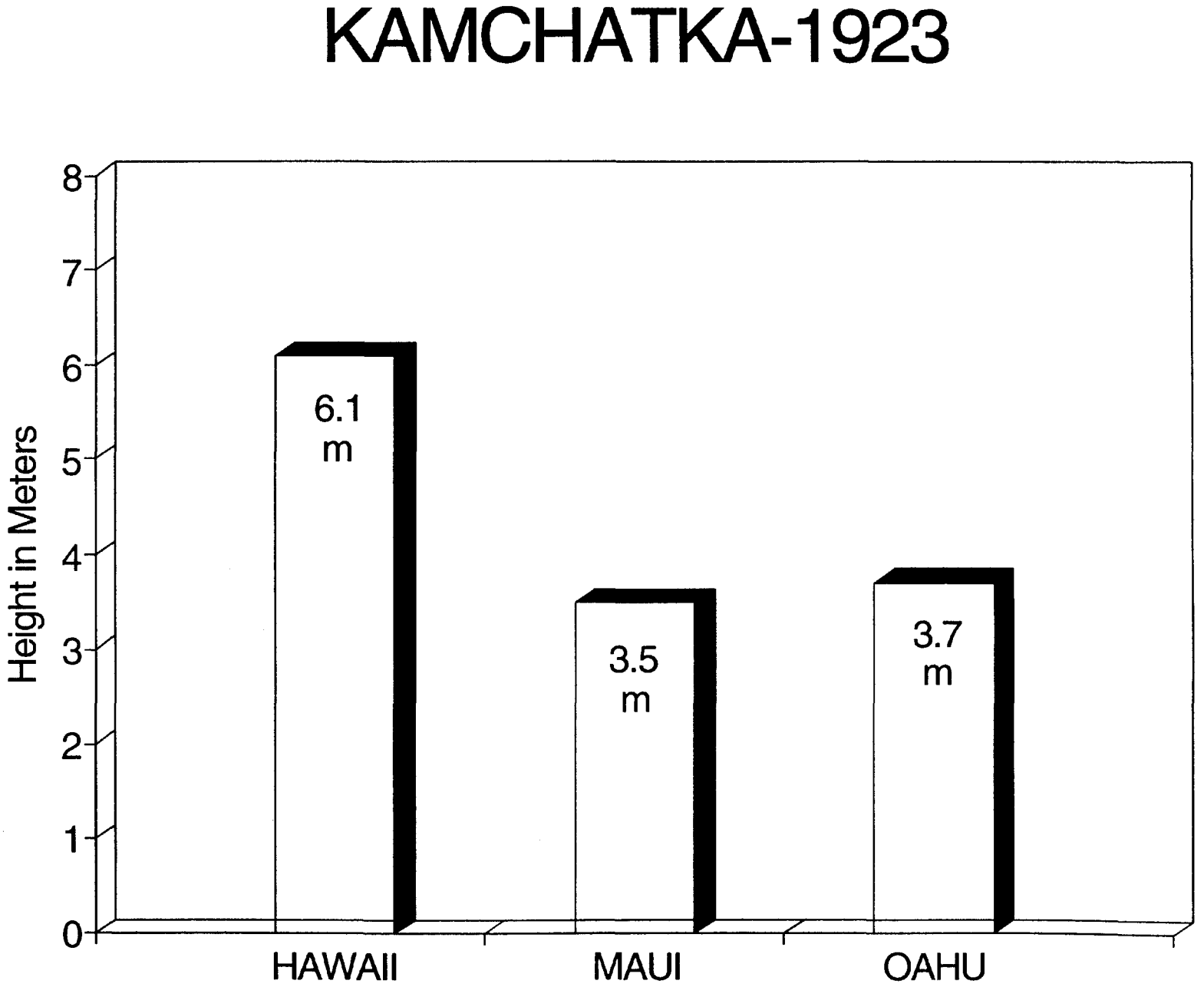

KAMCHATKA-1923
Height in Meters
0
1
2
3
4
5
6
7
8
6.1 m
3.5 m
3.7 m
HAWAII
MAUI
OAHU

Figure 13a.

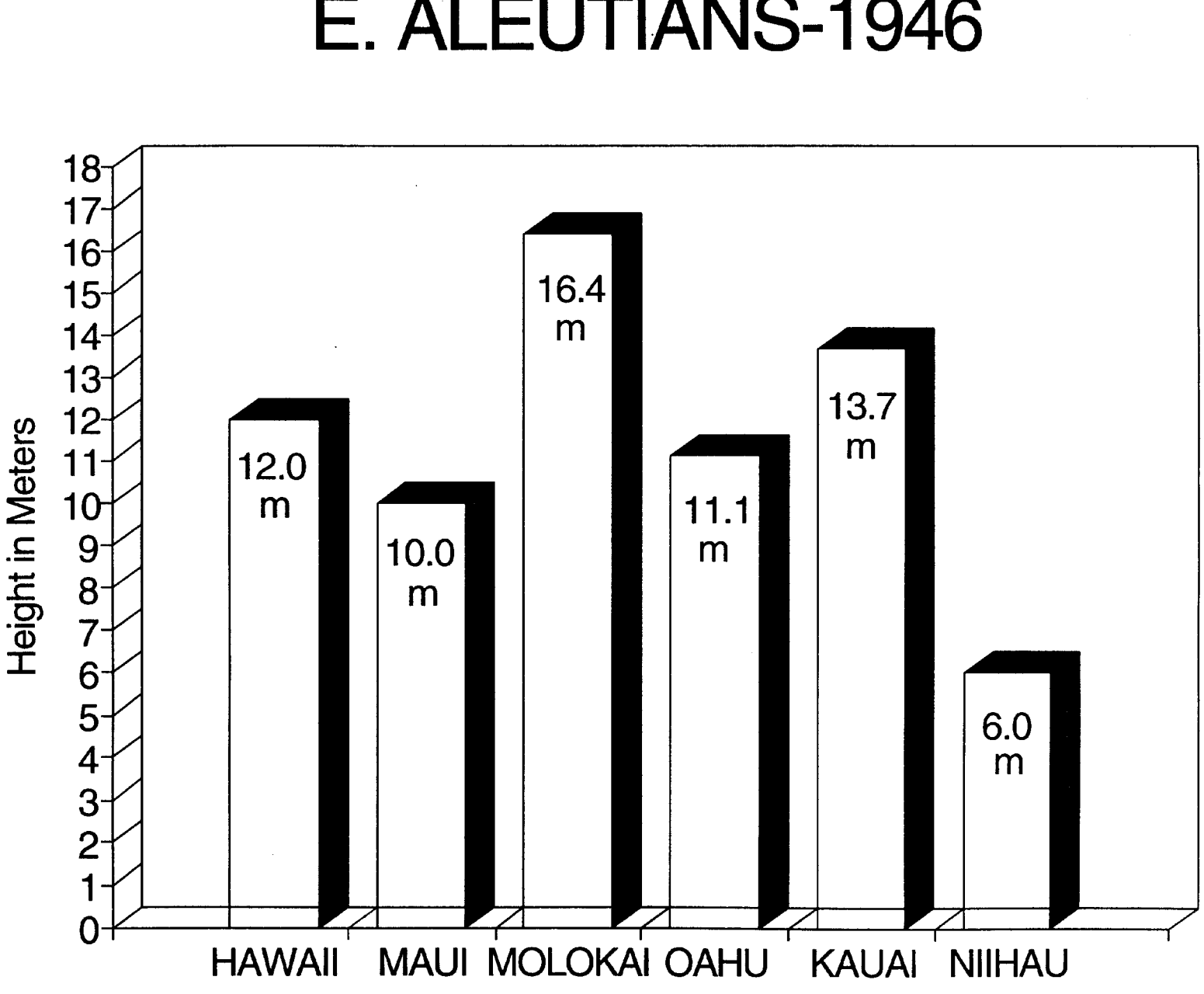


Figure 13a (Continued).

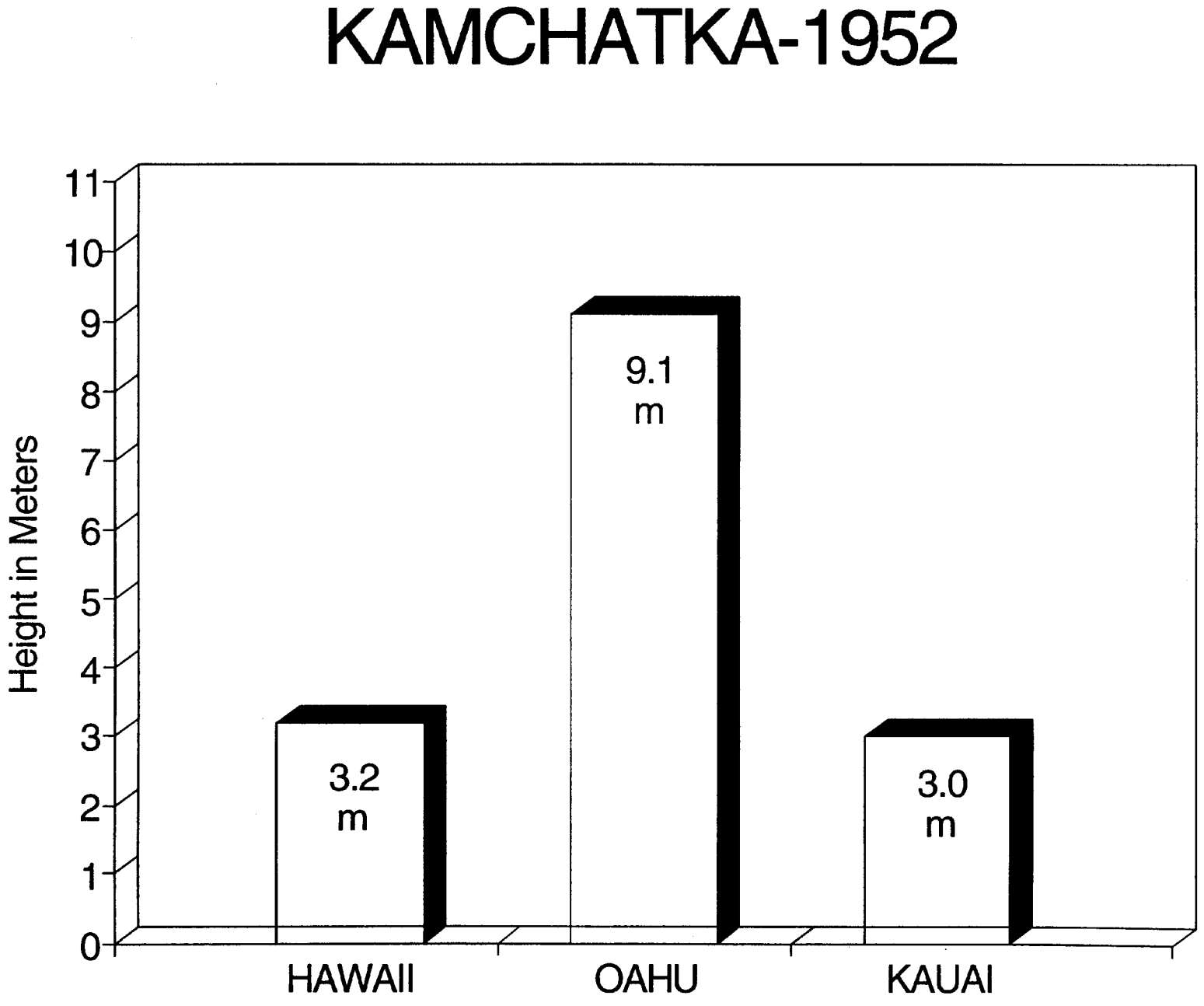


Figure 13a (Continued).

C. ALEUTIANS-1957

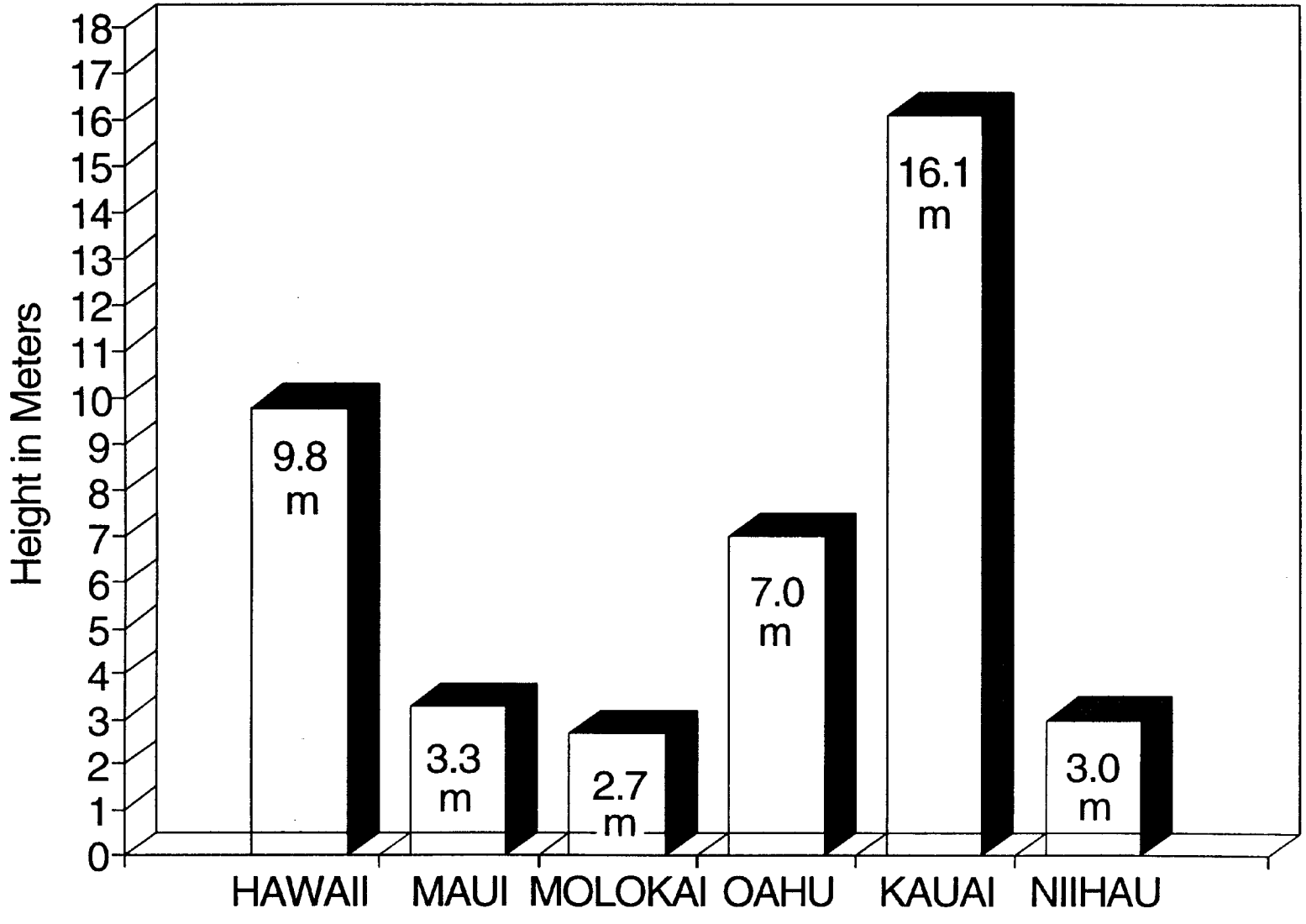


Figure 13a (Continued).

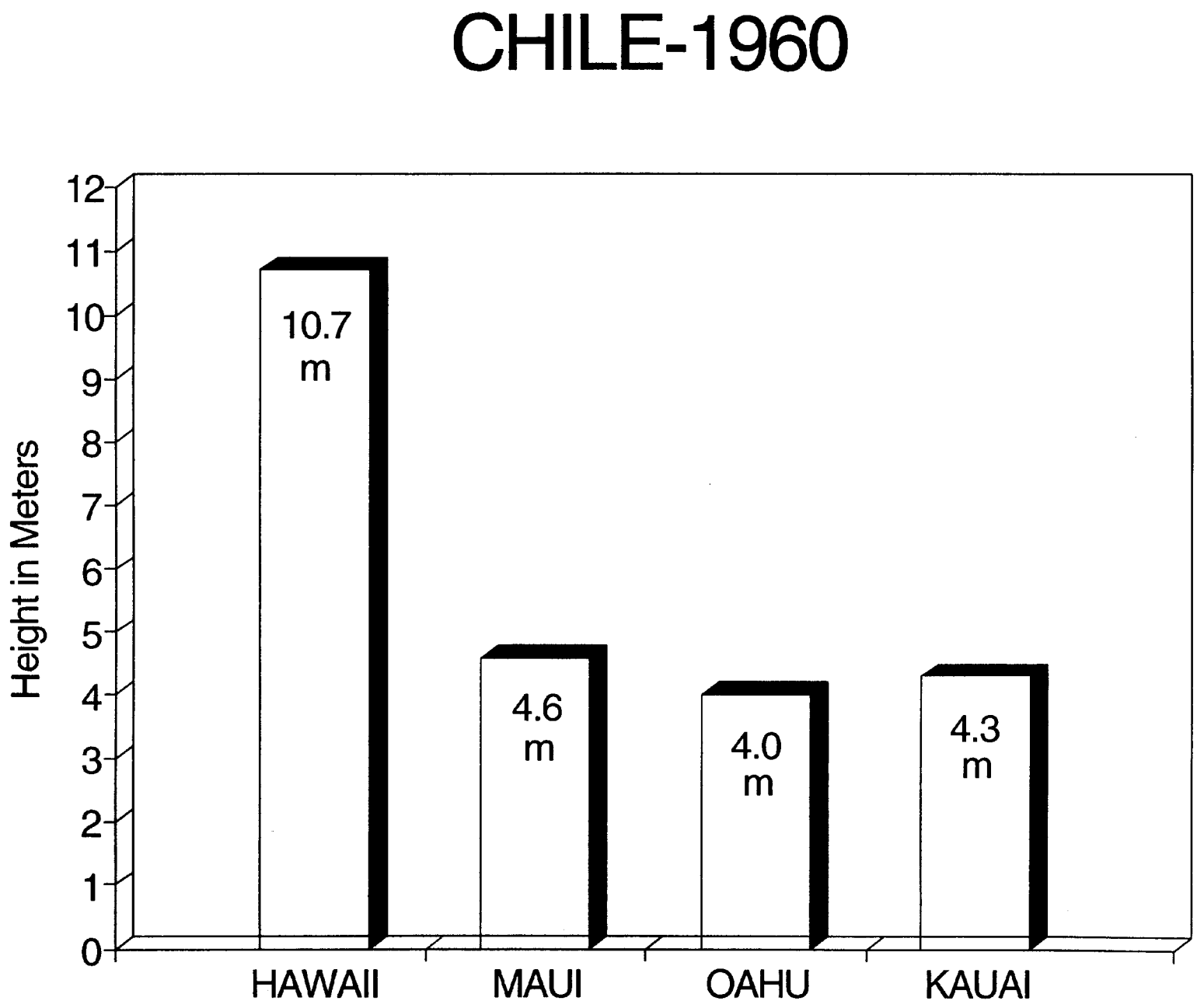


Figure 13a (Continued).

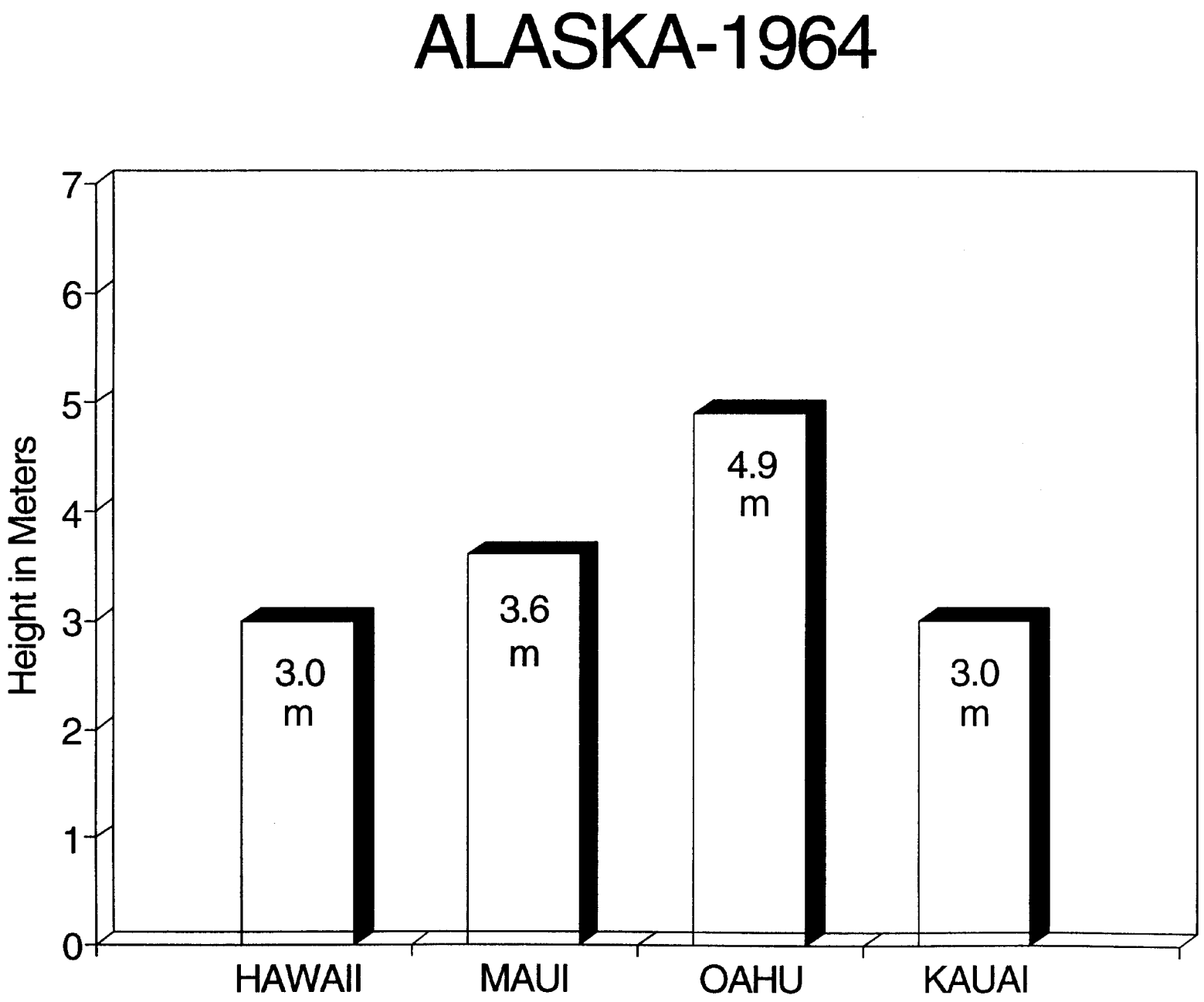


Figure 13a (Continued).

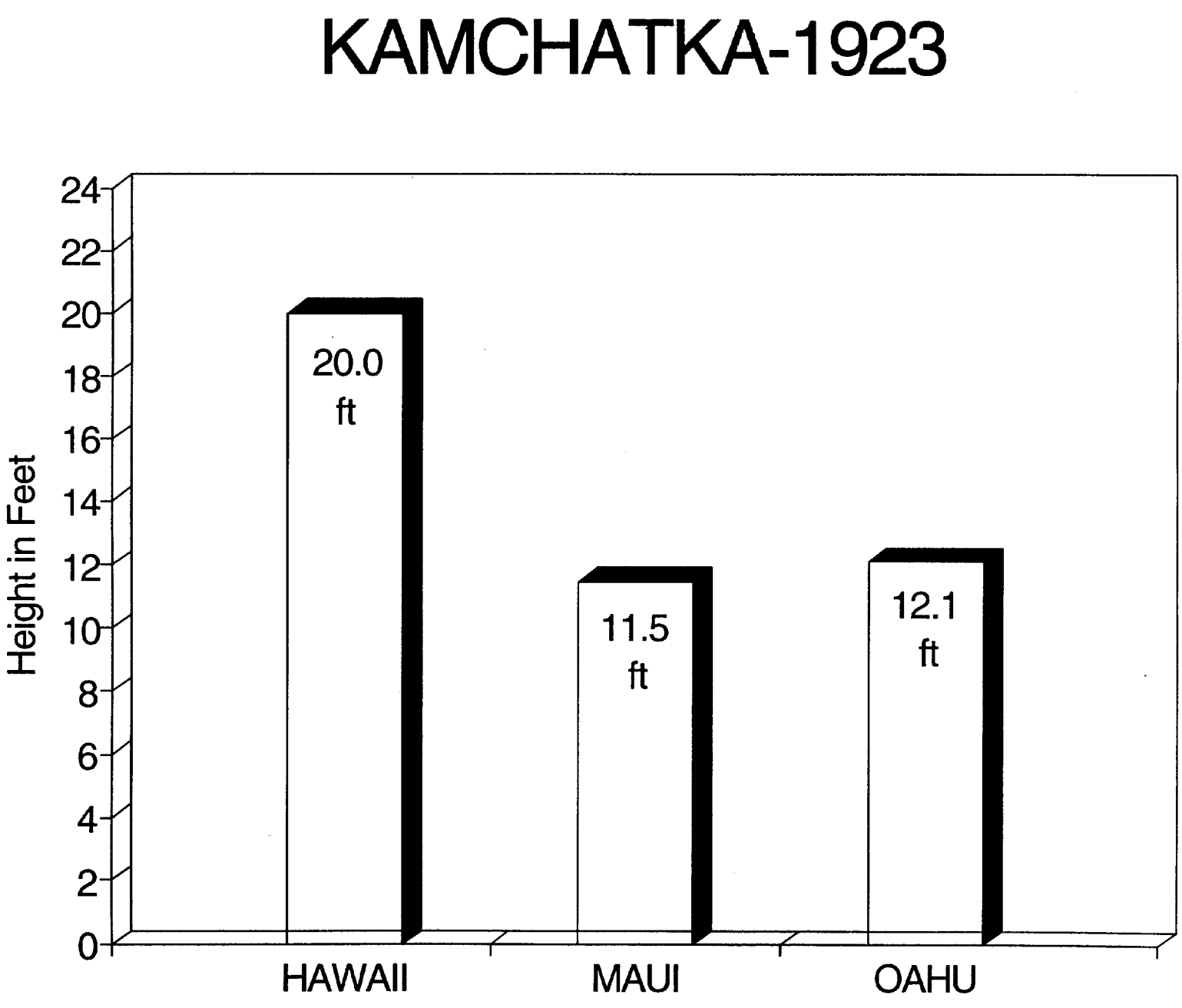

KAMCHATKA-1923
Height in Feet
24
22
20
18
16
14
12
10
8
6
4
2
0
20.0 ft
11.5 ft
12.1 ft
HAWAII
MAUI
OAHU

Figure 13b.

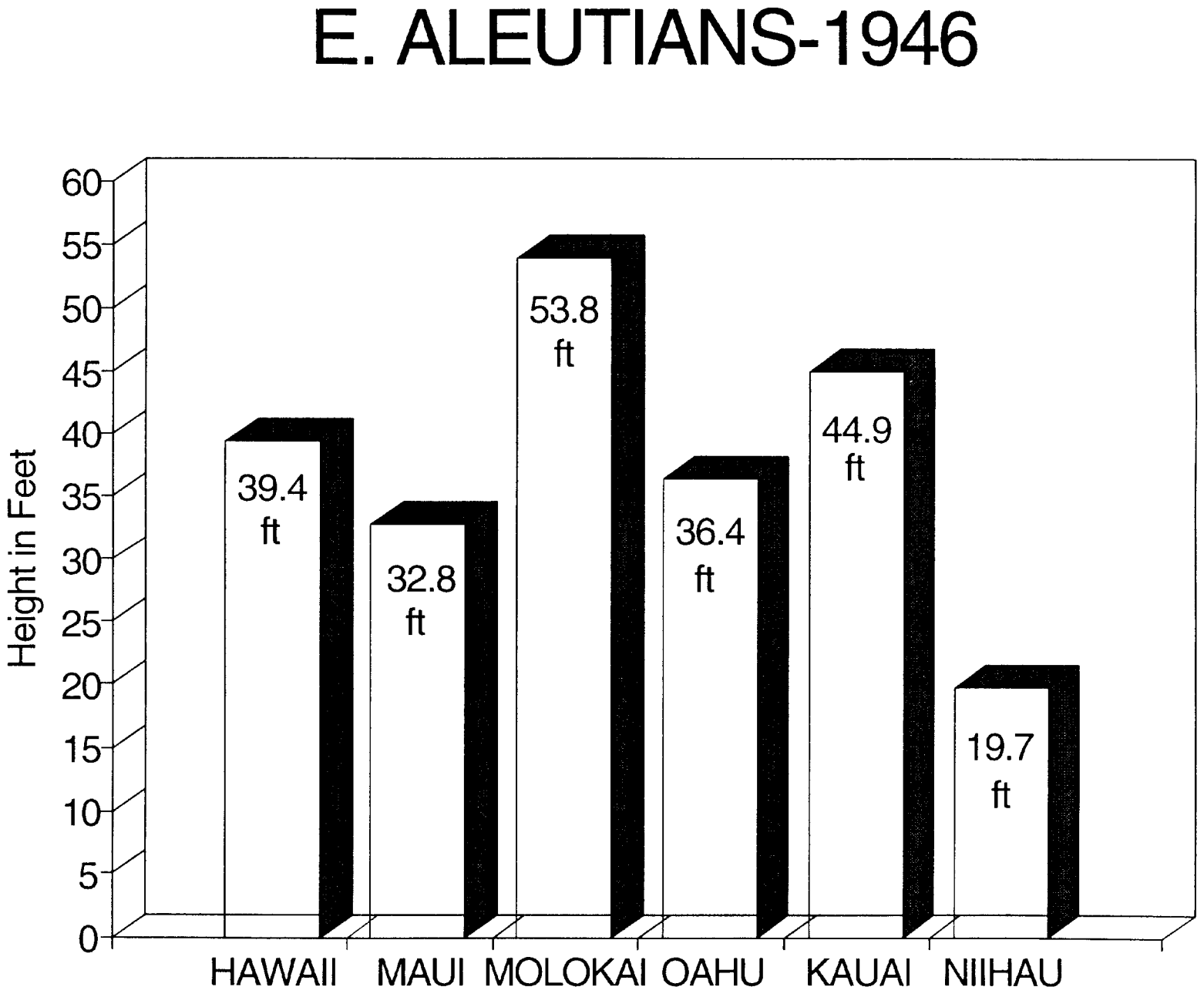


Figure 13b (Continued).

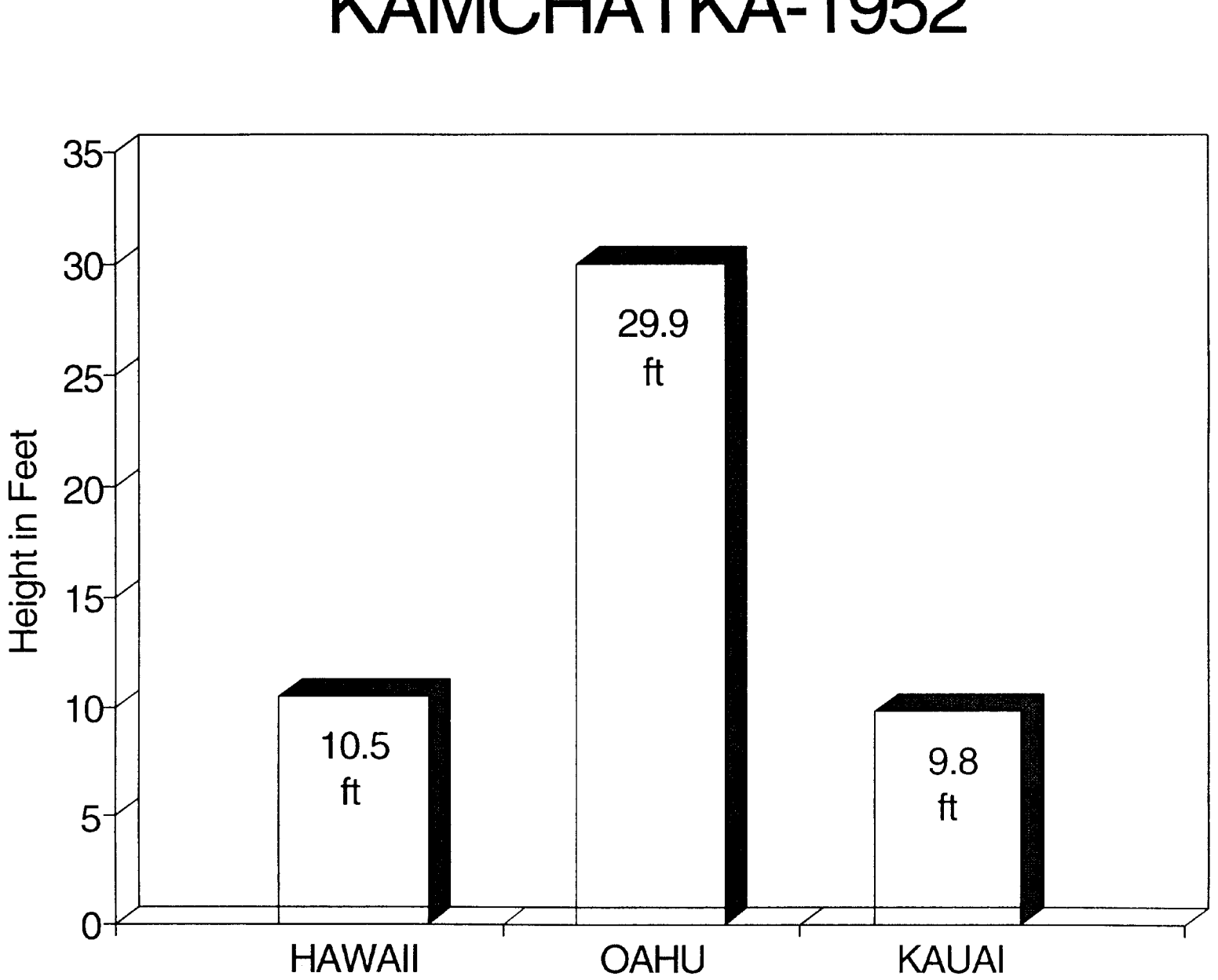


Figure 13b (Continued).

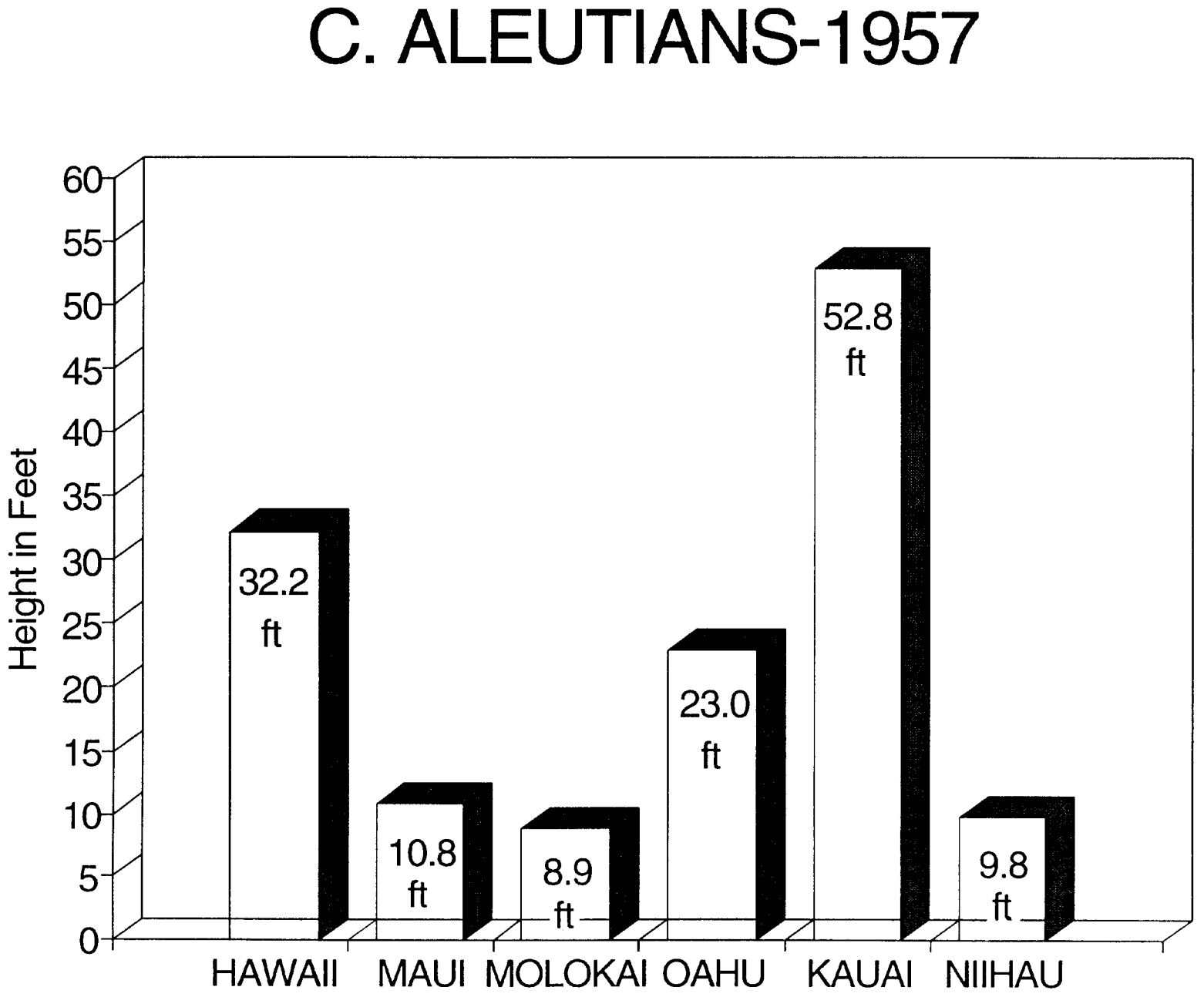


Figure 13b (Continued).

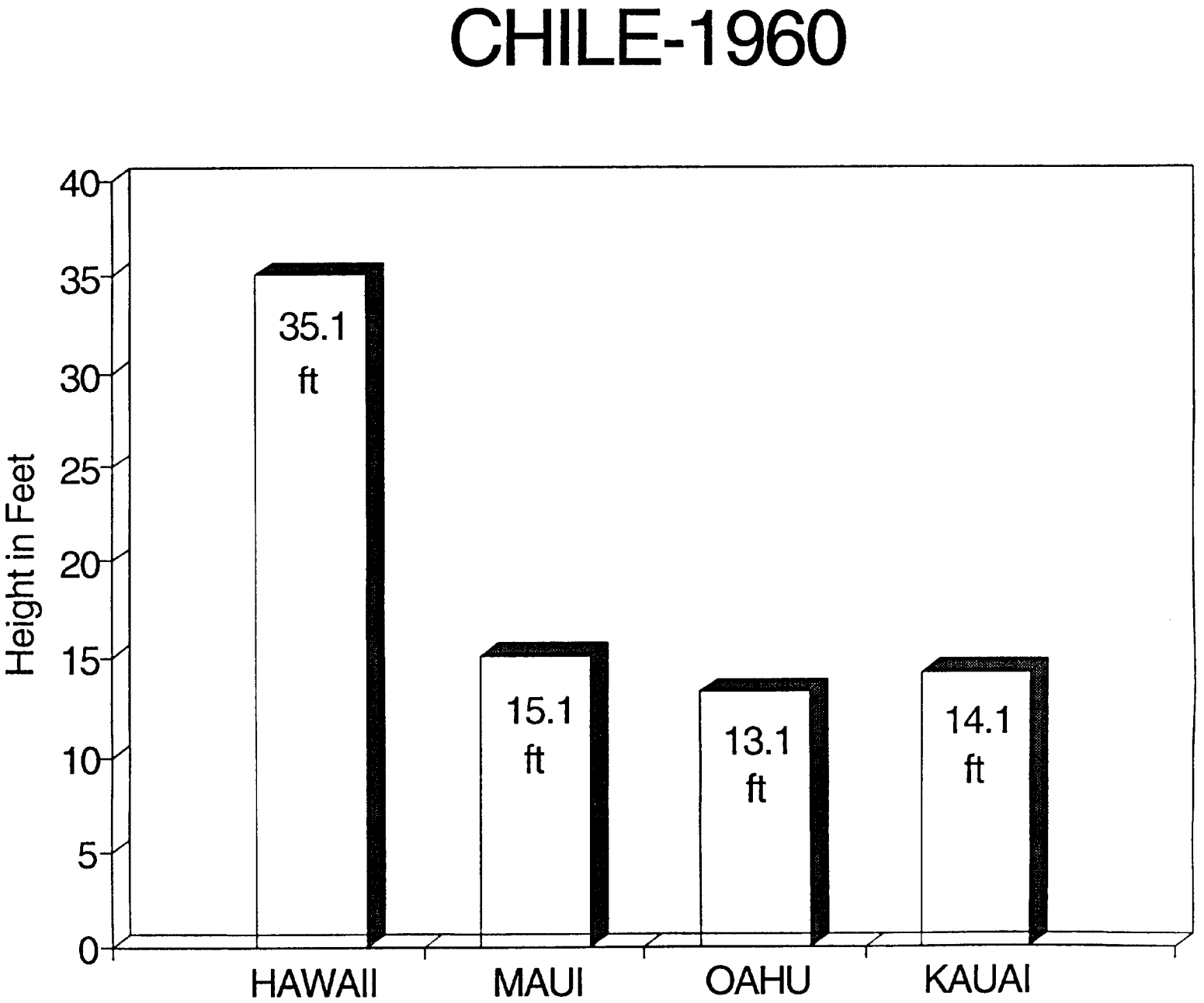


Figure 13b (Continued).

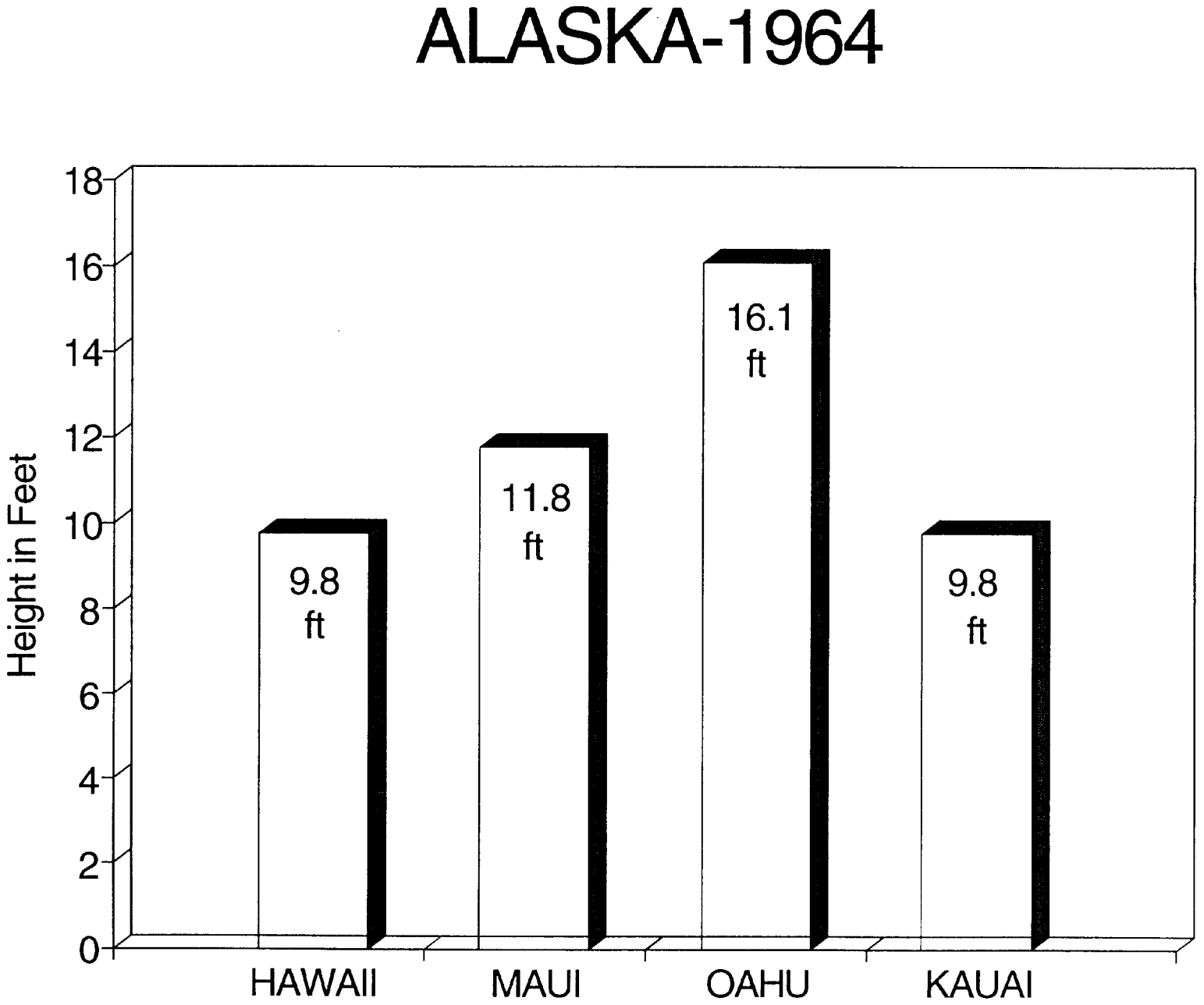


Figure 13b (Continued).

COMPARISONS OF RUNUPS AT HILO VERSUS RUNUPS ON THE NORTH SHORE OF OAHU FOR LARGE TSUNAMIS FROM THE NORTH PACIFIC

Table 7 and Figures 14 and 15 compare runup values reported at Hilo to runup values along Oahu's North Shore for large tsunamis originating in the North Pacific (i.e., Kamchatka, the Aleutians, and Alaska). These comparisons are important because Oahu is Hawaii's most populated island and the North Shore is a major ocean recreation area.

The lower value for the North Shore in 1923 may be misleading (Fig. 14) since the only reading was from Haleiwa. Runups greater than those for Hilo are reported at other North Shore sites for all other large tsunamis (Fig. 15). However, Hilo is more often thought of in terms of tsunamis than Oahu's North Shore because of the large losses of life which have occurred there, and the fact that Hilo is not only vulnerable to tsunamis from the North Pacific but also to tsunamis from South America.

The open space of Hilo's waterfront district will help to minimize future losses of life. However, growth continues along Oahu's North Shore—housing, hotels, tourist attractions, and campsites—with little apparent recognition of tsunami hazards. Many coastal areas of other islands have been similarly developed since the latest large tsunamis in 1957, 1960 (Chile), and 1964. Many of these areas will also continue to be struck by large tsunamis.

TABLE 7

Maximum Reported Runups on the North Shore of Oahu[1] and in Hilo for Large Tsunamis[2] from the North Pacific

Year	Source Area	North Shore (m)	North Shore (ft)	Hilo (m)	Hilo (ft)
1923	Kamchatka	3.7	12.1	6.1	20.0
1946	E. Aleutians	10.9	35.8	8.1	26.6
1952	Kamchatka	9.1	29.9	2.4	7.9
1957	C. Aleutians	7.0	23.0	3.9	12.8
1964	Alaska	4.9	16.1	3.0	9.8

1. From Kaena Point to Kahuku.

2. Tsunamis with runups of 1 meter or more on the North Shore and in Hilo.

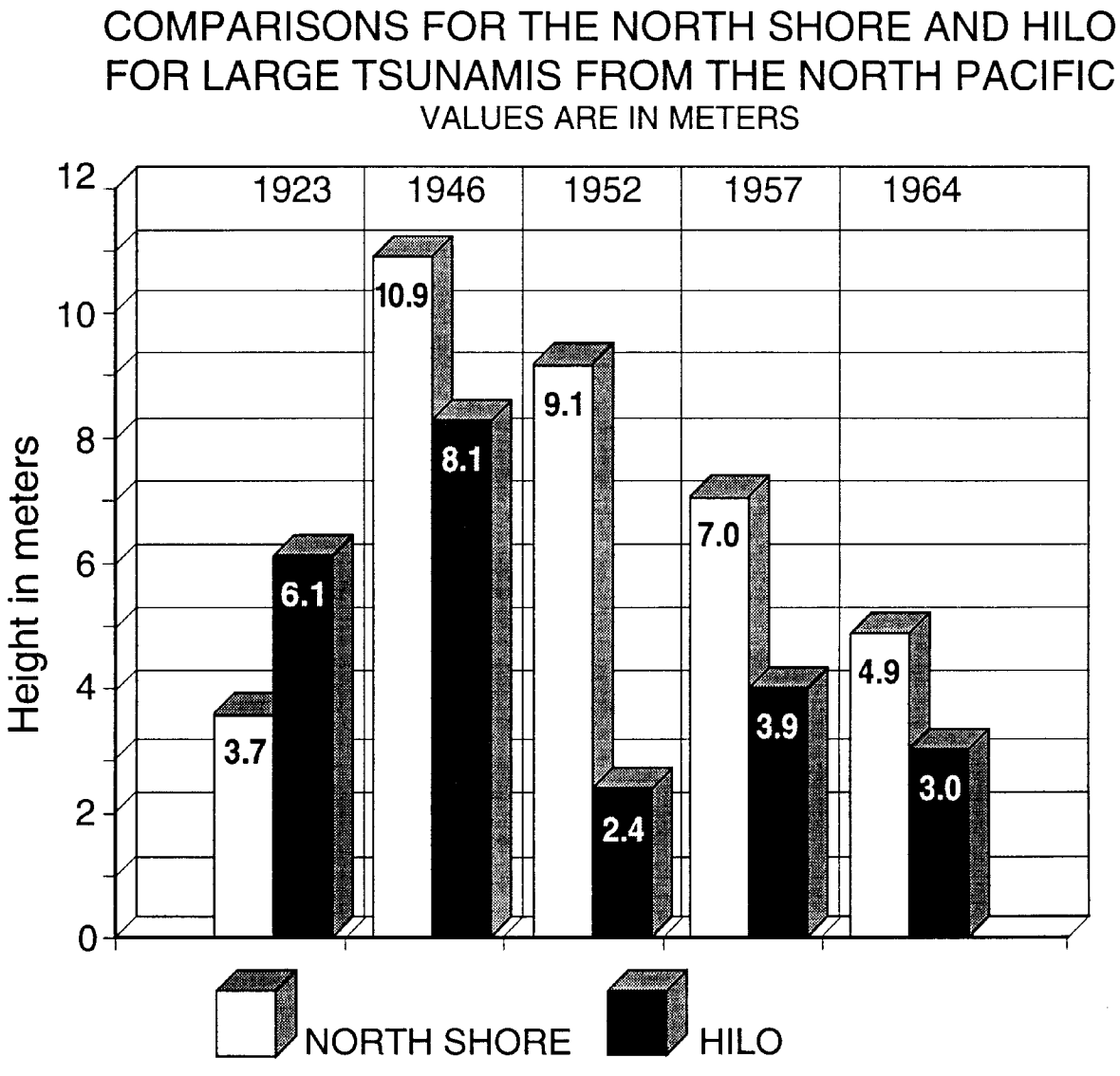

COMPARISONS FOR THE NORTH SHORE AND HILO
FOR LARGE TSUNAMIS FROM THE NORTH PACIFIC
VALUES ARE IN METERS
Height in meters
0
2
4
6
8
10
12
1923
1946
1952
1957
1964
3.7
6.1
10.9
8.1
9.1
2.4
7.0
3.9
4.9
3.0
NORTH SHORE
HILO

Figure 14a.

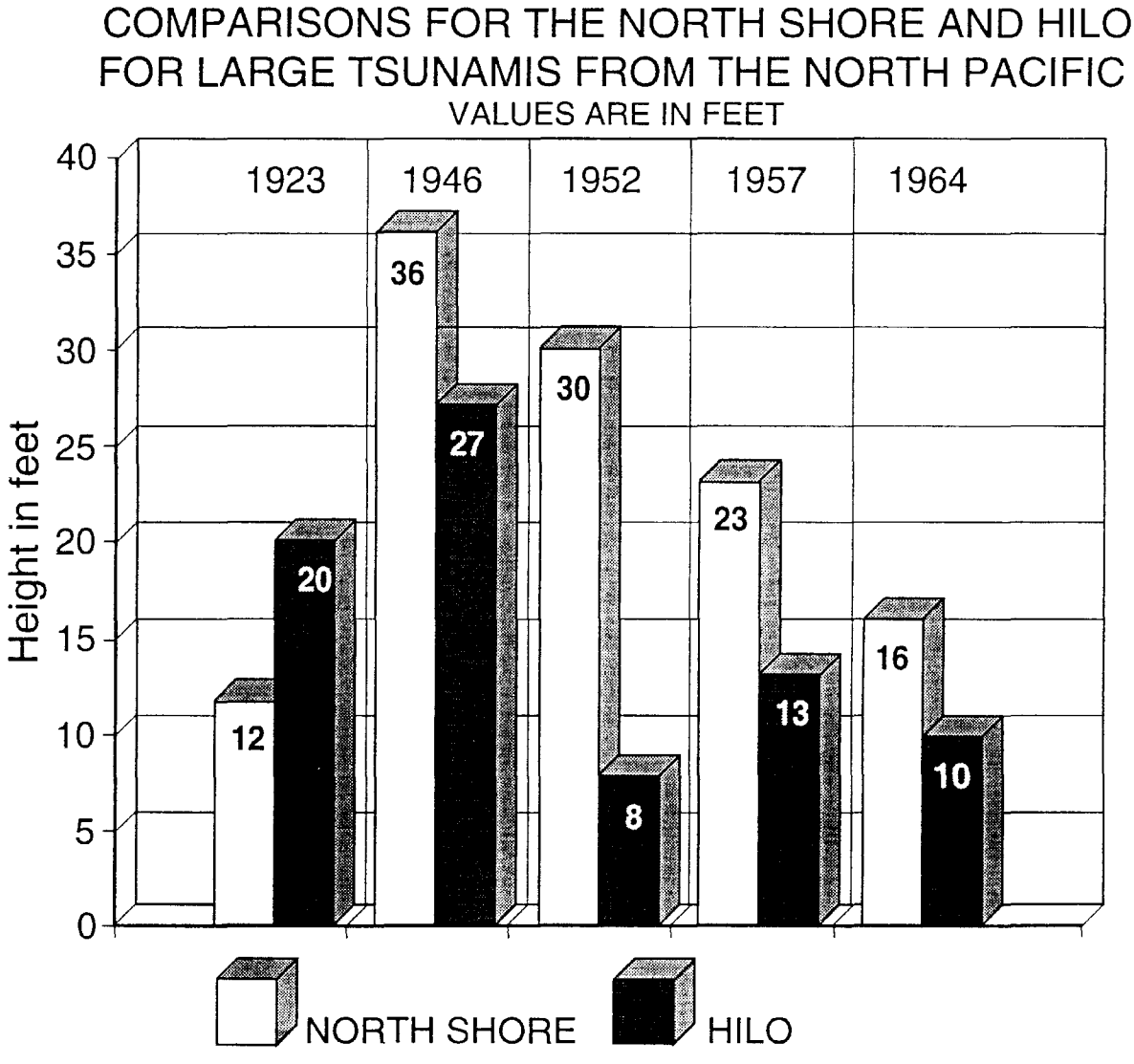

COMPARISONS FOR THE NORTH SHORE AND HILO
FOR LARGE TSUNAMIS FROM THE NORTH PACIFIC
VALUES ARE IN FEET
Height in feet
40
35
30
25
20
15
10
5
0
1923
1946
1952
1957
1964
12
20
36
27
30
8
23
13
16
10
NORTH SHORE
HILO

Figure 14b.

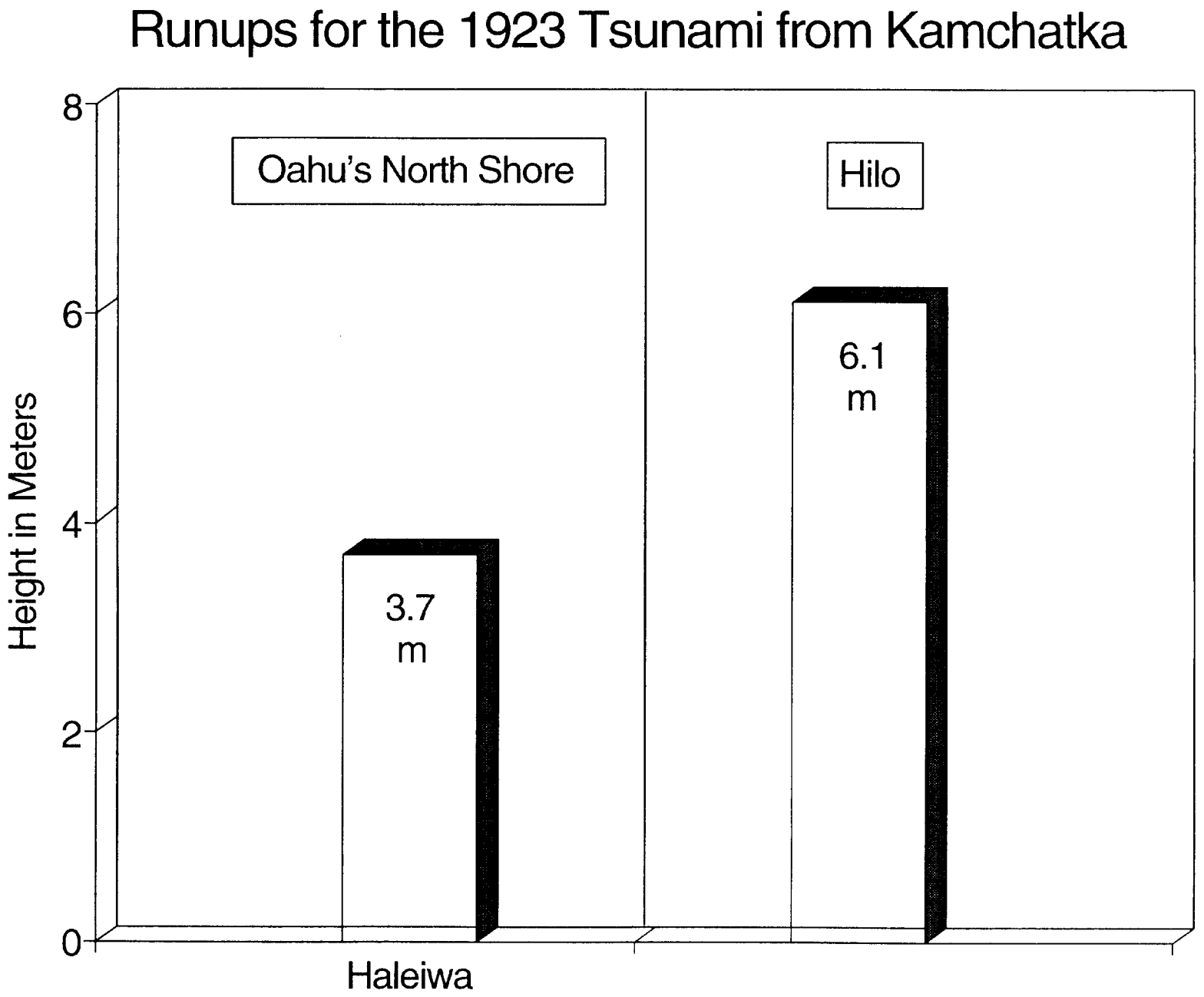

Runups for the 1923 Tsunami from Kamchatka
Height in Meters
8
6
4
2
0
Oahu's North Shore
Hilo
3.7
m
6.1
m
Haleiwa

Figure 15a.

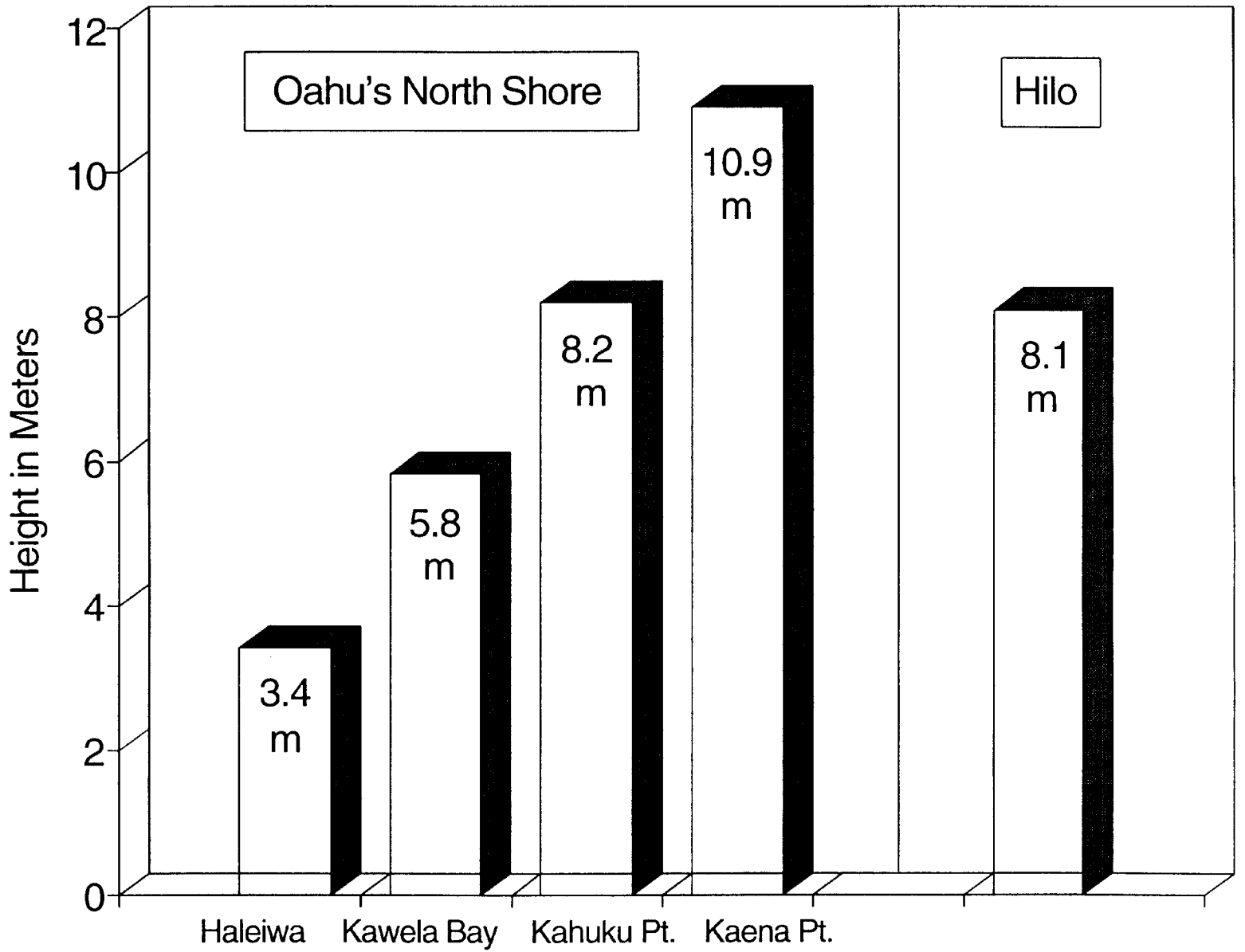


Figure 15a (Continued).

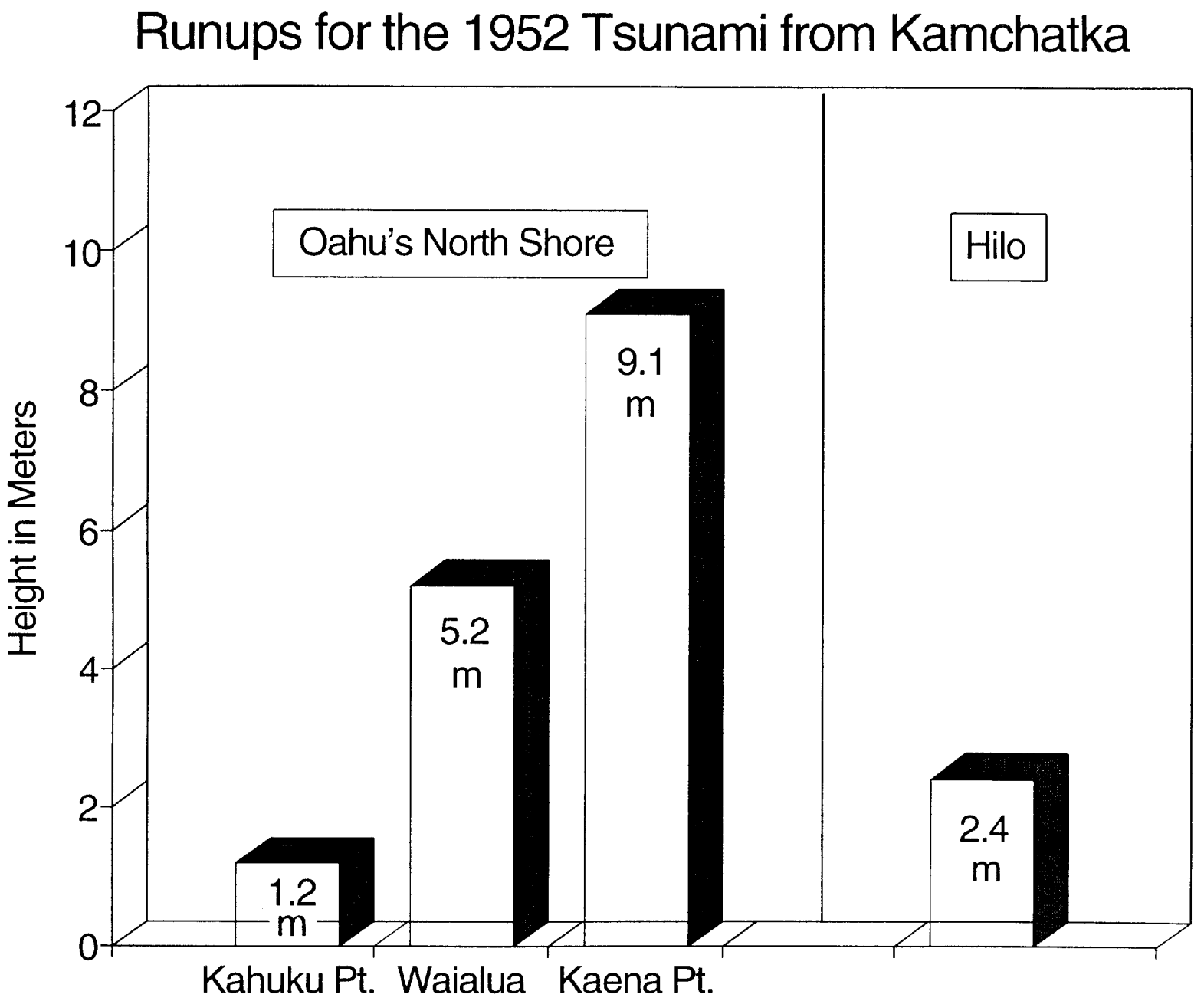


Figure 15a (Continued).

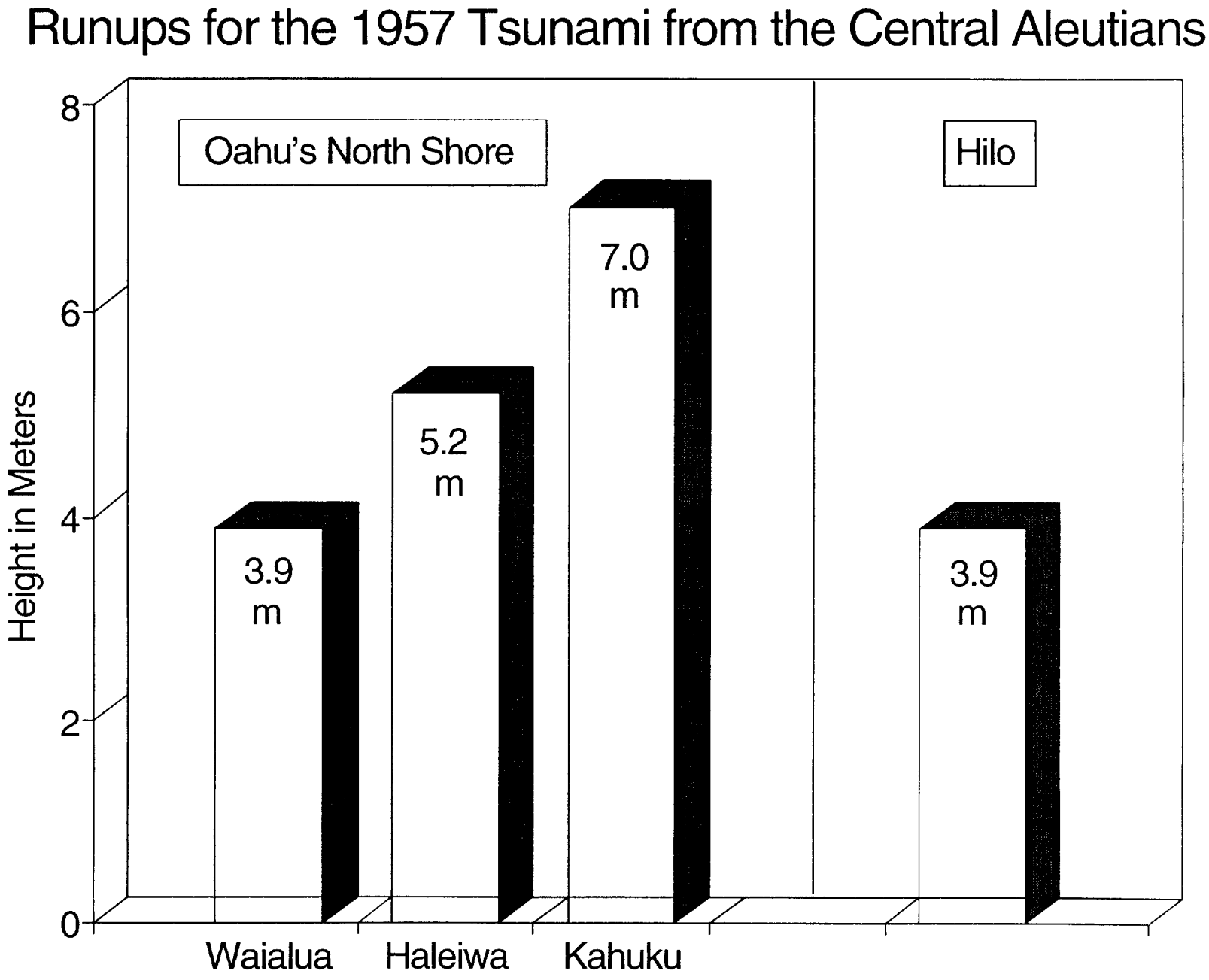


Figure 15a (Continued).

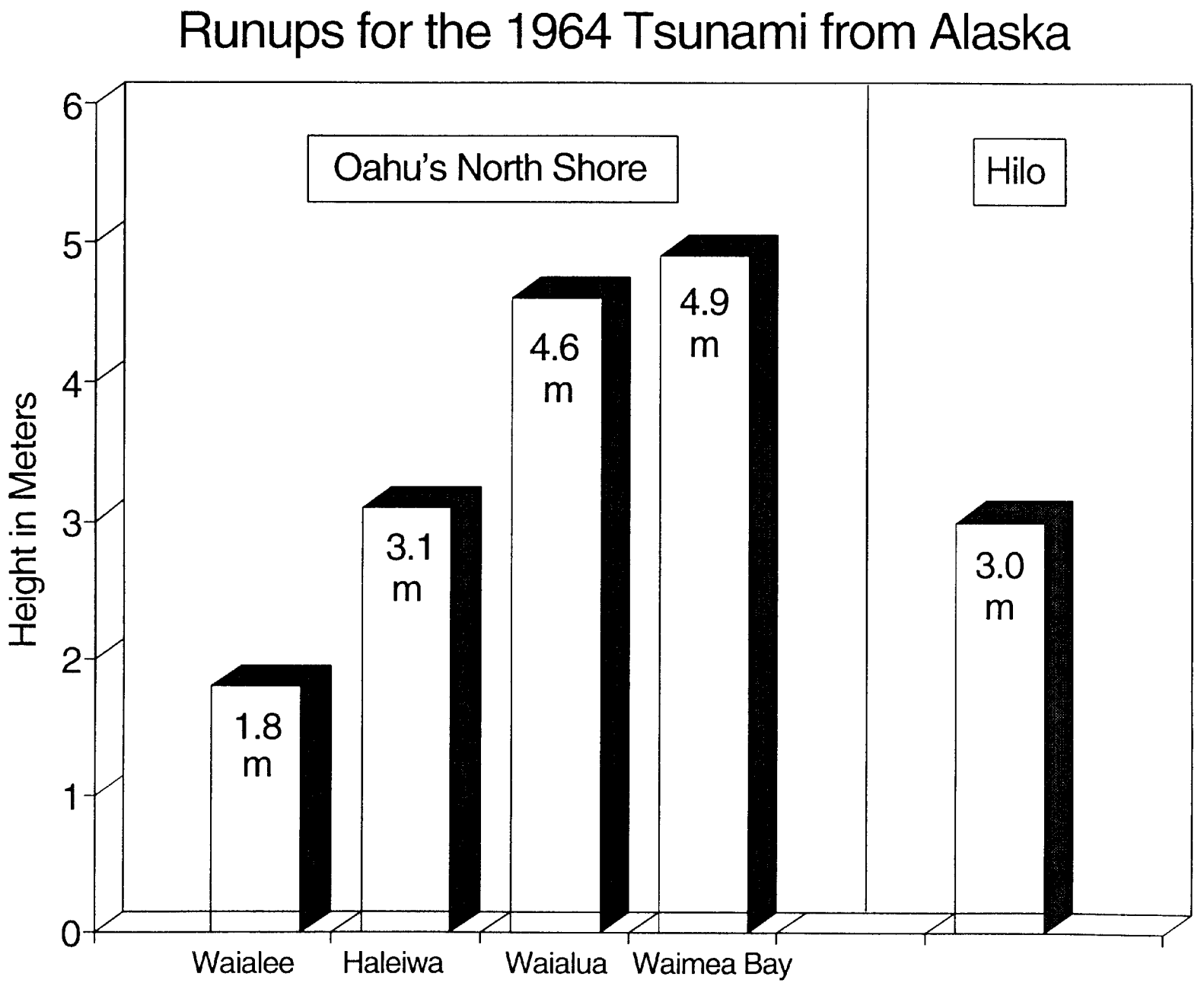


Figure 15a (Continued).

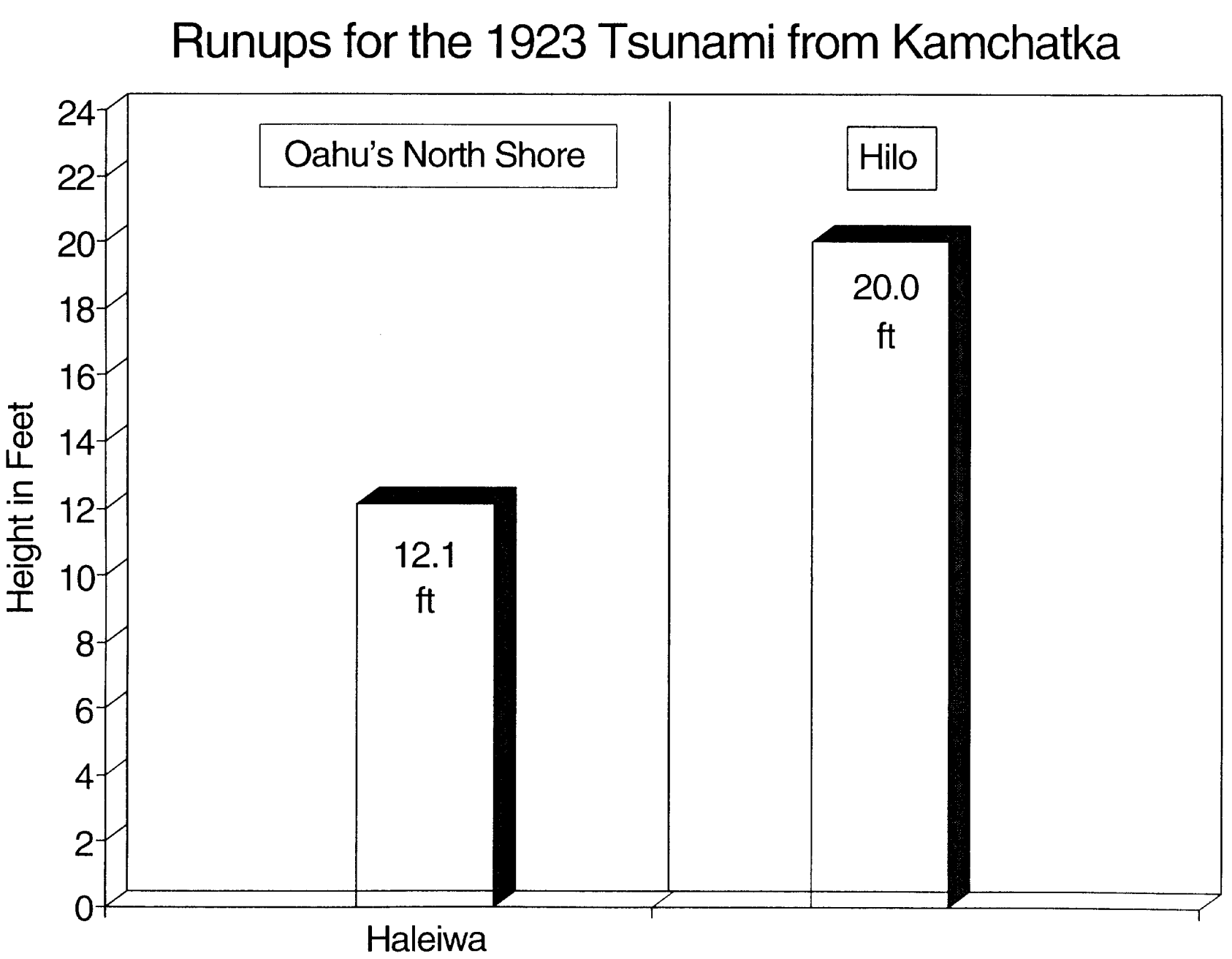

Runups for the 1923 Tsunami from Kamchatka
Oahu's North Shore
Hilo
Height in Feet
24
22
20
18
16
14
12
10
8
6
4
2
0
12.1
ft
20.0
ft
Haleiwa

Figure 15b.

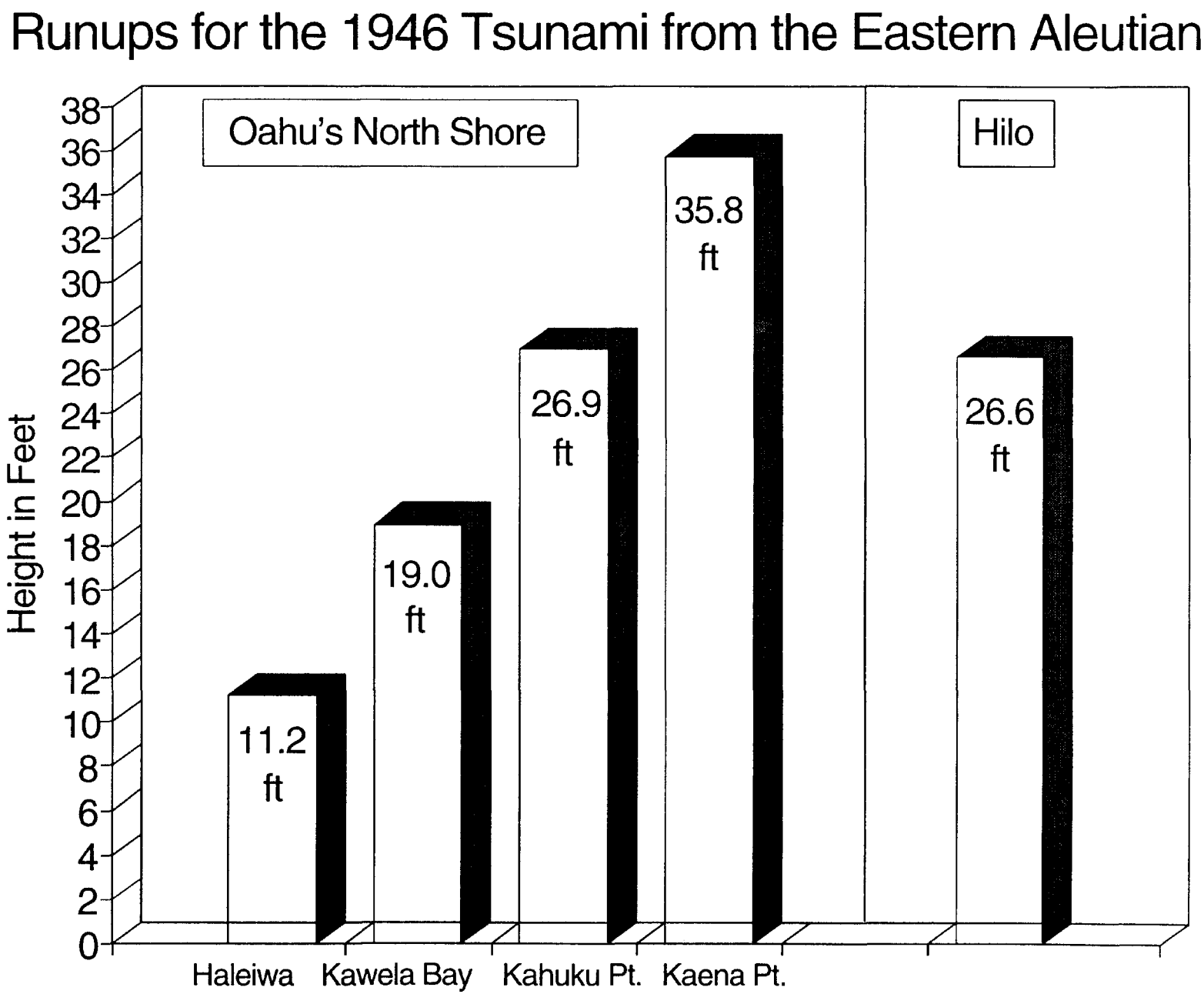


Figure 15b (Continued).

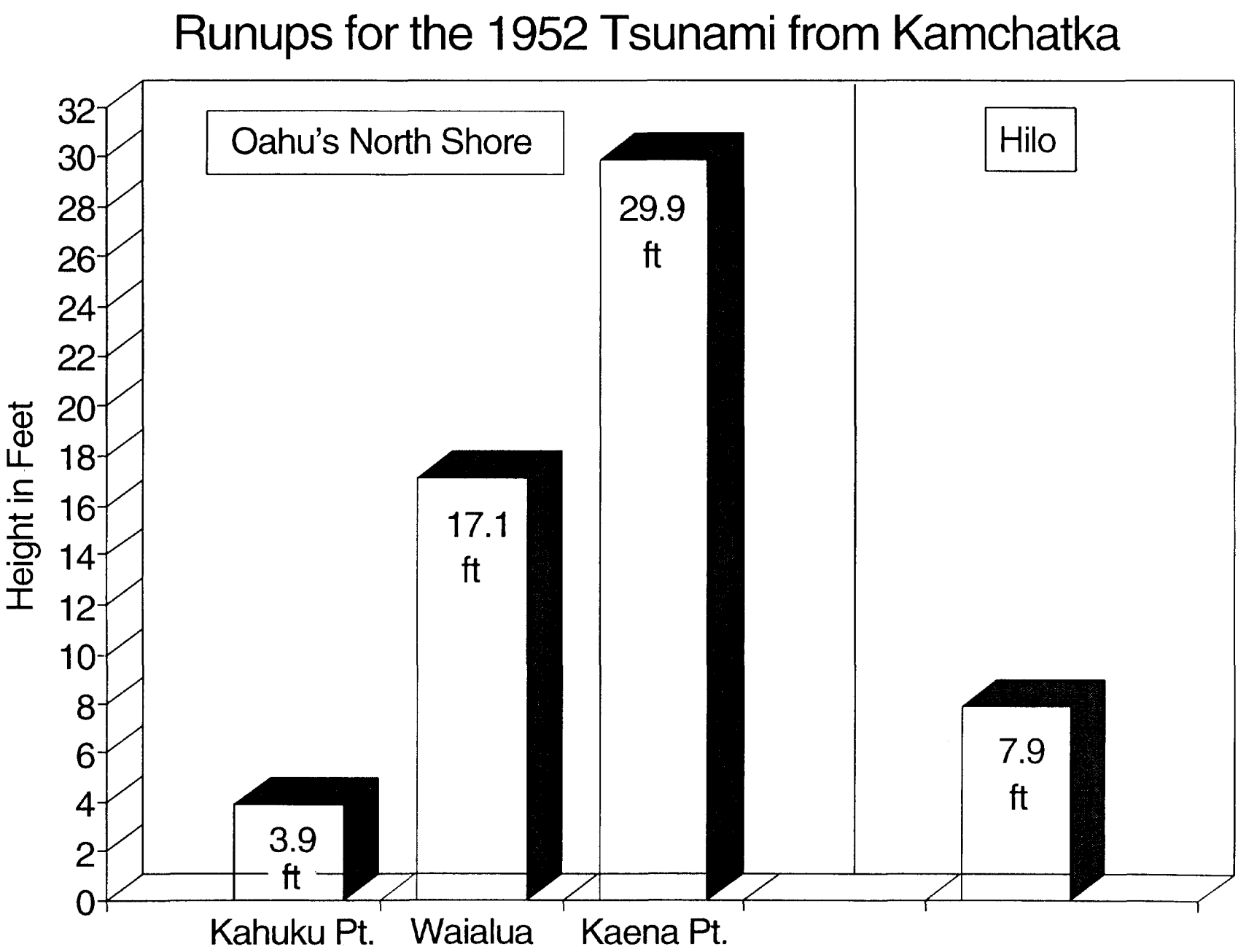


Figure 15b (Continued).

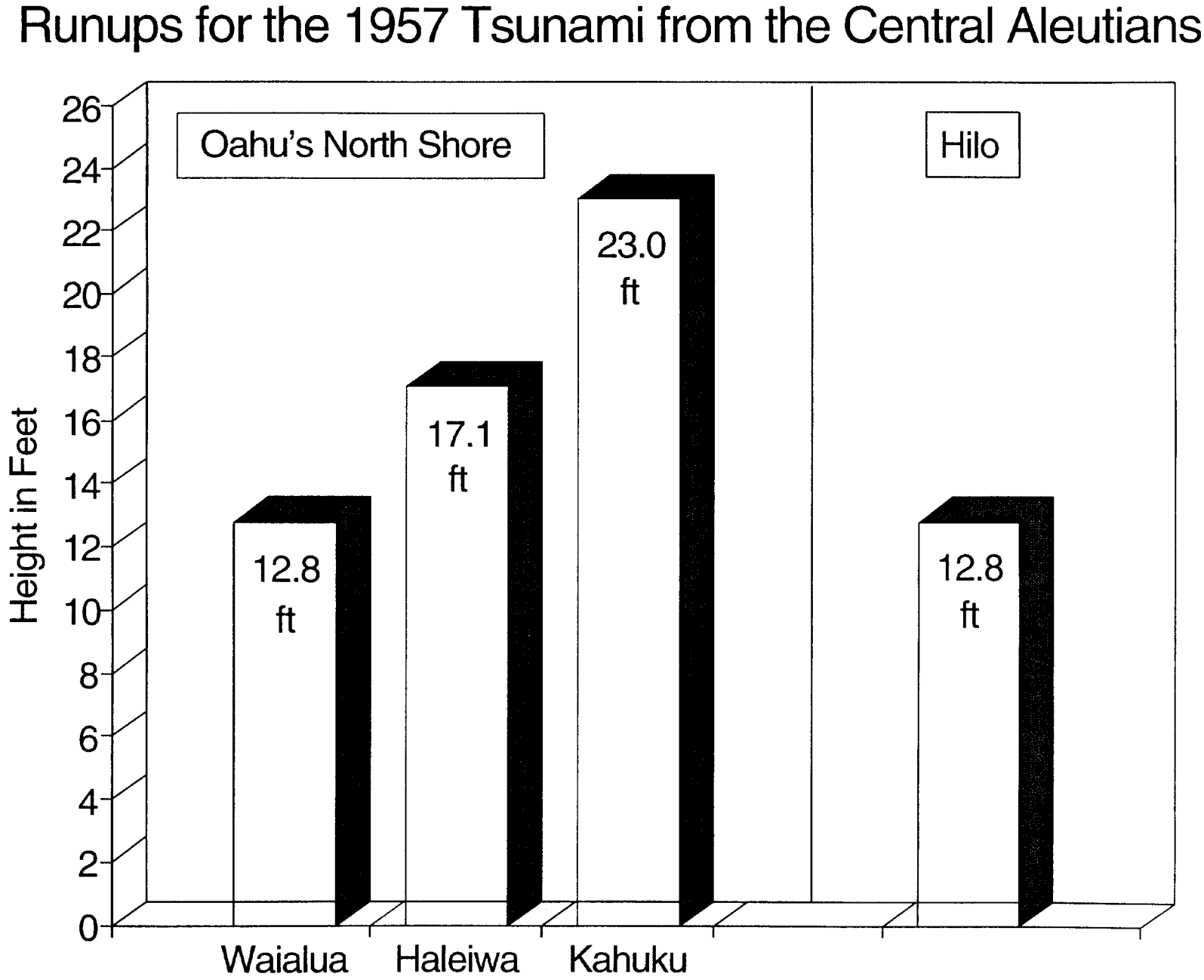


Figure 15b (Continued).

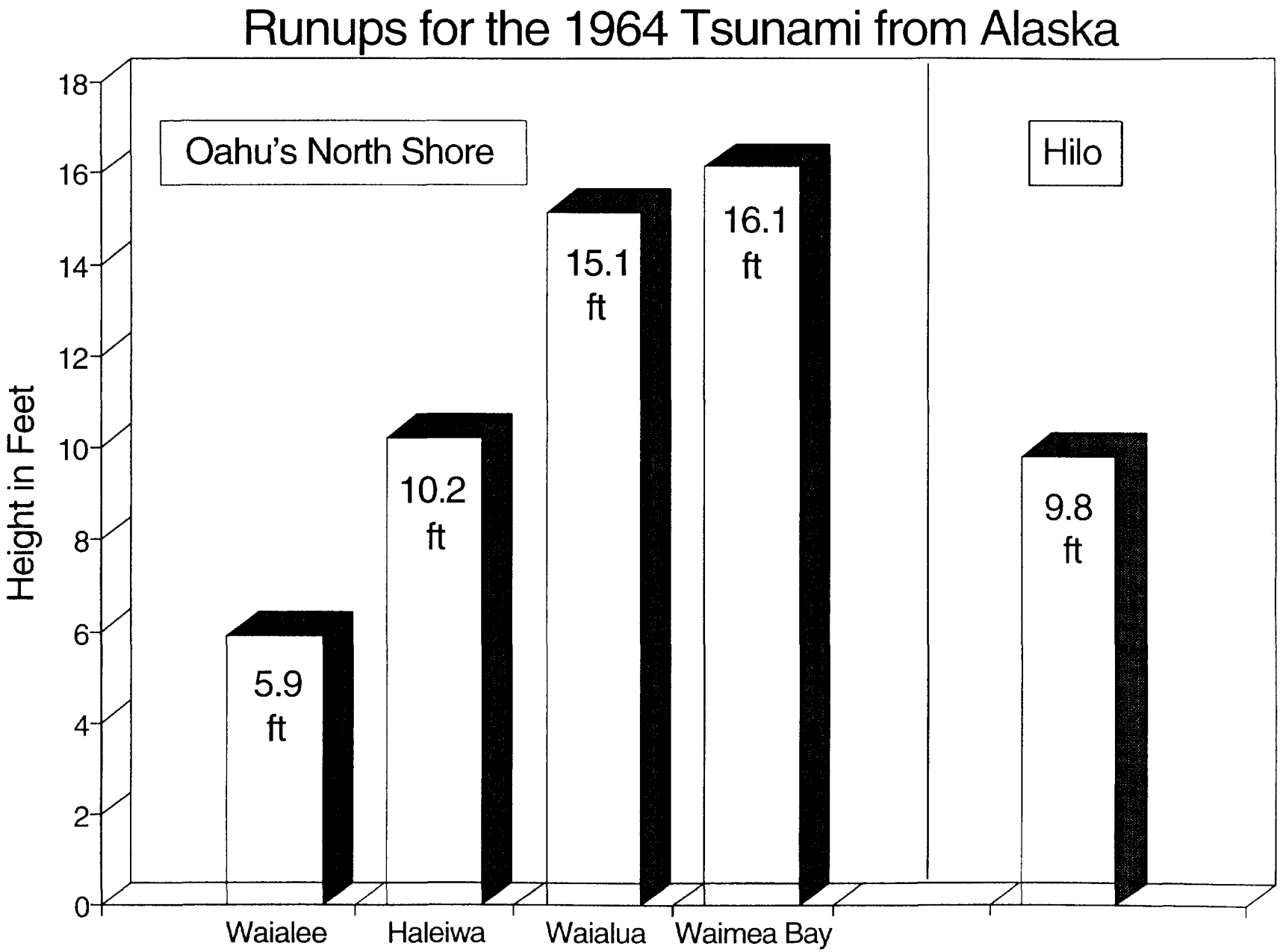


Figure 15b (Continued).

ISLAND-WIDE RUNUPS FOR THE 1 APRIL 1946 TSUNAMI

Figure 16 shows reported runups for the 1 April 1946 tsunami. This tsunami has the distinction of having both the largest runup and more reported runup values in the Hawaiian Islands than any other Pacific-wide tsunami in history. This earthquake had a surface wave magnitude of only 7.1 (Pacheco and Sykes, 1992).

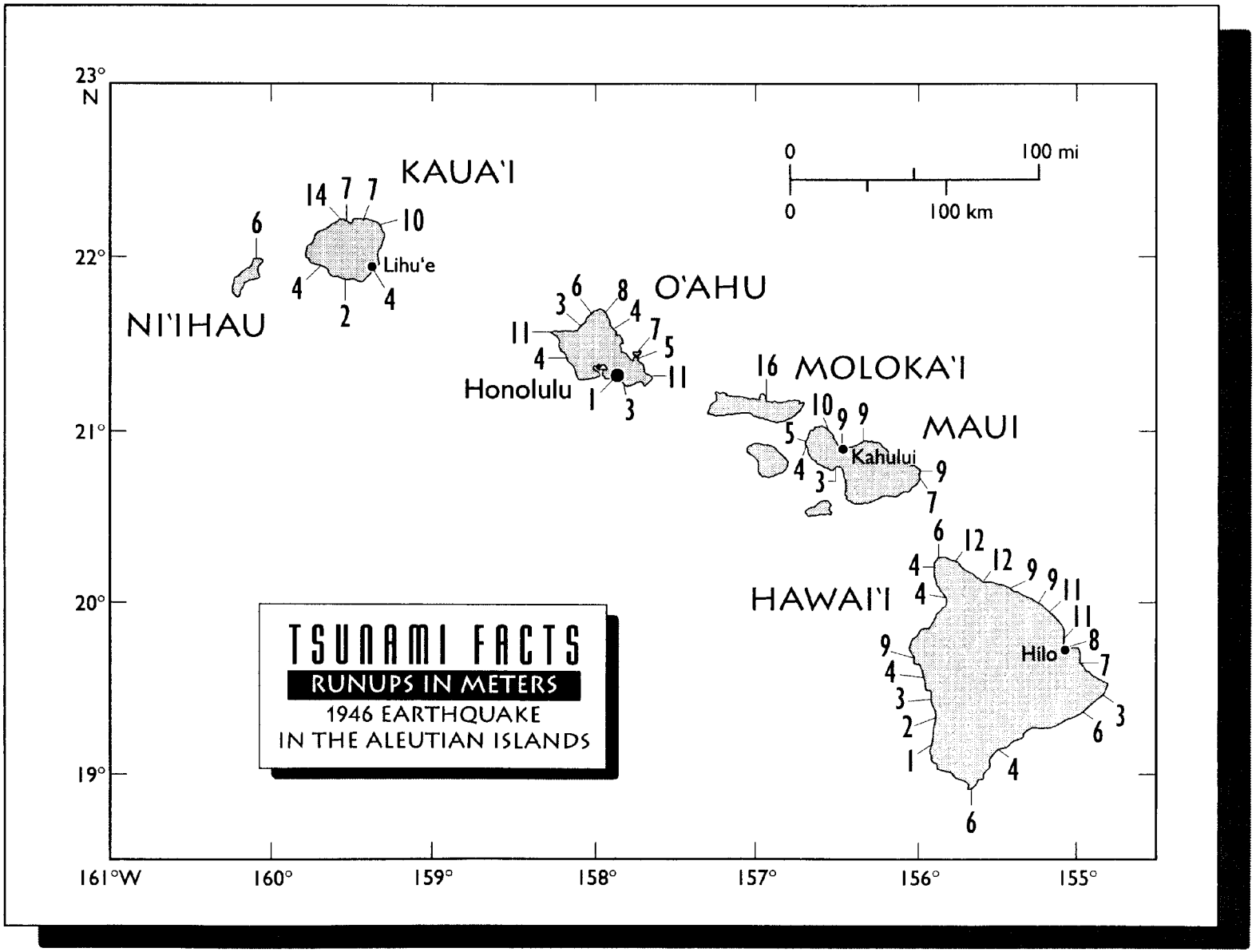

TSUNAMI FACTS
RUNUPS IN METERS
1946 EARTHQUAKE
IN THE ALEUTIAN ISLANDS
KAUA'I
NI'IHAU
O'AHU
Honolulu
MOLOKA'I
MAUI
Kahului
HAWAI'I
Hilo
Lihu'e
0 100 mi
0 100 km
23° N
22°
21°
20°
19°
161°W
160°
159°
158°
157°
156°
155°

Figure 16a

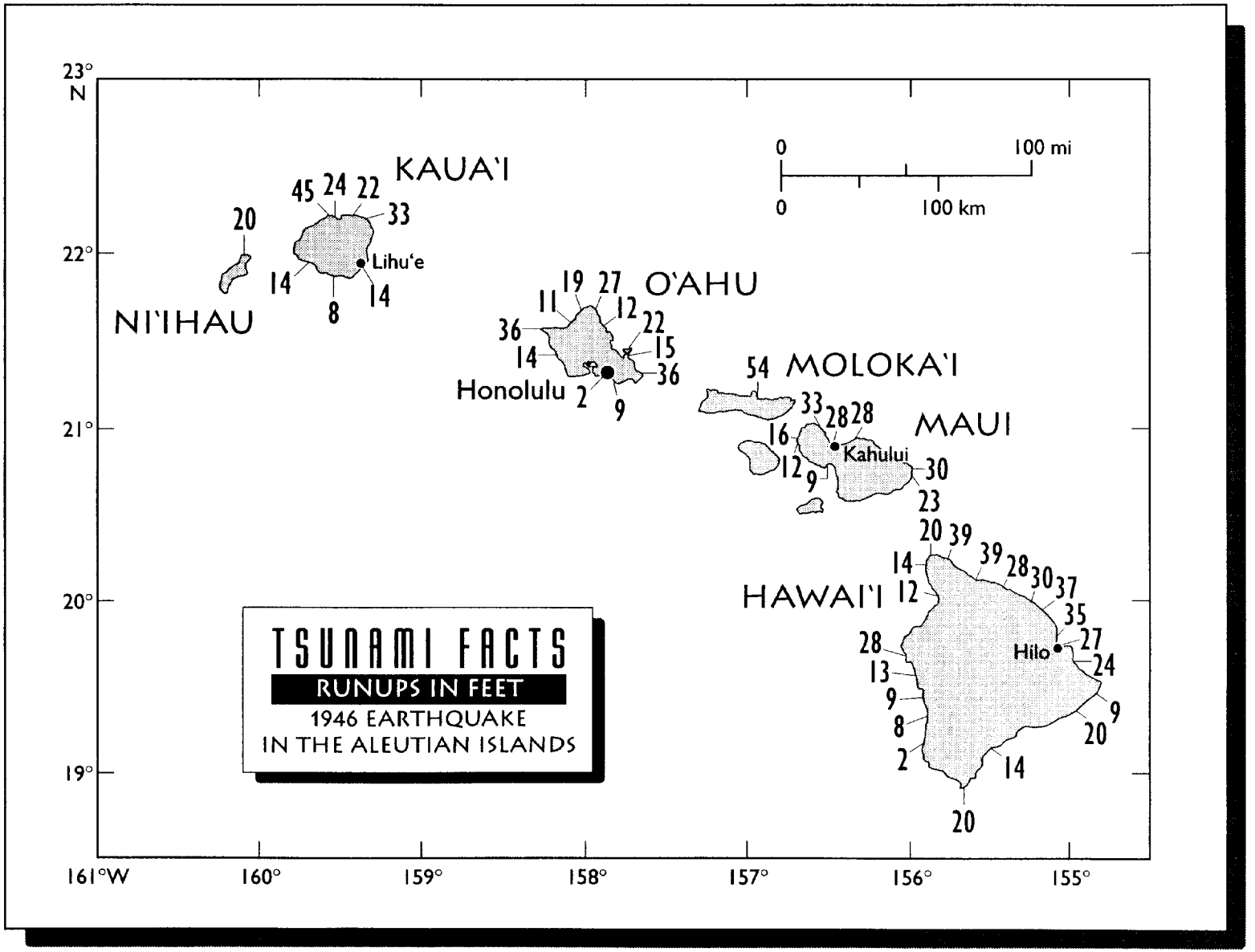

TSUNAMI FACTS
RUNUPS IN FEET
1946 EARTHQUAKE
IN THE ALEUTIAN ISLANDS
KAUA'I
NI'IHAU
O'AHU
MOLOKA'I
MAUI
HAWAI'I
Lihu'e
Honolulu
Kahului
Hilo
0 100 mi
0 100 km
23° N
22°
21°
20°
19°
161°W
160°
159°
158°
157°
156°
155°

Figure 16b.

TSUNAMI FACTS

- Tsunamis (also correctly called seismic sea waves and mistakenly called tidal waves) are produced by sudden changes of the sea-floor. These changes are caused by earthquakes which can occur at anytime along the margins of the Pacific Ocean or in Hawaii.
- In the deep ocean, tsunamis have very small amplitudes (the height of these waves may be only a few inches), long periods (the time required for two successive peaks to pass a particular location may be more than 45 minutes), and can travel with speeds of more than 500 miles per hour. Once a tsunamigenic earthquake has occurred along the margins of the Pacific, it maybe several hours before the tsunami strikes the Hawaiian Islands.
- As tsunamis encounter shallower water, their speed decreases and their amplitudes may increase to dangerous heights.
- Large tsunamis striking the Hawaiian Islands during this century have swept several hundred feet inland in low lying areas and have reported maximum heights of the sea surface in some of those inland areas of more than 50 feet.
- All of the major Hawaiian islands and all coasts are susceptible to large tsunamis. Also "wrap-around" effects may be significant. For example, a tsunami generated by an earthquake to the north of Hawaii in the Aleutian islands can "wrap-around" and have large amplitudes on the eastern, western, and southern shores, as well as northern shores, of many islands.
- A tsunami consists of a series of waves. Often the first wave is not the largest. The danger from a tsunami can last for several hours after the arrival of the first wave.
- Tsunamis can move faster than a person can run.
- Sometimes the first indication of a tsunami is a "sucking out", or drawdown, of water from a coastal area. This is very dangerous because it may cause curious people along the shore to walk out onto the newly exposed ocean floor. The drawdown can then be followed by a rapidly advancing wave which may catch those foolish enough to have remained in low lying coastal areas.

- For other tsunamis the first indication might be the disappearance of reefs or portions of offshore islands, or an unusual wall of water. In other instances a tsunami may merely be indicated by a gradual flooding of a low-lying area.
- The force of a tsunami can be enormous. Heavy equipment, such as large bulldozers, and large boulders weighing several tons have been moved hundreds of feet; homes and large buildings have been totally destroyed; and large trees have been ripped out of the earth. Without proper warnings, many people could be killed or injured by tsunamis.
- The unusual currents and loosened debris associated with a tsunami can also be very dangerous and destructive.
- From 1900 through 1965, 13 tsunamis with large amplitudes (i.e., wave heights of 3 or more feet) have struck the Hawaiian islands (an average of about one every five years).
- However, since 1965 no large tsunamis have struck Hawaii. Although we have been very lucky for many years, this "quiet period" has actually produced an increased danger because people in Hawaii have become less aware of tsunamis.
- In the next century we can expect the long-term average number of large tsunamis striking the Hawaiian Islands to be about one every five to ten years. However, as in the past, there could be significant short-term departures from these long-term averages.
- There is no perfect relationship between earthquake size and tsunami wave heights. For example, some earthquakes with Richter magnitudes of 7.0 to 7.9 have had larger tsunamis than those of earthquakes with magnitudes of 8.0 or greater.
- Although the Pacific Tsunami Warning Center (located in Ewa Beach, Oahu) may provide adequate warnings well in advance of the arrival of large tsunamis generated by earthquakes along the margins of the Pacific, there is a possibility that warnings for some parts of the State for tsunamis generated by earthquakes in Hawaii might not be issued soon enough. Also, even if the sirens are turned on well in advance of a potential tsunami, some individuals might not hear the sirens for a variety of reasons (e.g., other sources of noise, listening to loud music on headphones, being in remote coastal areas or under the ocean,

or malfunctioning sirens). In some of these situations, safety may depend on individual awareness.

- Civil Defense warning procedures, evacuation sites, and coastal areas of the State which may be damaged by a tsunami can be found in the front of your telephone book. Civil Defense procedures may vary from island to island, so be sure that you have a telephone book for your area.

WHAT YOU SHOULD DO

- Be aware of "Tsunami Facts." This knowledge could save your life!
- Tell your friends and relatives about these facts and tell them that tsunamis will again strike the Hawaiian Islands. This knowledge could save their lives!
- Tsunamis are rare events. Damaging tsunamis may occur on average only once every five or ten years. Occasionally they may be more frequent and sometimes there may be many years without any tsunamis. So you should enjoy Hawaii's beaches and coastlines, but be vigilant. You should be aware of the horizon or outer reefs for signs of unusually large waves; be aware of unusual lowerings of sea level; and try to have a planned rapid retreat to higher ground in case unusual wave conditions should begin to appear. If you feel the ground shake, or you know that a large local earthquake has just occurred, move immediately away from coastal areas to higher ground. Do not wait for the sirens to sound. If possible, advise other people in low lying areas of unusual observations.

SELF QUIZ

"Tsunami Facts" and "What You Should Do" provides information that could save your life or the lives of friends and relatives. The following quiz will allow you to evaluate your understanding of critical information.

1. Which of the following statements is true?

   (a) Tsunamis are produced by storms, and warnings for tsunamis will be given by State Civil Defense on the first business day of every month at 11:45 a.m.

   (b) Tsunamis are produced by earthquakes. They can occur at any time. If it has been determined that a tsunami may have been generated by an earthquake, Civil Defense will sound the sirens so that people can move from low lying areas. Turn on your radio or television for information, and check the front pages of your phone book to see if you are in an inundation area and to find the location of the nearest Civil Defense evacuation site.

2. If you are at the beach and the shoreline begins to move further and further out, exposing the ocean floor and portions of the reef, or if you see an unusually large wave on the horizon, you should:

   (a) take advantage of this once in a lifetime opportunity to explore the reef and to see a really large wave up close.

   (b) wait for sirens or instructions from government agencies before heading to higher ground.

   (c) move to higher ground immediately and tell as many people as you can of what you saw and why you are moving to safety.

3. You are camping along the coast of a remote valley on the northwestern shore of Kauai. You've heard on your short-wave radio that a powerful earthquake occurred in South America and that a Pacific-wide tsunami was generated. A warning has been issued for the Hawaiian Islands. You should:

   (a) not be concerned because only the southeastern shores will be affected by the tsunami.

   (b) wait for a siren to sound before evacuating your area.

   (c) move to higher ground and stay tuned to your radio. Do not wait for a siren to sound. One may not exist in that remote area. You already know from your radio that a warning has been issued and that tsunamis can wrap around islands.

4. You are scuba diving off Makaha. You come up to the surface and notice that everyone has left the beach. You should:

   (a) not be concerned. There is probably a big party somewhere. Finish your dive.

   (b) be concerned. An evacuation may be occurring. It may be due to an expected tsunami and you weren't able to hear the sirens. Tell others who are diving with you, and get out of the water as soon as possible. Move to higher ground and, in the process, try to find out what is happening.

5. A tsunami warning exists but news reports indicate that the earthquake was very far away and was only a 7.0 Richter magnitude. Which of the following statements is true?

   (a) A 7.0 is not that big—certainly not like the 1960 8.5 Chilean earthquake which produced a 35 foot tsunami in Hilo. So one should be careful, but not overly concerned. The tsunami will probably be small.

   (b) Some 7.0 earthquakes might produce very large tsunamis. Earthquake magnitude is not a perfect indicator of tsunami wave height. In fact a tsunami of 50 feet was reported along the northern coast of Molokai in 1946 from an earthquake in the Aleutian Islands with a magnitude of only 7.1. This earthquake generated large waves throughout the Hawaiian Islands and many people were killed.

6. You're checking the outside break at Hamoa Beach near Hana, Maui. You feel the ground shake and coconuts fall from the trees. You should:

   (a) get out into the break as soon as possible because some very large waves may soon be coming in from the Big Island.

   (b) tell the life guard to warn everyone in the water and move to higher ground as soon as possible. You may only have a few minutes before a tsunami strikes.

7. You think your home may be in an inundation area and you hear sirens. You turn on your radio and find that a tsunami warning has just been issued. You should:

   (a) run to higher ground as soon as possible.

   (b) check the front of your phone book to see if you are in an inundation area. If you are, also find the nearest evacuation site in the phone book. If possible, turn off the gas, water, and electricity coming into your home. Go to the evacuation site or any safe place outside of an inundation area. Move in an orderly, calm, and safe manner. If you can't determine whether your home is in an inundation area, it is best to move to higher ground.

8. If you are at school and you hear the Civil Defense sirens, you should:

   (a) move to higher ground.

   (b) follow the advice of your teachers or other school personnel.

9. What is "higher" ground?

   (a) 3 feet above sea level.

   (b) 10 feet above sea level.

   (c) The greatest tsunami wave height reported for the Hawaiian Islands in this century is about 50 feet. You should move out of inundation zones or to elevations of more than 50 feet as soon as you can do so in a safe manner.

10. Because of the threat of tsunamis, you should:

    (a) move to the mainland, preferably to Kansas or Iowa.

    (b) move to the middle of the island and stay in your house.

    (c) never go to the beach.

    (d) be alert; know about tsunamis; share your knowledge; save "Tsunami Facts", "What You Should Do", and this "Self Quiz" for future reference; and enjoy Hawaii's beautiful beaches, coastlines, and ocean as much as possible.

Answers: For all ten questions, the last choice is the best answer.

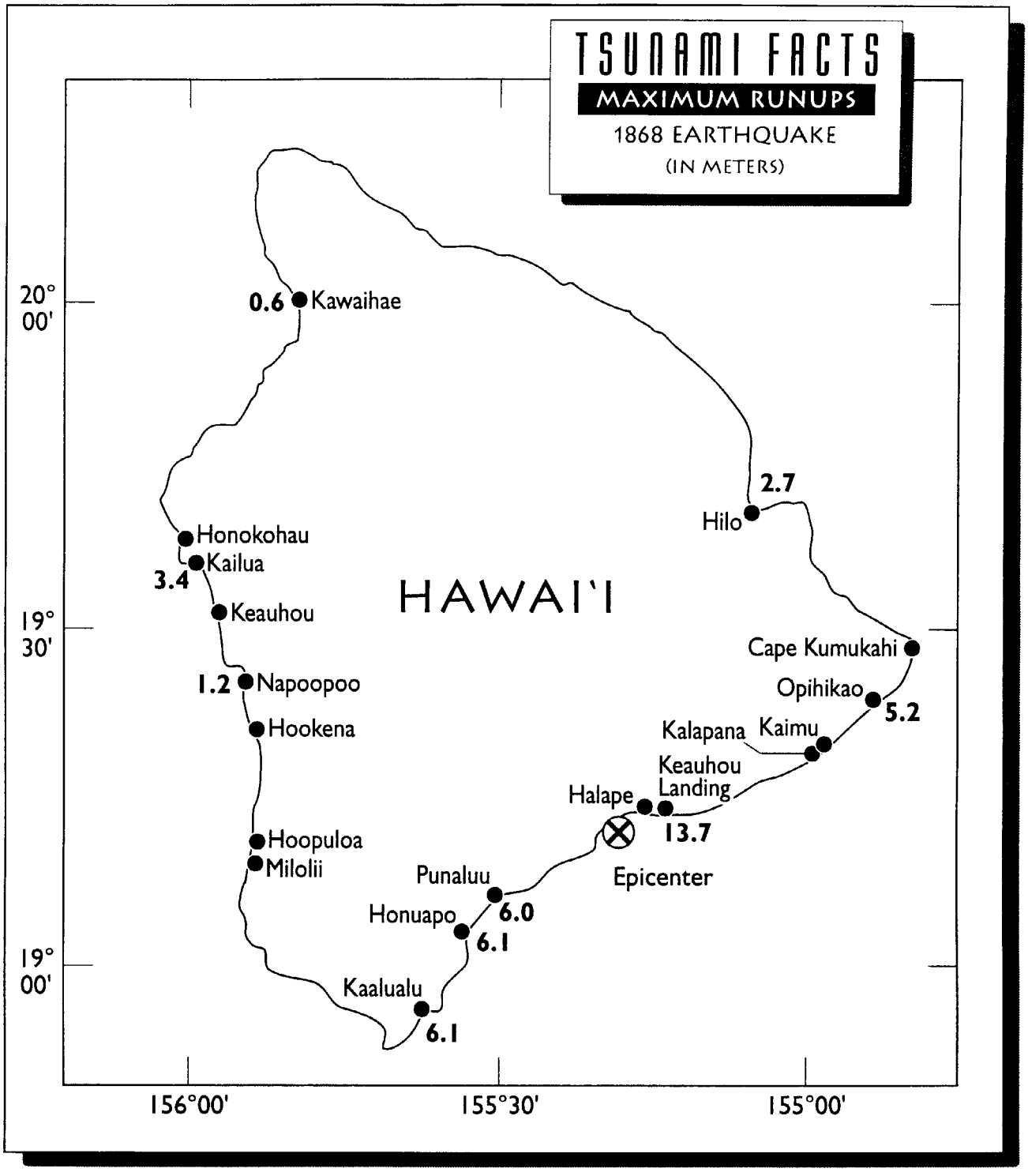
ACKNOWLEDGMENTS

This information is provided as part of an effort to increase tsunami awareness and education. This effort is supported by the Department of Education, State Civil Defense, the School of Ocean and Earth Science and Technology (SOEST) of the University of Hawaii, the International Tsunami Information Center, and the Pacific Tsunami Warning Center. We thank Kehaulani and Ian Walker for assistance with portions of the report, and Walter Dudley, University of Hawaii at Hilo, for his valuable comments and suggestions. Graphics were provided by Brooks Bays and Nancy Hulbirt. SOEST Technical Report 94-03. Hawaii Institute of Geophysics and Planetology contribution number 757 and Joint Institute for Marine and Atmospheric Research contribution number 94-271. A publication of the University of Hawaii pursuant to National Oceanic and Atmospheric Administration award number NA90RAH00074.

APPENDIX I

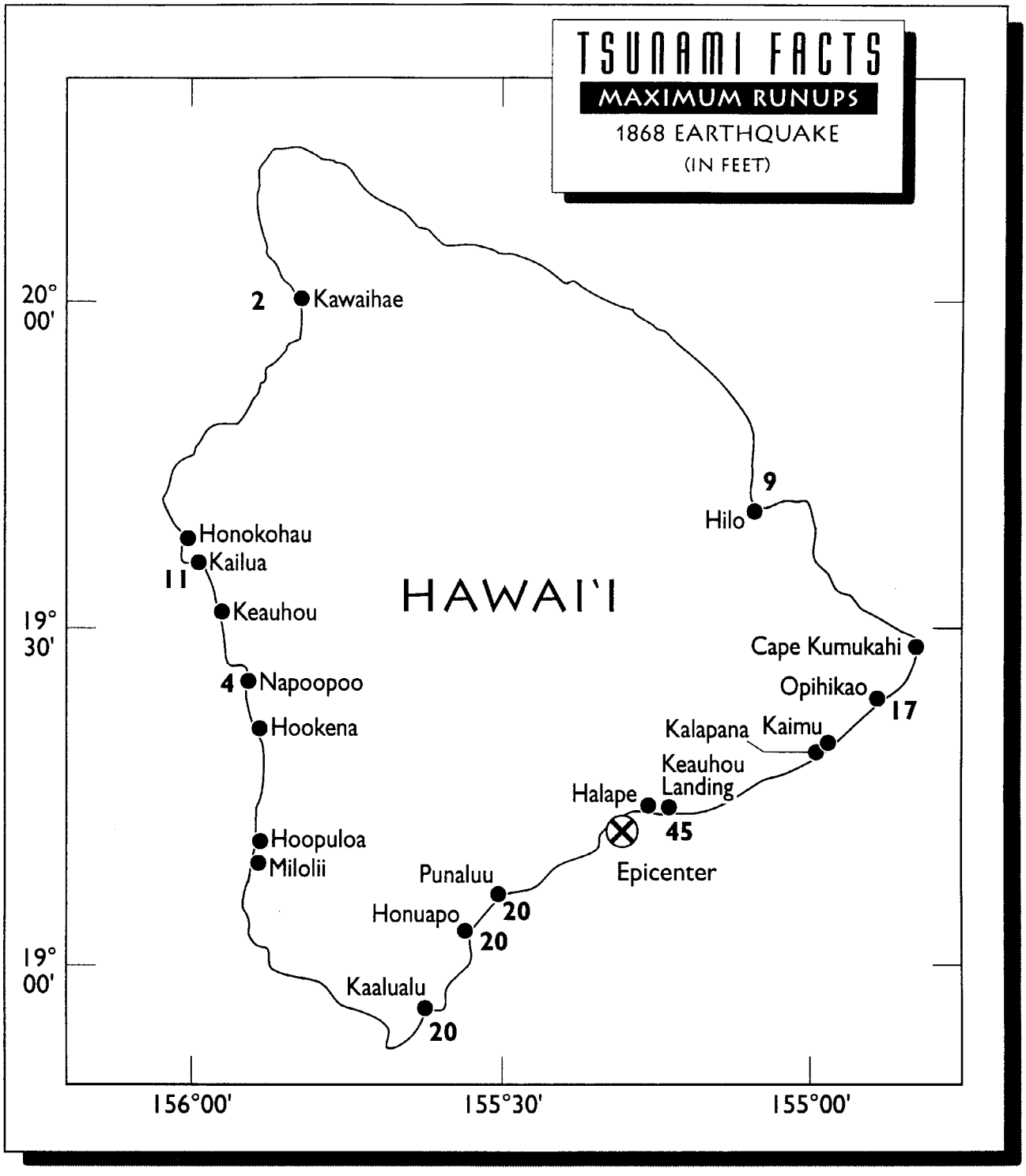
Locally Generated Tsunamis

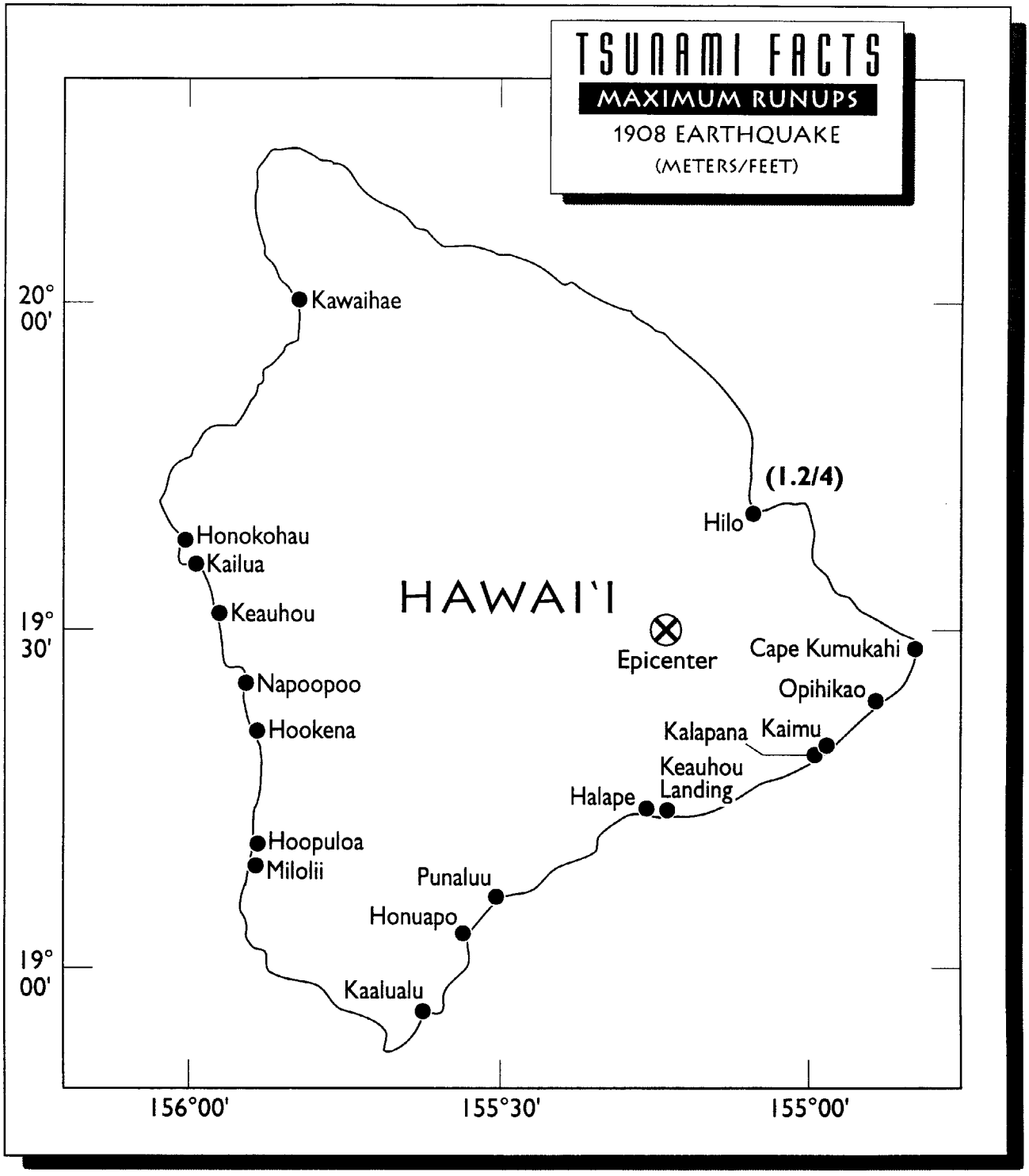
Tsunami runup data and earthquake epicenters are taken from Lander and Lockridge (1989; a complete reference is given on page 9). Only runups associated with confirmed locally generated tsunamis are plotted.



Additional notes:

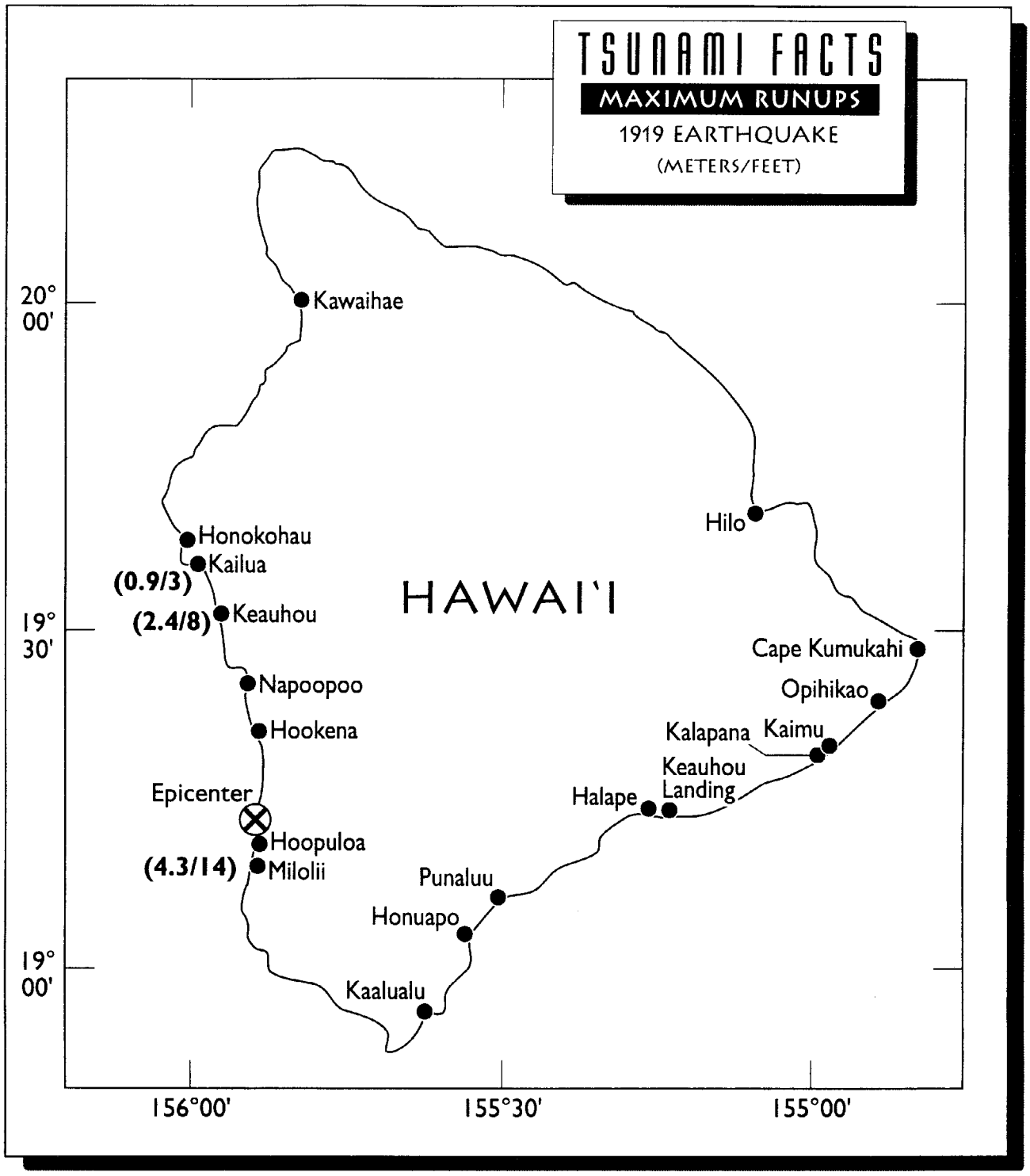
Honolulu, Oahu—0.6 meters
Lahaina, Maui—observed
Earthquake magnitude = 7.5


TSUNAMI FACTS
MAXIMUM RUNUPS
1868 EARTHQUAKE
(IN FEET)
20° 00'
19° 30'
19° 00'
156°00'
155°30'
155°00'
HAWAI'I
2
Kawaihae
9
Hilo
Honokohau
Kailua
11
Keauhou
4
Napoopoo
Hookena
Hoopuloa
Milolii
Cape Kumukahi
Opihikao
17
Kalapana
Kaimu
Keauhou Landing
Halape
45
Epicenter
Punaluu
20
Honuapo
20
Kaalualu
20



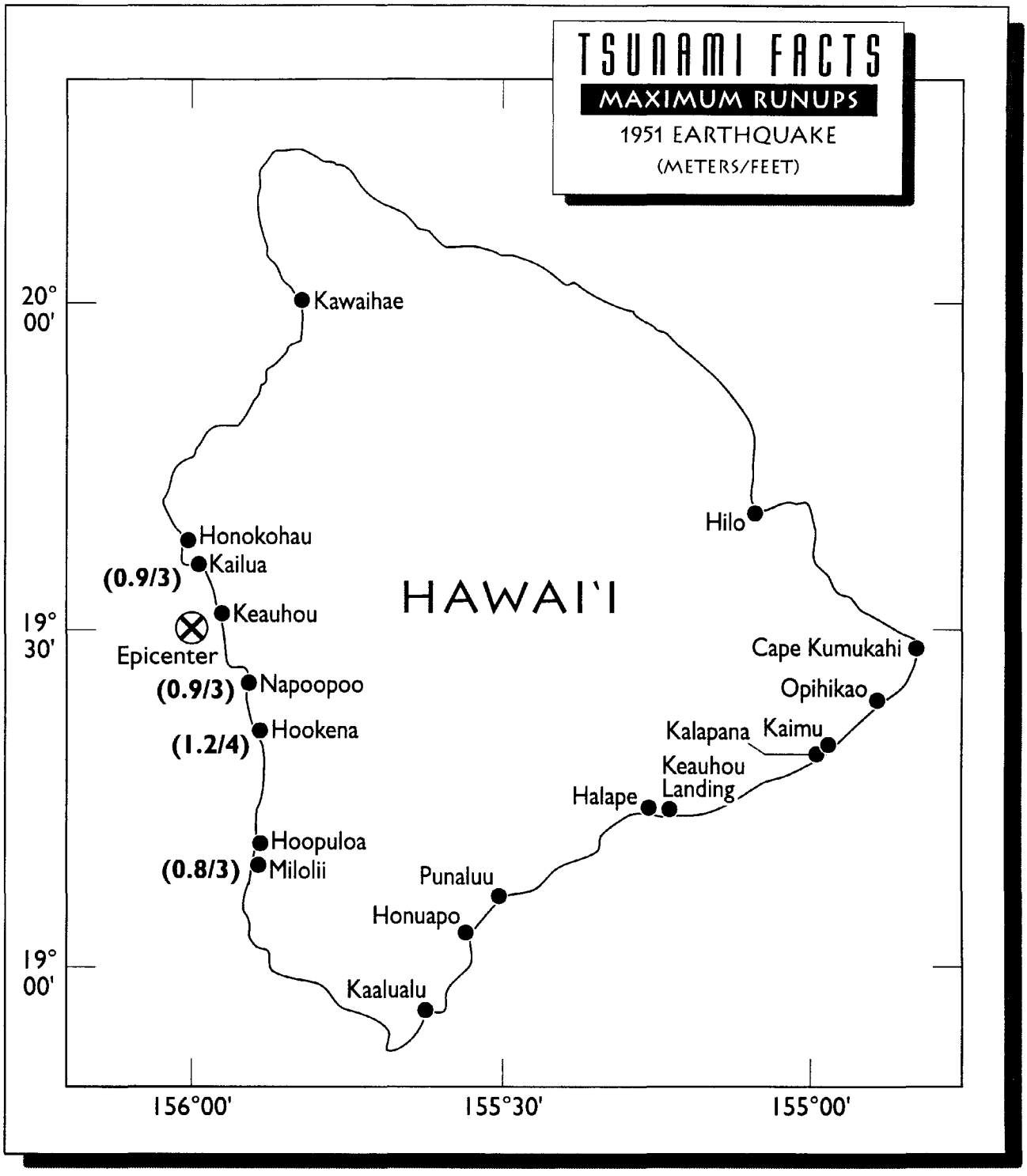
Additional notes:

Earthquake magnitude = 6.8



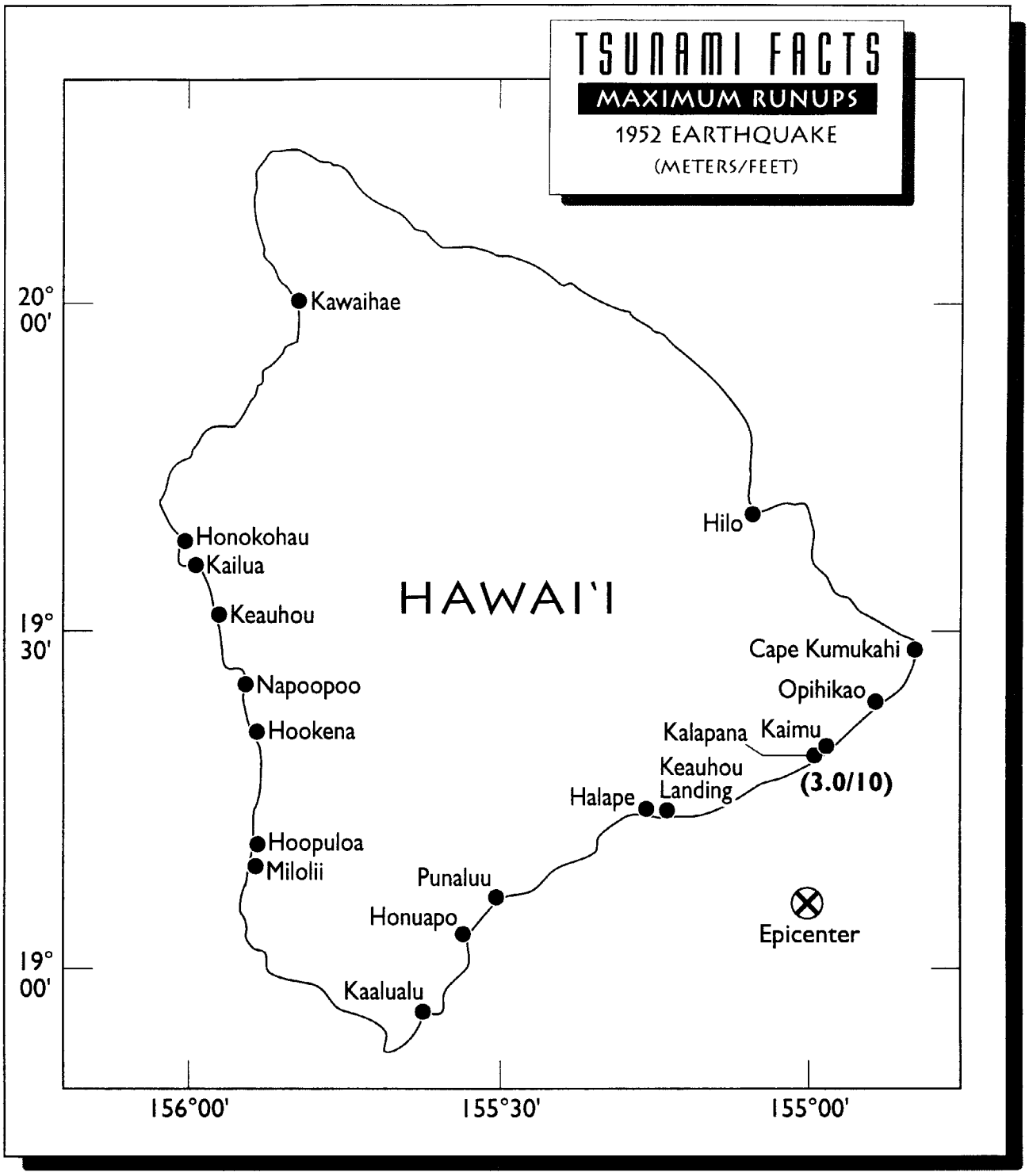
Additional notes:

Presumed epicenter. Tsunami seems to have been associated with submarine collapse near Alika Bay. No magnitude estimate is available.



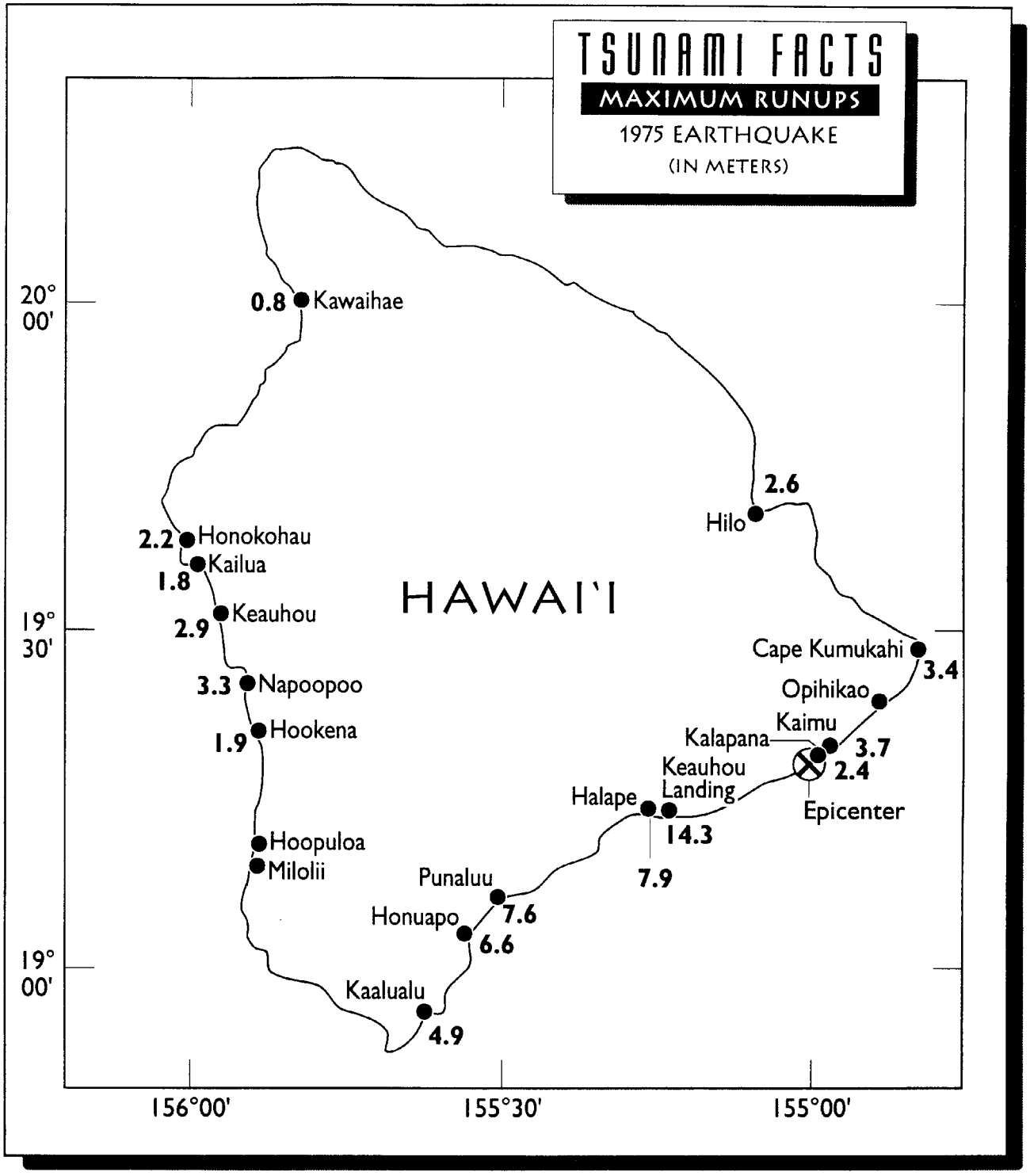
Additional notes:

Hilo, Hawaii—< 0.1 meters
Honolulu, Oahu—< 0.1 meters
Port Allen, Kauai—< 0.1 meters
Earthquake magnitude = 6.9



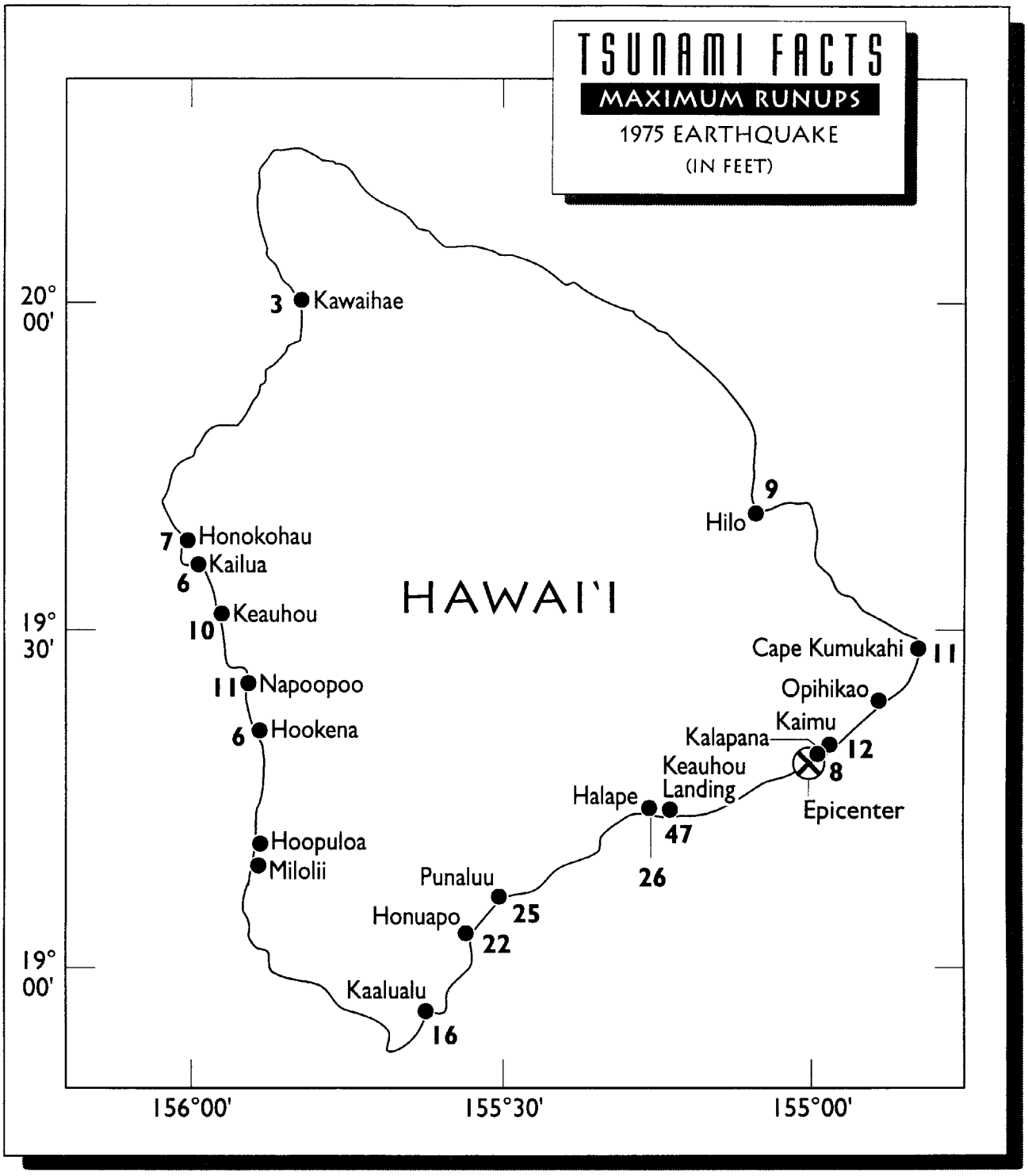
Additional notes:

Earthquake magnitude = 4.5



Additional notes:

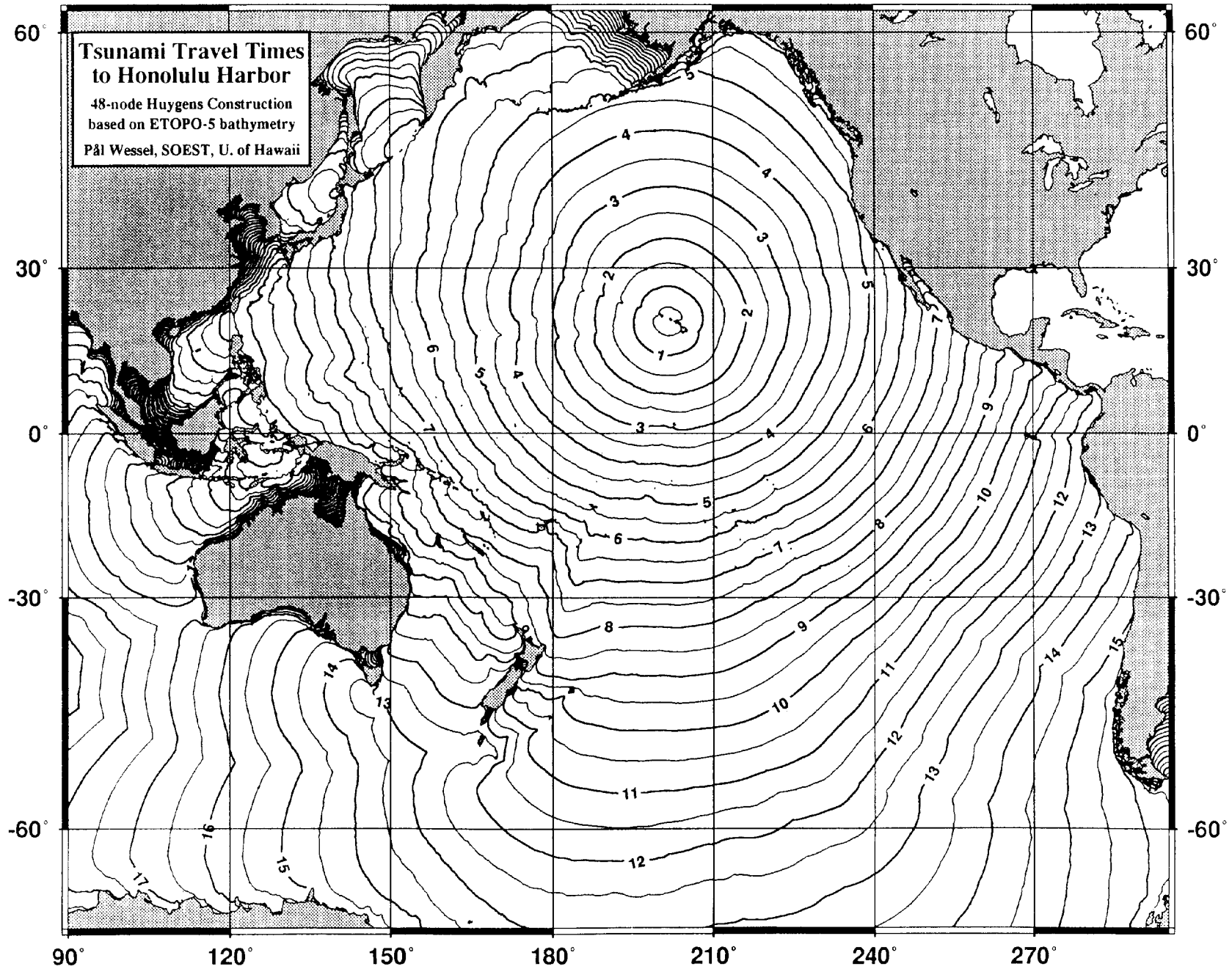
Honolulu, Oahu–< 0.1 meters
Hana, Maui—observed
Kahului, Maui—0.4 meters
Lahaina, Maui—observed
Nawiliwili, Kauai—0.1
Earthquake magnitude = 7.2


TSUNAMI FACTS
MAXIMUM RUNUPS
1975 EARTHQUAKE
(IN FEET)
HAWAI'I
20° 00'
19° 30'
19° 00'
156°00'
155°30'
155°00'
3 Kawaihae
9 Hilo
7 Honokohau
Kailua
6
Keauhou
10
11 Napoopoo
6 Hookena
Hoopuloa
Milolii
Punaluu
25
Honuapo
22
Kaalualu
16
Cape Kumukahi 11
Opihikao
Kaimu
Kalapana
12
8
Epicenter
Keauhou Landing
Halape
47
26

APPENDIX II

Tsunami Travel Times to Honolulu

These computations were made by Pål Wessel of the School of Ocean and Earth Science and Technology at the University of Hawaii. As examples of how to use this plot, note that tsunamis originating in Chile might take about 15 hours to reach Honolulu and some tsunamis originating in the Aleutian Islands would arrive in about 5 hours.


Tsunami Travel Times
to Honolulu Harbor
48-node Huygens Construction
based on ETOPO-5 bathymetry
Pål Wessel, SOEST, U. of Hawaii
60°
30°
0°
-30°
-60°
90°
120°
150°
180°
210°
240°
270°