UNITED STATES TSUNAMIS
(INCLUDING UNITED STATES POSSESSIONS)

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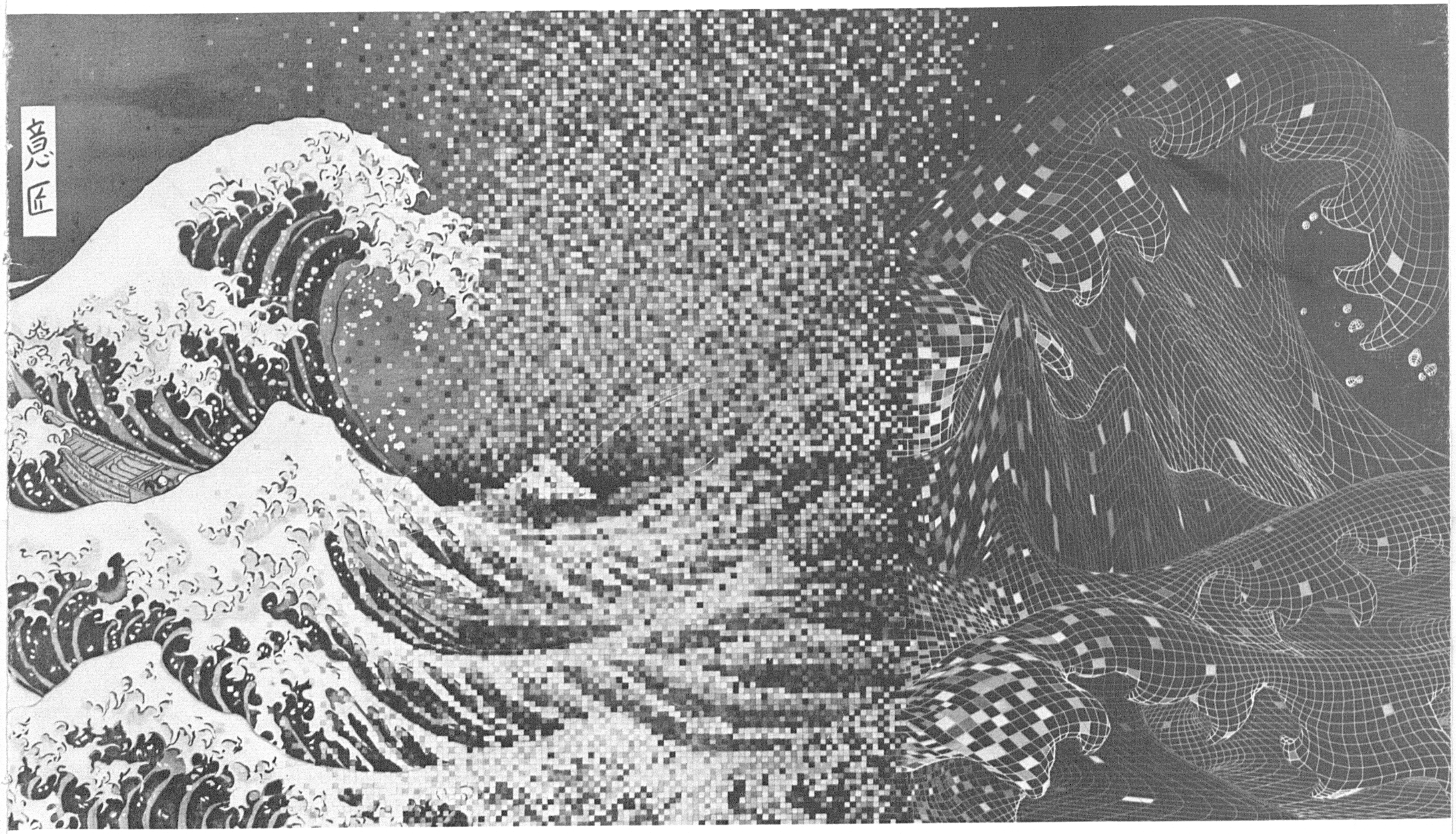

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service
National Geophysical Data Center
Boulder, Colorado
August 1989

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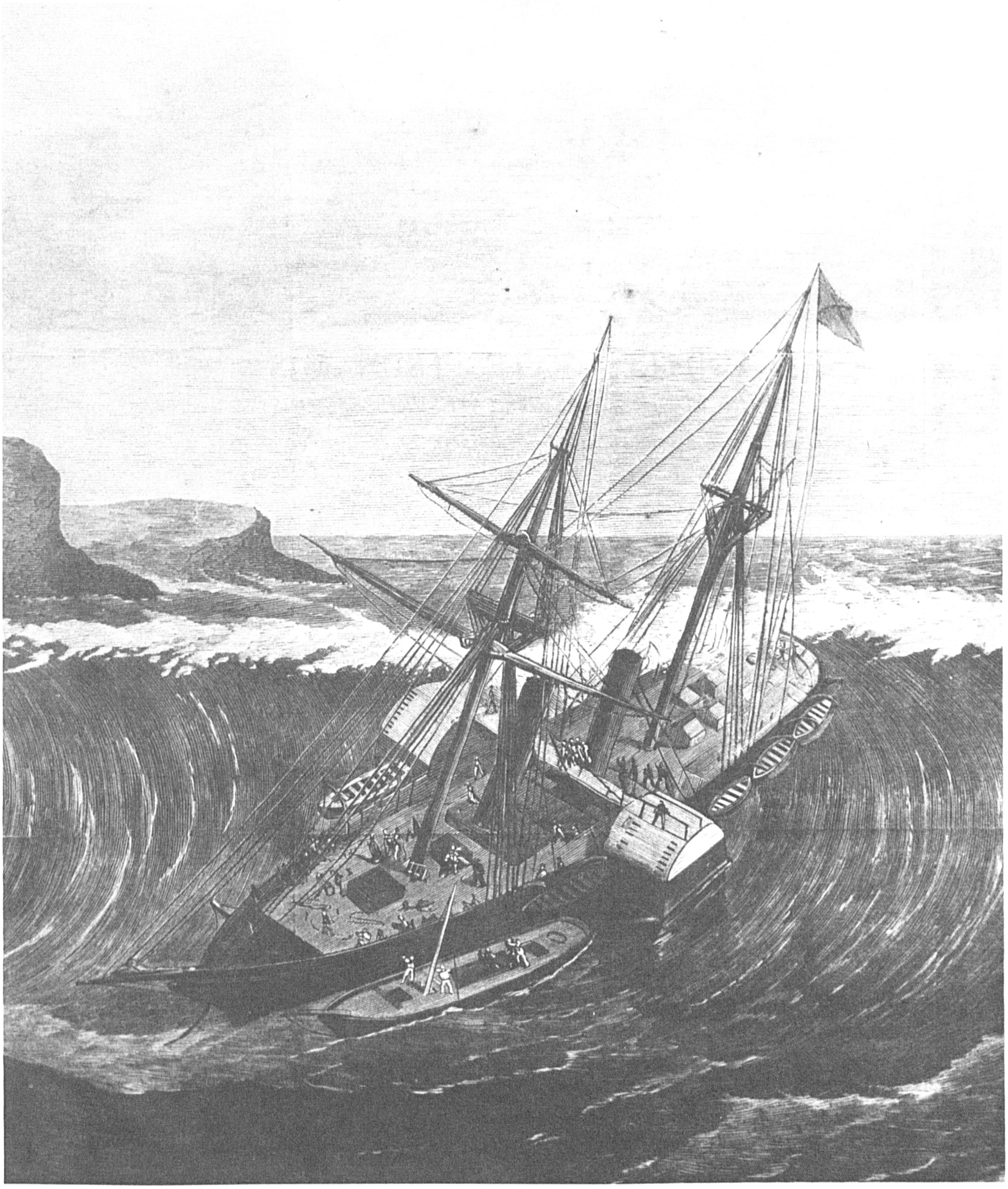

Frontispiece: The Royal Mail Steamer *La Plata* anchored near the southern point of Water Island about 4 km from Charlotte Amalie engulfed by the tsunami of November 18, 1867. Lithograph Credit: Harper's Weekly.

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UNITED STATES TSUNAMIS

(INCLUDING UNITED STATES POSSESSIONS)

1690-1988

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Finally, we thank the compilers of earlier regional catalogs. These are: *Catalog of Tsunamis in Alaska* by Doak C. Cox and George Pararas-Carayannis, and *Catalog of Tsunamis in Hawaii* by George Pararas-Carayannis, both with revisions by Jeffrey P. Calebaugh; *Catalog of Tsunamis in the Samoan Islands* by George Pararas-Carayannis and Bonnie Dong; and D. S. McCulloch's compilation and discussion of California tsunamis in *Evaluating Earthquake Hazards in the Los Angeles Region*, United States Geological Survey Professional Paper 1360.

Additionally, there were many scientists and others who responded to our direct requests for information. Doak Cox, whose name appears prominently above and who authored many other valuable reports, helped us on numerous other questions in a lively correspondence. During a sabbatical at the National Geophysical Data Center (NGDC) in 1980 he significantly improved the basic list of tsunamis, including locating the source of the 1872 tsunami in the Aleutian Islands. Together we were recently able to convert a vague 1813-1814 date for the earliest dated Hawaiian tsunami to a probable December 21, 1812 date associated with the Santa Barbara earthquake. V. J. Grouzinis, J.W. Joy and R.R. Putz generously shared their comments on their ongoing research on the southern California tsunami of 1812, and Joy has provided additional material and comments on California tsunamis. William McCann of the U.S. Geological Survey and Joseph Fischer of Geoscience Service supplied key additional information and comments on the tsunami of 1867 in the Virgin Islands. Poul Olsen, Danish Archivist, provided the key information clarifying the date of the 1690 tsunami. Jerome Kisslinger and John Davies provided manuscript material on their catalog of Alaskan earthquakes. Stephen Gill, Tidal Analysis Section, and Elmo Long, Tide and Current Prediction Section, both of NOAA, provided help in retrieving old marigrams and providing "predictions" of tides before tide gages were in use. George Carte and Paul Whitmore of the NOAA Alaskan Regional Tsunami Warning Center provided details for several of the Alaskan tsunamis. Sydney Wigen, Tide and Tsunami Services, Ltd., checked the Tofino, B.C. Canada marigrams for evidence of tsunamis which could have been produced by large Alaskan earthquakes. Bernard F. Cavalcante of the U.S. Naval Historical Center provided information of tsunami effects at Midway and other Pacific islands.

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James F. Lander
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1. INTRODUCTION

Tsunamis, commonly called seismic sea waves--or incorrectly, tidal waves--have been responsible for at least 470 fatalities and several hundred million dollars in property damage in the United States and its territories. These events are somewhat rare. Major tsunamis occur in the Pacific Ocean region only about once per decade. Therefore, it is important to learn as much as possible from the relatively short history available.

The preparation of this history was undertaken because of the evident need for an up-to-date and comprehensive compilation. The previously available history of tsunamis in the United States and environs was scattered through several regional catalogs, research papers, and unpublished works. The continued research of several people has improved these now-dated catalogs. The present history incorporated all works known to the compilers into a single, comprehensive volume.

"Tsunami" is a Japanese word meaning "harbor wave." It is a water wave or a series of waves generated by an impulsive vertical displacement of the surface of the ocean or other body of water. Other terms for "tsunami" found in the literature include: seismic sea wave, Flutwellen, vloedgolven, raz de marée, vagues sismique, maremoto, and, incorrectly, tidal wave. The term "tidal wave" is frequently used in the older literature and in popular accounts, but is now considered incorrect. Tides are produced by the gravitational attraction of the sun and moon and occur predictably with twelve hour periods. The effects of a tsunami may be increased or decreased depending on the level of the tide, but otherwise the two phenomena are independent.

Although there are warning systems for tsunamis occurring around the Pacific, including local and regional warning systems in Hawaii and Alaska, the risks from future tsunamis are still not fully known. Some events, such as that in Prince William Sound, Alaska, in March 1964, can be devastating over large distances. Even over short distances along a coast, the heights of a tsunami wave will vary considerably. An important part of the risk assessment is to gain a clearer understanding of the effects of past tsunamis.

1.1 WORLDWIDE OCCURRENCE OF TSUNAMIS

Tsunamis have been reported since ancient times. They have been documented extensively, especially in Japan and the Mediterranean areas. The first recorded tsunami occurred off the coast of Syria in 2000 B.C. Since 1900 (the beginning of instrumentally located earthquakes), most tsunamis have been generated in Japan, Peru, Chile, New Guinea and the Solomon Islands. However, the only regions that have generated remote-source tsunamis affecting the entire Pacific Basin are the Kamchatka Peninsula, the Aleutian Islands, the Gulf of Alaska, and the coast of South America. Hawaii, because of its location in the center of the Pacific Basin, has experienced tsunamis generated in all parts of the Pacific.

The Mediterranean and Caribbean Seas both have small subduction zones, and have histories of locally destructive tsunamis. Only a few tsunamis have been generated in the Atlantic and Indian Oceans. In the Atlantic Ocean, there are no subduction zones at the edges of plate boundaries to spawn such waves except small subduction zones under the Caribbean and Scotia arcs. In the Indian Ocean, however, the Indo-Australian plate is being subducted beneath the Eurasian plate at its east margin. Therefore, most tsunamis generated in this area are propagated toward the southwest shores of Java and Sumatra, rather than into the Indian Ocean.

1.2 TSUNAMI CHARACTERISTICS

Most tsunamis are caused by a rapid vertical movement along a break in the Earth's crust (i.e., their origin is tectonic). A tsunami is generated when a large mass of earth on the bottom of the ocean drops or rises, thereby displacing the column of water directly above it. This type of displacement commonly occurs in large subduction zones, where the collision of two tectonic plates causes the oceanic plate to dip beneath the continental plate to form deep ocean trenches. Most shallow earthquakes occur offshore in these trenches.

Subduction occurs along most of the island arcs and coastal areas of the Pacific, the notable exception being the west coast of the United States and Canada. Movement along the faults there is largely strike-slip, having little vertical displacement, and the movement produces few local tsunamis.

Volcanoes have generated significant tsunamis with death tolls as large as 30,000 people from a single event. Roughly one fourth of the deaths occurring during volcanic eruptions where tsunamis were generated, were the result of the tsunami rather than the volcano. A tsunami is an effective transmitter of energy to areas outside the reach of the volcanic eruption itself. The most efficient methods of tsunami generation by volcanoes include disruption of a body of water by the collapse of all or part of the volcanic edifice, subsidence, an explosion, a landslide, a glowing avalanche, and an earthquake accompanying or preceding the eruption. Roughly one-half of all volcanic tsunamis are generated at calderas or at cones within calderas. Submarine eruptions may also cause minor tsunamis.

Locally destructive tsunamis may be generated by subaerial and submarine landslides into bays or lakes. Lituya Bay, Alaska, has been the site of several landslide-generated tsunamis, including one in 1958 that produced a splash wave that removed trees to a height of 525 m. It also caused a tsunami of at least 50 m in the bay. The 1964 Prince William Sound earthquake triggered at least four submarine landslides, which accounted for 71 to 82 of the 106 fatalities in Alaska for the 1964 event. However, it is tectonic earthquake-generated tsunamis (those produced by a major deformation of Earth's crust) that may affect the entire Pacific Basin.

Other possible but less efficient methods of tsunami generation include: strong oscillations of the bottom of the ocean, or transmission of energy to a column of water from a seismic impulse (e.g., a deep-focus earthquake that has no surface rupture); transmission of energy from a horizontal seismic impulse to the water column through a vertical or inclined wall such as a bathymetric ridge; strong turbidity currents; underwater and above-water explosions. Several mechanisms commonly are involved in the generation of a tsunami (e.g., vertical movement of the crust by a seismic impulse or an earthquake, and a submarine landslide).

Our knowledge of tsunami generation is incomplete, because the generation phenomena has not been observed nor measured directly. However, studies of tsunami data suggest that the size of a tsunami is directly related to: the size of the shallow-focus earthquake, the area and shape of the rupture zone, the rate of displacement and sense of motion of the ocean-floor in the source (epicentral) area, the amount of displacement of the rupture zone, and the depth of the water in the source area.

It is also observed that long-period tsunamis are generated by large-magnitude earthquakes associated with seafloor deformation of the continental shelf; while, shorter period tsunamis are generated by smaller magnitude earthquakes associated with seafloor deformation in deeper water beyond the continental shelf.

Once the energy from an undersea disturbance has been transmitted to the column of water, the wave can propagate outward from the source at a speed of more than 1,000 km per hour depending on the depth of the water. Because the height of the long-period waves in the open ocean is commonly 1 m or less and their wavelength is hundreds of kilometers, they pass unnoticed by observers in ships or planes in the region. As the tsunami enters shallow water along coastlines, the velocity of its waves is reduced, and the height of each wave increases. The waves pile up on shore especially in the region of the earthquake source, producing a "local tsunami." Some dramatic examples of such local tsunamis include those generated by landslides or by volcanic eruptions, which have caused "runup" heights of 30 to 50 m in some coastal areas.

"Runup" is the maximum height of the water observed above a reference sea level. Two other terms may be determined from the runup value: (1) tsunami magnitude, which is defined (Iida and others, 1967) as

$$m = \log_2 H;$$

and (2) tsunami intensity, which is defined (Soloviev and Go, 1974) as

$$I = \log_2(2^{1/2} \times H),$$

where H in both equations is the maximum runup height of the wave.

If the energy produced by the generating disturbance is sufficiently large, such as that released by a major deformation of the crust in a trench area, the resulting tsunami wave may cross the open ocean and emerge as a destructive wave many thousands of kilometers from its source. The severity of a tsunami of this type--called a "remote-source" tsunami--decreases slowly with distance. However, it may be observed and perhaps cause damage throughout the Pacific Ocean Basin (e.g., the Chile tsunami of May 1960).

Radiation of a remote-source tsunami from the focus of an earthquake is directional, depending on the geometry of the seafloor in the source region. The source region for major tectonic earthquakes is usually elliptical, and the major axis is as much as 600 km long and corresponds to the activated part of the fault. The major part of the tsunami energy is transmitted at right angles to the direction of the major axis, both toward the near shore and along a great circle path toward the shore on the opposite side of the ocean. Thus, tsunamis in Chile have severe impact on Japan; and those in the Gulf of Alaska on the west coast of North America. Hawaii, which lies in the central Pacific Basin, is vulnerable to remote-source tsunamis generated both in the North Pacific and along the coast of South America.

The velocity (V) of a tsunami in the open ocean is expressed as the product of the square root of the depth of the water (d) and the acceleration of the force of gravity (g).

$$V = (dg)^{1/2}$$

Because the speed of the tsunami depends on the depth of the ocean basin, the waves decrease in speed as they reach shallower water. The wavelength is shortened, the energy within each wave is crowded into progressively less water, increasing the height of the wave. The tsunami may increase in height from 1 m in the open ocean to more than 20 m during runup. Also, if underwater ridges are present, they may act as collecting lenses and further intensify the tsunami.

If the tsunami encounters a coastal scarp, the height of its waves increases. Because the long-period wave can bend around obstacles, the tsunami can enter bays and gulfs having the most intricate shapes. Experience has shown that wave heights increase in bays that narrow from the entrance to the head, but decrease in bays that have narrow entrances. Shores of islands protected by coral reefs commonly receive less energy than unprotected coastlines lying in the direct path of an approaching tsunami. Islands in a group may "shadow" one another reducing the tsunami effect. Small islands may experience reduced runup as the tsunami waves may refract around them.

A tsunami wave may break on the beach, appear as flooding, or form a "bore" (violent rush of water with an abrupt front) as it moves up a river or stream. When the trough of the wave arrives first, the water level drops rapidly. Where this occurs the harbor or offshore area may be drained of its water, exposing sea life and ocean bottom. This phenomenon may be the only warning to residents that a large tsunami is approaching. Fatalities have occurred where people have tried to take advantage of this situation to gather fish or explore the strange landscape. The wave returns to cover the exposed coastline faster than the people can run. Although there may be an interval of minutes--or perhaps an hour--between the arrival of waves, the second, third, or later waves can be more destructive than the first. Residents returning too soon to the waterfront, assuming that the worst has past, represent another kind of preventable fatalities.

1.3 SEICHES

Seiches are wave activity related to tsunamis. Both are gravity waves depending on the depth of water for their characteristics. Unlike the tsunami, which is a traveling wave, a seiche is a standing wave oscillating about fixed points or nodes. They occur in fully or partially enclosed bodies of water such as lakes, rivers and harbors. In the case of an enclosed body of water such as a lake or partially closed body such as a wave traveling transverse to a river or harbor, a standing wave can be set up having a period "T" for the first mode in an idealized case determined by the distance across the body "l" and depth of water "d" as

$$T = 2l/(gd)^{1/2}$$

where "g" is the gravitational constant.

Figure 1 illustrates this for a rectangular cross section. A node would be set up in the middle. Higher modes may also be set up. In a real case, the depth would not normally be a single value but the principle is the same. In the case of a longitudinal wave in a harbor a seiche may be set up with the node at the harbor mouth. In this case the period of the wave would be twice that given in the above formula.

Seiches may be set up by wind, storm waves, earthquake waves, and tsunamis. When the period of the energizing source is close to that of one of the normal modes of a body of water, seiches can resonate and the amplitude builds up.

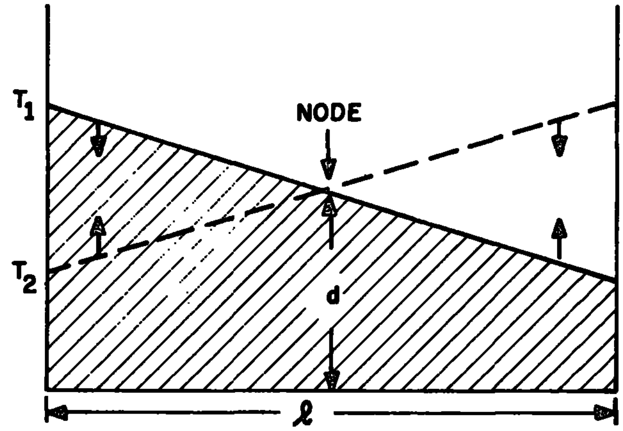


FIGURE 1.—Model of Seiche

Seismic surface waves (Rayleigh waves) can set up seiches over wide areas. The 1755 Lisbon, Portugal earthquake set up seiches which were widely observed as far away as the River Dal in Sweden 3,000 km away and perhaps as far as Fort Oswego, New York, on Lake Ontario 5,000 km away. Seiches from the event lasted 1.5 hours in Loch Lomond, Scotland with an amplitude of 70 cm and possibly exceeded 1 m at some lakes in Norway.

The 1964 Gulf of Alaska tsunami caused seiches which were widely observed in North America, and in Hawaii and Australia. The effects were particularly prominent near the coast of the Gulf of Mexico where several boats were sunk in the Louisiana bayous and roads were flooded. There were several thousand dollars in damage to boats and docks on canals and rivers in Texas. The effects of seismically or meteorologically induced seiches are not treated in this history except when they are confused for tsunami waves.

Tsunamis may also set up seiches and much of the continuing wave activity recorded on marigrams or observed are probably due to coupling of the harbor waves with the continental shelf.

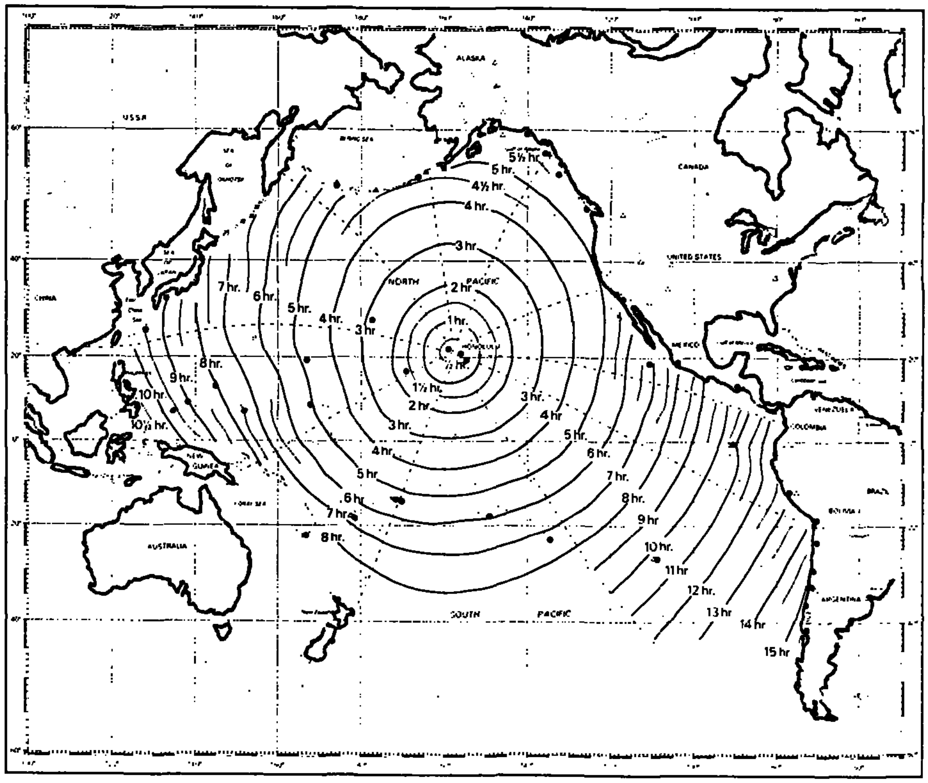


FIGURE 2.—Travel Time Chart for Pacific

1.4 TSUNAMI WARNING SYSTEMS

Following the disastrous Aleutian tsunami of April 1, 1946, the United States Coast and Geodetic Survey was asked to provide a tsunami warning system for the Hawaiian Islands. For such a warning system to function the following capabilities had to be developed: 1) detect rapidly and accurately the location of each earthquake; 2) determine the actual existence of a tsunami; and 3) calculate the expected time of arrival of the tsunami in the islands. This process can be done in an hour or less, and because tsunamis generated along the edge of the Pacific Basin take 4.5 to 15 hours to reach Hawaii, there is time to issue a warning (fig. 2).

One problem that had to be overcome was that most seismographs in use in 1946 recorded on photographic paper that was developed only once a day. The addition of pen and ink recorders, and later, heat sensitive recording paper gave an immediate visual copy of earth movement. Tsunami travel-time charts were developed to provide the technology for the early operation of the Seismic Sea Wave Warning System (SSWWS). Additional travel-time charts for other tide stations were developed later to assist the SSWWS in determining the existence or absence of a wave at these stations within the given time frame. Also, a seismic sea-wave detector was designed to sound an alarm when actuated by the motion of the tsunami wave.

At first, the SSWWS furnished tsunami warning information only to the civil and military authorities of the Hawaiian Islands. Not until 1953 was this information disseminated to the States on the west coast of the United States.

Following the 1960 tsunami in Chile, many countries and territories joined the SSWWS for warnings of future tsunamis. The 1960 tsunami effectively demonstrated that, in addition to requiring a warning system, public education was also needed. Sixty-one people were killed in Hilo, Hawaii, by this tsunami because they failed to heed the warnings that were issued. In fact, many went to the harbor to see the predicted wave (fig. 3).

FIGURE 3.—Sightseers on dock at Hilo, Hawaii, at midnight (note clock on wall) on May 22, 1960, awaiting the wave. The wave soon swept over the area. (Photo Credit: James Hamasaki)

Pararas-Carayannis, (1986) stated: "In 1965, the United Nations Educational, Scientific, and Cultural Organization's (UNESCO) Intergovernmental Oceanographic Commission (IOC) accepted an offer made by the United States to expand its existing Tsunami Warning Center in Honolulu to become the headquarters of the International Pacific Tsunami Warning System and, at the same time, accepted the offer of other IOC member countries to integrate their existing facilities and communications into this system.

A meeting was held in Honolulu, Hawaii, in 1965 establishing the International Tsunami Information Center (ITIC), and an International Coordination Group for the Tsunami Warning System (ICG/ITSU)... Twenty-three nations are now members of ITSU in the Pacific...The System makes use of 69 seismic stations, 65 tide stations, and 101 dissemination points scattered through the Pacific Basin. The Pacific Tsunami Warning Center (PTWC) at Ewa Beach near Honolulu is operated by the United States National Weather Service, Pacific Region."

The objectives of this system include detection and location of major, possibly tsunamigenic earthquakes; determination of the existence of an actual tsunami; and transmission of effective information and warnings to dissemination agencies.

The system begins to function only when an earthquake of magnitude 6.5 or larger centered anywhere in the Pacific Basin triggers the earthquake alarm. PTWC requests data from observatories in the system, and the National Earthquake Information Center at Golden, Colorado, to determine the epicenter and magnitude of the earthquake (fig. 4). If the earthquake has a magnitude of 7.5 or larger (7.0 or larger in the Aleutian Islands), and is centered in a location where a tsunami could be generated, a *tsunami watch* is issued. Participating tide stations in the area of the earthquake are then requested to monitor their gages. If unusual water level activity is reported by one of the tide stations in the area, the *tsunami watch* is upgraded to a *tsunami warning*. Travel times of the tsunami are then calculated, and the warning is transmitted to the disseminating agencies and relayed to the public. If reports from tide stations indicate that only a small tsunami or that no tsunami has been generated, PTWC cancels the *watch* or *warning*.

PTWC is most effective in warning against tsunamis that affect the entire Pacific Basin. Warnings for local and regional tsunamis occurring within 45 minutes to 1 hour of the earthquake event cannot be effectively disseminated by PTWC in the same way as they are for remote source tsunamis. There are plans to issue quick warnings based only on the size and location of the earthquake to warn areas in immediate danger. Also, regional warning systems have been established in some areas at the time of this writing. In areas near the earthquake epicenter, the earthquake itself is the best warning provided that people recognize it as such. Therefore, strong shaking of the earth lasting a minute or more is a urgent warning for people to evacuate coastal areas immediately.

Areas that may be more vulnerable to tsunami damage are those that the tsunami takes 15 minutes to one hour to reach. In such areas the earthquake may be felt less severely and perceived to be only a local tremor. No precautions or evacuation usually takes place, and the time interval is too short to disseminate proper warnings of an approaching tsunami from official warning systems. Areas closer to the epicenter are warned by the earthquake itself. Warning systems are effective in reaching areas further away.

Local and regional warning centers are operated by the United States for Hawaii and for Alaska and the West Coast. Similar systems are operated by Japan, USSR, French Polynesia, and Chile.

An updated system is being implemented that transmits real-time data from shore-based seismic sensors and tsunami sensors using synchronous meteorological satellites for data transmission. Future additions to the PTWC may include ocean-bottom sensors placed in the travel path of tsunamis to confirm that a tsunami has been generated. Use of these sensors should help to eliminate unnecessary warnings, and to provide scientists with critical data about the wave's characteristics undisturbed by shoaling processes.

FIGURE 4.—A seismologist examines seismograph records at the Pacific Tsunami Warning Center. (Photo Credit: Walter C. Dudley, University of Hawaii at Hilo)

Computer systems are constantly being upgraded to handle increased amounts of data efficiently. Refined historical data are also increasingly useful in predicting future events. The international community has much to gain from its cooperation in increasing the effectiveness of tsunami warnings, thereby reducing tsunami risk.

1.5 PROBLEMS WITH HISTORICAL DATA

The value of historical tsunami catalogs is diminished by errors of several kinds. These include confusion of tsunamis with several other phenomena (e.g., unusual astronomic tides and storm surges), problems in converting dates and times from various calendar and timing systems, incomplete or exaggerated accounts, errors introduced by compilers of both an accidental and a judgmental nature, and confusion of terms in the references for the amplitudes of the waves (e.g., amplitude for range or runup above mean sea level, mean lower low water, current tide stage, or other reference levels).

When the descriptions are reasonably complete, tsunamis can be differentiated from unusual tides and meteorological disturbances, including storm surges. Reports that include observations of large earthquakes or volcanic eruptions mention a periodicity measured in minutes, or describe effects at many locations are probably true reports of a tsunami. Storm surges and meteorological waves may result from wind blowing over a large area (the fetch) for a long time building up high waves. In the case of hurricanes (typhoons in the Far East) the low barometric pressure in the center leads to a doming of the sea surface. This dome of water follows the storm's eye and, if it crosses the shoreline can lead to extensive flooding. Smaller wind-driven waves may accompany the flooding wave. While the reports of such waves (particularly if they mention high winds or heavy rain) can usually be distinguished from tsunamis, there are many cases in which the nature of the waves is in doubt.

Calendar errors account for many invalid tsunami reports. The now universally used Gregorian calendar was proclaimed in 1582, but was only slowly adopted. When adopting it in 1752, England and its colonies added 11 days to the Julian calendar then in use. An extra day is added to any Julian dates still in use after 1799 and a 13th after 1899. Orthodox Catholic regions including the USSR, which governed Alaska until its sale to the United States in 1867, used the Julian calendar until 1918.

The time, too, can present problems. An international convention in Washington, D.C., in 1884 adopted the international time zones, based on 24 zones of 15-degrees each, to replace the many local times then in use. The adopted standard time zones may vary widely from that expected for a given longitude due to a variety of political or economic reasons. However, the principle of one time in use over a large area was adopted rather than using innumerable local "sun" times. Local or "sun" time in earlier literature can be converted to Universal Coordinated Time (UTC) by dividing 15 into the longitude of the locality. The whole number part of the quotient gives the hours to be added to the local time for West longitude or to be subtracted from the local time for East longitude. The fractional part of the quotient can be multiplied by 60 to get the minutes and fractions of minutes. Officials in some areas chose standard times other than whole hours. Hawaii, for example, chose 10.5 hours, after the time at Greenwich, England, and used this time from 1896 to 1947--except for a period during World War II when a war time of 9.5 hours was used. Hawaii has used 10 hours since 1947. The use of Daylight Savings Times at various dates and places reduces the correction to UTC by one hour and may create errors of conversion from local times.

Another complication with time is that a tsunami may take up to a day to travel from a source on the opposite side of the Pacific, and so it is common for the effects at the source and at a remote site to have different Universal dates. Also the International Date Line passes through the middle of the Pacific approximately along the 180 degree meridian line. Local dates west of the line are 1 day later than those to the east. This catalog uses the local date for the effects in the region of observation when the Universal date and time are not given. This is mainly true for earlier tsunamis that affect only a locality or region. Local times, particularly when given in a 24 hour form are occasionally confused with UTC. For this reason the twelve hour form with A.M. or P.M. is used for local times and the 24 hour system is used only for UTC.

Problems of exaggeration and transcription errors can only be dealt with by references to the original, and, if possible, the contemporary reference. The compilers of this catalog have not attempted to review all the contemporary references, but have included the results of such re-evaluations including the work of Cox and Morgan

(1977) and Cox (1984, 1987) for Hawaii, Kisslinger and Davies (1987) for Alaska, and Marine Advisors, Inc. (1965) for the west coast of the United States. References given with the descriptions were examined by the compilers unless specifically noted otherwise in the references. The references cited are a valuable source for additional references.

The uncertainty about a report is expressed in the tables by a validity factor of from 0 (did not occur as reported) to 4 (certain to have occurred). The term "validity" used here refers to the certainty that a tsunami occurred near the source on the date given. The table of tsunami data carries notations of all validities, because, if the 0 validities were deleted, a later compiler may find the mistaken reference and re-introduce it into the catalog. Not all events have yet been assigned validities.

At some locations the tsunami effects may have been "doubtful." For example, the December 23, 1854 event produced a 21 m wave in Japan and destroyed 816 houses. The event has a validity of 4. However, the reported effects of the tsunami in Hawaii are in dispute. (See Table 3. Tsunami Data for Hawaii)

Because many reports of tsunamis are based on eyewitness accounts of early settlers, hunters, and others who were not trained observers, the reports may at times be exaggerated or erroneous. Half Moon Bay, California, reportedly experienced a 4.6-m runup from a tsunami in 1859. However, Iida and others (1967) suggested that the runup height may be exaggerated, that the event is not a locally generated tsunami, and further that the date may be incorrect. It remains for future investigations to decide the accuracy of the report.

There are several terms in use to describe the "size" of the waves. Much of the earlier data refer to runup, the highest point reached by the wave, in reference to some datum such as high water strand, mean sea level or mean lower low water. Mean lower low water (MLLW) is the baseline for coastal charts in the United States chosen as an aid to navigation. Since it is in wide use for charts, it is referenced in tsunami runup reports (fig. 5). In Hawaii, where the diurnal tide is about 0.6 m, this uncertainty of the reference level may not be significant, but in Alaska where tides may be more than 5 m, knowing the state of the tide and the reference level are important. Smaller tsunami waves arriving at high tide may be more damaging than larger waves before or after high tide. At Seldovia, Alaska, for example, the height of the wave for the 1964 tsunami was reported as 5.5 m, but this was a 1.8-m tsunami riding a 3.7-m-high tide.

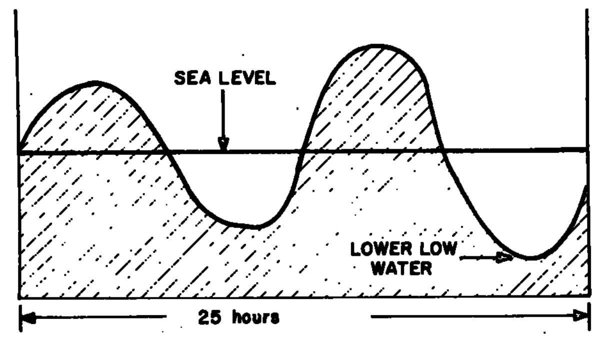


FIGURE 5.—Diagram of unequal twice daily tides. Mean of lower low water values and sea level are common reference points.

Tsunamis and other waves are recorded instrumentally on tide gages. These instruments routinely record tidal changes. The records produced by these gages are commonly called marigrams (fig. 10). There are problems with using tide gages designed to record the twelve hour tide to record tsunamis with periods measured in minutes. The largest waves may be clipped making it difficult to estimate the maximum amplitude, or a very large wave may cause a large gap in the record or destroy the recording altogether.

The reported size of the waves given from instrumental measurements is almost always the range, although it may be called height, maximum rise or fall, and, incorrectly, amplitude. In this compilation, the half range is reported as the amplitude (fig. 10).

The tide gages (marigraphs) in use now are of several types. Commonly, they have a stilling well connected to the ocean by a small opening. This damps out waves of short periods of no interest in the measurements of tides, and also reduces and

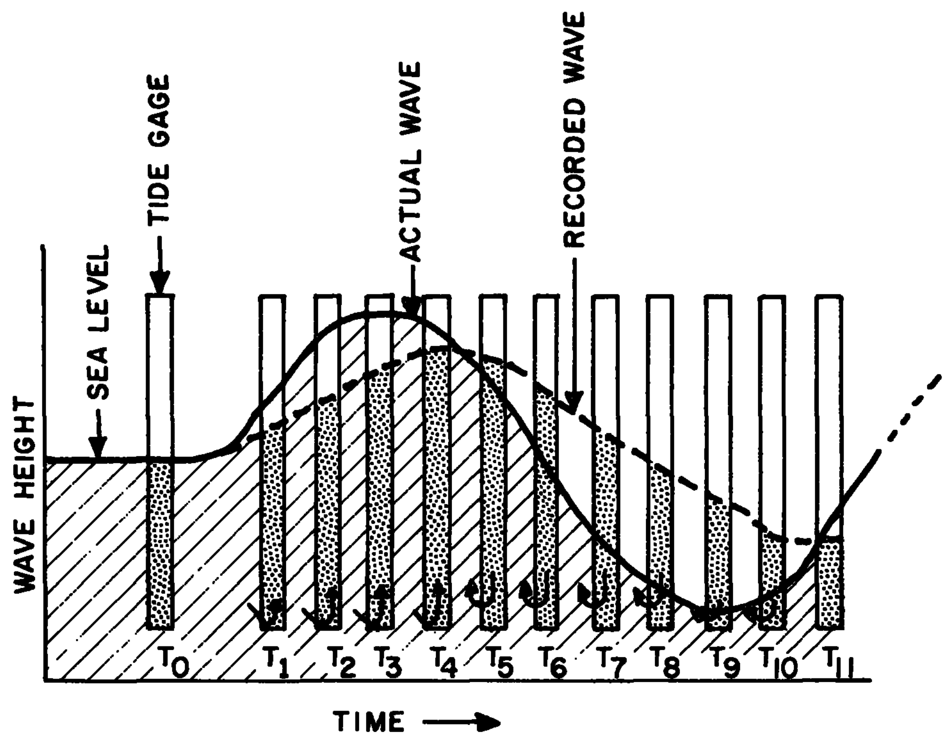


FIGURE 6.—Schematic illustrating how the stilling well in tide gage results in a decrease in recorded wave height and a delay in recorded peak heaght with respect to the actual wave.

delays the recording of tsunamis in a non-linear way. For example, a tide gage may record a tsunami with an amplitude of 25 cm and a period of 15 minutes as a 19-cm wave with a peak 1 minute and 48 seconds after the wave crest had passed. Similarly, a wave of 1 m amplitude may be recorded as a 50-cm wave 2 minutes and 40 seconds after the peak had past (fig. 6). The larger the wave and shorter the period, the greater the discrepancy between the real and recorded amplitudes (Noye, 1976).

Because areas affected by several early tsunamis were sparsely populated, observers were not present to report the effects. For example, a tsunami recorded in Hawaii on August 24, 1872, was first thought to have been caused by a local earthquake. However, evidence of a tsunami was later found on tide gage records at San Diego and San Francisco, California, and Astoria, Oregon. Knowing the arrival time at these locations the event then was traced to a source in the Aleutian Islands, even though there were no reports of an earthquake or a tsunami from that largely uninhabited area.

Another problem associated with historical tsunami data is the limited time span that is covered. The earliest dated event recorded in Alaska is 1788; in Hawaii and on the west coast of the United States it is 1812. Since many tectonic rupture zones have periodicities in excess of several hundred years, the recorded history of tsunami events is too brief to give a completely accurate appraisal for each region.

The metric system is used throughout this compilation. This continues the practice of most catalogs of tsunamis; however, as many of the descriptions were originally in the English system of units there is a potential problem with the implied accuracy. For example, a report of a tsunami inundating the shore for a distance of 100 yards would be understood to be an approximation, perhaps between 90 and 110 yards. Converting the 100 yards to the metric system yields 91.0 m with an implied accuracy of ± 1 meter. In the

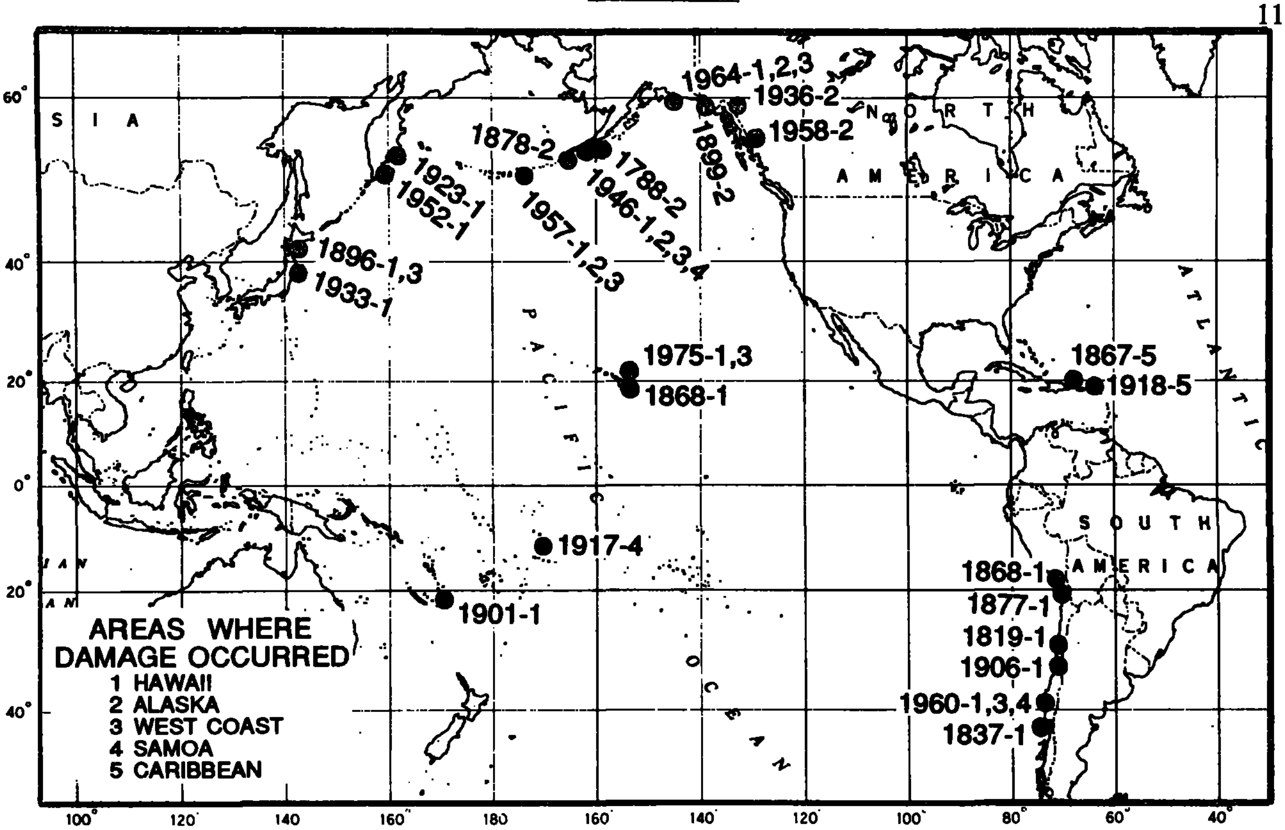


FIGURE 7.—Epicenters of earthquakes that generated destructive tsunamis in the United States and Possessions.

text this is left as 91 meters to facilitate reconversion to the original units but should be understood not to imply a high precision.

1.6 DESCRIPTION OF TEXT AND TABLES

The regions described in this volume are:

1. Hawaii
2. Alaska
3. West Coast of the United States
4. American Samoa
5. Other United States Possessions and Current and Former Trust Territories in the Pacific Ocean
6. East Coast of the United States
7. Puerto Rico and United States Virgin Islands

Each section consists of a descriptive text and a table of events. The references cited in the descriptive text are adequate to recover the information in the text but additional and more primary sources are frequently found in the referenced work. Also, in a history such as this many details obtained from these referenced studies must be omitted. In general, comments in the descriptive text following the last mentioned reference or enclosed in parentheses are our conclusions. Locations that experienced tsunami effects are identified by **bold type**.

This history was compiled largely from the works of others with corrections and, occasionally from original research by the compilers. The principal catalog sources are given in Table 1 and in the bibliography. The present work combines data from those sources into a single volume for the convenience of researchers, planners, and emergency service organizations. New information is still being found even a century or more after some events. Tsunami history is still being augmented, corrected, and clarified, and further improvements in detail can be expected.

Each section includes all effects known to have been observed in that region, for both remote and local sources of the tsunamis.

TABLE 1.—PRINCIPAL SOURCES OF DATA

AUTHOR	TITLE	PUBLICATION YEAR	TIME SPAN COVERED	NOTES
	General Catalogs			
Iida, Kumizi; Doak C. Cox; George Pararas-Carayannis	Preliminary Catalog of Tsunamis Occurring in the Pacific Ocean	1967	173-1967	Gives location, time, depth, and magnitude of the earthquake, tsunami magnitude, runup heights, locations of effects, bibliography. Organized chronologically.
Soloviev, S.L.; Ch.N. Go	A Catalogue of Tsunamis of the Western Shore of the Pacific Ocean	1974	1562-1974	Gives tabular data similar to Iida et al., 1967, plus descriptive material about individual events. U.S. Tsunamis uses page numbers from English translation. Has bibliography, maps, and marigram copies. Organized by regions.
Soloviev, S.L.; Ch.N. Go	A Catalogue of Tsunamis of the Eastern Shore of the Pacific Ocean	1975	416-1975	Gives tabular data similar to Iida, et al., 1967, plus descriptive material about about individual events. U.S. Tsunamis uses page numbers from English translation. Has bibliography, maps and marigram copies. Organized by regions.
Soloviev, S.L.; Ch.N. Go; Kh.S. Kin	A Catalog of Tsunamis in the Pacific	1986	1969-1982	Similar to above two publications, but organized chronologically and has place name index. English translation in MS at WDC-A.
	Regional Catalogs			
Cox, Doak C.; George Pararas-Carayannis, Jeffery P. Calebaugh	Catalog of Tsunamis in Alaska, SE-1	1976	1788-1973	Similar to Iida, et al., 1967; same parameters, but specific for area.
Cox, Doak C.; Joseph Morgan	Local Tsunamis and Possible Local Tsunamis in Hawaii	1977	1813-1976	Detailed descriptive information based on contemporary reports.
Kisslinger, Jerome; John W. Davis	Untitled manuscript of Alaskan earthquakes	1987	1737-1880	Unpublished.
McCulloch, D.S.	Evaluating Tsunami Potential	1985	1812 - 1985	Most complete analysis of tsunami threat on west coast of the United States
Pararas-Carayannis, George; Bonnie Dong	Catalog of Tsunamis in the Samoan Islands	1980	1837-1980	Table similar to Iida, et al., 1967 but specific for area and with expanded descriptive text.

TABLE 1.—PRINCIPAL SOURCES OF DATA (CONTINUED)

AUTHOR	TITLE	PUBLICATION YEAR	TIME SPAN COVERED	NOTES
Pararas-Carayannis, George; Jeffery P. Calebaugh	Catalog of Tsunamis in Hawaii, SE-4, 1967;	1977	1813-1975	Similar to Iida, et al., same parameters, but specific for area.
	Reports on Individual Events			
	United States Department of Commerce Reports			
Berkman, S.C.; J.M. Symons	Tsunami of May 22, 1960 as Recorded at Tide Gage Stations	1964		All these publications give descriptive information about tsunamis, runup data, wave arrival times, and travel times and have copies of marigrams.
Green, K.C.	Seismic Sea Wave of April 1, 1946 as Recorded on Tide Gages	1946		
Salsman, Garrett S.	Tsunami of March 9, 1957 as Recorded at Tide Gage Stations	1959		
Spaeth, M.G.; S.C. Berkman	Tsunami of March 28, 1964 as Recorded at Tide Gage Stations	1972		
Zerbe, W.B.	Tsunami of November 4, 1952 as Recorded at Tide Gage Stations	1953		
	Other Articles			
Marine Advisers, Inc.	Examination of Tsunami Potential at the San Onofre Nuclear Generating Station	1965		Extensive investigation of 1812 southern California earthquake.
Miller, Don J.	Giant Waves in Lituya Bay, Alaska	1966		Detailed description of July 9, 1958, and earlier events in the area.
National Academy of Sciences	The Great Alaskan Earthquake of 1964	1970-1972		Volumes on oceanography, coastal engineering, geology, and human ecology are especially helpful.
Shepard, F.P.; G.A. Mac Donald; D.C. Cox	Tsunami of April 1, 1946	1950		Detailed descriptive information about effects in Hawaii only.
Reid, Harry F.; Stephen Taber	The Porto Rico Earthquake of 1918 with Descriptions of Earlier Earthquakes	1919b		Two articles provide almost the only available information on Puerto Rico-Virgin Islands quakes.
Reid, Harry F.; Stephen Taber	The Virgin Islands Earthquakes of 1867-1868	1920		

ORIGIN DATA		V	C	TSUNAMI DATA							
DATE TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOT-ION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS

FIGURE 8.—TABLE HEADING.

The regions vary considerably with respect to the degree and nature of the risk and the completeness of the history. Consequently, there are limitations on the use of the past to predict the future, particularly when the recurrence rate for tsunamigenic earthquakes may equal or exceed the historical record. The main patterns are not likely to change, however.

Figure 8 depicts the heading for the tsunami data tables. The following is an explanation of the column headings.

ORIGIN DATA

Date - Time

If a time (hour/minute) is quoted at the beginning of an entry, the date and time are in Universal Coordinated Time (UTC); otherwise the date is the local date.

Latitude/longitude of Earthquake Epicenter or Source

The reference for the epicenter is identified by a code as shown in Table 2. If two sources are shown, the second is for the magnitude. Various references cover different regions or times so that many references were needed to cover all the earthquake events. The epicenter (latitude, longitude) is not too critical since it represents a single point where the rupture began while the actual rupture that generated the tsunami may cover thousands of square kilometers.

Magnitude

The magnitude is more useful for tsunami work but typically has an uncertainty of a quarter unit or more. The magnitudes are based on surface waves (Ms) or the equivalent derived from intensities for pre-instrumental events.

The following criteria were used in selecting the epicenter and magnitude. For North American earthquakes, the epicenter was taken from the Decade of North American Geology (DNAG) data base, if available. This is a computer file derived from numerous primary sources and was generated to produce the *Seismicity Map of North America* for the DNAG project. This file was extensively checked by regional experts. Earthquake epicenters in Japan and neighboring areas were taken from Iida (1984), *Catalog of Tsunamis in Japan and Its Neighboring Countries*. Earthquake epicenters from Peru and Chile were taken from Patricia A. Lockridge's *Tsunamis in Peru-Chile* which was coordinated with the Instituto Hidrografico de la Armada in Valparaiso, Chile. Epicenters for Hawaii were taken from a table in Cox (1986), *Frequency Distribution of Earthquakes Intensities on Oahu, Hawaii*. Other earthquake epicenters were taken from the International Seismological Summary beginning in 1913 and the International Seismological Centre beginning in 1964. When none of these sources was available, the epicenters were taken from Iida et al. (1967). A few other events were taken from other sources which can be identified in Table 2 on Epicenter and Magnitude Source Codes.

Earthquake magnitudes were taken from the source of the epicenter where available except for the period 1897-1912 where Abe and Noguchi's revisions were used. Epicenters and magnitudes before about 1898 are usually based on the maximum intensity of the earthquake. Other sources were used when needed and are identified in the table.

Depth

The depth of the earthquake is given in kilometers.

Area

This section gives the geographical name of the source area.

Validity
The validities range from "0", definitely not a tsunami to 4, definite tsunami. (See page 9.)

Cause
The source type codes are E for earthquake, V for volcanic, L for landslide, and M for meteorological.

TSUNAMI DATA

Tsunami Magnitude and Intensity
The tsunami magnitude and tsunami intensity are measurements of the size of the tsunami based on the logarithm of the runup as defined later. (See page 3.)

Location of Effects
The location of effects is the name of the city, town, beach, bay area, shore line, etc. where the tsunami had an impact.

Runup - Amplitude
The amplitude is in meters and may be half the range when that number is given (fig. 10). "OBS" refers to the fact that the tsunami or an effect of the tsunami was seen at that location but the amplitude was not given. "OBS?" indicates that the report of a tsunami being observed at that location is questionable. The runup is the height the tsunami reached above a reference level such as mean sea level but it is not always clear which reference level was used (fig. 9).

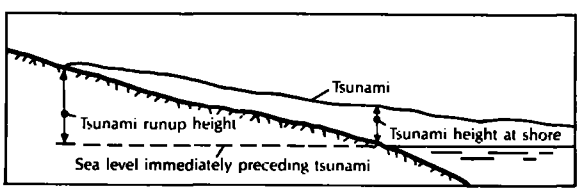


FIGURE 9.—Illustration of runup height (modified from *Earthquakes, Volcanoes, and Tsunamis*, Skandia America Group, New York, New York, 1982, p. 233).

Period
The period is in minutes and, when available, is the period of the first cycle (fig. 10).

First Motion
When the first arrival of the wave was a rise in the water level, it is denoted by an "R." An initial fall in the water level is denoted by an "F" (fig. 10).

Arrival Time
The arrival time is the universal time of the arrival of the tsunami at the location of the effects given in day, hour, and minutes (fig. 10).

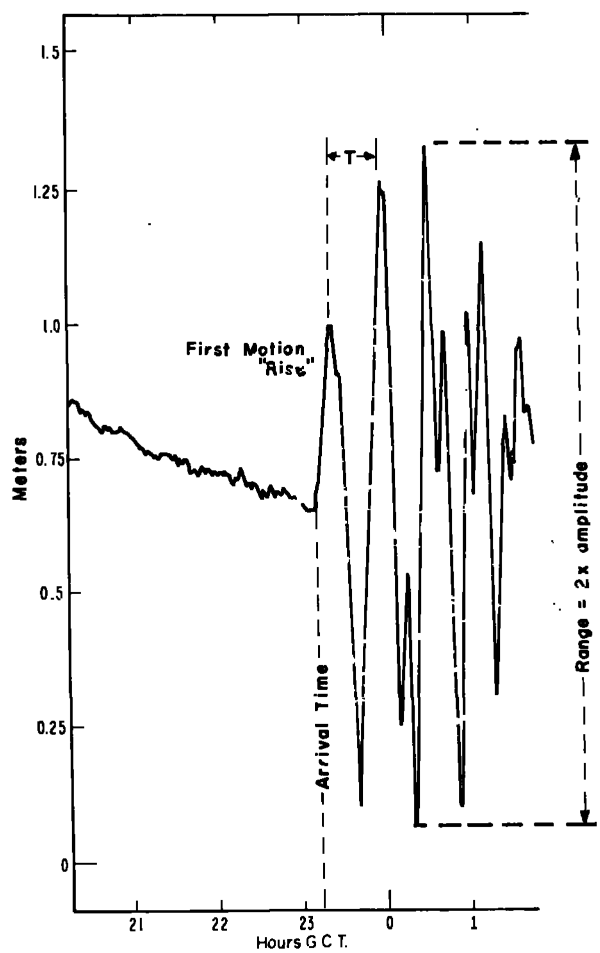


FIGURE 10.—Marigram illustrating arrival time, first motion, period (T), range, and amplitude.

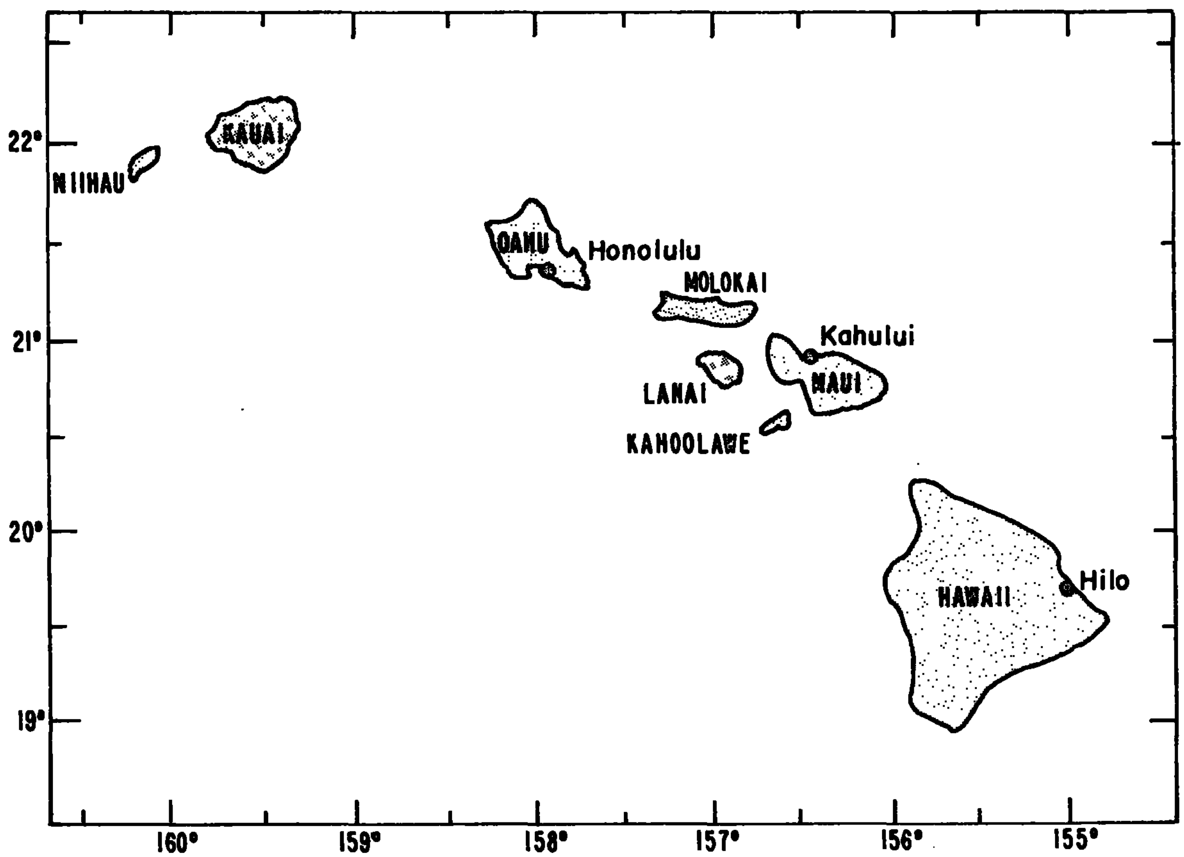
Travel Time
The travel time is the time in hours and tenths of hours that it took the tsunami to travel from the source to the location of effects.

Comments
Comments include effects at the location including damage and deaths, comments on the accuracy of the report, and references to other sections in the publication that have information about the tsunami event.

TABLE 2.—EPICENTER AND MAGNITUDE SOURCE CODES

ABE	Abe, Katsuyuki and Shin-ichi Noguchi, *Revision of Magnitudes of Large Earthquakes 1897-1912*; (1983).
AEC	Atomic Energy Commission.
BRK	University of California at Berkeley.
Cox	Cox, Doak C., *Frequency Distribution of Earthquake Intensities on Oahu, Hawaii*; (1986).
Coxa	Probable Aleutian Source of the Tsunami observed in August 1872 in Hawaii, Oregon, and California; (1984).
DNAG	Decade of North American Geology, Computer File, NOAA.
EQH	Coffman, et al., *Earthquake History of the United States*, (1982).
Guten	Gutenberg, Beno; "Great Earthquakes 1896-1903", (1956).
G&R	Gutenberg, Beno and Charles Richter, *Seismicity of the Earth*, (1954).
Iida	Iida, Kumizi, *Catalog of Tsunamis in Japan and Neighboring Countries*, (1984).
ISC	International Seismological Centre, 1964-1987.
ISS	International Seismological Summary, 1913-1963.
PAL	Lockridge, Patricia A., *Tsunamis in Peru-Chile*, (1985).
PAS	California Institute of Technology, Pasadena, CA.
PCT	Iida et al., *Preliminary Catalog of Tsunamis Occurring in the Pacific*, (1967).
PDE	Monthly Listing of Preliminary Determination of Epicenters, U.S. Geological Survey, Golden, CO.
S&G	Soloviev, S.L. and Ch.N. Go, *Catalog of Tsunamis on the Eastern Shore of the Pacific*, (1984).
TOP	Toppozada, Tousson R., *Preparation of Isoseismal maps and Summaries of Reported Effects for Pre-1900 California Earthquakes* (1981).
USE	*United States Earthquakes*, annual, 1928-1984.

2. HAWAII



2.1 EARLY SETTLERS

The main Hawaiian Islands comprise eight islands: Niihau, Kauai, Oahu, Molokai, Lanai, Kahoolawe, Maui, and Hawaii. The islands form an archipelago running northwest-southeast over a distance of 2400 kilometers in the central Pacific Ocean. All the above eight islands are inhabited except Kahoolawe. In the past, the Polynesians occupied two other islands in the chain—Nihoa and Necker—for a short time, but those islands have been uninhabited for many years.

The early Hawaiians came from a branch of the great Polynesian family, which (perhaps as early as 1000 A.D.) occupied islands in the Pacific Ocean. Ethnologists disagree as to when the Polynesians came into the Pacific and to the routes they followed to reach the far-separated island groups. However, it is generally accepted that there were successive arrivals of settlers, mainly from the Society Islands, extending over some hundreds of years.

Archaeological findings on the Islands of Nihoa and Necker indicate that the people who lived there arrived earliest in the islands. During the 14th and 15th centuries, Tahitian Polynesians "rediscovered" the islands, and most of their immigration to Hawaii occurred during this interval. For the next 300-400 years, until the arrival of Captain Cook in 1778, the Hawaiians lived in almost complete isolation from the rest of the world.

With the exception of a few surviving chants from the era before discovery by Europeans, the record of tsunamis begins with European discovery and settlement. The following brief history is intended to give an appreciation of the evolving western presence and the concurrent completeness of the history of tsunamis in Hawaii.

In early February 1778 a British expedition led by Captain James Cook sighted the Island of Oahu. He landed at the village of Waimea on the Island of Kauai two days later. The islands were named the Sandwich Islands by Cook, and the name persisted throughout the 19th century. Many groups of traders from Europe and Asia later visited the islands and stayed on as permanent residents. Captain Cook revisited the islands in January 1779 and was killed at Kealakekua Bay on the Island of Hawaii on February 14, 1779.

After the departure of the British expedition in 1779, foreigners did not visit the islands until 1786. However, the development of the fur trade along the northwest coast of North America brought ships of many nations into the North Pacific Ocean at the end of the 18th century. Four foreign ships visited the islands in 1786, two of which were associated with an English commercial enterprise; the other two were French naval vessels. From that time, ships visited the islands each year.

Hawaii became a well-established port of call by the vessels engaged in the fur trade, as well as the general trade that was growing between Asia and the Americas. In 1814, Russians from Alaska who were sent to form a colony in the islands were shipwrecked at Waimea, Kauai. More Russians arrived on another ship the following year, and they remained in the islands until they were expelled in 1817. The first New England missionaries arrived in the islands via Cape Horn on the Brig *Thaddeus* on March 31, 1820. In later years, 14 other groups of missionaries of several denominations arrived in Hawaii.

Beginning in August 1839 the first newspaper, *Sandwich Island Mirror and Commercial Gazette*, was published in Honolulu, and issued until July 1840. The *Sandwich Island News* was published from September 1846 to October 1848, and the *Pacific Commercial Advertiser* from July 1856 to March 1921; it then became the *Honolulu Advertiser*, which continues today. These newspapers and the journals and letters of early missionary and commercial enterprises provide a wealth of contemporary information covering most of the historic period.

The Kingdom of Hawaii, fearing territorial claims of France and Great Britain, took steps in 1842 to establish its status as a sovereign state and to negotiate treaties with them. In 1843, the Kingdom met some difficulties with representatives of the British government who wanted to annex the islands. The sovereignty of the Kingdom was quickly restored, however, and France and Great Britain jointly recognized the independence of the Kingdom of Hawaii on November 29, 1843. The United States earlier had recognized the independence of Hawaii.

Local commercial interest with ties to the United States overthrew the monarchy in 1893 and established a Republic which petitioned for annexation to the United States. In 1898, negotiations for the annexation of Hawaii by the United States were completed, and a resolution was signed by President McKinley on July 7, 1898. A territorial form of government was established in Hawaii by Congress in 1900, and Sanford Ballard Dole became the first governor. Statehood for Hawaii finally was approved on March 11, 1959.

At the beginning of the 20th century, seismological stations were established throughout the world. This facilitated the association of distant earthquakes with tsunamis observed in Hawaii. In 1912 the Hawaiian Volcano Observatory was set up, attracting scientists to Hawaii to study earthquakes and tsunamis as well as volcanoes. Tide gages were installed on Hawaii and Oahu by 1872. This made it possible to identify tsunami waves as small as 0.3 m that might otherwise have remained unobserved.

2.2 TECTONIC SETTING

Hawaii is part of a chain of islands that extends about 2,400 km in the north-central Pacific Ocean, from Kure Island in the northwest to Hawaii Island in the southeast. The northwest movement of the Pacific plate over a fixed "hot spot" (a source of magma rising from deep within Earth's mantle) formed this volcanic chain of islands and seamounts over about 25 million years. The chain has extinct volcanoes (mainly seamounts) at one end and active volcanoes (on the Islands of Hawaii and Maui) at the other.

Countless underwater eruptions in ocean depths of about 5,500 m have slowly built up the islands and the now submerged seamounts. The relentless action of the ocean waves and of subsidence has reduced most of the volcanoes at the northwest end of the chain to submerged seamounts. At the southeast end of the chain is the Island of Hawaii, which is the island where most active volcanism occurs today.

Earthquakes in Hawaii are either directly or indirectly connected to volcanism, but the relation is not always clear. Cox and Morgan (1977) reported that earthquakes may result from the distensions of the rift zones of the volcanoes and the accompanying rise of magma through them. These earthquakes are known as volcanic earthquakes. Also, earthquakes may result from collapses of underground magma chambers. Some earthquakes influence the times of occurrence and locations of volcanic eruptions in the area by shifting and changing the plumbing systems of the volcanoes.

Cox and Morgan (1977) have suggested that some submarine topography in this area results from slumping of the flanks of the volcanoes or seamounts and, further, that displacements of the seafloor in such areas represent movements of gigantic landslides capable of generating tsunamis. They noted that the largest earthquakes in the area are thought to be tectonic events, which occur along submarine extensions of the fault systems. Such tectonic movements have generated the two most important locally generated tsunamis in the history of Hawaii: those in April 1868, and November 1975.

2.3 LOCAL TSUNAMIS

Few local tsunamis are generated in Hawaii. The last 100 years, six tsunamis generated near the Hawaiian chain have been verified, and only two caused substantial damage to property and loss of human life. The locally generated tsunami on April 3, 1868, reportedly had a runup height of about 13.7 m along the south Puna coast of the Island of Hawaii. However, effects of this tsunami on the other islands were insignificant. A tsunami on November 29, 1975, generated along the same southeast coast of the Island of Hawaii, produced runup heights of as much as 14.1 m. The values are the highest ever recorded in the islands.

The tsunami hazard in the islands of Hawaii is not uniform. Runup heights are usually higher on the north side of the islands, mainly because of the many tsunamis generated from the north in the Kuril-Aleutian Islands region. Runup heights may vary significantly, even between locations on islands that are separated by short distances. Because of the complex interactions that occur in a tsunami, the reasons for such variations in runup heights are not always apparent. However, some of the reasons are known. For example, the extensive reefs in Kaneohe Bay on Oahu clearly protect the bay from tsunamis by reflecting or dissipating the waves. Also 86 percent of all tsunami fatalities in Hawaii have occurred on the Island of Hawaii, including all fatalities due to local tsunamis. Hilo alone accounted for 60 percent of all the tsunami fatalities in all of Hawaii.

2.4 REMOTE-SOURCE TSUNAMIS

The Hawaiian Islands are surrounded by the deep waters of the Pacific Ocean Basin. Almost the entire margin of the basin is seismically active. No large land masses lie between the margin of the basin and the islands that form Hawaii. Hence, the islands are vulnerable to tsunamis generated by large earthquakes occurring around the margin of the basin (fig. 11). It is not surprising that the State of Hawaii has a long history of damaging tsunamis. The earliest documented tsunami apparently occurred on

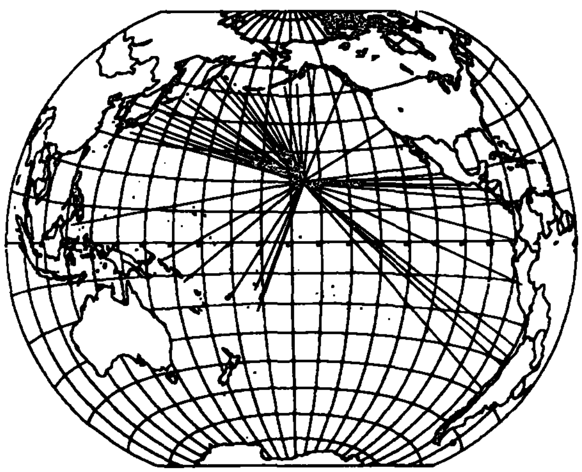


FIGURE 11.—Source areas of tsunamis recorded in Hawaii, 1900-1988.

December 21, 1812, when a wave generated off the Southern California coast was probably observed as a single wave at Hookena on the west coast of Hawaii Island. This 1812 event was the first recorded event of a remote sourced tsunami, although tsunamis undoubtedly reached the islands prior to this.

More than 100 tsunamis have been observed in the Hawaiian Islands, but only 16 have caused significant damage. About one-half the tsunamis recorded in Hawaii have originated in the Kuril-Kamchatka-Aleutian Islands regions of the North and Northwest Pacific, and about one-fourth along the coast of South America.

Although they may be destructive in the immediate area of generation, tsunamis generated in the seas adjacent to the Pacific Ocean--the Philippine, Sulu, Sulawesi, Molucca, Java, and South China Seas--do not affect Hawaii because their energy is confined by the many islands.

2.5 TIME AND LOCATION

Most of the locations mentioned in the following descriptions are shown in figures 12 through 15.

Until standard times were introduced in 1884, each area of the world used its own version of sun time. For Hawaii this was probably close to the Hawaiian Standard Time adopted

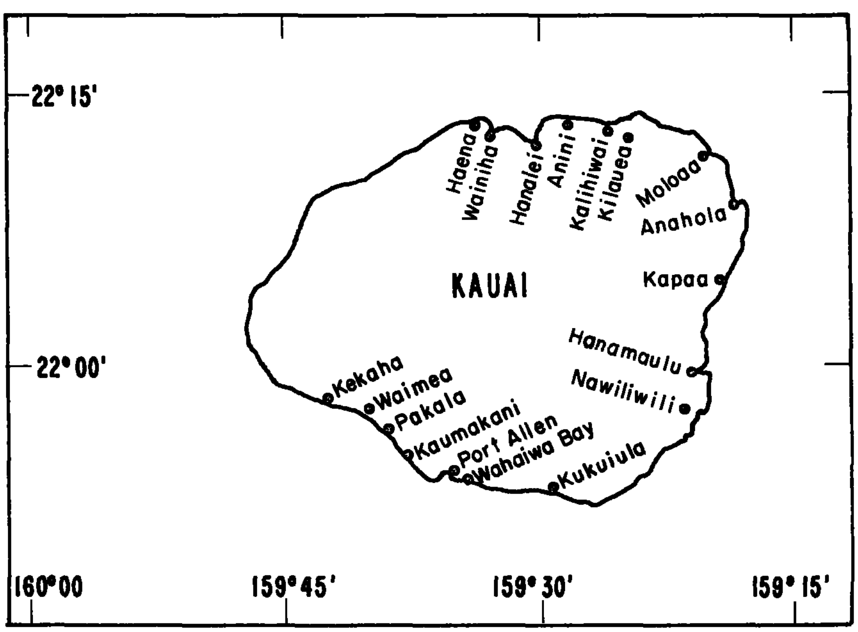


FIGURE 12.—Location map of the Island of Kauai.

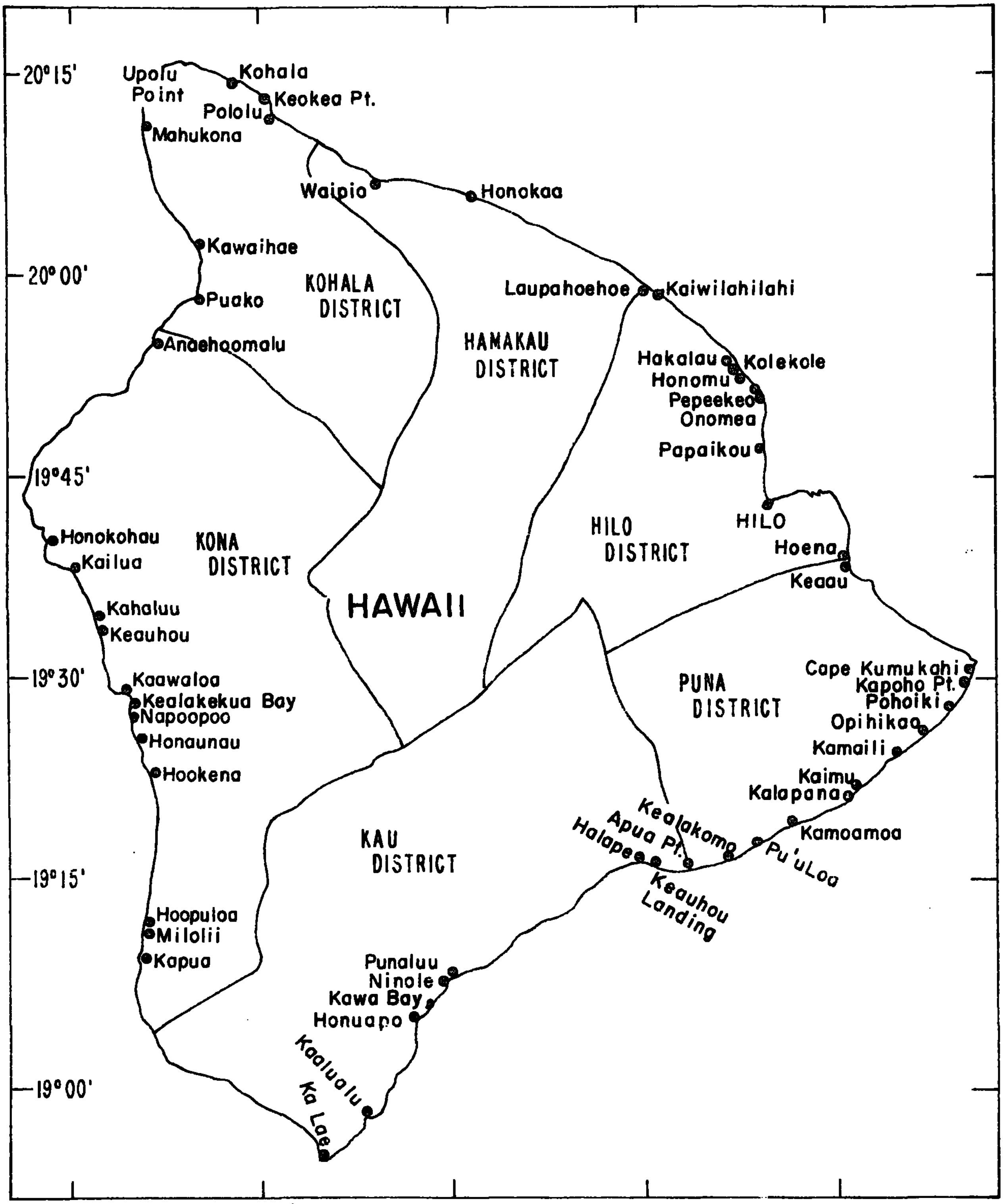


FIGURE 13.—Location map of the Island of Hawaii.

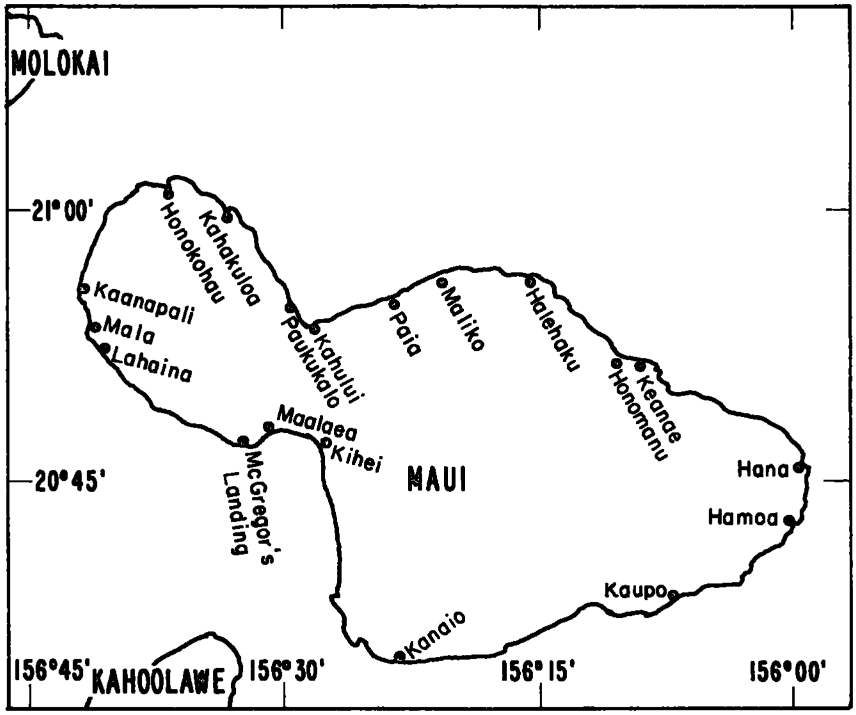


FIGURE 14.—Location map of the Island of Maui.

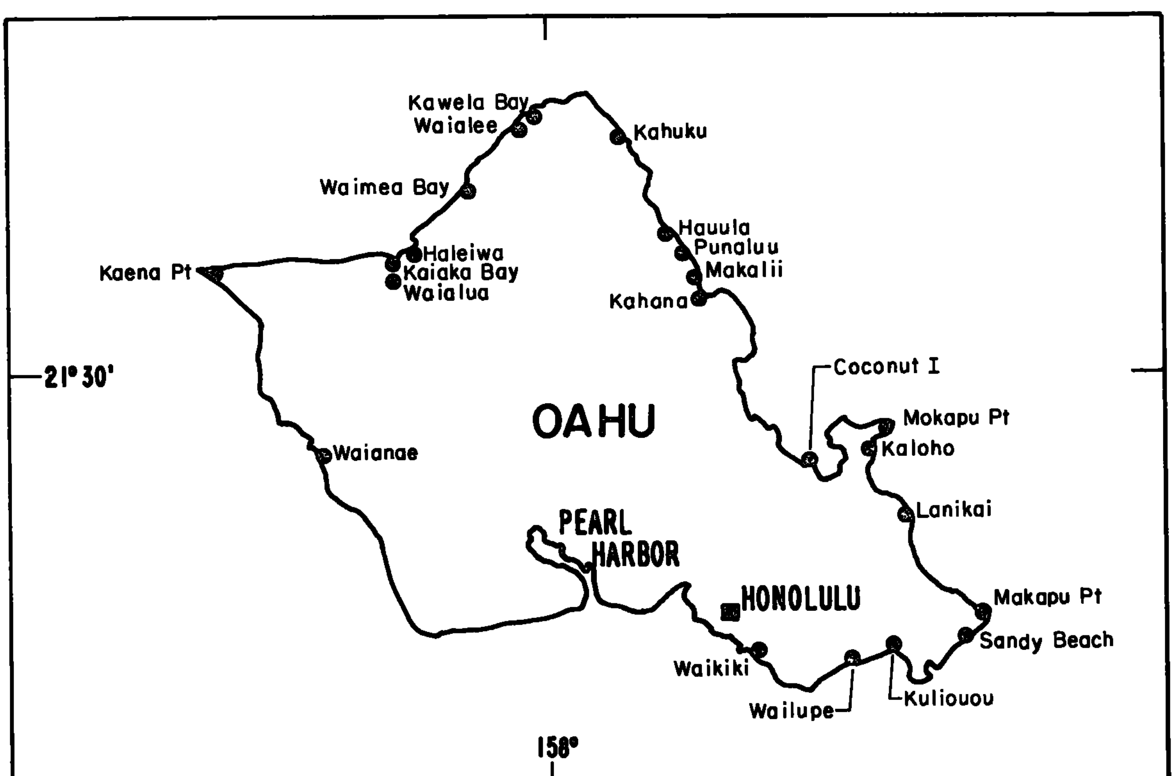


FIGURE 15.—Location map of the Island of Oahu.

in January 1887, which was Greenwich Civil Time minus 10.5 hours. This standard time was in use until January 1947, except for the period February 1942 to September 1945 when Hawaiian War Time (Universal Coordinated Time (UTC) minus 9.5 hours) was used. Since January 1947, the standard time has been UTC minus 10 hours.

2.6 DESCRIPTION OF TSUNAMI EVENTS

1500-1600. The earliest reference to a tsunami came from the following chant attributed to Huluamana and composed in the 16th century: "The sun shines brightly at **Kalaeloa** which sank into the sea. A huge wave came and killed its inhabitants, scattering them and leaving only Papala'au; their cries are all about." It describes a tsunami-like event on the west coast of **Molokai**. (Cox, 1987)

1812, December 21, 19:00. The following account of a probable tsunami is given by Cox (April, 1989). When King Kamehameha I moved his court from Oahu on August 12, 1812, to Hawaii, he was accompanied by Papa Ii, guardian of Liholiho, Kamehameha's heir. His nephew, John Papa Ii, who wrote the account of the move about 50 years later, followed several days later. On arrival at Kailua-Kona, he learned that his uncle was ill. After spending some time in the uplands, John returned to the coast because Papa Ii's health was deteriorating. Papa Ii wished to go to Hookena in South Kona, but it was the time of Makahini. (The Makahini was a religious and athletic celebration beginning about October 19 and lasting 4 months. During a portion of this period corresponding approximately with December 11 to 16th, the use of canoes was forbidden.) At the end of the kapu (taboo) period, Papa Ii was taken to **Hookena** where a ti leaf thatched house was erected for him on the beach. While Papa Ii was lying in the house, the sea rose, flooded the house, and wet him. He died a few days later. The events of the story indicate that the tsunami probably occurred in late December. Cox (1989) estimates the runup to be 3 m ±1.2 m. (Ii, John Papa, 1959; Cox and Morgan, 1977, p. 12-13; Soloviev and Go, 1975, p. 231; Iida et al., 1967; Cox, April, 1989, draft) There is confusion as to whether the year given in Ii's account is 1812, 1813, or 1814, but the 1812 date seems fixed by other sources. If so, the date of this tsunami event closely matches the date of the Santa Barbara tsunami of December 21, 1812, and the wave in Hawaii may have been generated off the California coast. There are no reports from the eastern side of Hawaii including Hilo, but the survival of this account at all is fortunate.

1819, April 12, 03:45. A severe earthquake in the area of Copiapo, Chile, at 11:00 P.M. April 11 produced a damaging tsunami in Chile. Nine oscillations of the sea level were observed on April 12 on the western shore of the **Island of Hawaii**. The oscillations, starting with an ebb flow, occurred at intervals of 10-11 minutes. The water level rose to 2 m, but there were no casualties. In **Honolulu** there were 13 oscillations of sea level within a few hours. The event was also observed at **Hilo** and at **Kahului**. This event is erroneously listed in several catalogs as occurring in May. (Soloviev and Go, 1975, p. 53; Pararas-Carayannis and Calebaugh, 1977; Iida et al., 1967; Cox, June 1987, p. 37; Gast and Conrad, 1973; Coan, 1838; Armstrong, 1838)

In a letter to the Hawaiian language newspaper *Ka Hae Hawaii* of December 12, 1860, J.W. Timoteo in reference to the December 1, 1860, tsunami reported "Never has such a huge wave similar to this been seen since olden times. There has been only one. A huge wave which ran into **Hakaaano**, breaking there, destroying three houses, smashing to bits four native canoes. One person, Hinamoo, escaped certain death." Hakaaano is on the north coast of Molokai. The effects are not more precisely dated than "olden times" and the reference may relate to the 1819 event, to the November 7, 1837, tsunami originating in Chile, or to the May 17, 1841, tsunami from Kamchatka. (Cox, May 22, 1988) The detail of the description suggests a direct source of information and a more current date than the phrase "older times" suggests. The description could, of course, be associated with some other event, but this seems less likely.

1835, February 20, 16:22. A destructive earthquake occurred at about 11:30 A.M. near

(1835, February 20 continued)
Concepcion in the southern part of Chile and generated a tsunami that was destructive along the Central Chile coast. It reportedly did moderate damage on **Kauai Island.** (Soloviev and Go, 1975, p. 58 & 65; Iida et al., 1967; Pararas-Carayannis and Calebaugh, 1977). Although the tsunami might well have been big enough to have been observed in Hawaii, Cox (1988) has not found any contemporary reports of its actual observance there. There are no other reports of its observation outside of Chile.

1837, November 7, 12:51. A strong earthquake that destroyed Valdivia, Chile, generated a tsunami that caused widespread damage on the Hawaiian Islands and was observed in Samoa, the Tonga Islands, and Japan. At **Hilo** the first recession of the water at 7:00 P.M. left a broad expanse of harbor bottom dry. Many people ventured out on the exposed seafloor in search of fish, only to be caught by the returning wave. Fortunately, the English whaler, *Admiral Cockborn*, was riding at anchor in the bay at the time of the tsunami, and the ship's crew saved 12 Hawaiians who had been washed out to sea. According to the captain of the ship, the current velocity was 15-18 km/hr, the anchorage depth varied from 6 to 9 m, and most of the bay emptied at ebb tides. Hundreds of other residents, who were attending a meeting in **Hilo**, were caught off-guard by the wave. Sixty-six houses and many animals were washed away. Fourteen persons drowned in the area of **Hilo** at the communities of **Kanokapa**, **Kaahelu**, **Waiolama**, **Hauna**, and **Kauwale**. (Cox, 1987a, p.4)

The eddy-like movements of the water were accompanied by a thunderous noise. After a rise of water of 3.3-6.0 m above the flood tide mark that lasted 15 minutes, the water retreated beyond the low tide mark (more than 2.7 m), paused briefly, then came on shore a second time in a slightly less forceful wave. The water oscillations continued to diminish in size until the seas returned to normal. When the waters receded, the shore of the bay was strewn with the debris of houses, tree branches, and other debris. Areas of low elevation along the coast and in river valleys were flooded destroying crops, fish ponds, houses and furnishings, fuel, and canoes.

Reports in the Iida et al. (1967) and subsequent catalogs that the tsunami destroyed 108 houses and killed 46 people in the Kau district are erroneous and refer to the April 1868 tsunami. Pararas-Carayannis (1969) and Pararas-Carayannis and Calebaugh (1977) also refer to the arrival times of 06:30 at **Hilo** and 05:00 at **Honolulu**. This must be 6:30 P.M. and 5:00 P.M.

When the sea retreated 36 m at **Kahului, Maui**, the inhabitants rushed to the drained area to collect fish. Suddenly, the sea rose in the form of a steep wall and rushed onshore, overflowing the beach slopes. One of the villagers was at home at the time of the tsunami arrival. Quickly lifting a small child into his arms, he ran to safety on a small sand dune. Looking around, he saw that the entire village of 26 grass huts, and all the residents and property were being carried 240 m inland. Most of the men, women, and children, destroyed houses, broken canoes, poultry, and cattle were tossed into a small lake having a diameter of 5.5 km located just behind the village. Although almost no one had expected this rapid and sudden deluge, all but two of the inhabitants were able to safely reach higher ground. Two less destructive waves followed the first before the sea returned to normal. The water rose 2.5 m on the south side of the Island of **Maui** near **Lahaina**.

At **Honolulu, Oahu**, the tsunami began as a recession at 6:00 P.M. The first ebb, estimated at a little more than 2.5 m, was the greatest. The reefs surrounding the harbor dried up, and most of the fish died. Several ships ran aground. The water returned in 28 minutes and reached the height of the regular high flood tides. Barely halting, the water again retreated and fell by 2 m. All this was repeated at intervals of 28 minutes. The third rise was 0.1 m above the normal high tide mark, and the recession was 1.9 m. After the fourth flood tide, the duration of rises and falls varied, and their magnitude decreased gradually and irregularly. The oscillations continued on the morning of the 8th.

The rate of recession of water varied in different parts of the bay. On the eastern shore, the peak rate noted was 0.15 m per minute. On the northern coast during the third ebb the peak rate was 0.9 m in 30 seconds. The flood tide never rose above the regular spring flood tide mark, but the ebb tide fell 2 m below the ebb tide mark. (Iida et al., 1967; Pararas-Carayannis, 1969; Pararas-Carayannis and Calebaugh, 1977; Soloviev and Go, 1975, p. 66, 68, 69) See also the description of effects at **Hakaaano** given in the 1819 entry above that may also be a description of the effects of this tsunami.

1839, March. This may be a distorted and misleading report of "tidal waves" incidental to the death of Kinau, the Kuhina-Nui, (the executive officer of the monarchy) in April 1839. (Cox, 1987)

1840 (about). A brief account by Mark Twain in "Roughing It," published in 1872, describes a tsunami associated with an eruption of Kilauea and an earthquake on Hawaii. "The earthquake caused some loss of human life, and a prodigious tidal wave swept inland carrying everything before it and drowning a number of natives." Cox did not find any contemporary report of this and believes a tsunami did not occur with this eruption. (ITIC, 1972; Cox, 1987)

1841, May 17, 21:30. A tsunami generated by an earthquake in Kamchatka was reportedly observed only on the shores of Kamchatka and Hawaii. It reached Hawaii after a travel time of 6.4 hours. The water of **Honolulu** harbor suddenly turned white and rushed forward. Then it swiftly rolled back, leaving part of the harbor and all of the reefs dry. The water level fell an estimated one meter. These oscillations repeated twice in the next 40 minutes; then the sea returned to normal. Meanwhile at **Lahaina, Maui** there were repeated oscillations of roughly one meter with intervals of 4 minutes as the waves broke on the reefs and rolled across them with a deafening roar. The amplitude at **Hilo, Hawaii** was reported to be 4.6 m, and no lives were reported lost. (Soloviev and Ferchev, 1961; p. 14; Iida et al., 1967; Pararas-Carayannis, 1969; Pararas-Carayannis and Calebaugh, 1977). See also the description of effects at **Hakaaano** given in the 1819 entry above that may also be a description of the effects of this tsunami.

1848, July 12. An earthquake in Tahiti produced a strong tsunami, which was "just as strong in the Hawaiian Islands" according to Soloviev and Go (1975, p. 19). Cox and Morgan (1977, p. 13-14) quote a newspaper account of the December 1860 tsunami described below as "resembling the same phenomena that occurred in that district 12 to 15 years ago and which consisted of several waves following each other at short intervals." The account implies that the date of the tsunami was sometime in 1845 to 1848 and the location was the **north coast of Maui.** Cox and Morgan (1977) believe the event is possibly a local tsunami although there was no mention of a Hawaiian earthquake on those dates. Cox and Morgan also suggest a tsunami with a remote source to the north, or waves of meteorological origin, but they do not a suggest a tsunami from Tahiti as do Soloviev and Go. Strong earthquakes affected Chirikof Island, Unga Island, and the Alaskan Peninsula on April 15, 1847, at 5:00 or 6:00 A.M. and the Sitka area on March 29, 1848, at 12:45 P.M. There was no mention of tsunamis from either area.

1854, January 27. A report from **Hilo** by the missionary T. Coan dated January 30, 1854, states: "The recently renewed oscillations in sea level off the coast of **Hawaii Island** made us think that an underwater eruption had taken place at the foot of the island or somewhere among the mountain chains or individual volcanoes hidden under the waters of the Pacific." Coan did not identify the date. Soloviev and Go (1975) associate it with an earthquake and tsunami observed at Saint Paul Harbor, Kodiak Island, Alaska, on January 16. Cox and Morgan (1977) point out that this is the Julian calendar date and give the date as January 28. However, the International Date Line convention was not yet established and the correct Gregorian date should be January 27. (Soloviev and Go, 1975, p. 231; Cox and Morgan, 1977, p. 14, 15).

1854, December 23, 00:00. The great (magnitude 8.3) Enshunada earthquake and tsunami in Japan caused great damage and

(1854, December 23, continued)
1,000 fatalities in Japan. It was recorded by the tide stations of Astoria, Oregon, and San Francisco and San Diego, California. Iida et al. (1967) reported that it was observed in Hawaii but give no details. This is repeated by subsequent catalogs (Pararas-Carayannis, 1969; Pararas-Carayannis and Calebaugh, 1977, p. 10). Cox (1980, p. 5-7) found no mention of the tsunami being observed in contemporary English or Hawaiian language papers and no evidence that it was observed in Hawaii.

1854, December 24, 08:00. This is known as the great (magnitude 8.4) Nankaido earthquake and tsunami in Japan where it caused great damage and 3,000 fatalities. The same comments for the Enshunada earthquake above apply to this Nankaido earthquake event, which was also mentioned by Soloviev and Go (1974, p. 70).

1860, December 1. A sudden "swell" of the sea occurred early in the day in clear weather. An earthquake or underwater eruption was not observed. Damage was done on **Maui** and **Molokai** Islands. At **Kahului**, water burst into the port and reached a level of 2.5 m above high tide. Damage was slight. Later, at high tide, the water in the bay churned and receded. At **Maliko**, the water flooded a group of huts in a small valley, moving two or three off their foundations. A wharf was carried inland. The gradual rise of water allowed residents time to flee, and no one died. The source is not known. Soloviev and Go (1975) list it as originating in Hawaii, but Cox and Morgan believe a North Pacific source is more probable. (Soloviev and Go, 1975, p. 231; Cox and Morgan, 1977, p. 14-15)

1862, January 28. A slight and unexplainable rise in the level of the sea occurred in the area of **Waialua, Molokai** Island. Fish ponds were flooded and devastated. On the night of the 29th, an earthquake was felt for more than 5 seconds on the Hawaiian Islands. (Soloviev and Go, 1975, p. 231) There were reports of storms with hail, gale winds, and waterspouts at this time, and the effects on **Molokai** are probably due to meteorological causes. (Soloviev and Go, 1975, p. 231; Cox and Morgan, 1977, p. 15-16)

1868, April 3, 02:24. A destructive (magnitude 7.5) earthquake in Hawaii at 3:40 or 4:00 P.M. April 2 local time gave rise to a tsunami, which had its greatest intensity on the southeastern coast of **Hawaii Island**, approximately from **Ka Lae Cape** to **Kealakomo.** According to reports, the first wave on the coast of **Kau** and **Puna** districts had a height of 3-3.5 m above the usual tide line. Then the sea level fell at least 5.5 m below low tide. Returning in an enormous wave, the sea washed away 108 houses on the coast and 47 residents drowned. At least eight wave advances were observed. Iida et al. (1967) and several subsequent catalogs give 81 fatalities, but this total includes victims of the earthquake and landslides. (Cox, 1987, p. 7-13) The following is taken largely from Soloviev and Go (1975).

The flooding was markedly greater at some places than at others, and this was possibly due to the propagation of waves in a southwestern direction, at an angle of 45° to the coast. The water level rose highest at the capes and the prominent parts of the coast, while the water penetrated farthest inland along lowlands where it encountered no obstacles. Since the wave reportedly passed over the tops of the coconut palms, its height was originally estimated at 18 m. After measurements on palm trunks and shore slopes, Coan (1870) concluded that the maximal rise of water at **Punaluu** and **Honuapo** was only 6 m; that is, it was 1/3 of the initial magnitude indicated by witnesses and the press. Cox and Morgan (1977, p. 19) give a maximum height as 13.7 m + 1.5 m at **Keauhou Landing.**

Descriptions of the effects of the tsunami at various locations follows:

Hawaii Island

Punalúu: Shortly after the earthquake, the water became agitated. Soon an enormous wave rolled onto the coast. When it receded, it took all the houses, the large stone church, and all but two of the coconut palms with it. The wave produced a fresh trench perpendicular to the shore. Fishermen on and off shore were drowned. Dunes were washed away, a fresh-water spring was filled with sand, and the configuration of the shore-line was changed. The wave was erroneously reported to have passed over the tops of the coconut palms. Drifting debris was carried 0.4 km inland.

Punaluu to **Honuapo**: The coast was devastated. Churches, houses, frame buildings, dikes, roads, fish ponds, canoes, nets, working implements, machines, and domestic goods were destroyed. In places along the coast the road was washed away or was so littered with debris that it was impassable. Groves of coconut palms were washed away.

Ninole, Kawaa, and **Honuapo**: These three villages were totally destroyed, with the exception of a small hut on the edge of the hill at **Honuapo**. One of the residents of **Ninole** reportedly was carried out to sea with his house. He secured a large board from the remains of his home, and by using it as a surf board, he made it to shore on the next crest. The water rose 6.1 m at **Ninole**.

Kaalualu: The water rose about 6 m and carried debris 61 m inland. Several houses were washed away, and a number of people were killed.

Kealakomo: The salt works were all destroyed. Houses nearest to the beach were washed away.

Apua: The waves washed away all houses, a section of beach, and a small harbor for canoes. An old woman drowned trying to save her dwelling.

Kaimu: Litter was tossed onto the meadow.

Opihikao-Pohoiki: A runup height of 5.2 m was observed. Enormous boulders were washed away at **Pohoiki**.

Hilo Bay: The water retreated 45-60 m along the horizontal, and then rose 2.7 m above the high tide mark. The bridge at **Waiakea** was flooded by a 2.1-m wave. Several houses and the king's fish pond were damaged. Coan's (1868) report that the tsunami arrived "as this awful shock died away" suggests to Cox and Morgan (1977, p. 25-26) the possibility of a second source near Hilo, since the waves would need about 20 minutes to reach Hilo from the main source.

Kealakekua: Oscillations in sea level of about 2.25-m range occurred for several hours, stranding fish.

Keauhou (east limit of **Kau** district, now called Keauhou Landing): Immediately after the earthquake, the water rose 12-15 m and washed away all houses and warehouses; destroying 167 bales of pulu, a fiber from tree ferns used as a packing material. The residents later rebuilt on a higher site.

Kawaihae: During the flood and ebb tides that began immediately after the earthquake, alternately the reefs were exposed and flooding occurred above the high tide mark. There were 13 oscillations before the sea returned to normal.

Kailua: Tilling et al. (1976) plotted a runup of 3.4 m, but Cox and Morgan (1977, p. 21) did not find contemporary records of this.

Kawa Bay: Seven were killed and the village was destroyed.

Maui Island

Lahaina: At about 4:00-5:00 P.M., the sea retreated from shore, and the bottom dried up in many places between the shore and the reef. There were 13 oscillations with an average period of 7-8 minutes.

Oahu Island

Honolulu: The first ebb tide occurred at 5:45 P.M. The water rose to the half high tide line at 6:00 P.M., it retreated to the ebb tide mark at 6:15, and at 6:25, the water rose to the full high tide mark. The maximum range of sea level oscillations was 1.5 m compared with 1 m for the highest lunar high tides.

SUBSIDENCE

The entire southeastern shore of Hawaii Island sank in varying amounts as a result of the earthquake.

(1868, April 3, continued)
Keahialaka (13 km southwest of Kapoho): A small pond of brackish water, along which ran a stone dike, was submerged during high tide to a depth of 1 m, and the water spread to the coconut palm groves, where it had never been before.

Kaimu: The sea flooded the beach of volcanic sand and encroached 60 m into a young grove of coconut palms.

Kalapana: A sandy beach shifted 30 m inland, into groves of screw pine and coconut palms, covering the trees with sand to a height of 2 m. The old stone church, previously 60 m from shore, had water covering its floor even during ebb tides. The plain at **Kalapana** dropped 1.5 m and submerged 8 hectares (20 acres) that had previously been dry land beneath 1 m of water. The bathing cabins, previously filled with water to within 1 to 2 m of their roofs, were completely filled with water.

Kealakomo: A cold water spring was lowered.

Apua: The water was 2 m deep on the site of the previous village. The vast anchorage there totally disappeared.

Punaluu: A new sandy beach was formed 30 m from the previous shoreline. (Soloviev and Go, 1975, p. 231, 233-236; Iida et al., 1967; Cox and Morgan, 1977, p. 15-29; Pararas-Carayannis and Calebaugh, 1977, p. 11; Brigham, 1909) Brigham (1868) reported a runup of 2.1 m at "Waiohina", but Waiohinu is inland. He probably was referring to the tsunami effects at **Punaluu** or **Ninole**, nearby coastal communities (Cox and Morgan, 1977, p. 20).

1868, April 4, 10, and 20. Erroneous dates for April 2, 1868, tsunami (from Milne). (Cox and Morgan, 1977, p. 28).

1868, August 13, 21:30 and August 14, 01:30. At about 4:45 P.M. and again at about 8:45 P.M., (71° W Sun time which converts to about 21:30 and 01:30 UTC) catastrophic tsunamis that affected locations throughout the Pacific Basin were generated at Arica, near the coast of southern Peru (now Chile). Waves from the first (magnitude 8.5) event arrived at the Hawaiian Islands about 1:00 A.M. local time and from the second at 5:00 A.M. August 14. Following is a list of locations in Hawaii that were affected by the wave. (Soloviev and Go, 1975, p. 74)

Hilo, Hawaii: From 2:00 A.M. (the first tsunami) on the 14th until the 16th of August, the sea was in constant movement. The period was 10 minutes. Judging by a mark left on a coconut tree and by other data, the water rose 1.5 m higher than regular flood tides, but according to Hitchcock (1909) it was 4.5 m above normal low tide. Along the Waiohi River at **Waiakea**, the water apparently rose higher and washed out a bridge. (Soloviev and Go, 1975, p. 89) Severe damage was reported by Iida et al. (1967), but no detail was given. At **Kalapana, Hawaii**, waves of 1.2 to 1.8 m flooded eight hectares (20 acres) of dry land. (Pararas-Carayannis and Calebaugh, 1977)

Kahului, Maui: The first oscillations in sea level came at dawn on the 14th and lasted all day. This would probably refer to the second tsunami. The reefs and rocks in the harbor dried up as the water level rose and fell about 3.6 m (range). The maximum oscillations were observed at 7:00 and 11:00 A.M. (Soloviev and Go, 1975, p. 89) Considerable damage is reported by Iida et al. (1967), but no details are given.

Molokai: On the 14th, about 10:00 A.M., the flood tide exceeded the usual tide mark by about 1.2 m. In the next 4 hours the sea rose and fell 12 times. The water rose so high that two houses in **Kanaio** were flooded, and the inhabitants collected fish in the dry places at ebb tide. The oscillations in level lasted two more days with a gradually increasing period. Note that Pukui, et al. (1974) locate Kanaio on Maui.

Honolulu, Oahu: The local residents at Fisherman's Spit, in the southern part of the city, noticed that the sea rose above its usual tide mark at about 9:00 P.M. on the 13th. The water reached the thresholds, but did not flood any houses. (This seems too early as the waves from the earlier earthquake would be expected about 1:00 or 1:30 A.M. and about 5:00 or 5:30 A.M.) At about midnight the residents were awakened by a terrible roar produced by the retreating ocean passing over the reefs. The sea continued to rise and fall from the first tsunami. About 7:00 A.M. on the 14th, a strong ebb tide was observed in which the water level fell 1.1 m from its highest position probably from the second tsunami. Then the ocean fell and rose every 15 to 20 minutes. At 2:35 P.M. the greatest rise, 1.6 m above the highest high tide mark, occurred. During the rise, water flowed into the harbor through the channel entrance with great velocity, and rapids formed at the embankment in the northern part of the harbor.

In **Waimea Bay** on the southwest coast of **Kauai Island**, on the 14th between 10:00 A.M. and 4:00 P.M., the sea rose and fell about 1.8 m (range). (Soloviev and Go, 1975, p. 74, 89, 90)

Many sources (Cox and Pararas-Carayannis (1976), Pararas-Carayannis and Calebaugh (1977), Iida et al. (1967), Lockridge (1985) quote 16:45 origin time as UTC, but this is the local time. Rear Admiral L.G. Billings, commander of the U.S.S. *Wateree*, reports the first shock at "about 4:00 P.M." A tsunami sank the United States store ship *Fredonia* and others in the harbor shortly thereafter. At about 8:30 P.M. huge waves carried the *Wateree*, a flat-bottomed vessel, some 0.4 km inland according to Cox and Pararas-Carayannis, (1976). Billings (1915) reported that the ship had been carried 2 miles (3.2 km) inland but this is an exaggeration.

1868, October 2, 07:30. At Kawaihae (Hawaii Island), a strong underground shock made all the residents leave their houses. On the same day at 9:00 P.M., near **Kahaualea** (**Puna** district), unusually high tides flooded the church and many houses, and covered slipways with canoes. The water rose much higher than on April 2, 1868. (Soloviev and Go, 1975, p. 231) Cox and Morgan (1977) did not find a report of an earthquake at Kawaihae, but stream flooding a day earlier destroyed a fish pond there. (Kawaihae is on the northwest coast of Hawaii and the effects there are unrelated to any effects at Kahaualea.) The effects at **Kahaualea** were possibly the result of a tsunami from a remote source. Cox and Morgan (1977) estimate the height to be 6.1 m plus or minus 3 m.

1869, July 24 or 25. An unusual flood tide 8.2 m high passed over the reefs on the **Puna coast**, partially destroying them (Cox and Morgan, 1977, p. 31). Debris weighing 1 to 2.7 metric tons was tossed on land on the coast of the **Puna** district. The water rose 9 m and passed tens of meters inland in a foaming roller. Houses that survived the flooding of April 2, 1868, were washed away by waves that were 3-4.5 m higher than the waves of that earlier event. In the region of **Kahaualea** almost everything was destroyed, even on the high cliffs, while the cliffs themselves were abraded by the waves. The depth of the water in baths, situated in the ravine at **Punaluu**, was doubled.

At **Kalapana**, the sea "reconquered" some of the land. The high water covered most of the cultivated plain around this settlement and channeled two new ditches into the beach. The waves passed over the old stone church, which was strewn deeply with sand and rocks carried by the tsunami. From **Kamaili** to **Kapoho**, the cliffs were abraded by the waves. The road running along the coast between the villages of **Pohoiki** and **Opihikao** was washed out on a 2-km stretch, which had never before been reached by high tides. The waves penetrated 300 m inland southwest of **Cape Kumukahi**, destroying several houses. (Soloviev and Go, 1975, p. 237) In some places near **Kaupo, Maui**, the sea rolled inland 180 to 270 m over an embankment 4.5 m high. (Cox and Morgan, 1977, p. 29-32)

Since these reports are not associated with an earthquake, a local origin is not probable. However, no large earthquake has been identified elsewhere which could be a source. A newspaper article in the *Pacific Commercial Advertiser* on August 14 cites the July 24 date. (Soloviev and Go, 1975, p. 237) Iida et al. (1967) suggest that this is an erroneous date and Pararas-Carayannis (1969) attempt to identify this account with earlier and later reports of storm waves or surges. Cox and Morgan (1977, p. 29-32) show that these choices are largely untenable and consider it to be a probable tsunami of

(1869, July 24, continued)
uncertain but remote source. There was a magnitude 7-7.75 aftershock of the August 13, 1868, Arica event on August 24th, and it is tempting to think there was an error of one month in the earthquake date. However, Kausel (1987) reports that the August date is confirmed.

1871, February 20, 08:41. One of the strongest earthquakes (magnitude 7.0) ever felt in the Hawaiian Islands occurred on Feb. 19 at about 10:11 P.M. Earthquake damage was reported, but reports of a tsunami are vague and doubtful. Several reports indicate that no waves were observed at Honolulu, Lahaina, or any quarter. An incorrect date of February 18 is in some accounts. (Cox and Morgan, 1977, p. 32,33; Cox, 1985)

1872, January 13. Meteorologically induced waves, inaccurately attributed to a tsunami at **Haleiwa**, Oahu, by the local contemporary press, occurred on this date. (Cox and Morgan, 1977, p. 33,34)

1872, January 22. Meteorologically induced waves, inaccurately attributed to a tsunami at **Kapua**, Hawaii, by the local contemporary press, occurred on this date. (Cox and Morgan, 1977, p. 33,34)

1872, August 23, 18:02. The water quickly rose in the bay at **Hilo** at 1:00 P.M. to a height of 1.3 m in still weather. In 6 minutes, it retreated to the lowest point and returned, reaching a height of 0.9 m. In 1.5 hours, 14 oscillations occurred, each one being weaker than the last. In the end, the water returned to its normal state. An earthquake was not felt. Soloviev and Go, (1975, p. 238) thought these effects might have been associated with an earthquake and tsunami originating in the Bonin Islands in the fall of 1872.

Cox (1984), reported that the waves were observed at **Hanalei** (no amplitude reported) and **Nawiliwili, Kauai**, with an amplitude of about 0.3 to 0.5 m at about noon and recorded on **Honolulu** at about 12:25 P.M. Jaggar (1931) and Powers (1946) mistakenly use August 27 as the date of occurrence. They correctly surmised that the source was to the north of the Hawaiian Islands.

Cox (1984) used arrival times on marigrams at Astoria, Oregon, and San Francisco, and San Diego, California, and observed times at Honolulu to determine a source near the Fox Islands, Aleutian Islands, although no tsunami was reported from there.

1877, February 24. An underwater eruption occurred 2 km from Kealakekua at about 3:00 A.M. It was accompanied by an earthquake, which was felt along the shores of the bay. A second earthquake was accompanied by a strong underground rumbling. At about the same time, according to Coan (1877), "a tidal or earthquake wave of considerable force was observed on the coast of the **Kona District.**" It is surmised that it was not a tsunami that was observed, but a "boiling" of water over the source of an underwater volcano. (Soloviev and Go, 1975, p. 239; Cox and Morgan, 1977, p. 34-35)

1877, May 4. A strong earthquake at 8:00 P.M. in the region of Mauna Loa volcano was accompanied by a renewal of the large eruption currently in progress and followed by a large tsunami. Cox and Morgan (1977) did not find any mention of an earthquake or tsunami in contemporary Honolulu newspapers and consider this report to be erroneous. (Soloviev and Go, 1975, p. 239; Cox and Morgan, 1977, p. 35)

1877, May 10, 00:59. A destructive magnitude 8.3 earthquake and catastrophic tsunami were generated off the northern coast of Chile. It was observed throughout the Pacific Basin including Samoa, New Zealand, Australia, Japan, Mexico, and California. The tsunami was observed at all the islands of the Hawaiian archipelago. The peak rise of water, depending on the contour of the coast, varied from 1 to 12 m above the lowest low tide mark. The following account is taken from Soloviev and Go (1975, p. 108-111):

Hilo, Hawaii: According to the local sheriff, unusual rises and falls of water in the bay started at 4:00 A.M. on the 10th. At about 5:00 A.M., the water rushed onshore in a large wave, which flooded almost all near-shore stores and washed away much lumber and all the stone barriers of the moorage. According to later measurements at the pier lamp post, the water had risen 3.7 m above the regular low tide mark. Thirty-seven houses were destroyed and 17 were heavily damaged. Five people died, seven were seriously injured, and 163 residents were left homeless.

Waiakea River area: In an instant all structures were washed away for a distance of 92 m from the shore. Debris from the steamship pier, a warehouse, the bridge across the river, and houses were tossed inland. The height of the wave in this region must have been 4.8 m. Seventeen horses and mules also drowned.

Coconut Island, Hawaii: Most of the island was flooded and the hospital was washed away. A little church was moved 60 m. An American whaler riding at anchor in the bay at a depth of 7 m touched bottom. Boats were lowered from the whaler and six residents were pulled from the water.

The rises and falls of sea level lasted all day. According to measurements of one of the oscillations at about 7:00 A.M., about 4 minutes elapsed from the minimal to the maximal water levels, and the water rose 4.2 m in this time. In the second half of the day, the water rose and fell three times per hour. As measured visually at 3:00 P.M., in 10 minutes the water rose 1.8 m above the high tide mark; 10 minutes later, the level fell to 0.6 m below the low tide mark; then the water rose in 8 minutes to 2.4 m above its mean level and fell in 12 minutes to the low tide mark. After this, it rose in 15 minutes to 1 m above the high tide mark.

The range of oscillations was 1.5 m at **Kawaihae**, on the western shore of **Hawaii Island**, and 9 m in **Kealakekua Bay**.

Kahului, Maui: The water retreated at about 4:45 A.M. and the bay dried up. Then the water began to flow through the mouth of the bay and rose 1.2-1.5 m above the regular flood tide mark. The second wave was not as large, the third was still smaller, but the fourth was almost the same size as the first. Flood and ebb tides were still larger than usual on the 12th, but the sea had calmed down.

Lahaina, Maui: On the southern coast of the island, the water rose 3.6 m.

Nawiliwili, Kauai: The water rose 0.9 m on the southeastern shore.

Honolulu, Oahu: At 5:20 A.M. on May 10th the water began leaving the bay rapidly. According to estimates, the water level fell 0.52 m in 5 minutes. The water returned at 6:00 A.M., and the level rose 0.85 m range in 10 minutes. Flood and ebb tides continued all day and night, but gradually abated with the greatest height being 1.45 m. (Soloviev and Go, 1975, p. 108-111)

1878, January 20. About midnight a 3-m wave flooded 150 m inland at **Waialua, Oahu,** overthrowing a stone wall, destroying a house, and damaging a cane field. A wave entered a native house soaking the sleeping inhabitants and half destroying the house. At **Honolulu** people noticed a sudden increase of noise of the surf on the reef and fishermen reported an unusually high tide. Two houses were destroyed and two damaged at **Halehaku Valley** on **Maui.** Eight grass houses and two canoes were also destroyed. At **Maliko, Maui,** a scow was sunk and a ship's boat was carried a long distance on the beach. Taro fields were flooded at **Honomanu.** Cox and Morgan (1977, p. 36-37) believe the source of the tsunami to be an Aleutian earthquake. They estimate runup heights of 3.0 plus or minus 0.6 m at **Waialua;** 3.0 plus or minus 1.8 m at **Halehaku** and **Honomanu** and 3.6 m plus or minus 1.2 m at **Maliko.** Iida et al. (1967) and Pararas-Carayannis and Calebaugh (1977) believe the waves may be of meteorological origin. Effects mentioned by Cox and Morgan for California on January 15, 1878, are clearly of meteorological origin. (Soloviev and Go, 1975, p. 239; Pararas-Carayannis and Calebaugh, 1977, Iida et al., 1967)

1883, August 27, 02:59. The explosive eruption of the volcano, Krakatau in the Sunda Strait, produced air-pressure waves, which were recorded by the **Honolulu** tide gage as a 0.2-m wave. These are not considered to be tsunami waves. (Pararas-Carayannis, 1969; Pararas-Carayannis and Calebaugh, 1977)

1887-1909, February 5. A tsunami, which is recorded in oral tradition and a song, affected **Milolii**, South Kona, Hawaii, on the 5th of February in a year not recorded. The tradition and song are considered to relate to a probable tsunami of local origin. (Cox, April 20, 1987, personal correspondence)

1895, January 28. A strong wave, apparently of meteorological origin, broke on the coast of **Maliko**, Maui Island, according to Soloviev and Go (1975, p. 239) citing Pararas-Carayannis, (1969). However, Pararas-Carayannis (1969) did not mention this event. Cox and Morgan (1977, p. 37-38) conclude from contemporary reports that there was no tsunami on this date.

1896, June 15, 10:33. A strong (magnitude 7.6) earthquake on the northeastern (Sanriku) coast of Honshu, Japan, generated a destructive tsunami on **Hawaii Island** that affected the other islands in the Hawaiian chain. It first reached **Kauai** at about 7:30 A.M. when a 1.5-m wave exposed the seafloor at **Kilauea Landing.** At **Kapaa** boats were stranded at the landing and the Steamer *James Makeel* was grounded at its anchorage. A road and bridge were flooded by a 1.5 m wave at **Nawiliwili.** On **Oahu** the tsunami was recorded at **Honolulu** as a wave of 0.5-m maximum height but the observed height was somewhat greater. However, thousands of fish were reported stranded at the mouth of Nuuanu Stream and the wave was observed by bathers at **Waikiki.** On **Maui** it was observed at **Kaanapali** but not at Lahaina.

The major effects were on **Hawaii**. Waves as high as 12 m were reported in some accounts but have been shown to be inaccurate. A maximum height of 5.5 m at **Keauhou** was observed. A wharf at **Kawaihae** was demolished. At **Kailua** a wharf was demolished; a warehouse, several stores, and a lumber yard were flooded, the Paris Hotel was flooded; two native houses and small buildings were swept away; six mules hitched to a wagon were swept off their feet. At **Keauhou** as many as nine houses were demolished; a Chinese store and the post office were destroyed, the wharf was demolished; barrels of oranges were swept away; and fish were caught in lantana plants. At **Kaawaloa** a wharf and house were dislodged, and a warehouse was flooded. At **Napoopoo** three houses and lumber from a lumber yard were washed away and the wharf was destroyed. At **Hookena** the wharf, a Chinese store, and bridge were demolished. Several houses were wrecked, and others were inundated. Wharves and several houses were destroyed at **Kaalualu** and **Kaiwilahilahi.** At **Hilo** two yachts were damaged. The wave was observed in both **Punaluu** and **Honuapo** with an amplitude of 3.6 m but no significant damage was reported. (Cox, 1980, p. 8-22; Soloviev and Go, 1974, p. 83; Pararas-Carayannis and Calebaugh, 1977)

1901, August 9, 13:01. A magnitude 7.9 earthquake occurred near the Tonga Islands. (Richter, 1958, p. 710; Gutenberg, 1956, p. 608-614). A wave reported to be about 1.2 m high appeared at **Kailua** on the western coast of **Hawaii** at 11:00 A.M. The pier was covered with 0.6 m of water. Several houses were inundated, and one was washed away. At **Keauhou,** 10 km south, two huts were destroyed, and water was 0.9 m over the wharf. One house was inundated at **Mahukona.** The wave was observed at **Napoopoo** and **Hookena** and recorded at **Honolulu** with a height of 0.12 m. No unusual oscillations were noted at other points on the Hawaiian Islands. (Soloviev and Go, 1974, p. 86; Shepard et al., 1950; Cox, 1980, p. 23-29)

The effects reported above are widely and incorrectly associated with either or both of the two strong tsunamigenic earthquakes of August 9, 1901, at 09:24 and August 10 at 18:34 UTC off the Sanriku coast of Japan. The travel times to both **Kailua** and **Honolulu** fit a source region near the Tonga Islands. However, inquiries to Apia and Fiji did not uncover any reports of local observations.

1903, October 6, 06:30. As the English Ship *Ormsery* approached the western shore of **Hawaii Island** at 8:00 P.M., crewmen noticed whirling currents and "the sea to appear to churn as if mighty springs were acting under the water surface." The ship felt a shock like a tidal wave coming from the shore and was turned with the stern forward.

The agitation continued until at least 6:00 A.M. on the 6th. The next day on October 6, the Mauna Loa volcano ejected a column of smoke and possibly a lava flow. (Soloviev and Go, 1975, p. 239; Cox and Morgan, 1977, p. 38-39). Cox (1984, p. 37) concludes the cause was probably a series of eddies generated in the wake of the **Island of Hawaii** by prevailing eastern currents. There are reports of choppy seas in the area at least through October 11 (Cox, 1984, p. 35-37).

1903, October 8, at night. An ebb tide at **Punaluu, Hawaii Island**, was succeeded on the following night by a powerful flood tide, which flooded the pier. This is a doubtful tsunami event. (Soloviev and Go, 1975, p. 239; Cox and Morgan, 1977, p. 38-39). Cox (1984, p. 43) also considers the tsunami to be doubtful.

1903, November 17. At **Punaluu** waves suddenly appeared on the previously quiet surface and lasted 10 minutes. Their origin could not be fully explained. However, at the same time (by other accounts, later in the day) a black smoke column of unusual size appeared above the Mauna Loa volcano. (The date is incorrectly given as November 24 by Hitchcock (1909), and repeated by Soloviev and Go (1975), p. 239.) Cox (1984, p. 44) considers the waves almost certainly to be of meteorological origin related to tremendous swells encountered by ships to the northwest. Reports of a similar disturbance on November 24 clearly refer to the November 17 event. (Cox, 1984, p. 44)

1903, November 29. A wave flooded the northern coast of the Islands of **Oahu** and **Molokai** and was registered by the tide gage at **Honolulu**. Waves reached 12.2-15.7 m at **Kalaupapa, Molokai**. Two houses were destroyed at **Honokohau, Maui**. A section of railroad track was washed out on **Oahu**. Waves began on November 29 and continued through the 30th, making cargo unloading difficult. (Cox and Morgan, 1977, p. 40-42) Cox (1984, p. 54) now considers the waves of the 29th probably an increase in the size of already large meteorological swells.

1906, January 31, 15:36. A catastrophic magnitude 8.2 earthquake off the coast of Ecuador and Colombia generated a strong tsunami that killed 500 to 1500 there. It was observed all along the coast of Central America and as far north as San Francisco and west to Japan. The following is taken largely from Soloviev and Go (1975). The wave arrived in **Hilo** at about 12.5 hours after the earthquake. It covered the floor of the old wharf at the end of Waianuenue Street and the railroad tracks between there and Waiakea. The range of oscillations in water level was 3.6 m and the period 30 minutes. The channels of the Wailuku and Wailoa Rivers alternately dried up, then disappeared under the tidal wave.

Kahului: Three waves arrived at 20-minute intervals. The second wave was larger than the first, and the third was larger than the second. The water rose about 0.30 m above the mean sea level mark. According to other sources, the water surface rose to the level of the old steamship pier and the road running along the coast.

The tide gage at **Honolulu** began to register oscillations about 12 hours after the earthquake. The tsunami apparently began with a flood; then the oscillations intensified, and the fourth wave, which was the highest, had a height of 0.25 m. The period of oscillations was 20-30 minutes. Three separate trains of oscillations were registered.

According to the accounts of witnesses, disturbances in water level on **Honolulu Bay** began to be observed at 3:30 UTC February 1. At 4:15 UTC there was an extremely great ebb. All the steam and sailboats in the bay were turned around. Then a sudden flood tide reached a considerable height. (Pararas-Carayannis and Calebaugh, 1977; Soloviev and Go, 1975, p. 163, 168)

1906, August 17, 00:40. A strong (magnitude 8.1) earthquake occurred in central Chile near Valparaiso. The tsunami it generated was observed in California and Japan as well as Hawaii. At **Hilo**, the rise of water was 1.5 m. **Off the northeast coast of Hawaii Island** a coaster began drifting when a sudden ebb current broke its anchor chain. On the south coast of **Maui Island**, the water rose 3.5 m. The piers were destroyed at **Maalaea** and **McGregor's Landing**. At **Kahului**, the road along the

(1906, August 17, continued)
beach was flooded. At **Honolulu**, a mild tsunami lasting 20 hours began on August 17 at 5:15 A.M. The period of oscillations was 25-35 minutes, the height (or range) was 0.07-0.10 m. (Soloviev and Go, 1975, p. 122)

Note: A magnitude 8.3 earthquake also occurred 30 minutes before the Chilean earthquake in the Aleutian Islands at 51° North, 179° East. If this event had produced a tsunami, the tsunami would have affected Hawaii 10 hours earlier than the Chilean event. However, no tsunami was observed on West Coast marigrams and apparently none was generated.

1908, September 21, 06:42. A magnitude 6.8 earthquake occurring on September 20 a few minutes after 8:00 P.M. local time with a source near the southeast coast of Hawaii Island caused the water in the harbors and rivers of **Hilo** to rise about 1.2 m. Some shore residents were frightened and came to town for the night. (Cox and Morgan, 1977, p. 42; Soloviev and Go, 1975, p. 240) There is some confusion regarding the time and location of this event. Pararas-Carayannis and Calebaugh (1977) give the time as 6:15 UTC by incorrectly converting a time of 8:15 P.M. local time to UTC by adding 10 hours instead of 10:30. Cox (1986) gives the local time as 20:12, possibly the average of 20:08 and 20:15 given by other sources and gives the Universal time as 06:22. Similarly, the locations vary by half of a degree in both latitude and longitude.

1913, October 11, 04:06. The second of two strong earthquakes (magnitude 7.8) in the New Guinea region on this date was reported to have produced a tsunami recorded at **Honolulu** "at the proper time" but not in the source region or elsewhere. (Iida et al., 1967; Soloviev and Go, 1974, p. 296; Heck, 1947; Pararas-Carayannis and Calebaugh, 1977)

1914, May 26, 14:23. A 7.9 earthquake on the north coast of New Guinea was recorded at **Honolulu**. (Iida et al., 1967; Soloviev and Go, 1974, p. 296; Pararas-Carayannis and Calebaugh, 1977)

1917, May 1, 18:27. A magnitude 8.0 earthquake occurred in the Kermadec Islands. It was recorded at **Honolulu** as a 0.3-m wave with a 20 minute period. (Iida et al., 1967)

1917, June 26, 05:50. A magnitude 8.3 earthquake between Samoa and Tonga generated a locally damaging tsunami that was recorded in **Honolulu** as a 0.10-m or less wave with a period of 20 minutes. (Iida et al., 1967; Soloviev and Go, 1975, p. 11)

1918, August 15, 12:18. Several earthquakes (largest magnitude 8.3) near Mindanao Island, Philippines, generated a tsunami that caused much destruction locally but was barely recorded in **Honolulu**. (Iida et al., 1967; Soloviev and Go, 1974, p. 210, 211)

1918, September 7, 17:16. A magnitude 8.3 earthquake in the south Kuril Islands generated a tsunami that was recorded at **Honolulu** with a 0.3-m wave height. At **Hilo** the height was 1.5 m with minor damage reported. (Iida et al., 1967; Pararas-Carayannis and Calebaugh, 1977; Soloviev and Ferchev, 1961, p. 20)

1919, January, April 9, or April 29. Errors in several reports have confused the dates and effects of two separate tsunamis. Finch (1924) mentioned that a tsunami occurred on April 9, 1919 "the origin of which appears to have been to the southwest of Hawaii." This may have been a simple transcription error for a Thrum (1919) report of the tsunami occurring on April 29. Both these reports refer to the April 30, 1919 event below. Jaggar (1931) mentioned short period tidal waves of a local nature which were three days after an eruption of Mauna Loa in 1919. Pararas-Carayannis and Calebaugh (1977) associate this report with the April 9 date which they conclude was a doubtful tsunami. They also list the correct date of October 2, 1919 for these effects. Soloviev and Go (1975, p. 240) list the dates as January or April 9 and also a separate entry for the September-October eruption of Mauna Loa and October 2 local tsunami. There were two tsunamis: one generated by an earthquake in the Tonga Islands on April 30, 1919, and another near Hoopuloa on October 2, 1919, from a submarine slump of volcanic material. (Cox and Morgan, 1977, p. 43)

1919, April 30, 07:17. A magnitude 8.3 earthquake in the Tonga Islands generated a tsunami that drained the bay at **Punaluu.** The water gradually returned, but on two occasions it rapidly receded. In **Hilo**, the tsunami had an amplitude of 0.6 m and a period of 70 minutes. In **Honolulu**, the tsunami had a height of 0.1 m and a period of 25 minutes. This event is given the incorrect date of April 9 in some accounts. (Soloviev and Go, 1975, p. 13; Iida et al., 1967; Pararas-Carayannis and Calebaugh, 1977)

1919, October 2. The Mauna Loa volcano eruption of September 28 poured lava into the sea at **Alika** on the Kona coast on September 30, generating unusual wave activity at times. Many tourists came to see the sight. One family was on the **Hoopuloa** wharf to get a canoe to see the flow better. Suddenly, the sea receded, exposing the bay floor. The waters soon returned as a 4.3-m wave washing the man, his wife, and one son off their feet. One son tried in vain to save the family auto and was swept into a wharf shed where he held onto some beams. The man was washed about 100 m to sea, but managed to get back. His wife was carried about 400 m to sea, but was rescued by two Hawaiians who swam to a still floating canoe to reach her. The man estimated that there were 10 waves. An 18,000-liter water tank was destroyed. At **Keauhou** the wave height was about 2.4 m and about 0.9 m at **Kailua**. There was not an accompanying earthquake nor could the velocity of the lava flow generate a tsunami. A possible explanation would be the sudden collapse of the 1.5-day accumulations of lava at or beyond the shoreline. (Soloviev and Go, 1975, p. 240; Cox and Morgan, 1977, p. 44 and 88; Pararas-Carayannis and Calebaugh, 1977)

1921, December 16. Probable strong storm waves caused some damage at **Hilo** and were erroneously ascribed to a tsunami. (Iida et al., 1967; Soloviev and Go, 1975, p. 240; Pararas-Carayannis and Calebaugh, 1977; Cox and Morgan, 1977, p. 46,47)

1922, November 11, 04:33. A magnitude 8.3 earthquake occurred in the southern part of Atacama Province, central Chile. Locally, the tsunami caused extensive damage. The tsunami arrived at **Hilo, Hawaii** in 14.5 hours. The period of oscillations was 20 minutes, and the height of the tsunami was 2.1 m; many boats were washed away, and some damage was done. The wave reached **Honolulu** in 15.0 hours. The period of oscillations of the waves was 23 minutes, the height of the wave 0.3 m. (Iida et al., 1967; Pararas-Carayannis and Calebaugh, 1977; Soloviev and Go, 1975, p. 132, 135)

1923, February 3, 16:01. A series of strong shocks that caused several fatalities occurred on the coast of the Gulf of Kronotski, Kamchatka. It was also observed in California, Japan, and Samoa. The locally damaging tsunami reached the Hawaiian Islands, where seven incoming waves were noted. Shepard et al. (1950) reported: "At **Honolulu** the retreating water exposed the reefs, and thereafter the oscillations continued with a period of 15 or 20 minutes. At **Kahului,** on the **Island of Maui** the ebb set a ship on a shoal at the bottom of the harbor. When the water returned, it flooded a part of the town, reaching a height 2-3.5 m above the normal level." At **Hilo** the ebb of the water was followed by a series of oscillations that continued for several hours. The third wave was the largest, rising more than 6 m at the mouth of the **Wailoa River**. (Soloviev and Ferchev, 1961, p. 21, 23) Much damage was done and one fisherman was beheaded when the sampan on which he was riding was driven under a railroad bridge across the mouth of the **Wailoa River** (Cox, 1987, p. 16). The railroad embankment between **Hilo** and **Kuhio** was washed down. Houses and wharves were badly damaged and the bridge was destroyed. At **Haleiwa, Oahu** 1.8-3.7 m waves were reported but reports of effects there are not available. A total of $1,500,000 in damage was done. (Soloviev and Ferchev, 1961, p. 20-23; Pararas-Carayannis and Calebaugh, 1977; Iida et al., 1967)

1923, April 13, 15:30. A magnitude 7.2 earthquake within the Gulf of Kamchatka generated a weak tsunami. It was recorded in Hawaii with a height of 0.2 m at **Honolulu** and 0.3 m at **Hilo**, but caused no damage. (Iida et al., 1967; Soloviev and Ferchev, 1961, p. 23,24; Pararas-Carayannis and Calebaugh, 1977)

1923, September 1, 02:58. There was a catastrophic (magnitude 7.9) earthquake in the Kanto region of Japan. Beyond the source, the tsunami was weak. The tide gage at **Honolulu** registered oscillations in sea level with a period of 21 minutes and a height of 0.03 m. (Iida et al., 1967; Pararas-Carayannis and Calebaugh, 1977)

1924, May 30-31. A damaging storm-generated wave reached 5 m at **Kaumalapau Harbor** on **Lanai Island**. A damaging wave also hit the shores of **Kauai Island** at **Nawiliwili**. High waves were observed at **Oahu**. Researchers express doubt that the event was a true tsunami, although it has been linked to an eruption of Kilauea. (Soloviev and Go, 1975, p. 241; Cox and Morgan, 1977, p. 47-48; Pararas-Carayannis and Calebaugh, 1977)

1925, October 4. The tide gage at **Honolulu** registered waves with a period of 20 minutes and an amplitude of 0.10 m. Waves were reported at Long Beach, California, at 12:15 UTC, but the time of the wave arrival at Hawaii was not given. (Iida et al., 1967; Soloviev and Go, 1975; p. 241; Pararas-Carayannis and Calebaugh, 1977; Cox and Morgan, 1977, p. 48) A small earthquake was thought to have originated at 10° N and 103° W at 03:45 (ISS, 1925) and 0.5° N and 106° W at 03:44 (Neumann, 1926). The expected travel time for a tsunami from these sources to Long Beach is about 2 hours and 3 hours respectively. A submarine volcano eruption or meteorological source are also possible causes.

1926, January 25, 00:36. A magnitude 7.4 earthquake in the Solomon Islands was recorded by the Hawaiian Volcano Observatory seismographs. If a tsunami were generated, it would arrive at Hawaii about 10:00 P.M. on January 24 local time. This is apparently the basis for mention in the "Seismological Notes" of the *Bulletin of the Seismological Society of America* (Vol. XVI, No. 1, 1926, p. 63) and in Pararas-Carayannis and Calebaugh (1977). However, Cox and Morgan (1977, p. 49) found no mention of the tsunami actually being observed on that date.

1926, March 20, 09:03. A local earthquake off the northeast coast of the Island of Hawaii near Kohala occurred at about 10:30 P.M., March 19 HST. The United States Naval radio station at **Wailupe, Oahu**, reported that a small tidal wave struck their building, jarring it considerably but doing no damage. The naval operators said the water rose almost 1.5 m at the instant of the shock. Cox (1986) points out that a wave would have taken some tens of minutes to reach the station from the epicenter and that in view of the absence of steep submarine slopes near **Wailupe**, a local submarine landslide source was improbable. The wave was not reported elsewhere and is considered doubtful.

1927, October 24, 16:00. A magnitude 7.1 earthquake occurred in southern Alaska, reportedly producing a wave at **Honolulu**. Submarine cables were broken between Petersburg and Wrangell, and between Juneau and Skagway. The United States Army cables between Ketchikan and Wrangell were also broken. (Soloviev and Go, 1975, p. 218) However, no tsunami was observed in Alaska or recorded on the Ketchikan gage. (Stephen Gill, 1987) Cox and Morgan (1977, p. 49) state that the wave was not recorded on the Honolulu gage and conclude that no tsunami occurred at this time.

1927, November 4, 13:51. The Point Arguello, California, earthquake (magnitude 7.3) in the area of the Murray fault zone generated a tsunami that was recorded in Hawaii. At **Hilo** the maximum wave amplitude was 0.10 m and the period was 12 minutes. At **Honolulu** oscillations of 0.02 m occurred with a period of 20 minutes. (Iida et al., 1967; Soloviev and Go, 1974, p. 218, 220; Pararas-Carayannis and Calebaugh, 1977)

1927, December 28, 18:20. A magnitude 7.3 earthquake in the Gulf of Kronotski, Kamchatka, (USSR) was recorded in **Hilo** and **Honolulu** with an amplitude of 0.1 m or less. The date of this event has been erroneously reported as December 23. Soloviev and Ferchev (1961 p. 25) could not find any information on local tsunamis, but the shores of the Gulf of Kronotski were uninhabited. (Iida et al., 1967; Pararas-Carayannis and Calebaugh, 1977)

1928, June 17, 03:19. A magnitude 7.8 earthquake near Acapulco, Mexico, produced a destructive local tsunami. It was recorded at **Hilo** with an amplitude of 0.2 m and at **Honolulu** with an amplitude of 0.05 m. (Iida et al., 1967; Soloviev and Go, 1975, p. 190; Pararas-Carayannis and Calebaugh, 1977)

1929, March 7, 01:35. A magnitude 7.5 earthquake in the Fox Islands of the Aleutian Islands produced a tsunami recorded at **Honolulu** with an amplitude of 0.05 m and at **Hilo** with an amplitude of 0.2 m. At **Hilo** the surge in the mouth of the **Wailoa River** was sufficient to break the stern lines of the Steamship *Haleakala* at Pier 2. The tsunami was not recorded or observed in Alaska. (Iida et al., 1967; Soloviev and Go, 1974, p. 22; Pararas-Carayannis and Calebaugh, 1977)

1930, February. A tsunami in the Hawaiian Islands was reported by Jaggar (1946), but it is considered erroneous. (Pararas-Carayannis and Calebaugh, 1977; Cox and Morgan, 1977, p. 49)

1931, October 3, 19:13. A tsunami from a 7.9 magnitude earthquake on San Cristobal Island in the Solomon Islands region destroyed 18 villages locally and was recorded on the tide gage at **Hilo** where the water first lowered about 0.07 m, then rose about 0.11 m. At **Honolulu** the range of oscillations was 0.05 m. (Iida et al., 1967; Soloviev and Go, 1974, 307, 308; Pararas-Carayannis and Calebaugh, 1977)

1932, June 3, 10:37. A 7.9 magnitude earthquake occurred on the coast of the Mexican States of Colima and Jalisco. The tsunami arrived at **Hilo** 6.9 hours later. It had an amplitude of 0.4 m and a period of 18 minutes. It reached **Honolulu** 7.7 hours after the earthquake and had an amplitude of 0.08 m and a period of 10 minutes. (Iida et al., 1967; Soloviev and Go, 1975, p. 190, 192; Pararas-Carayannis and Calebaugh, 1977)

1932, June 18, 10:12. A Mexican earthquake (magnitude 7.7) generated a 0.10-m tsunami at **Hilo**. (Iida et al., 1967; Soloviev and Go, 1975, p. 192; Pararas-Carayannis and Calebaugh, 1977, p. 22)

1932, June 22, 12:59. There was a destructive earthquake at Colima, Mexico, (magnitude 6.9). The tsunami was locally damaging and resulted in several deaths. It was recorded at **Hilo** with an amplitude of less than 0.10 m. (Iida et al., 1967; Soloviev and Go, 1975, p. 192, 193; Pararas-Carayannis and Calebaugh, 1977, p. 22)

1933, March 2, 17:31. An extremely destructive earthquake (magnitude 8.3) and tsunami occurred in Japan. Three small waves arrived in **Lahaina Harbor, Maui** on the afternoon of March 2 HST. The water receded 10-14 m horizontally, exposing the seafloor and reefs. Some damage at **Kawaihae, Hawaii**, was reported by Pararas-Carayannis (1969) and Pararas-Carayannis and Calebaugh (1977), but Cox (1980, p. 32) does not find it reported in contemporary records. At **Hilo** the first wave arrived at 3:36 P.M. A series of 10 large waves started at 3:20 P.M. at **Kailua-Kona, Hawaii**. The last was the highest. There was considerable damage. The retaining wall at Kona Inn was damaged, and water topped the porch and splashed into the lobby. A wall was broken, and the caretaker's house at the palace was moved. The American Factors, Ltd. lumberyard was inundated and the lumber scattered. A sampan on a marine railway near the Kona Inn was tossed over the seawall. Boats were set adrift. The water receded 2.4 m below mean sea level, and rose 2.9 m--a total vertical range of 5.3 m at **Napoopoo** on the **Island of Hawaii**. The seventh wave was the largest. The wave was also observed at **Honolulu** and on **Kauai**. At **Kaalualu, Hawaii**, a fishpond wall was destroyed. The sea inundated 92 m inland. At **Keauhou**, a boathouse and water tank were moved. Stone walls were damaged, and sampans, canoes, and a motorboat were washed ashore. The Hawaiian Volcano Observatory recorded the earthquake on its seismographs and heard on the radio of the earthquake and tsunami in Japan. The Observatory issued warnings to the Harbor Master at **Hilo** and the American Factors, Ltd. located at **Kailua** and **Napoopoo**. As a result, boats were moved out of the Wailoa estuary, cargo was removed from the wharves at Napoopoo, and no damage occurred at these places. Pararas-Carayannis and Calebaugh (1977) give the amplitude at

(1933, March 2, continued)
Midway as 4.5-6.5 m but this refers to the travel times to **Midway** in hours! (Iida et al., 1967; Cox, 1980, p. 30-36; Pararas-Carayannis and Calebaugh, 1977)

1935, November 21, 11:41. An earthquake, observed in the Hawaiian Islands, was reported to have been accompanied by a tsunami. At **Hilo** damage occurred to the railway and to many fishing vessels and yachts. (Soloviev and Go, 1974, p. 241) However, Cox and Morgan (1977, p. 50) report that a storm was in progress at the time and fishermen at the **Wailoa River** denied the report of a tsunami. Cox and Morgan consider the report to be very doubtful. (Pararas-Carayannis and Calebaugh, 1977, p. 23)

1938, March 6, 01:56. Waves of 0.04 to 0.05-m height were reported recorded at **Honolulu** beginning on March 6 at 3:30 P.M. (Neumann, 1940, p. 33). This event has been associated with an earthquake in the South Pacific on March 6, but this seems unlikely. The only earthquake on this date large enough to be reported in the *International Seismological Summary* (Jan.-Mar. 1938, p. 94) occurred on March 6 at 01:56 UTC in the New Britain region. Waves from that source would have arrived around midnight, March 5-6 local time. Iida et al. (1967) correctly give the arrival time of the wave as 3:30 P.M., but give the date as March 7. Pararas-Carayannis and Calebaugh (1977) give the correct date, but give both the earthquake origin time and the wave arrival time as 3:30 P.M. Soloviev and Go (1974, p. 309) quote a date of March 7, 01:30 UTC as the standard time for the wave's arrival in Hawaii rather than the correct 02:00 UTC. They suggest a possible association with a small South Pacific earthquake of March 6 at 4:55 P.M., which the observatory at Pasadena, California, believed to have a focal depth of 400 km making it an unlikely source for a tsunami. This is a doubtful tsunami. (Pararas-Carayannis and Calebaugh, 1977, p. 23)

1938, November 10, 20:19. A magnitude 8.3 earthquake that caused slight damage on the Alaskan Peninsula generated a tsunami that was recorded with heights of 0.1 m at **Honolulu** and 0.3 m at **Hilo**. The tsunami began with a flood tide at remote stations. (Iida et al., 1967; Soloviev and Go, 1974, p. 23; Pararas-Carayannis and Calebaugh, 1977, p. 24)

1943, April 6, 16:07. A magnitude 8.3 earthquake 200 km north of Santiago, Chile, generated a tsunami that was recorded locally and in the Hawaiian Islands, California, and Japan. At **Honolulu** the amplitude of oscillations was 0.01 m, the period 20 minutes. (Iida et al., 1967; Soloviev and Go, 1975, p. 148) Pararas-Carayannis (1969) and Pararas-Carayannis and Calebaugh (1977) give the amplitude as 0.10 m.

1944, December 7, 04:35. A magnitude 8.0 earthquake off the southeastern coast of the Kii Peninsula, in the Ryukyu trench, Japan, generated a 0.1-m tsunami at **Honolulu**, Oahu. (Iida et al., 1967; Soloviev and Go, 1974, p. 112-114; Pararas-Carayannis and Calebaugh 1977, p.24)

FIGURE 16.—Citizens of Hilo, Hawaii, fleeing up Ponahawai Street in advance of wave from the tsunami of April 1, 1946. Wave is barely visible in the background. (Photo Credit: Joint Tsunami Research Effort)

1946, April 1, 12:29. The catastrophic waves generated by a 7.3 magnitude earthquake in the Aleutian Islands engulfed the Hawaiian Islands suddenly and caused people to run for their lives in downtown Hilo (fig. 16). The tsunami cost the islands 159 lives (most probable total according to Cox, 1987, p. 30) including the man on Pier No. 1 in Hilo Harbor (fig. 17). Property damage amounted

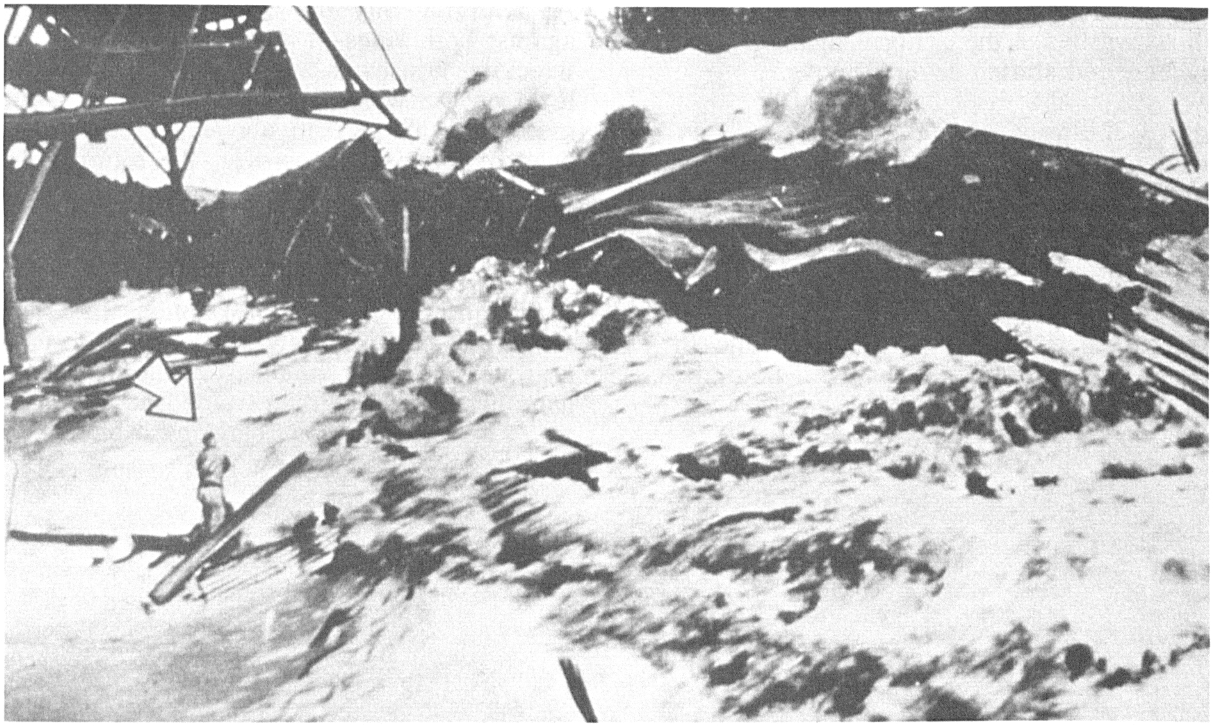


FIGURE 17.—Tsunami of April 1, 1946, breaking over Pier No. 1 in Hilo Harbor, Hawaii. The man in the foreground became one of the 159 fatalities in the Hawaiian Islands from the tsunami. The photograph was taken from the *Brigham Victory* which was in the harbor at the time of the event. (Photo has been retouched. Photo Credit: National Oceanic and Atmospheric Administration)

to $26 million (Shepard et al., 1950, p. 392). This tsunami has been the subject of a number of special papers. The effects, taken mainly from Shepard et al. (1950), are summarized below:

Island of **Kauai**: A gentle rise was reported on the western side of the bay at **Haena**. Farther east 0.8 km, the waves swept inland 485 m, knocking over trees, laying them in parallel rows, and destroying houses. Two women, one of them carrying a baby, were stranded when they were surrounded by rising water. Although they managed to swim to safety, their houses were destroyed. On the point just east of the bay the water rose 9.8 m. On the eastern side of the bay the head of the beach was cut back 9 to 15 m, leaving a scarp 1 to 3.5 m high. Coral blocks, some as large as 3.6 m in diameter, were carried as much as 150 m inland, and blocks of limestone that must have exceeded 9 metric tons in weight were tossed up on the reef. A large block of concrete and reef limestone, more than 18.5 m^2 in area and 0.60 m thick, which had been the porch of a house, was carried 18 m out on the reef by the receding water. Houses standing 6.5 m above sea level were demolished, and several persons lost their lives.

At **Kalihiwai Bay** the water rose 6.1 to 6.7 m. Houses as much as 3 m above sea level and 91 m inland were destroyed, and six lives were lost. One house was carried 300 m up the valley but left barely damaged. Between waves, the water receded until the riverbed was left almost dry for 150 m inland.

At the stream 0.2 km southeast of **Pakala Point**, 1.6 km northwest of **Moloaa**, the water rose 10 m at the shore, but rushed 227 m up the valley to a height of 11.5 m. At **Moloaa** all 12 houses were destroyed, but no lives were lost.

At **Hanamaulu Bay** most of the damage was caused by the violent withdrawal of the water between waves, which damaged a small

(1946, April 1, continued)
launch, washed the tug against the breakwater, and shifted several buoys.

Island of **Niihau**: The waves severely damaged this island, but caused no injury or loss of life. At **Naina**, on the northern coast, a cottage that had been in the same location for more than 60 years was destroyed. At **Kii Landing** the waves destroyed the small wharf, damaged houses and fences, washed cobbles inland over part of the area, and in other areas stripped the surface down to the hard pan. The wharf and some houses were badly damaged at **Nonopapa Landing**.

FIGURE 18.—Tsunami wave arrivals between 10 and 11 A.M. local time at Hilo, Hawaii, from the earthquake in the Aleutian Islands on April 1, 1946. Note that one span of the railroad bridge has already been destroyed by an earlier tsunami as it advanced up the Wailuku River. (Photo Credit: Univ. of California at Berkeley)

Island of **Oahu**: The highest amplitude on the island (11 m) occurred at **Makapuu Point** near **Koko Head**. At **Kawela Bay**, houses were damaged by the waves which came across the off-lying reefs and rose as high as 5.8 m just west of the bay. At the airport just east of **Kahuku Point** the waves drove inland across the dunes, flooding the lowlands inside the coastal dune ridge and causing extensive damage. There was one fatality at **Kahuku**. To the southeast of **Laie** the water caused extensive destruction to houses at **Haleaha** and **Makalii Point**. Sugar cane on 50 m^2 of Kahuku Plantation was damaged or destroyed by the force of the waves and by salt poisoning.

At **Kahana Bay** the waves swept violently against both sides of the entrance to the bay, wrecking houses as much as 3.5 m above sea level on the western side, but reached a little more than about 2 m above sea level at the head of the bay. However, the return of the water from the bay head swept a house into a fishpond on the southeastern side of the bay and drowned three children.

Although the water rose only 4.5 m at **Kaloko**, 1.6 km southwest of Makapuu Point, a group of houses inland from the beach was demolished. One man waded in the rising water up to his armpits carrying a picture

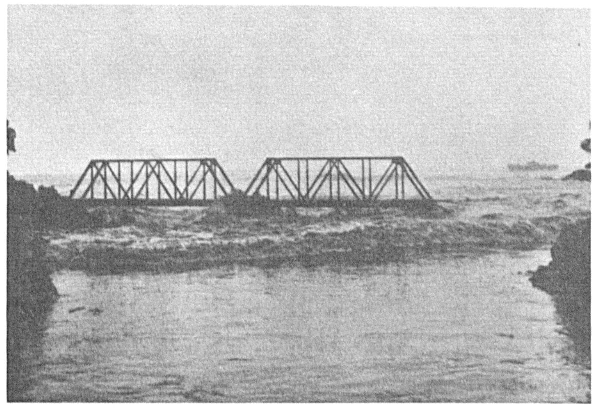


FIGURE 19.—Close-up of bridge shown on the left and a tsunami becoming a bore as it advances past the bridge and up the Wailuku River. (Photo Credit: Univ. of California at Berkeley)

over his head. His house was destroyed.

Island of **Molokai**: Many people observed the waves at **Kalaupapa**, and some houses were destroyed. The wave backwash undermined a road and washed away several houses.

Island of **Lanai**: This island sustained little damage.

Island of **Maui**: At **Kahului** several houses were damaged or destroyed, and a number of military amphibious tanks parked near the breakwater floated off. Along the beaches for about 10 km east of **Kahului** the waves rose 5 m or more above sea level. At **Spreckelsville** the waves reached 8.5 m and swept inland as much as 240 m. Several residences were destroyed, and many were badly damaged. At **Lower Paia**, where the waves reached to 6 m above low water, several buildings 76 m from shore and 3 m above sea level were wrecked, and some buildings were carried 15 to 30 m farther inland. In places the waves swept into cane fields about 240 m inland, damaging the cane and making necessary a premature harvesting.

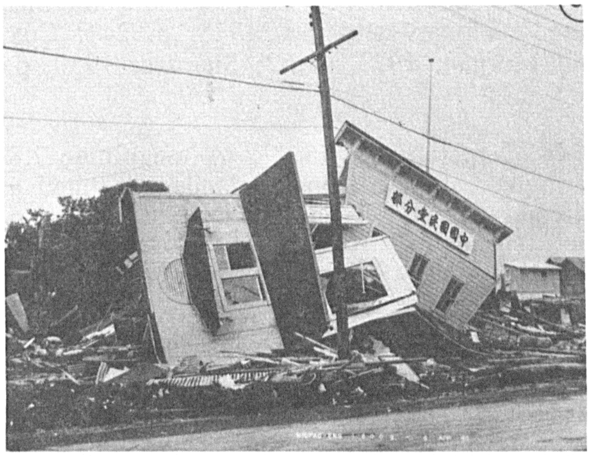


FIGURE 20.—The Koomintang Political Party Clubhouse on Kamehameha Avenue in Hilo, Hawaii, destroyed by the tsunami of April 1, 1946. (Photo Credit: U.S. Army Corps of Engineers)

At **Maliko Bay** houses below the highway were destroyed, and an automobile parked near the beach was rolled on the highway.

The waves swept over the entire end of **Keanae Peninsula,** damaging several buildings and killing 2 people and injuring 2 more.

At **Hamoa** 3.3 km south of **Hana**, the waves reached 6 to 7 m above low water. Almost all the houses below about 3 m above sea level were destroyed. Ten lives were lost.

At **Honokohau,** 3 km east of Honolua, the waves rose 8.5 m, smashed a bridge, eroded the upper beach, and destroyed some taro patches.

The largest wave heights on **Maui** were found at **Kahakuloa**. In the western gulch entering the bay at **Kahakuloa** the waves reached 9 m, destroying a house. In the eastern gulch the waves rose to 10 m, destroying 2 houses and uprooting or smashing many plum and hau trees.

At the northern side of **Paukukalo**, 4 km nearer **Kahului**, the water rose 6.1 m. Some of the many beach houses were damaged.

The **Island of Hawaii**: At **Pololu Valley** the beach was cut back about 45 m, and cliffs over 2 m high were cut on the northwestern end of the dune ridge. The water swept inland for about 300 m, destroying houses and rice paddies.

At **Laupahoehoe Peninsula** the water reached a height of 9.1 m above mean sea level and swept over the whole seaward end of the peninsula, leaving severe damage. Some houses swept 150 m inland diagonally to the northwest, were left more or less intact. Twenty-five people were killed.

At **Hakalau Gulch** the Hakalau Sugar Company's mill, which stood less than 3 m above sea level and near the water's edge, was badly wrecked. A large tank, small steel girders, and sheet-iron roofing from the mill were carried 240 m inland. Steel girders on the railroad trestle, inland from the mill, were bent by the impact of the debris-laden water. At **Kolekole Stream**, 2.2 km southeast of **Hakalau Gulch**, the water reached 11 m above sea level, tearing away the middle trestle of the railroad bridge and leaving it twisted 150 m inland.

At **Keauhou Bay** the water rose 4 m, badly damaging one house and washing several boats ashore. At the southern edge of **Kailua Bay**, near the Kona Inn, it rose 3.3 m, damaging masonry seawalls, but at the wharf on the northern side of the bay it rose only 2 m.

The old wharf at **Kawaihae** was almost destroyed and its pilings were carried away.

At **Hilo** the water rose about 5.1 m at the mouth of the **Wailuku River** (figs. 18 and 19). A steel span of the railroad bridge was torn from its foundation and tossed 273 m upstream. The waves were 7.5 m at **Coconut Island** and 8.1 m at Pier 1. Every

(1946, April 1, continued)
house on the main street facing **Hilo Bay** was smashed against the buildings on the other side (fig. 20). East of Hilo at Puumaile Tuberculosis Hospital waves were 6.1 m high overtopping the breakwater and causing minor flooding at the hospital (fig. 21). Heavy masses of coral 1.2 m wide were strewn on the beaches, and enormous sections of rock weighing several metric tons were wrenched from the bottom of the sea and thrown onto reefs. Houses were overturned, railroads ripped from their roadbeds, coastal highways buried, and beaches washed away. The waters off the island were dotted with floating houses, debris, and people. Ninety-six people were killed. (Shepard et al., 1950; Iida et al., 1967; Pararas-Carayannis and Calebaugh, 1977)

FIGURE 21.—A major tsunami generated by the earthquake in the Aleutian Islands on April 1, 1946, is shown striking the beachfront at the Puumaile Tuberculosis Hospital Hilo, Hawaii. (Photo Credit: Mrs. Harry A. Simms, Sr.)

1946, November 1, 11:14. A magnitude 7.0 earthquake in the Near Islands, Aleutian Islands, was reported to have produced small fluctuations in ocean level at the predicted time. This is a doubtful tsunami reported as such by Soloviev and Go (1974, p. 23) and Pararas-Carayannis and Calebaugh (1977). The report came from police who were dispatched to check sea conditions and who reported a sea rise at **Sandy Beach, Oahu** in the dawn light (5:00 A.M. local time). However, the wave was not recorded at any of the tide gages nor were there other reports. Cox and Morgan (1977, p. 51) also consider the tsunami doubtful.

1946, December 20, 19:19. A magnitude 8.1 earthquake at Nankaido, Japan, generated a tsunami with amplitudes of 0.1 m or less at **Honolulu** and **Hilo**. (Iida et al., 1967; Pararas-Carayannis and Calebaugh, 1977; Soloviev and Go, 1974, p. 117)

1947, January. Waves of meteorological origin reached heights on the Hawaiian coast larger than those of the April 1946 tsunami. There is no evidence of a tsunami on this date. (Soloviev and Go, 1975, p. 241; Cox and Morgan, 1977, p. 52; Shepard, 1950, p. 403)

1948, September 8, 15:09. A magnitude 7.8 earthquake in the Tonga Islands generated a tsunami that was recorded at **Port Allen** on the **Island of Kauai**; at **Honolulu** and **Waianae** on the **Island of Oahu**; and at **Hilo** on the **Island of Hawaii**--all with wave amplitudes of about 0.1 m. (Iida et al., 1967; Soloviev and Go, 1975, p. 14 Pararas-Carayannis and Calebaugh, 1977)

1949, August 22, 04:01. A magnitude 8.1 earthquake near the Queen Charlotte Islands, British Columbia, Canada, was recorded in Hawaii at **Port Allen, Kauai; Honolulu, Oahu; and Hilo, Hawaii**--all with wave amplitudes of less than 0.1 m. (Iida et al., 1967; Pararas-Carayannis and Calebaugh, 1977; Soloviev and Go, 1975, p. 225)

1949, October 19, 21:01. A magnitude 7.5 earthquake in the Solomon Sea generated a 0.6-m local tsunami that was also recorded in Hawaii at **Port Allen, Kauai; Honolulu, Oahu**; and **Hilo, Hawaii**--all with wave amplitudes of 0.1 m or less. (Iida et al., 1967; Pararas-Carayannis and Calebaugh, 1977)

1950, October 5, 16:09. A magnitude 7.7 earthquake in Costa Rica generated a small tsunami locally and at **Hilo, Hawaii,** where the amplitude of oscillations was 0.10 m, the period 18 minutes. It was also recorded with smaller amplitudes at **Port Allen, Kauai** and **Honolulu, Oahu**. (Iida et al., 1967; Soloviev and Go, 1975, p. 194; Pararas-Carayannis and Calebaugh, 1977)

1950, October 23, 16:13. A magnitude 7.1 earthquake in Guatemala generated a small local tsunami that was registered 9.3 hours later at **Hilo** and **Honolulu**, with a height of 0.10 m and periods of 16 minutes and 22 minutes, respectively. It was also recorded at **Port Allen, Kauai**, with a smaller amplitude. (Iida et al., 1967; Soloviev and Go, 1975, p. 195; Pararas-Carayannis and Calebaugh, 1977)

1950, December 14, 14:16. A magnitude 7.3 earthquake near Guerrero, Mexico, produced a small tsunami with an amplitude of less than 0.1 m at **Port Allen, Kauai**. (Pararas-Carayannis and Calebaugh, 1977; Soloviev and Go, 1975, p. 75)

1951, August 21, 10:57. After a magnitude 6.9 local earthquake, the sea level fell 1.2 m at **Napoopoo** and then rose 0.6 m above the normal level. At **Milolii**, the level fell 1.2 m and then rose 0.8 m above the normal position, washing away a canoe. Tide gage measurements registering 38 minutes later at **Honolulu** indicated a wave height of 0.03 m and a period of 14 minutes. Small oscillations were noted at **Hilo** and reported to have been recorded at **Port Allen, Kauai** with less than 0.1-m runup. (Iida et al., 1967; Soloviev and Go, 1975, p. 241; Cox and Morgan, 1977, p. 52-55; Pararas-Carayannis and Calebaugh, 1977)

1952, March 4, 01:23. A magnitude 8.1 earthquake on the southeast shore of Hokkaido Island, Japan, generated a damaging tsunami in Japan. The tsunami was recorded on March 3 at 11:15 P.M. with an amplitude of 0.3 m at **Kahului, Maui**, 0.1 m at **Honolulu, Oahu** and **Port Allen, Kauai**, and **Hilo, Hawaii**. (Soloviev and Go, 1974, p. 120; Pararas-Carayannis and Calebaugh, 1977) The earlier date in Hawaii is due to the International Date Line. Reports by Pararas-Carayannis and Calebaugh (1977) of runup heights of 1.2 m at Hookena and Napoopoo and 0.9 m at Kalapana and Keauhou and about 0.6 m at Kailua and Kawaihae are apparently in error and refer to the November 4, 1952 tsunami.

1952, March 18, 03:58. A strong shock in Hawaii of magnitude about 4.5, one of a swarm that began March 13 and continued to mid April, caused a small tsunami at **Kalapana** at about 6:00 P.M. The water passed 180 m inland and reached the school yard. The wave had to top a 3-m barrier dune to reach the school. A tsunami warning was issued for the duration of the swarm for all communities on the southeast shore. The school at **Kalapana** was closed for this period. Damage was not reported. The tide gage at Hilo did not register any unusual wave action. (Iida et al., 1967; Pararas-Carayannis and Calebaugh, 1977; Soloviev and Go, 1975, p. 243; Cox and Morgan, 1977, p. 55-57)

1952, September 26, 03:33. A series of submarine volcanic explosions beginning on September 16 produced tsunamis on Chichi Jima, Japan. Only one of these tsunamis was measured at **Hilo, Hawaii** (amplitude of less than 0.1 m). (Pararas-Carayannis and Calebaugh, 1977)

1952, November 4, 16:58. A severe and locally damaging tsunami generated on Kamchatka by a magnitude 8.2 earthquake struck the Hawaiian Islands at 1:00 P.M. Property damage from these waves was estimated at $800,000 to $1,000,000; however, no lives were lost. The waves beached boats, caused houses to collide, destroyed piers, scoured beaches, moved road pavement, etc. A farmer on **Oahu** reported 6 cows killed. In **Honolulu** harbor, waves tore a cement barge from its moorings and hurled it against the freighter *Hawaiian Packer*. At **Pearl Harbor**, Oahu, the tsunami was evidenced by the periodic rise and fall of the water, but no damage was done. Loomis (1976) reports wave heights of 9.1 m at **Kaena Point**, Oahu. Pararas-Carayannis and Calebaugh, (1977) report much damage on Oahu's north coast including **Waialua**. A boathouse worth $13,000 was demolished in **Hilo** when water 2.4 m high swept over the wharf. One span of the bridge to **Coconut Island** was destroyed. The highest wave on Hawaii of 3.5 m above MLLW (or 3.2 m above the tide stage) was reported here and at **Reed's Bay**. The Naniloa Hotel had flood damage. Houses were knocked from their foundations (fig. 22). Coast Guard buoys weighing 11 metric tons were ripped loose from their moorings. Damage in **Hilo, Hawaii** was estimated at $400,000. Damage on Maui was greatest in the **Kahului-Spreckelsville** area. The wave caused the

(1952, November 4, continued)
tide gage at **Kahului** to go off scale and stop recording. Pararas-Carayannis and Calebaugh report 10.4 m at Haena Point, Kauai, but this is identical to the value for the March 3, 1957 tsunami and is probably a misplaced value. They also report much damage to the north coast of **Kauai**.

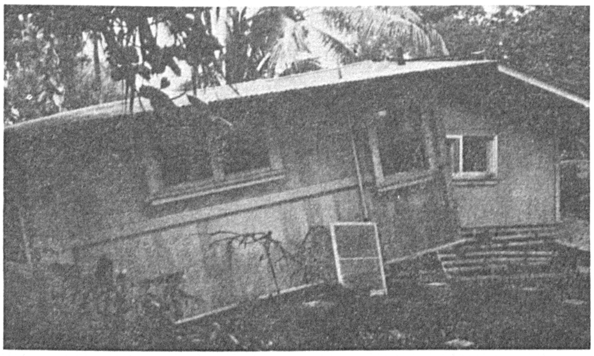


FIGURE 22.—Damage to small home in Reeds Bay area near Hilo, Hawaii, from the tsunami of November 4, 1952. Note foundation blocks from which building was lifted. (Photo Credit: National Oceanic and Atmospheric Administration)

At **Midway** the wave reached 1.9 m flooding low spots and depositing sand 300 m up a runway (fig. 23). Buildings were moved, picnic grounds uprooted, and barges and debris deposited hundreds of meters from the beach. (U.S. Navy, 1953, Iida et al., 1967; Soloviev and Ferchev, 1961, p. 28; Zerbe, 1953; Pararas-Carayannis and Calebaugh, 1977)

1953, September 14, 00:27. A magnitude 6.8 earthquake in the Fiji Islands generated a tsunami that was locally damaging and recorded in Hawaii at **Honolulu, Oahu**; **Port Allen, Kauai**; and **Hilo, Hawaii**, with 0.06 to 0.10-m amplitude. (Soloviev and Go, 1975, p. 14,18; Pararas-Carayannis and Calebaugh, 1977; Iida et al., 1967)

1953, November 25, 17:48. A magnitude 7.4 earthquake near Kashima, Japan, generated a tsunami that was weakly recorded at **Hilo** and at **Midway**. (Pararas-Carayannis and Calebaugh, 1977; Soloviev and Go, 1974, p. 122)

FIGURE 23.—Flooding on Midway Island as a result of the tsunami generated in Kamchatka on November 4, 1952. The administration building is on the right. (Photo Credit: U.S. Navy)

1955, April 19, 20:24. A magnitude 7.1 earthquake near Coquimbo, Chile generated a tsunami that was barely recorded at the tide stations in Hawaii with amplitudes of 0.1 m or less. (Pararas-Carayannis, 1969, Pararas-Carayannis and Calebaugh, 1977) This event is not reported for Hawaii by other sources.

1956, March 30, 06:11. An air wave from a gigantic explosion of the Bezymianny volcano on the Kamchatka Peninsula generated a tsunami or air wave that was recorded by four tide stations in Hawaii. The maximum wave height reported was 0.3 m at **Kahului, Maui**. There is some controversy as to whether the wave was a true tsunami generated off the Kamchatka coast or the recording of a sea wave produced near the tide gage by an atmospheric pressure wave from the explosion. (Iida et al., 1967; Pararas-Carayannis and Calebaugh, 1977; Gorshkov, 1959)

1957, March 9, 14:23. A magnitude 8.3 earthquake south of the Andreanof Islands, Aleutian Islands, generated a tsunami that did severe damage on Adak Island. However, the most damage (about $5 million) was done in the Hawaiian Islands. There were two indirect fatalities, a reporter and a pilot, and injury to a photographer when their small chartered plane crashed in the ocean near Oahu. The reporter and photohgrapher were trying to cover the tsunami's arrival.

FIGURE 24.—First big wave of the tsunami of March 9, 1957, breaks over the seawall at Waialua Bay, Oahu, flooding a house. (Photo Credit: W.G. VanDorn)

The north shore of **Kauai** was hit by waves up to 16 m high at **Haena**. Four houses were washed out in **Wainiha**, and several houses in **Kalihiwai** were destroyed. Four sampans were disabled on the north shore of **Kauai** by 2.7-m waves. The damage was twice that of the 1946 tsunami; bridges were knocked out and highways flooded. The submarine U.S.S. *Wahoo*, in **Nawiliwili Harbor, Kauai**, was expecting small waves from the Alaska-generated tsunami. The water changed height rapidly, however, causing the harbor where the submarine *Wahoo* was situated to alternately be drained and filled. The *Wahoo*, while attempting to leave the harbor at 28 km/hr, was actually carried backward by the current. The water rose to a height of 7.0 m along the north shore of **Oahu**, flooding at least 50 houses. Heavy damage occurred at **Waialua Bay** (figs. 24, 25, 26). Another 30 houses were moved off their foundations. The water washed over the highway at **Haleiwa**, and also caused much damage to buildings and bridges. The **Kahului, Maui** harbor tide gage recorded 5 waves with heights exceeding 1.4 m. The highest wave was 1.8 m. The tsunami lasted 90 minutes. According to an eyewitness, the bay drained only once in 1946, but it nearly drained several times during this tsunami. In **Hilo Bay, Coconut Island** was covered by about 1 m of water, and the bridge was

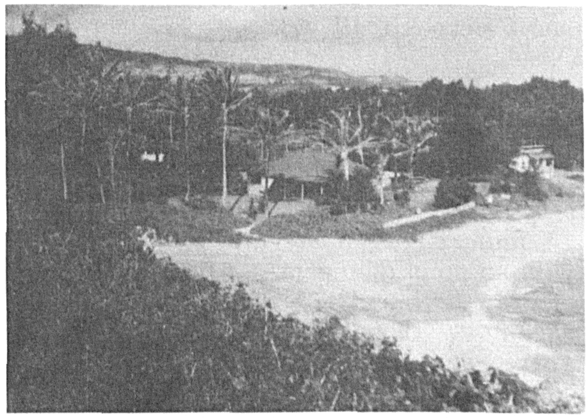


FIGURE 25.—This photograph and the one below show conditions before and after the arrival of a major wave at Laie Point, Oahu, from the tsunami on March 9, 1957. In this photograph the sea level is normal prior to the arrival of the first wave. (Photo Credit: Henry Helbush)

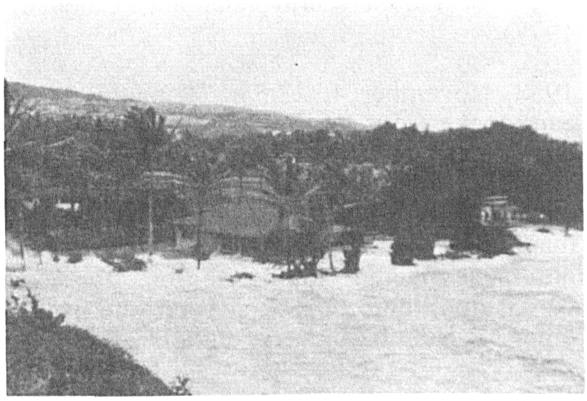


FIGURE 26.—This photograph shows the maximum extent of the inundation at the area shown above as a result of the tsunami. (Photo Credit: Henry Helbush)

destroyed. At Pier 1 water rose 1 meter causing $300,000 in damage to cargo stored in the warehouse. Fishing boats were carried inland and some overturned. A restaurant was washed away. Buildings along the waterfront were badly damaged. Water

(1957, March 9, continued)
flooded the Naniloa Hotel to a depth of 0.15 m. A marine dry dock was destroyed. A 15-m section of a store wall was destroyed. (Iida et al., 1967; Soloviev and Go, 1974, p. 25-29; Salsman, 1959; Pararas-Carayannis and Calebaugh, 1977)

1957, November 1, 05:00. At 7:00 P.M. October 31, oscillations with an amplitude of 0.10 m and period of 12 minutes began on **Midway Island.** Oscillations with an amplitude of less than 0.10 m and a period of 14 minutes began at **Nawiliwili**; oscillations with an amplitude of about 0.1 m and periods of 21, 25, and 27 minutes, respectively, began at **Honolulu, Kahului**, and **Hilo**. There was no earthquake. This event is considered by most to be of meteorological origin. (Soloviev and Go, 1975, p. 243; Cox and Morgan, 1977, p. 56-57; Pararas-Carayannis and Calebaugh, 1977)

1958, July 10, 06:16. A magnitude 7.5 earthquake-induced subaerial landslide in Lituya Bay, Alaska, generated a huge splash (520 m) and a large local tsunami in the bay (50 m) that was recorded in Hawaii with an amplitude of 0.10 m or less. (Iida et al., 1967; Soloviev and Go, 1975, p. 230, 228-230; Pararas-Carayannis and Calebaugh, 1977)

1958, November 4, 22:55. A magnitude 6.0 earthquake from the East Pacific rise is listed by Pararas-Carayannis (1967) as having possibly generated a tsunami that was recorded at **Midway**. Given the low magnitude of the earthquake, the usually non-tsunamigenic source region, the small wave amplitude of 0.1 m and the lack of other reports, this is a very doubtful tsunami.

1958, November 6, 22:58. A magnitude 8.1 earthquake in the South Kuril Islands (USSR) generated a tsunami recorded with a maximum amplitude of 0.3 m at **Kahului, Maui,** and lesser heights on **Oahu, Kauai,** and at **Hilo** on **Hawaii Island**. (Iida et al., 1967; Pararas-Carayannis and Calebaugh, 1977)

1958, November 12, 20:23. A strong aftershock of the November 6 earthquake (magnitude 7.0) generated a tsunami with an amplitude of 0.1 m at **Honolulu, Oahu; Kahului, Maui;** and **Hilo, Hawaii.** (Pararas-Carayannis and Calebaugh, 1977) Cox (1968) believes that the oscillations are only normal background oscillations and not a tsunami.

1959, May 4, 07:16. A magnitude 8.0 earthquake in the Kuril Islands (USSR) generated a tsunami that was recorded in Hawaii with a maximum amplitude of 0.2 m at **Kahului** (Eppley and Cloud, 1961). Pararas-Carayannis and Calebaugh (1977) mention that it was recorded at **Nawiliwili, Kauai; Honolulu, Oahu;** and **Hilo, Hawaii,** --all with wave amplitudes of about 0.1 m. (Iida et al., 1967)

1960, May 21, 10:03. A foreshock (magnitude 7.3) of the May 22 earthquake off the coast of Chile generated a tsunami that was recorded in **Hilo, Hawaii,** with an amplitude of about 0.1 m. (Iida et al., 1967; Pararas-Carayannis and Calebaugh, 1977; Loomis, 1976)

1960, May 22, 19:11. A devastating earthquake (magnitude 8.6) off the coast of central Chile generated a tsunami affecting the entire Pacific Basin. In general the wave action along Hawaiian shores was quiet, resembling that of the tide, although it had a shorter period and a greater range. It killed 61 and seriously injured 43. (Cox, 1987, p. 31-34) In **Hilo Bay**, however, the third wave was converted into a bore that flooded inland to the 6 m contour. Nearly 240 hectares (600 acres) inland of **Hilo** harbor were inundated, and all the deaths and $23.5 million of the damage occurred in this area. (The estimates of damage in Hawaii vary from $75 million in Talley and Cloud (1962), to $20 million in Wall (1960). A total of about $24 million for Hawaii is given by the Hawaiian office of Civil Defense.) In nearly half of this area total destruction occurred. In the area of maximum destruction, only buildings of reinforced concrete or structural steel, and a few others sheltered by these buildings, remained standing--and even these were generally gutted. Frame buildings either were crushed or floated nearly to the limits of flooding (figs. 27 and 28). Dozens of automobiles were wrecked; a 10-metric ton

FIGURE 27.—Aftermath of the tsunami of May 22, 1960, in the Waiakea area of Hilo, Hawaii. Note the scattered debris, gutted foundation, and the bent parking meters. (Photo Credit: Sunset Newspaper)

tractor in a showroom was swept away; heavy machinery, mill rollers, and metal stocks were strewn about. Rocks weighing as much as 20 metric tons were plucked from a sea wall and carried as far as 180 m inland. Damage elsewhere on the **Island of Hawaii** was restricted to the west and southern coasts, where about a dozen buildings, mostly of frame construction, were floated off their foundations, crushed, or flooded. There was half a million dollars of damage on the Kona coast alone. Six houses were destroyed at **Napoopoo**.

On **Maui** the damage was concentrated in the **Kahului** area on the north coast. A warehouse and half a dozen houses were demolished, and other warehouses, stores, offices, and houses, and their contents were damaged. A church floated 6.1 m away from its foundation. Other buildings were damaged at **Paukukalo**, just outside and west of the harbor. At **Spreckelsville** and **Paia**, east of **Kahului**, houses were damaged, and one house at each place was demolished. Additional damage occurred at **Kihei** on the south coast and **Lahaina** on the west coast. On the island of **Molokai** there was some damage to houses, fish ponds, and roads, and a beachhouse was demolished on the **Island of Lanai**. The islands of **Kauai** and **Oahu** escaped with only minor damage. Fifty houses at **Kuliouou**, an eastern suburb of **Honolulu**, were flooded, and $250,000 in damage was done. Elsewhere on **Oahu** no damage was reported, even where there was inundation of areas occupied by houses. On **Kauai**, so far as is known, the only damage consisted of one frame building being floated off its foundation on the south coast. (Cox and Mink, 1963; Iida et al., 1967; Pararas-Carayannis and Calebaugh, 1977, Loomis, 1976)

FIGURE 28.—Aerial view of damage at Hilo, Hawaii, from the tsunami of May 22, 1960. (Photo Credit: National Oceanic and Atmospheric Administration)

1960, November 20, 22:02. A magnitude 6.8 earthquake in Northwest Peru generated a measurable tsunami with a 0.10-m amplitude at **Hilo** and a 14-minute period. (Iida et al., 1967; Soloviev and Go, 1974, p. 154; Pararas-Carayannis and Calebaugh, 1977)

1962, December 21, 08:43. A magnitude 6.8 earthquake in the Fox Islands, Aleutian Islands, caused a tsunami warning to be issued. Oscillations reported by **Honolulu** observatory started 4.75 hours too early to be a tsunami from this source, and so this is a doubtful tsunami. (Iida et al., 1967; Cox, 1968; Pararas-Carayannis and Calebaugh, 1977)

1963, October 13, 05:17. A magnitude 8.1 earthquake in the Kuril Islands generated a tsunami that was widely recorded in Hawaii. The maximum amplitude of 0.4 m was reported at **Hilo, Hawaii**, and **Kahului, Maui**. (Iida et al., 1967; Pararas-Carayannis and Calebaugh, 1977)

1963, October 20, 00:53. An aftershock of the October 13 earthquake in the Kuril Islands (magnitude 6.7) generated a tsunami that was widely recorded in Hawaii. The maximum reported amplitude was 0.4 m at **Kahului, Maui.** (Iida et al., 1967; Pararas-Carayannis and Calebaugh, 1977)

1964, March 28, 03:36. An extremely large and devastating earthquake in the Gulf of Alaska (magnitude 8.4) generated a tsunami that caused 106 fatalities and $86 million in damage in Alaska and 16 fatalities and $12 million damage on the West Coast. It caused only minor damage in Hawaii, although wave heights in excess of 3 m were recorded at **Hilo, Hawaii,** and waves in excess of 3.6 m were recorded at **Kahului, Maui.** In **Hilo,** four restaurants and a residence were flooded near the head of Reeds Bay. The highest of the flooded restaurants had a floor about 1.8 m above sea level. This floor was flooded to a depth of 0.30 m. The west end of the Waiakea Bridge over the **Wailoa River** was partially undermined, and the sidewalk collapsed, creating a hole about 2.7 by 3 m. Civil Defense estimated the total damage to be $15,000. Considerable damage was reported from **Maui** where Civil Defense estimated damages of $52,590. The major damage was limited to facilities at **Kahului Harbor**, and all damage, resulting mainly from flooding, was restricted to the immediate waterfront area including a shopping center. The Kahului Railroad Company where most of the tsunami damage occurred, reported damage to freight and to the wooden supports of concrete piers. (Iida et al., 1967; Pararas-Carayannis and Calebaugh, 1977; Spaeth and Berkman, 1972)

1965, Feb. 4, 05:01. A magnitude 8.2 earthquake in the Rat Islands of the Aleutian Islands generated a tsunami that was recorded in Hawaii at **Midway, Nawiliwili, Honolulu,** and **Hilo.** The maximum height of 1.1 m was recorded on the north coast of **Kauai.** (Soloviev and Go, 1975, p. 30-31; Iida et al., 1967; Pararas-Carayannis and Calebaugh, 1977)

1965, March 30, 02:27. A magnitude 7.4 earthquake in the Fox Islands, Aleutian Islands, generated a tsunami that was recorded in **Hilo, Hawaii,** with an amplitude of 0.10 m. (Soloviev and Go, 1975, p. 31; Iida et al., 1967; Pararas-Carayannis and Calebaugh, 1977)

1965, July 2, 20:59. A magnitude 6.5 earthquake near Unalaska Island, Alaska, reportedly generated a tsunami with a height of 0.1 m at **Hilo, Hawaii.** (Pararas-Carayannis and Calebaugh, 1977) However, Cox (1968) does not think this represents a tsunami and that none was generated.

1966, October 17, 21:42. A destructive earthquake (magnitude 8.0) in Peru generated a tsunami that had a 0.20-m amplitude at **Kahului, Maui,** a 0.13-m amplitude at **Hilo** (Coffman and Cloud, 1970), a 0.06-m amplitude at **Nawiliwili, Kauai,** and a 0.05-m amplitude at **Honolulu** and **Midway.** (Iida et al., 1967; Soloviev and Go, 1975, p. 158, Pararas-Carayannis and Calebaugh, 1977)

1966, December 28, 08:18. A magnitude 7.8 earthquake in north Chile generated a tsunami that registered 0.17 m at **Kahului** and 0.15 m at **Hilo** in **Hawaii.** (Iida et al., 1967; Soloviev and Go, 1975, p. 160; Pararas-Carayannis and Calebaugh, 1977; von Hake and Cloud, 1968)

1968, May 16, 00:49. A magnitude 7.9 earthquake in the Japan trench off Honshu generated a tsunami that was recorded in Hawaii with a maximum amplitude of 0.5 m at **Kahului, Maui** and less at other places in Hawaii. (Soloviev and Go, 1974, p. 136; Cox, 1980, p. 40,41; Pararas-Carayannis and Calebaugh, 1977)

1968, August 1, 20:19. A magnitude 7.3 earthquake off east Luzon Island in the Philippines generated a tsunami that produced a 0.02-m wave at **Honolulu, Oahu,** and 0.05 m at **Nawiliwili, Kauai.** (Soloviev and Go, 1974, p. 222, 224; Coffman and Cloud, 1970; Pararas-Carayannis and Calebaugh, 1977)

1969, August 11, 21:27. A magnitude 7.8 earthquake in the area of Hokkaido Island, Japan, and the Kuril Islands (USSR) generated a tsunami that was recorded in Hawaii with a maximum amplitude of 0.22 m at **Kahului, Maui.** (Pararas-Carayannis and Calebaugh, 1977; Soloviev et al., 1986)

1969, November 22, 23:10. A magnitude 7.3 earthquake off the east coast of Kamchatka generated a tsunami that was recorded in Hawaii with a maximum amplitude of 0.1 m at **Kahului, Maui.** (von Hake and Cloud, 1971; Pararas-Carayannis and Calebaugh, 1977; Soloviev et al., 1986)

1971, July 14, 06:11. A magnitude 7.9 earthquake in the Bismarck Sea, New Guinea, generated a tsunami that was recorded in Hawaii with a maximum amplitude of 0.12 m at **Kahului, Maui.** (Pararas-Carayannis and Calebaugh, 1977; Soloviev et al., 1986)

1971, July 26, 01:23. A magnitude 7.9 earthquake in the Bismarck Sea generated a tsunami that was recorded in Hawaii with a maximum amplitude of 0.15 m at **Kahului, Maui.** (Pararas-Carayannis and Calebaugh, 1977; Soloviev et al., 1986)

1971, December 15, 08:30. A magnitude 7.8 earthquake off Kamchatka, USSR, generated a tsunami that was recorded in Hawaii with a maximum amplitude of 0.09 m at **Hilo, Hawaii.** (Pararas-Carayannis and Calebaugh, 1977, p. 41; Soloviev et al., 1986)

1973, January 30, 21:01. A magnitude 7.3 earthquake along the coast of southern Mexico generated a tsunami that was recorded in Hawaii with a maximum amplitude of 0.10 m at **Kahului, Maui** and **Hilo, Hawaii.** (Pararas-Carayannis and Calebaugh, 1977, p. 41; Coffman and von Hake, 1975; Soloviev et al., 1986)

1973, June 17, 03:55. A magnitude 7.4 earthquake located in the Hokkaido-southern Kuril Islands region generated a tsunami that was recorded in Hawaii with a maximum amplitude of 0.15 m at **Kahului, Maui,** and less than 0.1 m at **Honolulu, Oahu; Hilo, Hawaii,** and **Nawiliwili, Kauai.** (Pararas-Carayannis and Calebaugh, 1977; Coffman and von Hake, 1975)

1974, October 3, 14:21. A magnitude 8.1 Peruvian earthquake generated a tsunami that was recorded in Hawaii with a maximum amplitude of 0.19 m at **Hilo, Hawaii,** and **Kahului, Maui** and less than 0.1 m at **Honolulu, Oahu, Nawiliwili, Kauai** and **Midway.** (Pararas-Carayannis and Calebaugh, 1977; Coffman and Stover, 1976). Copies of marigrams for Kahului, Hilo, and Honolulu are reproduced in the *ITIC Newsletter*, Vol. VIII, No. 1, January, 1975.

1975, June 10, 13:47. This earthquake in the Hokkaido, Japan and southern Kuril Islands region (magnitude 7.0) generated a tsunami that was recorded in Hawaii with a maximum amplitude of 0.06 m at **Kahului, Maui.** (Pararas-Carayannis and Calebaugh, 1977; Coffman and Stover, 1976)

1975, November 29, 14:47. This local earthquake (magnitude 7.2) generated the largest local tsunami of the century in Hawaii. Thirty-two campers at **Halape** near the base of Puu Kapukapu and most of the residents of the Island of Hawaii were awakened by the foreshock at 3:39 A.M. Rockfalls caused by the foreshock and the main shock an hour later forced the campers including a group of Boy Scouts to move closer to the beach. The shaking from the earthquake was so violent that they could not stand without holding on to trees. Using flashlights in the predawn darkness, the campers saw that the sea was rising after a minute or so. They turned and ran for higher ground, but were caught by the swiftly advancing waves. Most were tumbled about under the water and pushed 100 m farther inland where they became lodged in a preexisting ditch 5 to 7 m deep and 10 m wide. One camper either drowned or was battered to death, while another washed out to sea and was never seen again. The Scout Master was one of those killed. Nineteen people were injured and seven required hospitalization. Four horses were drowned. Subsidence occurred of up to one meter along the Kau Coast resulting in the permanent flooding of the area containing the coconut grove near where the campers were (fig 29). The maximum wave was 6.1 to 7.9 m.

At **Punaluu**, the rising sea level forced people to flee through ankle-deep water. The largest wave arrived about 10 minutes later, penetrating 137 m beyond the shore, and destroying seven houses, a large restaurant and gift shop, (figs. 30 and 31) and two vehicles--a total of $1 million in damage. In **Honuapo**, the tsunami damaged a fishing pier, park facilities, and a warehouse. The

(1975, November 29, continued)

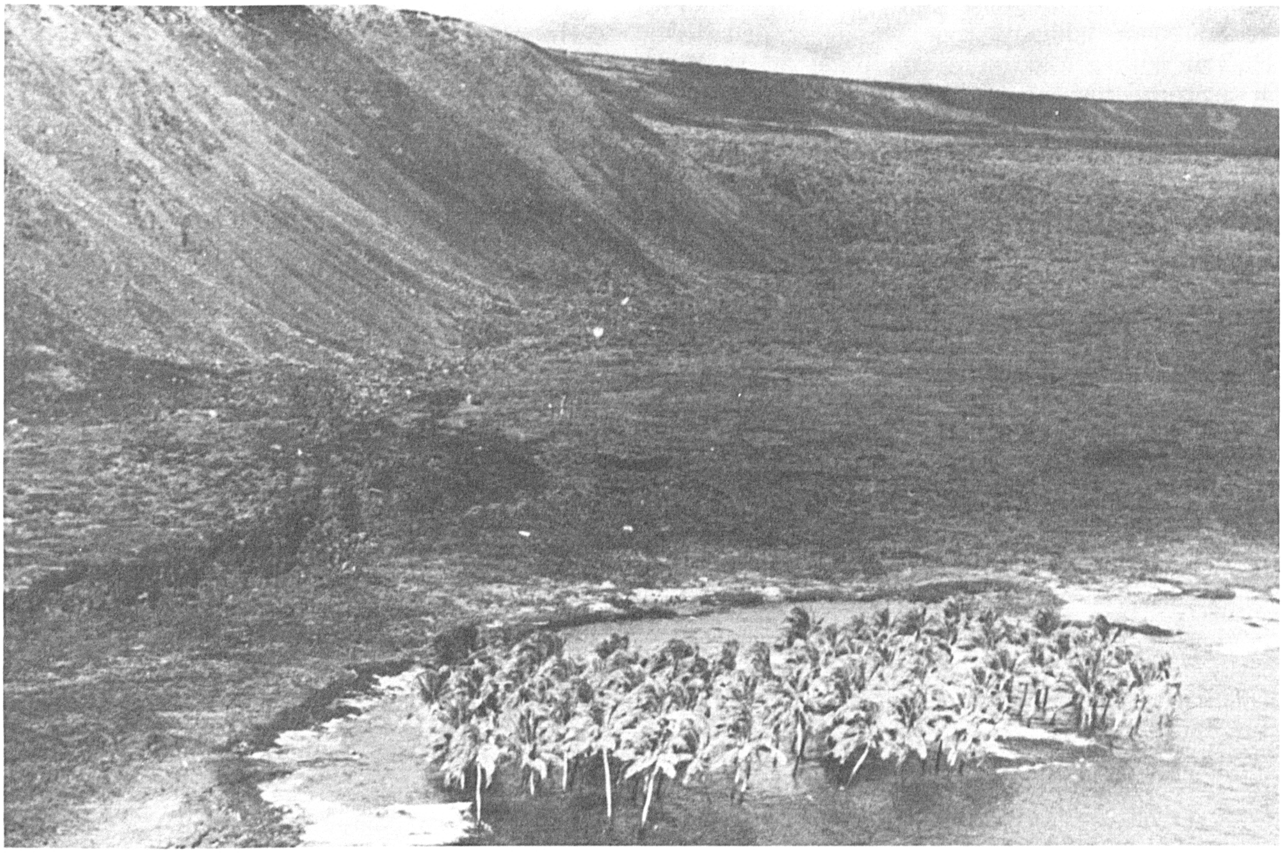


FIGURE 29.—Aerial view of Halape coconut grove on the Island of Hawaii following the tsunami and subsidence caused by the earthquake of November 29, 1975. Note fault scarps from previous earthquakes. (Photo Credit: National Park Service)

tsunami swept on to **Kaalualu Bay**, damaging vehicles and campsites and badly frightening seven campers. The canoes were destroyed, and a shed moved at **Napoopoo**. At **Keauhou Bay** one boat was deposited in the parking lot. Another boat sank, and other boats and the dock facilities were damaged.

At **Hilo** a tsunami watch was called and the low-lying areas were evacuated. The wave arrived at 5:10 A.M. when the ebb tide drained the harbor. The Coast Guard Cutter U.S.S. *Cape Small* settled into the muddy bottom and began to list. Four boats were sunk and three damaged. A car was washed off the pier into the bay. One man was thrown from his boat to the pier, then washed back to his boat.

At **Hana, Maui,** a fisherman noted the unusual recession of the water at 5:30 A.M. and waded out to cast his net. The returning water was neck deep and drove him back. Sailboats hit the bottom of the small boat harbor at **Lahaina, Maui**.

The tsunami was recorded at **Honolulu** and **Nawiliwili** and at many stations on the West Coast, Alaska, Japan, and Pacific islands. (Cox and Morgan, 1977, p. 57-72; Pararas-Carayannis and Calebaugh, 1977; Soloviev et al., 1986, Loomis, 1975) Copies of marigrams from Hawaiian tide gages are in the *Tsunami Newsletter*, Vol. VIII, No. 4, December, 1975.

1976, January 14, 16:48. A magnitude 8.0 earthquake in the Kermadec Islands generated a minor tsunami that was recorded with wave amplitude of 0.03 m at **Honolulu** and 0.15 m at **Kahului, Maui**. (Spaeth, 1978; Soloviev et al., 1986)

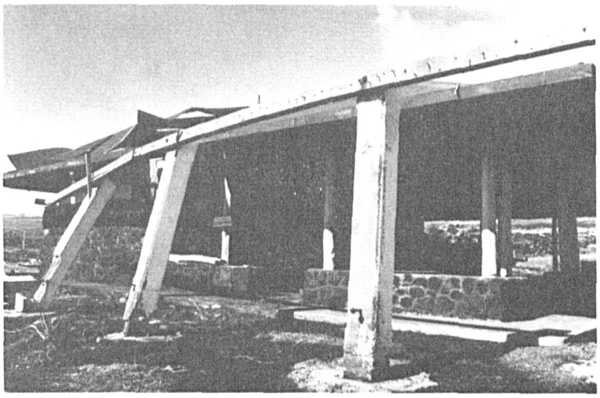


FIGURE 30.—Structural damage to restaurant and gift shop at Punaluu, Hawaii, as a result of the tsunami of November 29, 1975. (Photo Credit: International Tsunami Information Center)

1977, June 22, 12:09. A magnitude 7.2 earthquake in the Tonga trench generated a tsunami recorded in Hawaii with amplitude of 0.13 at **Kahului** and less than 0.1 m at **Hilo, Hawaii**; **Nawiliwili, Kauai;** and **Honolulu, Oahu**. (Coffman and Stover, 1979; Soloviev et al., 1986)

1978, March 24, 19:48. A magnitude 7.7 earthquake in the Kuril Islands generated a tsunami that was recorded at **Midway**. (Soloviev et al., 1986)

1979, December 12, 07:59. A magnitude 7.7 earthquake near the coast of Ecuador generated a tsunami with an amplitude of 0.19 m at **Hilo, Hawaii**, and at **Kahului, Maui**, and 0.04 m at **Nawiliwili, Kauai**. (Stover and von Hake, 1981)

1980, July 17, 19:42. A magnitude 7.5 earthquake in the Santa Cruz Islands, South Pacific, generated a tsunami that had a maximum amplitude of 0.14 m at **Kona, Hawaii,** and **Kahului, Maui**. (Stover and von Hake, 1982)

1982, December 19, 17:44. A magnitude 7.5 earthquake that occurred in the Kermadec Islands, South Pacific, generated a measurable tsunami at **Honolulu** with an amplitude of 0.02 m and at **Kailua-Kona** with an amplitude of 0.03 m. (Stover, 1985)

1985, March 3, 22:47. A magnitude 7.8 earthquake near Valparaiso, Chile, generated a tsunami that was widely recorded in Hawaii and throughout the Pacific Basin. The maximum amplitude in Hawaii was 0.24 m at **Hilo, Hawaii**, 0.19 m at **Kahului, Maui** and less than 0.1 m elsewhere in Hawaii. (ITIC, 1985).

1985, September 19, 13:18. A magnitude 7.9 earthquake occurred along the coast of Mexico where the Cocos crustal plate underthrusts the North American plate along the mid-American trench. A small tsunami propagated across the Pacific and was recorded by several tide stations in Hawaii and elsewhere across the Pacific. The maximum amplitude in Hawaii was 0.12 m at **Kahului, Maui** and 0.11 m at **Hilo, Hawaii**. Reports of damage were not received outside the source region. (Pararas-Carayannis, 1985)

1986, May 7, 22:47. This widely recorded tsunami from a magnitude 7.4 earthquake in the Andreanof Islands, Aleutian Islands, generated waves large enough at Adak in the Aleutian Islands and at **Midway** to cause concern that a destructive Pacific-wide tsunami had been generated. However, this tsunami did not produce significant runup in the Hawaiian Islands or elsewhere. The amplitude of the 1986 tsunami as recorded at **Midway** was abnormally high (0.34 m) compared to the amplitude of the 1957 tsunami (0.5 m) generated in nearly the same area. The abnormally small runups in other areas can be attributed to the short fault length and a shallow angle of subduction. (ITIC, 1987) The highest waves were recorded on **Kauai** where **Kapaa** had waves of amplitude 0.6 m, **Hanalei**, 0.5 m and **Nawiliwili**, 0.4 m.

1986, October 20, 06:46. A magnitude 7.9 earthquake in the Kermadec Islands produced a tsunami that was recorded in Hawaii with a maximum amplitude of 0.1 m at **Hilo, Hawaii** and less than 0.1 m at **Honolulu, Oahu**, **Kahului, Maui**, and **Kailua-Kona, Hawaii**. (Preliminary Determination of Epicenters, October 1986)

1987, November 30, 19:23. A magnitude 7.6 earthquake about 75 km south of Cape Yakataga, Alaska on the Pacific plate produced a tsunami that was recorded at **Hilo** (0.07 m), **Nawiliwili** (0.05-0.06 m), and **Honolulu** (0.02 m). (George Carte, 1987; Tsunami Newsletter, Vol. 20, No. 2, Dec. 87, p. 1)

FIGURE 31.—Buildings washed off foundations and trees stripped by the tsunami of November 29, 1975, at Punaluu. Damaged palm branches indicate apparent wave height. (Photo Credit: International Tsunami Information Center)

(Hawaii tables begin on next page.)

TABLE 3. TSUNAMI DATA FOR HAWAII

ORIGIN DATA					TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PERIOD (MIN)	1ST MOTION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1500-1600		Unknown	2			Kalaeloa, Molokai	OBS					Huge wave killed all but one inhabitant, according to an ancient chant.
1812 12 21	19:00 34.2N 119.7W 7.7 (DNAG)	S. California?	2	E	1.0 1.0	Hookena, Hawaii	3.0±1.2					Single wave inundated hut. Association with Dec. 21, 1812 probable. (See also West Coast section.)
1819 04 12	03:45 27.0S 71.5W 8.5 (PAL)	N. Central Chile	4	E	2.0 2.0	Hakaaano, Molokai	OBS?					Huge wave destroyed 3 houses and 4 canoes. Date of effects uncertain, See also Nov. 7, 1837 and May 17, 1841.
						Hilo, Hawaii	OBS					
						Honolulu, Oahu	OBS	13.0				13 oscillations.
						Kahului, Maui	OBS					Less severe than 1837 event.
						W. Hawaii Island	2.0	11.0	F			9 oscillations.
1835 02 20	16:22 36.8S 73.0W 8.2 (PAL)	Central Chile	4	E	4.0 3.0	Kauai	OBS?					Moderate damage?
1837 11 07	12:51 42.5S 74.0W 8.5 (PAL)	S. Central Chile	4	E&L	3.0 3.0	Hakaaano, Molokai	OBS?					Date of effects uncertain. See also Apr. 12, 1819 and May 17, 1841.
						Hilo, Hawaii	6.0	15.0	F		16.0- 16.5	14 deaths, 66 houses and many animals washed away.
						Honolulu, Oahu	2.5	28.0	F		15.5	
						Kahului, Maui	OBS		F			2 deaths, substantial damage. (See also Samoa section.)
						Lahaina, Maui	2.5					
1839 03		Hawaii	1			Hawaii						Probably distorted report incidental to death of a Hawaiian leader.
1840		Hawaii				Hawaii						A number of natives reportedly drowned. Probably distorted report.
1841 05 17	21:30 52.0N 158.0E	Kamchatka Pen., USSR	4	E	2.0 1.0	Hakaaano, Molokai	OBS?					Date of effects uncertain. See also Apr. 12, 1819 and Nov. 7, 1837.
						Hilo, Hawaii	4.6	25.0				
						Honolulu, Oahu	1.0	20.0	F		6.4±	Three waves observed.
						Lahaina, Maui	1.0	04.0				
1848 07 12		Tahiti?	1	E		N. Maui	OBS					Date and source uncertain. Doubtful tsunami.
1854 01 27		Gulf of Alaska		E		Hilo, Hawaii	OBS					(See also Alaska section.)
1854 12 23	00:00 34.0N 137.9E 8.3 (Iida)	Enshunada, Japan	4	E	4.0	Hawaii						Probably not observed in Hawaii. (See also West Coast section.)
1854 12 24	08:00 33.1N 135.0E 8.4 (Iida)	Nankaido, Japan	4	E	4.0 3.0	Hawaii						No reports of observation in Hawaii. (See also West Coast section.)
1860 12 01		N. Pacific?	2			Kahului, Maui	2.5					Source of waves unknown. Wharf and huts destroyed.
					1.5	Maliko, Maui	3.6					Houses flooded and several washed off foundations. Wharf destroyed.
						Molokai	OBS					Some damage.
1862 01 28		N. Pacific?	2	M	1.0	Waialua, Molokai	OBS					Fishponds inundated and damaged. Waves probably of meteorological origin.
1868 04 03	02:24 19.2N 155.3W (Cox) 7.5	Hawaii	4	E	4.1 3.4	Apua, Hawaii	2.0		R			Town submerged and obliterated, 1 death.
						Hawaii Island						108 houses destroyed and 47 fatalities.
						Hilo, Hawaii	2.7		F			Severe damage from Kahuka to Kapoho. Minor damage in Hilo. 45 - 60 m recession. Possible 2nd tsunami generated near Hilo.
						Honolulu, Oahu	0.6	15.0	F			
						Honuapo, Hawaii	<6.1	15.0				Coconut grove and all but 1 house in town destroyed, 27 deaths.
						Ka Lae Cape, Hawaii	OBS					Area of greatest tsunami intensity.

ORIGIN DATA: DATE TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	IST MOTION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1868 04 03 (continued)					Kaalualu, Hawaii	6.1					Houses destroyed and some people killed.
					Kailua, Hawaii	3.4					
					Kaimu, Hawaii	OBS					Litter tossed onto grass.
					Kalapana, Hawaii	OBS					Old church submerged. 1.2-1.8 m of subsidence.
					Kawa Bay, Hawaii	OBS					Seven killed, village destroyed.
					Kawaa, Hawaii	6.1					All houses, stone church and coconut grove destroyed.
					Kawaihae, Hawaii	0.6					
					Keahialaka, Hawaii	OBS					Pond submerged.
					Kealakekua, Hawaii	1.2					Fish stranded, 0.9 m of subsidence.
					Kealakomo, Hawaii	1.2					Salt works destroyed.
					Keauhou Landing, Hawaii	13.7		R		00.1	Town destroyed, and 167 bales of pulu lost. 2.1 m of subsidence.
					Lahaina, Maui	OBS	06.0-08.0	F			13 waves.
					Ninole, Hawaii	6.1		R			Town destroyed.
					Opihikao-Pohoiki, Hawaii	5.2		R			Boulders washed away.
					Punaluu, Hawaii	6.0		R			Village destroyed. Stone church, wooden houses, and all coconut trees except two were washed down. Land was lost from the beach. Shoreline was rearranged.
					S. Puna to Kau, Hawaii	OBS	07.0-08.0				108 houses destroyed, 47 deaths.
					Waiakea, Hawaii	2.1					Fishpond walls broken. (See also West Coast section.)
1868 04 10	Hawaii	1			Hawaii						Erroneous date for April 2, 1868. Other erroneous dates are April 4, and April 20, 1868.
1868 08 13 21:30 18.6S 71.0W 8.5 (PAL)	N. Chile	4	E	4.3 3.5	Chile						Two tsunamis at about 4:45 P.M. and 8:45 P.M. local Chilean time. Effects from both are mixed.
					Hilo, Hawaii	4.5	10.0			14.2	Severe damage, bridge washed out.
					Honolulu, Oahu	1.6		F		14.6	Arrival of both tsunamis reported.
					Kahului, Maui	1.8					Considerable damage. Arrival of second tsunami observed.
					Kalapana, Hawaii	1.8					
					Kanaio, Maui	OBS					2 houses flooded.
					Kauai I.	1.8					
					Molokai	1.2	20.0				Some damage.
					Waiakea, Hawaii	OBS					Bridge washed out.
					Waimea Bay, Kauai	0.9					(See also West Coast, Alaska, and Samoa sections.)
1868 08 14 01:30 18.6N 71.0W 8.5 (PAL)	N. Chile	4	E			OBS					(See above event.)
1868 10 02 07:30	S. Pacific?	3	E		Kahaualea, Hawaii	6.1					Unusual tides flooded canoes, church, and many houses.
1869 07 24-25	S. Pacific?	3			Cape Kumukahi, Hawaii	OBS					Several houses destroyed.
				3.0	Kahaualea, Hawaii	OBS					School and several buildings washed away.
					Kalapana, Hawaii	OBS					Cultivated land flooded and lost.
					Kamaili to Kapoho, Hawaii	OBS					Cliffs eroded.
					Kaupo, Maui	4.6					Fields flooded, church buried in debris.
					Pohoiki to Opihikao,Hawaii	OBS					Road washed out.
					Puna Coast, Hawaii	8.2					Houses, a road, sea cliffs, and barriers destroyed.
					Punaluu, Hawaii	OBS					Baths, situated in the ravine at Punaluu, were doubled in depth.
1871 02 18	Hawaii										Erroneous date for Feb. 20, 1871.
1871 02 20 08:41 20.7N 157.0W (Cox) 7.0	Hawaii	1									Strong earthquake, doubtful tsunami report. Cox gives Feb. 19 incorrectly for both local and UT dates.
1872 01 13	Hawaii		M		Haleiwa, Oahu						Meteorologically induced waves.
1872 01 22	Hawaii		M		Kapua, Hawaii						Meteorologically induced waves.
1872 08 23 18:02 52.0N (Cox a) 170.0W	Fox Is., Aleutian Is.	4			Hanalei Bay, Kauai	OBS			23-22:04		
					Hilo, Hawaii	1.3	06.0	R	23-23:30		14 oscillations observed.
					Honolulu, Oahu	0.2			23-22:40		(See also West Coast section.)
					Nawiliwili, Kauai	0.5					

ORIGIN DATA					TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOT-ION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1877 02 24		Hawaii	0	V		Kealakekua Bay, Hawaii						Submarine eruption of Mauna Loa.
						Kona Coast, Hawaii						"Boiling water," probable submarine eruption.
1877 05 04		Hawaii	0	V		Hawaii						A doubtful report of a tsunami associated with a volcanic eruption.
1877 05 10	00:59	N. Chile	4	E	4.0	Coconut I., Hawaii	4.2					Hospital destroyed,
	19.6S				3.5							church destroyed.
	70.2W					Hilo, Hawaii	3.7	08.0			14.0	37 houses destroyed or heavily damaged, 5 deaths, 7 seriously injured.
	8.3	(PAL)										
						Honolulu, Oahu	1.5	20.0	F		14.4	
						Kahului, Maui	1.5		F			
						Kawaihae, Hawaii	0.8					
						Kealakekua Bay, Hawaii	4.5					
						Lahaina, Maui	3.6					
						Nawiliwili, Kauai	0.9					
						Waiakea, Hawaii	4.8					See comments for Hilo, above. (See also West Coast section.)
1878 01 20		Aleutian Is.?	3	E		Halehaku, Maui	3.0					Two houses destroyed, two damaged.
					1.5							
						Honolulu, Oahu	OBS					
						Honomanu, Maui	3.0					Fields flooded.
						Maliko, Maui	3.6		R			Scow sunk.
						Waialua, Oahu	3.0					A 3-m wave flooded 150 m inland.
1883 08 27	02:59	S. Java Sea (Krakatau)	4	V		Honolulu, Oahu	0.2	17.0				Atmospheric pressure wave, recorded on tide gage. Not a true tsunami. (See also Alaska and West Coast sections.)
	6.7S				4.5							
	105.4E											
1887 - 1909 02 05						Milolii, Hawaii	OBS					Oral tradition. Land subsided and church relocated between these dates.
1895 01 28		Hawaii	1	M		Maliko, Maui						Erroneous report.
1896 06 15	10:33	Sanriku, Japan	4	E	4.0	Hilo, Hawaii	2.4	06.0			07.9	2 yachts were damaged.
	39.5N				3.8	Honolulu, Oahu	0.5	20.0		15-18:08	07.6	Fish stranded.
	144.0E					Honuapo, Hawaii	3.6					
	7.6	(Iida)				Hookena, Hawaii	3.3					Wharf, bridge, and store demolished. Several houses wrecked.
						Kaalualu, Hawaii	3.6					Wharf & 4 houses washed away.
						Kaanapali, Maui	1.1					
						Kaawaloa, Hawaii	5.3					Wharf and 1 house destroyed, warehouse flooded.
						Kailua, Hawaii	3.0	10.0				Warehouse, hotel & stores flooded.
						Kaiwilahilahi, Hawaii	3.0					Wharf and house destroyed.
						Kapaa, Kauai	1.2				07.5	Steamer grounded,
						Kawaihae, Hawaii	2.6					Wharf demolished
						Keauhou, Hawaii	5.5					9 houses, store, post office, and wharf demolished.
						Kilauea Landing, Kauai	1.5			15-18:00		
						Kohala, Hawaii	OBS					
						Napoopoo, Hawaii	5.3					Three houses and lumber yard washed away. Wharf destroyed.
						Nawiliwili, Kauai	1.5					Road & bridge flooded.
						Punaluu, Hawaii	3.6					
						Waikiki, Oahu	0.6					(See also West Coast and Samoa sections.)
1901 08 09	13:01	Tonga Islands	4	E		Honolulu, Oahu	0.1			09-22:00		Recorded.
	22.0S					Honuapo, Hawaii	OBS					
	170.0E	(Guten)				Hookena, Hawaii	OBS					
	7.9	(Abe)				Hoopuloa, Hawaii	1.2					
						Kailua-Kona, Hawaii	1.2			09-21:30		Several houses were inundated, and 1 washed away. The water rose 0.6 m over the wharf.
						Keauhou, Hawaii	OBS					2 huts lost.
						Mahukona, Hawaii	OBS					1 house inundated.
						Napoopoo, Hawaii	OBS					
1903 10 06	06:30	Hawaii		M		Hawaii	OBS					Probable eddy currents.
1903 10 08		Hawaii		M		Punaluu, Hawaii						A report of water retreating and returning the following night. Doubtful tsunami.
1903 11 17		Hawaii??	1	M		Punaluu, Hawaii						Sudden waves observed; probably meteorological origin.
1903 11 24		Hawaii		M		Punaluu, Hawaii						Incorrect date for above.

DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOT-ION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1903 11 29		Hawaii		M		Honokohau, Maui						Wave probably of meteorological origin.
						Honolulu, Oahu	OBS					
						Kalaupapa, Molokai	15.7					Houses washed away.
1906 01 31	15:36	Colombia-Ecuador	4	E	1.0	Hilo, Hawaii	1.8	30.0	F	01-04:00	12.4-	Wave covered wharf and railroad tracks.
	1.0N				3.0						12.9	
	81.5W	(DNAG)				Honolulu, Oahu	0.2	23.0		01-03:30	11.7	
	8.2	(Abe)				Kahului, Maui	0.3	20.0				Wave overflowed coastal road. (See also West Coast section.)
1906 08 17	00:40	Central Chile	4	E	2.0	Hilo, Hawaii	1.5				16.7	
	33.0S				2.0	Honolulu, Oahu	0.1	25.0		17-15:45	15.1	
	72.0W	(PAL)				Kahului, Maui	OBS					Flooded road along beach.
	8.1	(Abe)				Kailua, Hawaii	OBS					Some damage.
	25					Maalaea, Maui	3.6					Damage to wharves.
						McGregor's Landing, Maui	OBS					Damage to wharf. (See also West Coast section.)
1908 09 21	06:42	Hawaii	4	E		Hilo, Hawaii	1.2					
	19.5N											
	155.4W	(Cox)										
	6.8	(Abe)										
1913 10 11	04:06	New Guinea	1	E	1.0	Honolulu, Oahu	0.1	17.0				Recorded on tide gage.
	7.0S											
	148.0E											
	7.8	(PCT)										
1914 05 26	14:23	NW Irian, New Guinea	4	E	1.0	Honolulu, Oahu	0.1					Recorded on tide gage.
	2.0S											
	137.0E											
	7.9	(PCT)										
1917 05 01	18:27	Kermadec Islands	2	E	1.0	Honolulu, Oahu	0.3	20.0			07.9	Recorded on tide gage. (See also West Coast and Samoa sections.)
	29.2S											
	177.0W	(ISS)										
	8.0	(G&R)										
1917 06 26	05:50	Samoa Islands	4	E	3.0	Honolulu, Oahu	0.1	20.0			07.7	Recorded on tide gage. (See also West Coast and Samoa sections.)
	16.0S				3.0							
	171.0W	(ISS)										
	8.3	(G&R)										
1918 08 15	12:18	Celebes Sea, Indonesia	4	E	2.5	Honolulu, Oahu	<0.1	17.0				Weakly recorded on tide gage.
	5.4N				2.5							
	125.2E	(ISS)										
	8.3	(G&R)										
1918 09 07	17:16	Kuril Islands	4	E	3.6	Hilo, Hawaii	1.5					Minor damage. (See also West Coast and Samoa sections.) (Both runups may be ranges.)
	45.5N					Honolulu, Oahu	0.3	29.0			07.1	
	152.0E											
	8.3	(Iida)										
	33											
1919 01		Hawaii	0									Erroneous report for the Oct. 2, 1919 tsunami.
1919 04 09		Hawaii	0				0.0					Erroneous report for the April 30 and Oct. 2, 1919 tsunamis.
1919 04 29		Tonga Islands?	0									Erroneous report for April 30, 1919 tsunami.
1919 04 30	07:17	Tonga Islands	4	E	1.0	Hilo, Hawaii	0.6	70.0				
	21.2S					Honolulu, Oahu	0.1	25.0			06.5	
	172.5W	(ISS)				Punaluu Bay, Hawaii	0.9	90.0	F			Bay almost completely drained. (See also West Coast and Samoa sections.)
	8.3	(G&R)										
1919 10 02		Hawaii	4	L		Hoopuloa, Hawaii	4.3	03.0	F			Small tsunami on the Kona coast. 1 family narrowly survived after being swept out to sea. Wharf flooded, car dislodged, canoes wrecked, water tank destroyed, 10 waves.
						Keauhou, Hawaii	2.4					
						Kailua, Hawaii	0.9					
1921 12 16		Hawaii		M		Hilo, Hawaii						Waves of meteorological origin.
1922 11 11	04:33	N. Central Chile	4	E	3.0	Hilo, Hawaii	2.1	20.0			14.5	Minor damage.
	28.5S				2.5	Honolulu, Oahu	0.3	23.0	R		15.0	(See also West Coast and Samoa sections.)
	70.0W	(PAL)										
	8.3											
	25											
1923 02 03	16:01	Kamchatka Pen., USSR	4	E	3.0	All Hawaii						$1.5 million in damage for all islands.
	54.0N											
	161.0E					Haleiwa, Oahu	3.7				06.0	
	8.3	(Iida)				Hilo, Hawaii	6.1		F		06.5	Bridge destroyed, railroad embankment washed away, houses and wharves badly damaged. 1 death.

ORIGIN DATA					TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOTION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1923 02 03 (continued)						Honolulu, Oahu	0.9	23.0	F		06.0	
						Kahului, Maui	3.5		F		03.7	Heavy damage. Town flooded. (See also West Coast and Samoa sections.)
1923 04 13	15:30 56.5N 162.5E 7.2 (Iida)	Kamchatka Pen., USSR	4	E	4.0	Hilo, Hawaii	0.3				07.6	(See also West Coast section.)
						Honolulu, Oahu	0.2	38.0			06.6	
1923 09 01	02:58 35.1N 139.5E 7.9 (Iida)	Kanto, Japan	4	E	2.0	Honolulu, Oahu	<0.1	21.0				Wave barely detectable.
1924 05 30-31		Hawaii		M		Kaumalapau, Lanai	5.0					Damaging storm wave.
					2.0	Nawiliwili, Kauai	OBS					Damaging storm wave.
						Oahu	OBS					High waves.
1925 10 04		California			-1.0	Honolulu, Oahu	<0.1	20.0				There was no earthquake that could have caused a tsunami at this time. The waves were possibly of meteorological origin. (See also West Coast section.)
1926 01 25	00:36 9.0S 159.5E (ISS) 7.4 (G&R)	Solomon Islands		E		Hawaii						Doubtful tsunami.
1926 03 20	09:03 20.5N 155.5W (COX)	Hawaii	1	E		Wailupe, Oahu	1.5					Doubtful tsunami.
1927 10 24	16:00 57.5N 137.0W 7.1 (DNAG)	S. Alaska	1	E		Honolulu, Oahu						Doubtful tsunami. (See also Alaska section.)
1927 11 04	13:51 34.9N 120.7W 7.3 (DNAG)	N. to S. California	4	E	1.0	Hilo, Hawaii	0.1	12.0			05.1	(See also West Coast section.)
					1.0	Honolulu, Oahu	<0.1	20.0				
1927 12 28	18:20 55.0N 161.0E 7.3 (PCT) 33	Kamchatka Pen., USSR	4	E	1.0	Hilo, Hawaii	0.1	17.0			07.8	Event recorded on tide gage. The date of this event has been erroneously reported as Dec. 23.
						Honolulu, Oahu	<0.1	20.0			07.7	
1928 06 17	03:19 16.3N 97.7W 7.8 (DNAG)	S. Mexico	4	E	1.0	Hilo, Hawaii	0.2	12.0			08.3	(See also West Coast and Samoa sections.)
					1.0	Honolulu, Oahu	<0.1	16.0			09.0	
1929 03 07	01:35 51.0N 170.0W 7.5 (DNAG) 55	E. Aleutian Islands	4	E		Hilo, Hawaii	0.2	15.0		07-06:15	04.7	Stern lines of moored steamship broken.
						Honolulu, Oahu	<0.1	12.0			04.4	Not observed in Alaska. (See also Alaska section.)
1930 02		Hawaii				Hawaii						Erroneous report.
1931 10 03	19:13 10.6S 161.7E (ISS) 7.9 (G&R)	Solomon Islands	4	E	1.0	Hilo, Hawaii	0.1	15.0	F		08.3	(See also West Coast section.)
					2.5	Honolulu, Oahu	<0.1	15.0			07.5	
1932 06 03	10:37 19.8N 103.0W 7.9 (DNAG)	Central Mexico	4	E		Hilo, Hawaii	0.4	18.0			06.9	
					2.0	Honolulu, Oahu	<0.1	10.0			07.7	
1932 06 18	10:12 19.5N 103.5W 7.7 (DNAG) 16	Central Mexico	4	E	1.0 0.5	Hilo, Hawaii	0.1					
1932 06 22	12:59 18.7N 104.7W 6.9 (DNAG)	Central Mexico	4	E	1.0 1.5	Hilo, Hawaii	<0.1					Recorded. (See also Samoa section.)
1933 03 02	17:31 39.1N 144.7E 8.3 (Iida) 10	Sanriku, Japan	4	E	3.0	Hilo, Hawaii	0.5	15.0		03-02:02	08.6	
					3.5	Honolulu, Oahu	0.3	15.0		03-01:10	07.6	Recorded.
						Kaalualu, Hawaii	3.3					Fishpond wall destroyed. 92 m of inundation.
						Kawaihae, Hawaii	OBS	10.0				Some damage.
						Kailua-Kona, Hawaii	3.0	10.0		03-01:50	08.3	Considerable damage.
						Keauhou, Hawaii	3.2					Boathouse and water tanks moved. Boats & stone wall damaged.
						Kukuiula, Kauai	1.2					
						Lahaina, Maui	0.6		F			Water receded 10-14 m.
						Midway I.	OBS				04.5	Train of waves.

DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOT-ION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1933 03 02 (continued)						Napoopoo, Hawaii	2.9	10.0		03-04		
						Nawiliwili, Kauai	1.2					(See also West Coast and Samoa sections.)
						Pakala, Kauai	1.2					
1935 11 21	11:41 19.5N 155.5W (Cox) 8	Hawaii	1	M	2.0	Hilo, Hawaii	<0.1					Many fishing ships and yachts were thrown on shore. Doubtful tsunami. Storm in progress.
1938 03 06	01:56 5.1S 153.1E (ISS)	Solomon Is.	1	E		Honolulu, Oahu	<0.1	30.0				Doubtful tsunami.
1938 11 10	20:19 55.5N 158.0W 8.3 (DNAG)	Alaska Peninsula	4	E		Hilo, Hawaii	0.3	30.0				(See also Alaska and West Coast sections.)
						Honolulu, Oahu	0.1	30.0	R		05.0	
1943 04 06	16:07 30.8S 72.0W 8.3 (PAL) 33	N. Central Chile	4	E		Honolulu, Oahu	<0.1	20.0			15.5	See also West Coast section.)
1944 12 07	04:35 34.0N 137.1E 8.0 (Iida) 30	Ryukyu Trench, Japan	4	E	3.0 2.5	Honolulu, Oahu	0.1	21.0			08.5	(See also Alaska, West Coast, and Samoa sections.)
1946 04 01	12:29 52.8N 163.5W 7.3 (DNAG) 50	E. Aleutian Islands	4	E	5.0 4.0	Anaehoomalu, Hawaii	OBS					1 killed.
						Coconut Island, Hawaii	7.5					
						Haena, Kauai	13.7		R			7 killed, houses destroyed.
						Hakalau, Hawaii	11.3					Sugar mill badly wrecked.
						Haleaha, Oahu	OBS					Houses destroyed.
						Haleiwa, Oahu	3.4					
						Hamoa, Maui	7.0					10 killed.
						Hana Bay, Maui	9.1					
						Hanalei Bay, Kauai	5.8					
						Hanamaulu Bay, Kauai	OBS					Launch damaged.
						Hilo, Hawaii	8.1	15.0		01-17:24	04.9	$26 million in damage, 96 deaths at Hilo. 153 serious injuries on Hawaii.
						Honaunau, Hawaii	2.1					
						Honokaa, Hawaii	8.5					
						Honokohau, Hawaii	8.5					Bridge smashed.
						Honolulu, Oahu	0.6	15.0	R	01-17:03	04.6	
						Honomu, Hawaii	11.3					
						Honuapo, Hawaii	4.3					
						Hookena, Hawaii	2.4					
						Kaanapali, Maui	4.9					
						Kaena Pt., Oahu	10.9					
						Kahakuloa, Maui	10.0					3 houses destroyed.
						Kahana, Oahu	2.1					3 killed.
						Kahuku Pt., Oahu	8.2					1 killed.
						Kahului, Maui	8.5					Amphibious tanks floated off.
						Kailua-Kona, Hawaii	3.3					
						Kaimu, Hawaii	6.1					
						Kalapana, Hawaii	6.1					
						Kalaupapa, Molokai	2.1					Many homeless.
						Kalihiwai Bay, Kauai	6.7					6 killed, houses destroyed.
						Kaloko, Oahu	4.5					Houses demolished.
						Kaumakani, Kauai	2.4					
						Kaunakakai, Molokai	0.6					
						Kawaihae, Hawaii	3.7					Old wharf destroyed.
						Kawela Bay, Oahu	5.8					Houses damaged.
						Keaau, Hawaii	7.3					
						Keanae, Maui	OBS					2 killed. 2 injured. Several buildings damaged.
						Keauhou, Hawaii	4.0					
						Keokea Pt., Hawaii	9.8					
						Kii Landing, Niihau	OBS					Wharf destroyed, houses damaged.
						Kolekole Stream, Hawaii	11.0					Railroad trestle torn away.
						Lahaina, Maui	2.0					
						Lanikai, Oahu	2.1					
						Laupahoehoe, Hawaii	9.1					Houses swept 150 m inland, 25 killed.
						Lower Paia, Maui	6.0					Buildings wrecked, cane fields inundated. 1 killed.
						Maalaea, Maui	2.7					
						Mahukona, Hawaii	4.3					
						Makalii Pt, Oahu	OBS					Houses destroyed.
						Makapuu Pt., Oahu	11.1					Highest amplitude on Oahu.
						Mala, Maui	3.7					1 killed.
						Maliko Bay, Maui	8.5					Houses on bayside of highway destroyed.
						Maui	OBS					2 seriously injured.
						Milolii, Hawaii	0.6					
						Mokapu Pen., Oahu	6.6					Some damage to outlying buildings and roads around the Naval Air Station.

ORIGIN DATA					TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOTION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1946 04 01 (continued)						Moloaa, Kauai	OBS					All 12 houses destroyed.
						Napoopoo, Hawaii	2.7					
						Nawiliwili, Kauai	4.2					1 killed.
						Naina, Niihau	OBS					House destroyed.
						Niihau I.	6.0					
						Nonopapa Landing, Niihau	OBS					Wharf and houses damaged.
						Oahu	11.1					5 seriously injured.
						Onomea, Hawaii	10.4					
						Pakala Point, Kauai	10.0					Inundation was 227 m. (Near Moloaa, Kauai)
						Papaikou, Hawaii	10.7					
						Paukukalo, Maui	6.1					Houses damaged.
						Pepeekeo, Hawaii	8.2					
						Pohoiki, Hawaii	2.7					
						Pololu Valley, Hawaii	12.0					Houses, rice paddies destroyed.
						Port Allen, Kauai	2.4					
						Punaluu Bay, Hawaii	4.3					
						Punaluu, Oahu	3.7					1 killed.
						South Point, Hawaii	6.1					
						Spreckelsville, Maui	8.5					Residences destroyed.
						Upolu Pt., Hawaii	6.1					
						Waianae, Oahu	4.3					1 killed.
						Wainiha, Kauai	7.3					3 killed. Several houses wrecked.
						Waikiki, Oahu	2.7	15.0				
						Waikolu Valley, Molokai	16.4					(See also Alaska, West
						Waimea Bay, Kauai	4.2	10.0	R	01-16:25	03.9	Coast and Samoa sections.)
						Waipio Valley, Hawaii	12.0					
1946 11 01	11:14	Aleutian Islands	1	E		Sandy Beach, Oahu						Small elevation of sea reported. Doubtful data.
	51.5N											
	174.5W											
	7.0 (DNAG)											
	40											
1946 12 20	19:19	Nankaido, Japan	4	E	2.4	Hilo, Hawaii	0.1	16.0			09.8	(See also West Coast
	33.0N					Honolulu, Oahu	<0.1	14.0			09.3	section.)
	135.6E											
	8.1 (Iida)											
	20											
1947 01		Hawaii		M		Hawaii						Waves of meteorological origin.
1948 09 08	15:09	Tonga Islands	4	E	1.0	Hilo, Hawaii	0.1	21.0			07.1	(See also Samoa section.)
	21.0S					Honolulu, Oahu	0.1	12.0			06.6	
	174.0W (ISS)					Port Allen, Kauai	0.1	20.0				
	7.8 (G&R)					Waianae, Oahu	0.1	08.0				
1949 08 22	04:01	British Columbia, Can.	4	E		Hilo, Hawaii	0.1	20.0			05.3	(See also Alaska section.)
	53.6N					Honolulu, Oahu	OBS	43.0				
	133.3W					Port Allen, Kauai	<0.1	11.0				
	8.1 (DNAG)											
1949 10 19	21:01	Solomon Sea	4	E		Hilo, Hawaii	<0.1	16.0				
	6.5S				-1.0	Honolulu, Oahu	<0.1	21.0				
	153.2E (ISS)					Port Allen, Kauai	<0.1	19.0				
	7.5 (G&R)											
	60											
1950 10 05	16:09	Costa Rica	4	E		Hilo, Hawaii	0.1	18.0				
	10.4N				-2.0	Honolulu, Oahu	<0.1	28.0				
	85.2W					Port Allen, Kauai	<0.1	16.0				
	7.7 (DNAG)											
1950 10 23	16:13	Guatemala	4	E		Hilo, Hawaii	0.1	16.0			09.3	
	14.3N				-1.0	Honolulu, Oahu	0.1	22.0				
	91.7W					Port Allen, Kauai	<0.1	19.0				
	7.1 (DNAG)											
	30											
1950 12 14	14:16	S. Mexico	4	E		Port Allen, Kauai	0.1	25.0				
	17.2N											
	98.1W											
	7.3 (DNAG)											
1951 08 21	10:57	Hawaii	4	E		Hilo, Hawaii	<0.1	15.0		21-12:38	00.7	Weakly recorded.
	19.5N					Honolulu, Oahu	<0.1	14.0		21-11:35	00.6	
	156.0W					Hookena, Hawaii	1.2					Non-instrumental observation.
	6.9 (Cox)					Kailua-Kona, Hawaii	0.9					Kona coast: minor damage.
	12					Milolii, Hawaii	0.8		F			Canoe washed away.
						Napoopoo, Hawaii	0.9		F			
						Port Allen, Kauai	<0.1	27.0				
1952 03 04	01:23	SE. Hokkaido, Japan	4	E	2.0	Hilo, Hawaii	0.1	19.0	R		07.7	(See also Alaska,
	42.2N				2.0	Honolulu, Oahu	0.1	27.0	R	04-09:15	07.9	West Coast, Samoa,
	143.9E					Kahului, Maui	0.3	23.0	R			and Pacific Territories
	8.1 (Iida)					Pearl Harbor, Oahu	<0.1	30.0	R			sections.)
	45					Port Allen, Kauai	0.1					
1952 03 17	03:58	Hawaii	4	E		Kalapana, Hawaii	3.0					School yard, 180 m inland inundated.
	19.1N											(See also Samoa section.)
	155.0W (Cox)											
	4.5											

ORIGIN DATA			V	C	TSUNAMI DATA							
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1952 09 26	03:33	Chichi Jima, Japan	4	V	-1.0	Hilo, Hawaii	<0.1	30.0				One of a series of submarine volcanic eruptions.
	31.9N											
	140.0E (Iida)											
1952 11 04	16:58	Kamchatka Pen., USSR	4	E	4.0	All Hawaii	OBS					$800,000 to $1,000,000 damage.
	52.8N											
	159.5E					Coconut Island, Hawaii	3.2					Bridge and hotel damaged. Highest waves on Hawaii of 3.5 m above MLLW reported here and at Reed's Bay.
	8.2 (Iida)											
	30											
						Hilo, Hawaii	2.4	27.0	R	04-23:35	06.6	$0.4 million damage. $13,000 boat house destroyed.
						Honolulu, Oahu	1.3	38.0	R	04-23:14	06.3	Barge torn loose from moorings.
						Hookena, Hawaii	1.2					
						Kaena, Oahu	9.1					
						Kahuku Point, Oahu	1.2					
						Kahului, Maui	OBS	21.0			06.4	Sustained the greatest damage in Maui.
						Kailua, Hawaii	0.6					
						Kalapana, Hawaii	0.9					
						Kauai	OBS					Much damage to north side of island.
						Kawaihae, Hawaii	0.6					
						Keauhou, Hawaii	0.9					
						Mokapuu Pt., Oahu	3.0					
						Midway I.	1.9	12.0	R		04.4	Flooding and some damage.
						Napoopoo, Hawaii	1.2					
						SE Coast Maui	OBS					Much damage.
						Oahu	4.5					Much damage to north-east side of island.
						Pearl Harbor, Oahu	0.2	20.0	R		06.4	
						Port Allen, Kauai	0.3	15.0	R	04-23:00	06.0	
						Wahiawa Bay, Kauai	3.0					
						Waialua, Oahu	5.2					Some damage. (See also Alaska, West Coast, Samoa, and Pacific Territories sections.)
1953 09 14	00:27	Fiji Islands	4	E&L	1.0	Hilo, Hawaii	<0.1	30.0				(See also Samoa section.)
	18.3S					Honolulu, Oahu	<0.1	16.0			07.3	
	178.2E (ISS)					Kahului, Maui	0.1	20.0				
	6.8 (PAS)					Port Allen, Kauai	0.1	17.0				
	60											
1953 11 25	17:48	Kashima, Japan	4	E	1.0	Hilo, Hawaii	<0.1	34.0				(See also Alaska section.)
	34.0N				1.5	Midway I.	0.1	12.0			05.1	
	141.7E											
	7.4 (Iida)											
	60											
1955 04 19	20:24	N. Central Chile	4	E		Hilo, Hawaii	0.1	21.0				
	30.0S					Honolulu, Oahu	<0.1	20.0				
	72.0W					Kahului, Maui	0.1	18.0				
	7.1 (PAL)											
	33											
1956 03 30	06:11	Kamchatka Pen., USSR	4	V		Hilo, Hawaii	0.1	16.0			06.2	Explosion of Bezymianny volcano generated tsunami or air wave recording on tide gage. (See also Alaska, West Coast, and Pacific Territories sections.)
	55.0N					Honolulu, Oahu	0.1	30.0			06.1	
	160.9E (PCT)					Kahului, Maui	0.3	25.0				
						Midway I.	<0.1	15.0			02.1	
						Nawiliwili, Kauai	0.1	11.0				
1957 03 09	14:23	Central Aleutian Is.	4	E	3.5	All Hawaii	OBS					$5 million damage, 2 deaths.
	51.5N					Cape Kumukahi, Hawaii	3.6					
	175.7W					Coconut Island, Hawaii	OBS					1 m of water covered island. Bridge destroyed.
	8.3 (DNAG)											
	33					Haena, Kauai	10.4					
						Hakalau, Hawaii	3.0					
						Halawa, Molokai	2.8					
						Haleiwa, Oahu	5.2					Water washed over the high-way causing much damage.
						Hilo, Hawaii	3.9	19.0	R	09-19:11	04.8	$300,000 damage. Fishing boats carried inland and overturned. Buildings badly damaged and bridge to island destroyed.
						Honaunau, Hawaii	1.8					
						Honokaa, Hawaii	3.0					
						Honolulu, Oahu	1.0	14.0	R	09-18:50	04.5	
						Honomu, Hawaii	3.4					
						Honuapo, Hawaii	2.1					
						Hookena, Hawaii	2.1					
						Kahuku, Oahu	7.0					
						Kahului, Maui	1.8	22.0	R	09-19:06	04.7	Much damage along NE coast of island.
						Kailua-Kona, Hawaii	1.5					
						Kaimu, Hawaii	3.0					
						Kalapana, Hawaii	2.1					
						Kalihiwai, Kauai	6.1					Several houses were destroyed.
						Kauai	16.1					$1.5 million in damage.
						Kaunakakai, Molokai	OBS					
						Kawaihae, Hawaii	1.5					
						Keaau, Hawaii	2.4					
						Keauhou, Hawaii	2.1					
						Laupahoehoe, Hawaii	3.0					
						Maalaea, Maui	3.3					
						Mahukona, Hawaii	2.1					
						Midway I.	0.5	12.0	R	09-17:33	03.2	Salsman (1959) gives 0.8 m.
						Milolii, Hawaii	1.5					
						Napoopoo, Hawaii	2.1					
						Nawiliwili, Kauai	3.0	12.0	R	09-18:42	04.3	
						Niihau I.	3.0					
						Oahu	7.0					50 houses flooded, much damage to bridges and other structures on the north coast at Haleiwa.
						Onomea, Hawaii	5.2					
						Papaikou, Hawaii	2.7					
						Pepeekeo, Hawaii	3.7					

ORIGIN DATA					TSUNAMI DATA							
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1957 03 09 (continued)						Pohoiki, Hawaii	2.1					
						Pololu Valley, Hawaii	9.8					
						Punaluu Bay, Hawaii	2.1					
						South Point, Hawaii	3.0					
						Upolu Pt., Hawaii	2.4					
						Waialua, Oahu	3.9					Heavy damage.
						Waikiki, Oahu	1.5					
						Wainiha, Kauai	11.6					4 houses washed away.
						Waipio Valley, Hawaii	5.2					(See also Alaska, West Coast, Samoa, and Pacific Territories sections.)
1957 11 01	05:00	Hawaii?		M		Hilo, Hawaii	0.1	27.0				Doubtful tsunami.
					-3.0	Honolulu, Oahu	<0.1	21.0				Possible meteorological origin.
						Kahului, Maui	0.1	25.0				
						Midway I.	0.1	12.0				
						Nawiliwili, Kauai	<0.1	14.0				
1958 07 10	06:16	S. Alaska	4	E&L	-2.0	Coconut I., Oahu	<0.1	75.0				(See also Alaska section.)
	58.4N					Hilo, Hawaii	0.1	34.0			06.7	
	136.4W					Honolulu, Oahu	0.1	27.0				
	7.5 (DNAG)					Kahului, Maui	0.1	18.0				
						Nawiliwili, Kauai	0.1	20.0				
1958 11 04	22:55	East Pacific Rise	1	E		Midway I.	0.1	12.0			15.6	Doubtful tsunami.
	50.0S											
	115.0W											
	6.0 (PCT)											
1958 11 06	22:58	S. Kuril Is., USSR	4	E	2.0	Coconut I., Oahu	<0.1	25.0			07.0	(See also Alaska, West Coast, Samoa, and Pacific Territories sections.)
	44.3N					Haleiwa, Oahu	0.1	08.0			06.4	
	148.5E					Hilo, Hawaii	0.2	20.0			07.3	
	8.1 (Iida)					Honolulu, Oahu	0.1	23.0			06.7	
	80					Kahului, Maui	0.3	19.0			07.2	
						Midway I.	0.2	12.0			04.2	
						Nawiliwili, Kauai	0.1	14.0			06.4	
1958 11 12	20:23	S. Kuril Is., USSR	2	E	2.0	Hilo, Hawaii	0.1	23.0				Doubtful tsunami.
	44.2N					Honolulu, Oahu	0.1	30.0				Marigram unclear.
	148.8E					Kahului, Maui	0.1	20.0				(See also Alaska section.)
	7.0 (Iida)											
1959 05 04	07:16	N. Kuril Is., USSR	4	E		Coconut I., Oahu	<0.1	34.0				(See also Alaska section.)
	53.4N					Hilo, Hawaii	0.1	25.0			06.7	
	159.8E (ISS)					Honolulu, Oahu	0.1	23.0			06.2	
	8.0 (PAS)					Kahului, Maui	0.2	30.0			06.3	
	74					Midway I.	<0.1	20.0				
						Nawiliwili, Kauai	<0.1	27.0			05.9	
1960 05 21	10:03	S. Central Chile	4	E		Hilo, Hawaii	0.1	17.0			14.7	
	37.5S				-1.0							
	73.5W											
	7.3 (PAL)											
	33											
1960 05 22	19:11	S. Central Chile	4	E	4.5	All Hawaii						About $24 million in damage, 61 deaths, 43 injured.
	39.5S				4.0							
	74.5W					Aneoweonui (sp?), Kauai	3.3					Aweoweoniu (alternate spelling)
	8.6 (PAL)					Anini, Kauai	0.6					
	33					Cape Kumukahi, Hawaii	0.9					
						Coconut I., Oahu	0.3	27.0		23-10:40	15.5	Also called Mokuoloe Island.
						Haena, Kauai	4.1					
						Hakalau, Hawaii	2.7					
						Halape, Hawaii	1.5					
						Hilo, Hawaii	10.7	30.0	F	23-09:58	14.8	$23.5 million in damage. 61 deaths, 43 injured.
						Honaunau, Hawaii	1.5					
						Honokaa, Hawaii	1.8					
						Honolulu, Oahu	0.8	33.0	F	23-10:33	15.4	
						Honomu, Hawaii	3.7					
						Honuapo, Hawaii	5.2					
						Hookena, Hawaii	2.1					
						Kaalualu, Hawaii	5.2					
						Kahaluu, Hawaii	3.0					
						Kahului, Maui	3.4	18.0	F	23-10:18	15.1	Warehouse and six houses destroyed. $0.5 million damage.
						Kailua-Kona, Hawaii	2.4					
						Kaimu, Hawaii	4.0					
						Kalapana, Hawaii	2.1					
						Kauai	4.5					1 frame building floated off foundation.
						Kaumakani, Kauai	2.7					
						Kawaihae, Hawaii	2.7					
						Keaau, Hawaii	3.7					
						Keauhou, Hawaii	3.7					
						Kekaha, Kauai	3.0					
						Kihei, Maui	2.4					Some damage.
						Kuliouou, Oahu	OBS					50 houses flooded and $250,000 in damages done.
						Lahaina, Maui	2.1					Some damage.
						Lanai Island	OBS					A beachhouse demolished.
						Laupahoehoe, Hawaii	2.1					
						Mahukona, Hawaii	1.2					
						Midway I.	0.6	16.0		23-13:30	18.3	
						Milolii, Hawaii	0.9					
						Molokai	OBS					Some damage to houses, fish ponds, and roads.
						Napoopoo, Hawaii	4.9					6 houses destroyed.
						Nawiliwili, Kauai	1.5	15.0	R	23-10:40	15.5	
						Oahu	4.0					
						Onomea, Hawaii	3.4					
						Opihikao, Hawaii	1.8					
						Paia, Maui	3.7					1 house demolished and others damaged.
						Pakala, Kauai	3.2					(Near Makaweli, Kauai)
						Papaikou, Hawaii	2.7					
						Paukukalo, Maui	4.6					Buildings damaged.
						Pepeekeo, Hawaii	1.5					
						Pohoiki, Hawaii	1.8					
						Pololu Valley, Hawaii	3.4					
						Punaluu Bay, Hawaii	3.4					

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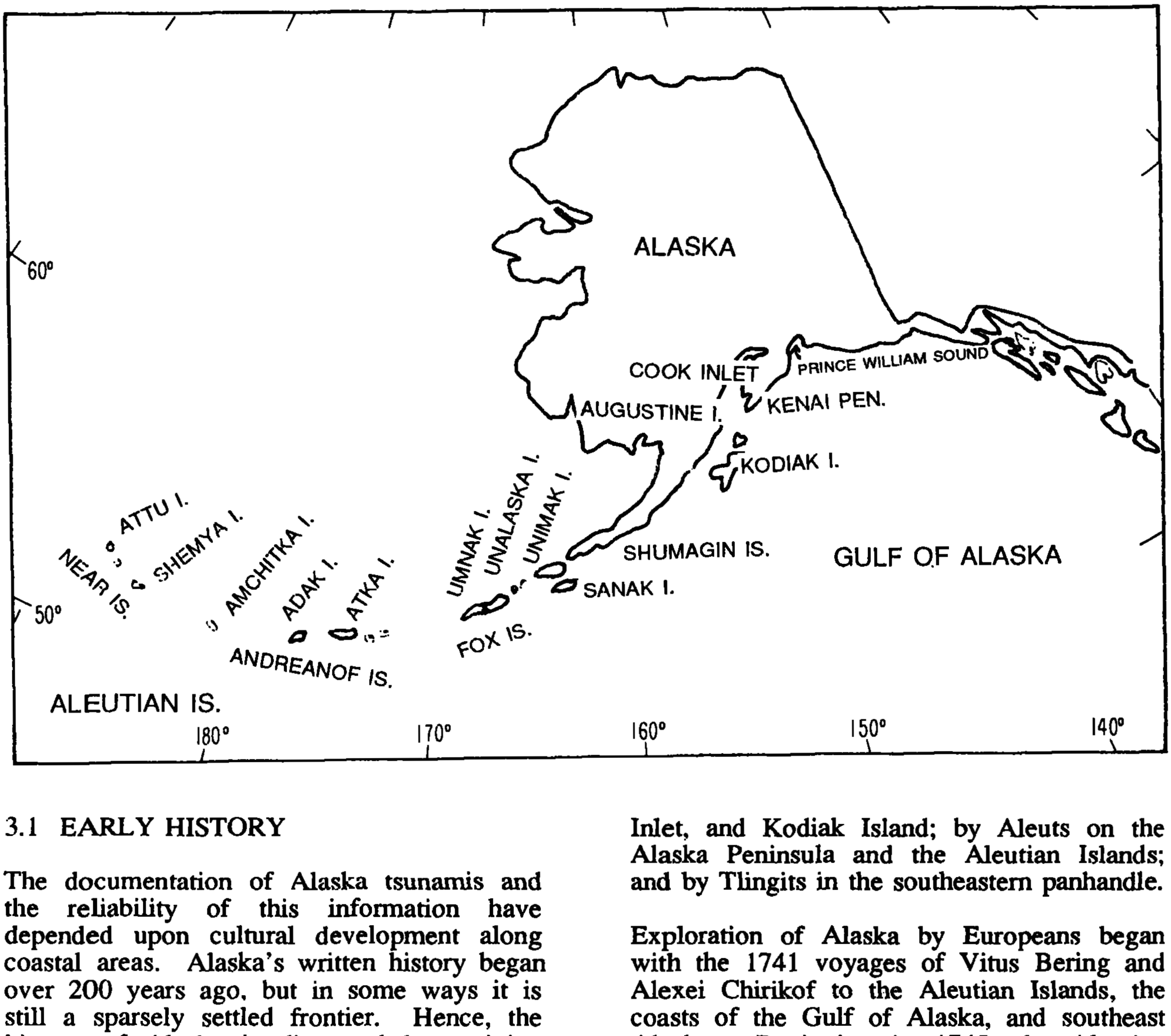
1960 05 22 (continued)						South Point, Hawaii	3.7					
						Spreckelsville, Maui	3.4					1 house demolished and others damaged.
						Upolu Pt., Hawaii	2.1					
						Wahiawa Bay, Kauai	4.3					(See also Alaska, West Coast Samoa, and Pacific Territories sections.)
						Wailua, Kauai	1.5					
						Waipio Valley, Hawaii	2.4					
1960 11 20	22:02 6.8S 80.7W 6.8 (PAL) 93	Peru	4	E	-1.0	Hilo, Hawaii	0.1	14.0			12.0	
1962 12 21	08:43 52.5N 168.5W (ISS) 6.8 (PAS)	Fox Is., Aleutian Is.	1	E		Honolulu, Oahu						Reported oscillations arrived too early to be generated by this quake. Doubtful tsunami.
1963 10 13	05:17 43.8N 150.0E 8.1 (Iida)	Kuril Islands, USSR	4	E	2.0	Ala Wai Hbr. Oahu	0.1					(See also Alaska, West Coast, Samoa, and Pacific Territories sections.)
						Coconut I., Oahu	<0.1					
						Haleiwa, Oahu	0.3	14.0			06.6	
						Hilo, Hawaii	0.4	15.0			07.1	
						Honolulu, Oahu	0.2	23.0			06.9	
						Kaanapali, Maui	0.1					
						Kahului, Maui	0.4	15.0			06.9	
						Midway I.	0.3	15.0			04.2	
						Nawiliwili, Kauai	0.2	15.0				
						Port Allen, Kauai	0.3	15.0				
1963 10 20	00:53 44.1N 150.1E 6.7 (Iida) 0	Kuril Islands, USSR	4	E	2.0	Coconut Island, Oahu	<0.1	32.0				(See also West Coast, Samoa, and Pacific Territories sections.)
						Haleiwa, Oahu	0.1	22.0				
						Hilo, Hawaii	0.1	18.0				
						Honolulu, Oahu	0.1	14.0			07.1	
						Kahului, Maui	0.4	10.0				
						Midway I.	0.2	15.0			04.6	
						Nawiliwili, Kauai	0.1	13.0				
1964 03 28	03:36 61.1N 147.5W 8.4 (DNAG) 23	Gulf of Alaska	4	E	4.5	Anahola Bay, Kauai	1.0					
						Coconut Island, Oahu	0.3		R	28-18:45	05.2	Also called Mokuoloe Island.
						Haena, Kauai	3.0					
						Haliewa, Oahu	3.1					
						Hanalei, Kauai	1.9					
						Hauula, Oahu	1.2					
						Hilo, Hawaii	3.0	19.0	R	28-09:00	05.4	$15,000 in damage. 4 restaurants and a residence flooded.
						Honolulu, Oahu	0.5	21.0	R	28-08:53	05.3	
						Kahului, Maui	3.6	23.0	R	28-08:47	05.2	$53,000 in damage. Shopping center flooded, railroad damaged.
						Kaiaka Bay, Oahu	4.6					(See also Alaska, West Coast, Samoa and Pacific Territories sections.)
						Kapaa, Kauai	2.2					
						Kawaihae, Hawaii	1.0					
						Laupahoehoe, Hawaii	0.7					
						Lower Paia, Maui	2.8					
						Mahukona, Hawaii	1.9					
						Maliko Bay, Maui	2.5					
						Midway I.	0.1	15.0	F	28-08:27	04.9	
						Moloaa, Kauai	1.0					
						Nawiliwili, Kauai	0.4	13.0	R	28-08:33	05.0	
						Puaena Pt. Oahu	2.4					
						Puako, Hawaii	0.6					
						Waialee, Oahu	1.8					
						Wailua, Kauai	1.3					
						Waimea Bay, Oahu	4.9					
						Waipio Bay, Hawaii	1.2					
1965 02 04	05:01 51.3N 178.6W 8.2 (DNAG) 36	W. Aleutian Islands	4	E	3.0	Hilo, Hawaii	0.3					(See also Alaska and Samoa sections.)
						Honolulu, Oahu	0.1					
						Midway I.	0.2					
						N. Kauai	1.1					
						Nawiliwili, Kauai	0.3					
1965 03 30	02:27 50.3N 177.9W 7.4 (DNAG) 20	W. Aleutian Islands	4	E	-1.0	Hilo, Hawaii	0.1				05.4	(See also Alaska and Samoa sections.)
1965 07 02	20:59 53.0N 167.6W 6.5 (DNAG) 40	E. Aleutian Islands	4	E	-1.0	Hilo, Hawaii	0.1					Doubtful tsunami. (See also Alaska and Samoa sections.)
1966 10 17	21:42 10.7S 78.8W 8.0 (PAL) 40	Peru	4	E	1.0	Hilo, Hawaii	0.1	16.0		18-10:00	12.3	(See also Alaska, West Coast, Samoa and Pacific Territories sections.)
					1.5	Honolulu, Oahu	<0.1	36.0		18-10:30	12.8	
						Kahului, Maui	0.2	21.0		18-10:19	12.6	
						Midway Island	<0.1					
						Nawiliwili, Kauai	<0.1					
1966 12 28	08:18 25.5S 70.6W 7.8 (PAL) 32	N. Chile	4	E		Hilo, Hawaii	0.2					(See also Samoa and Pacific Territories sections.)
					0.5	Kahului, Maui	0.2					
1968 05 16	00:49 40.7N 143.6E 7.9 (Iida) 0	Honshu, Japan	4	E	-1.0	Coconut I., Oahu	<0.1	12.0		16-08:26	07.6	(See also Alaska, West Coast, Samoa, and Pacific Territories sections.)
					-0.5	Hilo, Hawaii	0.3	21.0		16-08:45	07.9	
						Honolulu, Oahu	0.1	22.0		16-08:23	07.5	
						Kahului, Maui	0.5	23.0		16-08:29	07.6	
						Midway I.	0.2	14.0		16-04:42	03.9	
						Nawiliwili, Kauai	<0.1	13.0		16-08:03	07.2	

DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PERIOD (MIN)	1ST MOTION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1968 08 01	20:19	E.Luzon I.,Philippines	4	E		Honolulu, Oahu	<0.1					(See also Alaska, Samoa, and
	16.5N					Nawiliwili, Kauai	<0.1					Pacific Territories sections.)
	122.2E	(ISC)										
	7.3	(USE)										
	36											
1969 08 11	21:27	Hokkaido I.-Kuril Is.	4	E	1.0	Coconut I. Oahu	<0.1					(See also Alaska, Samoa, and
	42.7N					Hilo, Hawaii	0.2					Pacific Territories sections.)
	147.6E					Honolulu, Oahu	0.2					
	7.8	(Iida)				Kahului, Maui	0.2					
	30					Midway I.	0.2					
						Nawiliwili, Kauai	0.2					
1969 11 22	23:10	Kamchatka, USSR	4	E		Hilo, Hawaii	<0.1					(See also Alaska, Samoa, and
	57.7N					Honolulu, Oahu	<0.1					Pacific Territories sections.)
	163.6E	(ISC)				Kahului, Maui	0.1					
	7.3	(USE)				Midway I.	<0.1					
	51					Nawiliwili, Kauai	<0.1					
1971 07 14	06:11	Bismarck Sea,	4	E		Hilo, Hawaii	<0.1					(See also Alaska, Samoa and
	5.5S	New Guinea				Honolulu, Oahu	<0.1					Pacific Territories sections.)
	153.9E	(ISC)				Kahului, Maui	0.1					
	7.9	(USE)				Midway I.	<0.1					
	43					Nawiliwili, Kauai	<0.1					
1971 07 26	01:23	Bismarck Sea,	4	E		Hilo, Hawaii	<0.1					(See also West Coast and
	4.9S	New Guinea				Honolulu, Oahu	<0.1					Pacific Territories sections.)
	153.2E	(ISC)				Kahului, Maui	0.2					
	7.9	(USE)				Midway I.	<0.1					
	43					Nawiliwili, Kauai	<0.1					
1971 12 15	08:30	Kamchatka, USSR	4	E		Hilo, Hawaii	<0.1					(See also Alaska and Pacific
	56.0N					Honolulu, Oahu	<0.1					Territories sections.)
	163.2E	(ISC)				Kahului, Maui	<0.1					
	7.8	(USE)				Nawiliwili, Kauai	<0.1					
	39											
1973 01 30	21:01	S. Mexico	4	E		Hilo, Hawaii	0.1					(See also Samoa section.)
	18.4N					Kahului, Maui	0.1					
	103.2W	(DNAG)				Nawiliwili, Kauai	<0.1					
	7.3											
	32											
1973 06 17	03:55	Hokkaido I.-Kuril Is.	4	E	1.0	Hilo, Hawaii	<0.1					(See also Alaska and Pacific
	43.0N					Honolulu, Oahu	<0.1					Territories sections.)
	146.0E					Kahului, Maui	0.1					
	7.4	(Iida)				Nawiliwili, Kauai	<0.1					
	40											
1974 10 03	14:21	Peru	4	E		Hilo, Hawaii	0.2		F			(See also West Coast, Samoa
	12.3S					Honolulu, Oahu	<0.1	26.0	F			and Pacific Territories
	77.8W					Kahului, Maui	0.2		F			sections.)
	8.1	(PAL)				Midway I.	<0.1					Questionable recording.
	13					Nawiliwili, Kauai	<0.1					Questionable recording.
1975 06 10	13:47	Kuril Is.-Hokkaido I.	4	E	1.0	Kahului, Maui	<0.1	15.0				(See also Alaska and Pacific
	42.8N											Territories sections.)
	148.2E											
	7.0	(Iida)										
	0											
1975 11 29	14:48	Hawaii	4	E		All Hawaii						$1.5 million in damage, 2 fatalities, 19 injuries.
	19.3N											
	155.0W					Cape Kumukahi, Hawaii	3.4					
	7.2	(Cox)				Coconut I., Oahu	<0.1	10.0				
	8					Halape, Hawaii	7.9					Campers caught by wave killing 2, injuring 19.
						Hana, Maui	OBS					
						Hilo, Hawaii	2.6	15.0	R	29-15:12	00.4	4 boats sunk and 3 damaged.
						Honokohau, Hawaii	2.2					
						Honolulu, Oahu	<0.1	12.0	R	29-15:41	00.9	
						Honuapo, Hawaii	6.6					Fishing pier, warehouse, and port facilities damaged.
						Hookena, Hawaii	1.9					
						Kaalualu Bay, Hawaii	4.9					Vehicles and campsites damaged.
						Kahului, Maui	0.4	15.0	R	29-15:42	00.7	
						Kailua, Hawaii	1.8					
						Kaimu, Hawaii	3.7					
						Kalapana, Hawaii	2.4					
						Kamoamoa, Hawaii	6.9					
						Kawaihae, Hawaii	0.8					
						Keauhou Landing, Hawaii	14.3					
						Keauhou Bay, Hawaii	2.9					Dock facilities and boats damaged.
						Lahaina, Maui	OBS					
						Napoopoo, Hawaii	3.3					Canoes destroyed and shed moved.
						Nawiliwili, Kauai	0.1	13.0	R	29-15:46	01.0	
						Punaluu Bay, Hawaii	7.6					Inland inundation of 137 m. 7 houses, restaurant and shop and 2 vehicles destroyed. $1 million in damages. (See also Alaska, West Coast, Samoa, and Pacific Territories sections.)
1976 01 14	16:48	Kermadec Islands	4	E		Honolulu, Oahu	<0.1					
	29.0S					Kahului, Maui	0.1					
	177.4W	(ISC)										
	8.0	(USE)										
	56											

ORIGIN DATA					TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOT-ION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1977 06 22	12:09	Tonga Trench	2	E		Hilo, Hawaii	<0.1					(See also West Coast and Samoa sections.)
	22.9S					Honolulu, Oahu	<0.1					
	175.7W	(ISC)				Kahului, Maui	0.1					
	7.2	(BRK)				Nawiliwili, Kaui	<0.1					
	69											
1978 03 24	19:48	S. Kuril Is., USSR	4	E	-1.0	Midway I.	<0.1					(See also Pacific Territories section.)
	44.1N											
	148.6E											
	7.7	(ISC)										
	62											
1979 12 12	07:59	Ecuador	4	E		Hilo, Hawaii	0.2					(See also Pacific Territories section.)
	1.6N					Kahului, Maui	0.2					
	79.3W					Nawiliwili, Kauai	<0.1					
	7.7	(ISC)										
	62											
1980 07 17	19:42	Santa Cruz Islands South Pacific	4	E		Hilo, Hawaii	<0.1					
	12.5S					Honolulu, Oahu	<0.1					
	166.1E					Kahului, Maui	0.1					
	7.5	(ISC)				Kailua-Kona, Hawaii	0.1					
1982 12 19	17:44	Kermadec Islands South Pacific	4	E		Honolulu, Oahu	<0.1					(See also Samoa section.)
	24.2S					Kailua-Kona, Hawaii	<0.1					
	176.0W											
	7.5	(ISC)										
	40											
1985 03 03	22:47	Valparaiso, Chile	4	E		Hilo, Hawaii	0.2	17.0				(See also Alaska section.)
	33.2S					Honolulu, Oahu	<0.1	17.0		04-14:16		
	72.0W					Honuapo, Hawaii	<0.1	15.0		04-13:33		
	7.8	(PAL)				Kahului, Maui	0.2					
	33					Kailua-Kona, Hawaii	<0.1	10.0		04-13:48		
						Mahukona, Hawaii	<0.1	17.0				
						Pu'uloa, Hawaii	<0.1	24.0		04-14:37		
1985 09 19	13:18	Mexico	4	E		Hilo, Hawaii	0.1					(See also Samoa section.)
	18.1N					Kahului, Maui	0.1					
	102.8W											
	7.9	(DNAG)										
	18											
1986 05 07	22:47	W. Aleutian Islands	4	E		Hanalei, Kauai	0.5					(See also Alaska, West Coast, Samoa, and Pacific Territories sections.)
	51.5N					Hilo, Hawaii	0.3	14.0	F			
	174.8W					Honolulu, Oahu	0.2					
	7.4	(ISC)				Honuapo, Hawaii	<0.1					
	19					Kahului, Maui	0.2					
						Kailua-Kona, Hawaii	<0.1					
						Kapaa, Kauai	0.6					
						Mahukona, Hawaii	<0.1					
						Midway I.	0.3	12.0				
						Nawiliwili, Kauai	0.4					
1986 10 20	06:46	Kermadec Islands South Pacific	4	E		Hilo, Hawaii	0.1					
	28.1S					Honolulu, Oahu	<0.1					
	176.4W					Kahului, Maui	<0.1					
	7.9	(ISC)				Kailua-Kona, Hawaii	<0.1					
	29											
1987 11 30	19:23	Gulf of Alaska	4	E		Hilo, Hawaii	<0.1					(See also Alaska, and West Coast sections.)
	58.7N					Honolulu, Oahu	<0.1					
	142.8W					Nawiliwili, Kauai	<0.1					
	7.6	(PDE)										
	10											

3. ALASKA



3.1 EARLY HISTORY

The documentation of Alaska tsunamis and the reliability of this information have depended upon cultural development along coastal areas. Alaska's written history began over 200 years ago, but in some ways it is still a sparsely settled frontier. Hence, the history of Alaska is discussed here giving special emphasis to its exploration, to development of early permanent settlements by Russians, and to other aspects bearing on the probability that events such as tsunamis would not have been merely noted, but permanently recorded.

Prior to its discovery by Europeans, Alaska was populated by Indians in the northeast and the interior; by Eskimos on the coasts and islands of the Bering and Arctic Seas, Cook Inlet, and Kodiak Island; by Aleuts on the Alaska Peninsula and the Aleutian Islands; and by Tlingits in the southeastern panhandle.

Exploration of Alaska by Europeans began with the 1741 voyages of Vitus Bering and Alexei Chirikof to the Aleutian Islands, the coasts of the Gulf of Alaska, and southeast Alaska. Beginning in 1745, the Aleutian Islands and the Alaska Peninsula were visited frequently by Russian fur traders, and some wintered on the islands. They established a settlement about 1760 or 1770 at Iliuliuk on Unalaska.

The Fox Islands were explored in some detail by an official Russian expedition led by P. Krenitsin and Mikhail Levashev, and the Prince William Sound was explored by an English expedition led by James Cook in

1778. Information about the Alaska-Aleutian coasts was augmented by later 18th century Russian, Spanish, and French expeditions.

The first permanent village in Alaska was settled in 1784, at Three Saints Bay (Old Harbor) on Kodiak Island, by a Russian fur company headed by Gregory Shelikoff. The second settlement followed in 2 years at Kasilof on Cook Inlet. In 1792, the settlement on Kodiak Island was moved to the present town of Kodiak, and a rival fur trading company established a post on Cook Inlet. A settlement was established near Yakutat in 1795, and a shipyard was established on Resurrection Bay. By 1818, there were 321 Russians living in nine communities. Dwindling fur trade and Russia's involvement in the Crimean War resulted in the sale of Alaska to the United States in 1867.

Chances of reporting a tsunami were slight prior to 1784 when the first permanent Russian settlement was established on Kodiak Island. The first noted tsunami reportedly occurred 4 years later in the Shumagin Islands. Although the first written record of this tsunami was included in a publication by the Russian, Davydov (1812), it undoubtedly was first reported by fur traders of the sea-otter station at Unga.

A particular problem with dates exists for tsunamis occurring during the Russian period (1784-1867). Local historians used the older Julian calendar, which gains 1 day about every 128 years. By the 1700's it was 11 days ahead (earlier) of the Gregorian calendar (12 days ahead after 1800). The Gregorian calendar compensates for the fact that a year is slightly less than 365 1/4 days by skipping the leap year extra day at the beginning of each century--unless the century is divisible by 400 (i.e., 1600 and 2000). A second problem is that the Julian date used in Alaska was the same as that used in Russia, when it should have been 1 day later because the settlers arrived from the east. They gained an hour of sun time for every 15 degrees they traveled east, rather than losing an hour had they traveled west. The International Date Line now compensates for this effect. However, Julian dates for Alaskan tsunamis need to be increased by 10 days for 18th century events and 11 days for 19th century events to match the dates of effects reported from Hawaii, the West Coast, or elsewhere.

In spite of the almost total lack of local government following the sale to the United States, some industries were maintained and others were born in the early years of the American administration of Alaska. First, fish salteries and later fish canneries were established, most of which operated in the summer only. Gold was discovered in 1876, and Juneau was established in 1880 following a gold find there. The capital was moved to Juneau from Sitka in 1906. A placer operation was begun in 1887 at Yakutat; shortly after, a lode mine opened on Unga Island in the Shumagin Islands; and in 1895, settlers rushed to a gold find on the Turnagain Arm of Cook Inlet.

C.W.C. Fuchs (1879), the German who continued earthquake cataloging after Alexis Perry, the French compiler of annual catalogs from 1846 to 1872, is responsible for the publication of the report about the destruction of the Aleut village of Makushin by a tsunami in 1878. The report probably was sent to him from the Russian settlement of Iliuliuk on Unalaska.

Activities of personnel of the United States Coast and Geodetic Survey (C&GS) were responsible for the reports of tsunamis (or tsunami-like waves) of 1868 and 1883. Records of the Chilean tsunami of 1868 and of the Krakatau blast waves of August 1883 were taken from a tide gage that probably was established at Kodiak by a C&GS field party. The party was led by George Davidson, who was sent to Alaska in the summer of 1867 in anticipation of transfer of Alaska to the United States. The report of the October 1883 St. Augustine tsunami was published by Davidson himself (1884).

The development of mining activities and ensuing transportation needs led to the birth of several ports on the Gulf of Alaska and Prince William Sound. Cordova was established about 1890, Valdez in 1898, and Seward in 1902. Other towns were built as a result of fishing needs, and schools were established at Indian, Aleut, Eskimo, and Tlingit villages.

Prior to about 1900, there was an insufficient number of seismographs operating worldwide to detect and locate major earthquakes everywhere. Therefore, many great earthquakes that produced tsunamis in the Aleutians probably were unreported. One such event was discovered by Cox (1986) by using time differences for a tsunami observed at three tide stations on the west coast of the United States and at tide stations in Hawaii. Cox was able to determine a source in the Fox Islands for the August 23, 1872 tsunami although Alaskan records do not mention this earthquake.

The United States Geological Survey is responsible for the completeness of the records for the events of September 1899 as well as for those of February 1908 and September 1911. Effects of the 1899 Yakutat earthquake are prevalent, but they would not have been reported reliably nor in such detail except for the special survey made by Tarr and Martin (1912).

Because the coastlands of Alaska have been sparsely settled during much of its history, most reports of tsunamis are incomplete. For example, earthquakes were recorded in Alaska on October 24, 1927 (magnitude 7.1) and on March 7, 1929 (magnitude 8.1). Although the tsunami was not apparent on the tide gage records from Alaska for either event, a wave was observed in Hawaii from the 1927 tsunami and a 0.2-m wave was recorded at Hilo from the 1929 event. Either the few Alaskan tide stations in operation at the time were not at a location where the highly directional waves could be recorded, or the signature of the waves was masked by noise. Much of the Alaskan coast has high tides with ranges up to 6 m. This and the choppiness of the sea makes it unlikely that smaller tsunamis would have been noted before the introduction of tide gages.

3.2 TECTONIC SETTING

The Pacific and North American tectonic plates collide along the subduction zone marked by the Aleutian-Alaskan trench. The Pacific plate underthrusts the continental plate and produces ideal conditions for tsunami generation. Boundaries between these tectonic plates are highly seismic, and most earthquakes occur along these boundaries.

The high seismicity of the region, along with the vertical crustal motions associated with a subduction zone, makes the Aleutian-Alaskan trench region highly tsunamigenic. Twelve destructive tsunamis have been recorded in Alaska, and at least three have generated massive tsunamis in the Pacific Basin. These have produced extensive damage outside Alaska, particularly in Hawaii.

The seismic belt which nearly encircles the Pacific basin consists of seismic zones associated with tectonic features such as island arcs. Within these seismically active zones there exist regions in which no great earthquakes have occurred in a significantly long period of time relative to surrounding areas. These seismic gaps are considered prime locations for future major earthquakes.

At least three significant seismic gaps exist along this plate boundary. One lies in the east section of the Gulf of Alaska, another along the Alaskan Peninsula, and a third in the central Aleutians. Large tsunamis have occurred in all of these areas in the past, and more are almost certain to occur in the future. Because of the directional nature of the tsunami waves, those spawned along the Alaska Peninsula have the highest potential for producing damaging tsunamis on the west coast of the United States.

The earliest recorded tsunami in the Aleutian-Alaskan trench region occurred in 1788, and four major tsunamis have been generated in this region since then. These tsunamis include: the 1946 tsunami in the eastern Aleutian Islands, the 1957 tsunami in the central Aleutian Islands, the 1964 tsunami in the Gulf of Alaska, and the 1965 tsunami in the western Aleutian Islands.

In addition to tectonically generated tsunamis in the Aleutians, volcanic eruptions also have generated tsunamis there. One of the most notable was the tsunami generated by the eruption of Mount St. Augustine in 1883. Twenty-five minutes after the eruption, a giant wave of about 9 m inundated Port Graham, the nearest American settlement. The events of 1820, 1825, 1856, and 1901 also are linked to volcanic activity, but are doubtful tsunamis.

Landslides and ice and rockfalls have caused large tsunamis in southern Alaska. Lituya Bay in particular has a history of events of that kind. Four or five large waves have occurred in this bay in the last 150 years, but the largest and best documented occurred in 1958. An earthquake that year caused a large section of rock to plunge into the bay, producing a surge of water that cleared trees to a height of as much as 525 m on the opposite shore.

In general, tsunamis produced in southeastern Alaska have been small, and most have been caused by subaerial and submarine landslides. The Fairweather fault, the main active fault in the area, has a history of vertical displacements of 12 m or more, but it lies inland and extends through the bays and inlets of the coastal area.

The Gulf of Alaska region has both landslide and tectonic tsunamis. Tsunamis generated in the Gulf of Alaska pose a greater threat to Alaska than those generated elsewhere because of the population concentration in this area. Also the area has the potential to generate large tectonic tsunamis as it has in the past. These pose a major threat to Alaska and because of the orientation of the fault and the directionality of the tsunamis, they also pose the greatest threat to the west coasts of Canada and the United States.

The Aleutian Islands region has predominantly tectonic tsunamis, which are a hazard principally to Hawaii. The 1946 Aleutian Islands tsunami caused 159 fatalities and $26 million in damage in Hawaii which gave rise to the Pacific Tsunami Warning Center. Tsunamis generated outside Alaska have not been damaging in Alaska historically.

The 1964 Alaskan tsunami demonstrated the destructive force of major tsunamis generated locally in Alaska. This tsunami caused more than $80 million in property damage and killed 106 people in Alaska. In addition to the waves that were generated by the large-scale tectonic displacement, huge waves were set into motion in other areas by submarine slides. These landslides generated local tsunamis, and caused between 71 and 81 of the fatalities in Alaska; consequently, they pose a special difficulty for assessments and warnings for tsunamis in Alaska. These landslides may be triggered by large earthquakes as was the case in 1946 or without such triggers as was the case with the 1936 Lituya Bay tsunami. Tsunamis generated by subaerial and submarine landslides have caused most of Alaska's tsunami fatalities, a phenomena almost unknown in other areas of the United States affected by tsunamis. Typically these very local waves arrive in less than two minutes and give little or no opportunity for warning or evacuation.

Landslides generated by the 1964 earthquake caused local waves in several Alaskan communities. These local waves were not a part of the major tsunami that was generated in a large area of uplift (including most of Prince William Sound and the continental shelf from Kayak Island to Sitkinak Island; Spaeth and Berkman, 1972). The towns of Seward, Valdez, and Whittier sustained major damage to docks, railroad yards, fishing boats, and other waterfront structures owing to the submarine slides and the resulting waves.

Information on the Alaska tsunami of March 28, 1964 is voluminous, and the bibliography is extensive. The volumes published by the National Academy of Sciences for *The Great Alaskan Earthquake of 1964*, particularly the *Geology*, *Oceanography and Coastal Engineering*, and *Human Ecology* volumes, are excellent sources for more detail on this event. For tsunamis occurring more than a few decades ago, most of the available information is incomplete and, in some events, confusing. For older tsunamis, the present report contains essentially all the data available, although substantial quantities of additional material from the Russian-American Company period held in the National Archives have not yet been interpreted by researchers. However, it is probable that information is complete for all destructive tsunamis in the areas inhabited by Western settlers the last 200 years.

3.3 REGIONAL TSUNAMI WARNING SYSTEM

The Alaska Regional Warning System was established in 1967 at Palmer Observatory, north of Anchorage. This site is the operations center for a special network of tide stations and seismograph stations throughout Alaska. Direct communications are maintained with Civil Defense units and other emergency forces in Alaska, Canada, and the west coast of the United States. The center also maintains direct communications with the Pacific Tsunami Warning Center in Honolulu. Whenever an earthquake of magnitude 7 (6.75 in the Aleutian Islands) or larger occurs along the Pacific coast of Alaska, a tsunami watch is issued to the Alaskan, Canadian, and mainland United States-Pacific coastal population through the appropriate Civil Defense authorities (Dohler, 1983).

In Alaska, the elapsed time between the occurrence of an earthquake that generates a tsunami and the inundation of coastal areas by the first wave is too short for adequate warnings to be given by the Pacific Tsunami Warning System. Consequently, most decisions to warn coastal residents must be made prior to the collection and analysis of marigraphic data, which is the main basis for issuing a tsunami warning in the Pacific System. Hence, the Alaska System relies primarily on rapid analysis of seismic data, and secondarily on marigraphic data, telemetered to the Palmer operations center.

Appraisal of the tsunami risk involved for any earthquake, whether or not a tsunami has been generated, depends upon a knowledge of the range of tsunami effects that may be expected. In spite of the research in recent years on tsunami generation, propagation, and effects, many uncertainties vital to the problem of issuing warnings in general still exist. These uncertainties are even more critical in areas like Alaska, where the historical record of tsunamis is rather short and incomplete and the coastal configuration is unique.

Figures 32 to 34 show most of the locations mentioned in the following destcriptions.

3.4 DESCRIPTION OF TSUNAMI EVENTS

1788, July 21. A large earthquake estimated to be a magnitude 8 shook the new Russian settlements in Alaska. The source seemingly extended at least from the Sanak Islands to Kodiak Island. Eyewitnesses at Three Saints Bay (Old Harbor), Kodiak reported that before they had come to their senses after the tremor, a flood came in from the sea. The natives (Koniags) and Russians fled to the mountains. After the mooring lines of a ship were parted, the ship was deposited on a dwelling. Landslides occurred in the mountains and along the coasts. It caused a deluge in the **Three Saints Bay** harbor. Eyewitnesses reported that it carried away a barabora (half-sunk hut) with the remaining trade goods and another outbuilding with a fenced-in garden. All the sod was washed away from a kitchen garden, and the water rose to almost half the height of bedroom windows. The water was very swift and remained only briefly; there were two large waves while the rest were smaller. (Letter from V. Merkul'ev to G.T.Shelekhov, May 2, 1789, in Soloviev, 1968)

Two more large waves and a subsidence of the coast were observed. St. Augustine volcano began to erupt. On **Unga Island,** the water rose 91 m (50 sazhens, a Russian fathom equivalent to 233.6 cm) (Sykes, et al., 1980), causing many deaths among the Aleuts. It is not clear if this is the height or distance of inundation. The water passed over **Sanak Island** in "strong, uncommon rollers." Some swine were drowned. In **Pavlof Village** (now **Saint Pauls Harbor, Kodiak**) a much smaller wave was observed. The inhabitants of the northern side of Unimak Island detected no waves at all. (Soloviev and Go, 1974, p. 17; Sykes et al., 1980; Kisslinger and Davies, 1987; Iida et al., 1967; Cox and Pararas- Carayannis, 1976). The earthquake occurred on July 11 of the Julian calendar, converted to July 22 in the Gregorian calendar. However, because of the International Date Line this should be July 21. Sykes et al. (1980) conclude: on the basis of Dall's 1870 report; that a second shock occurred 16 days after the shock at Kodiak owing to rupture of the western half of the Shumagin gap on August 6. This may

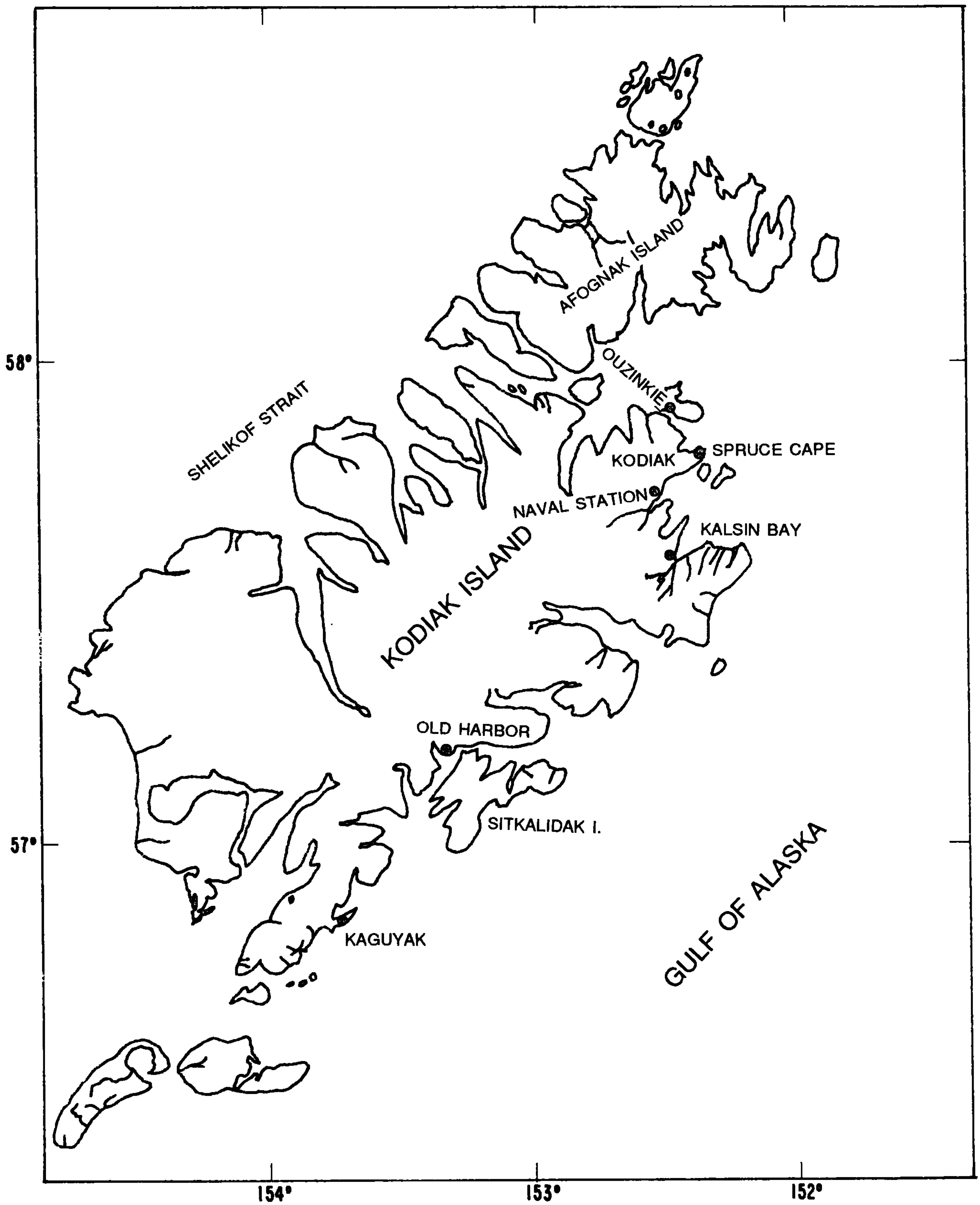


FIGURE 32.—Map of Kodiak Island.

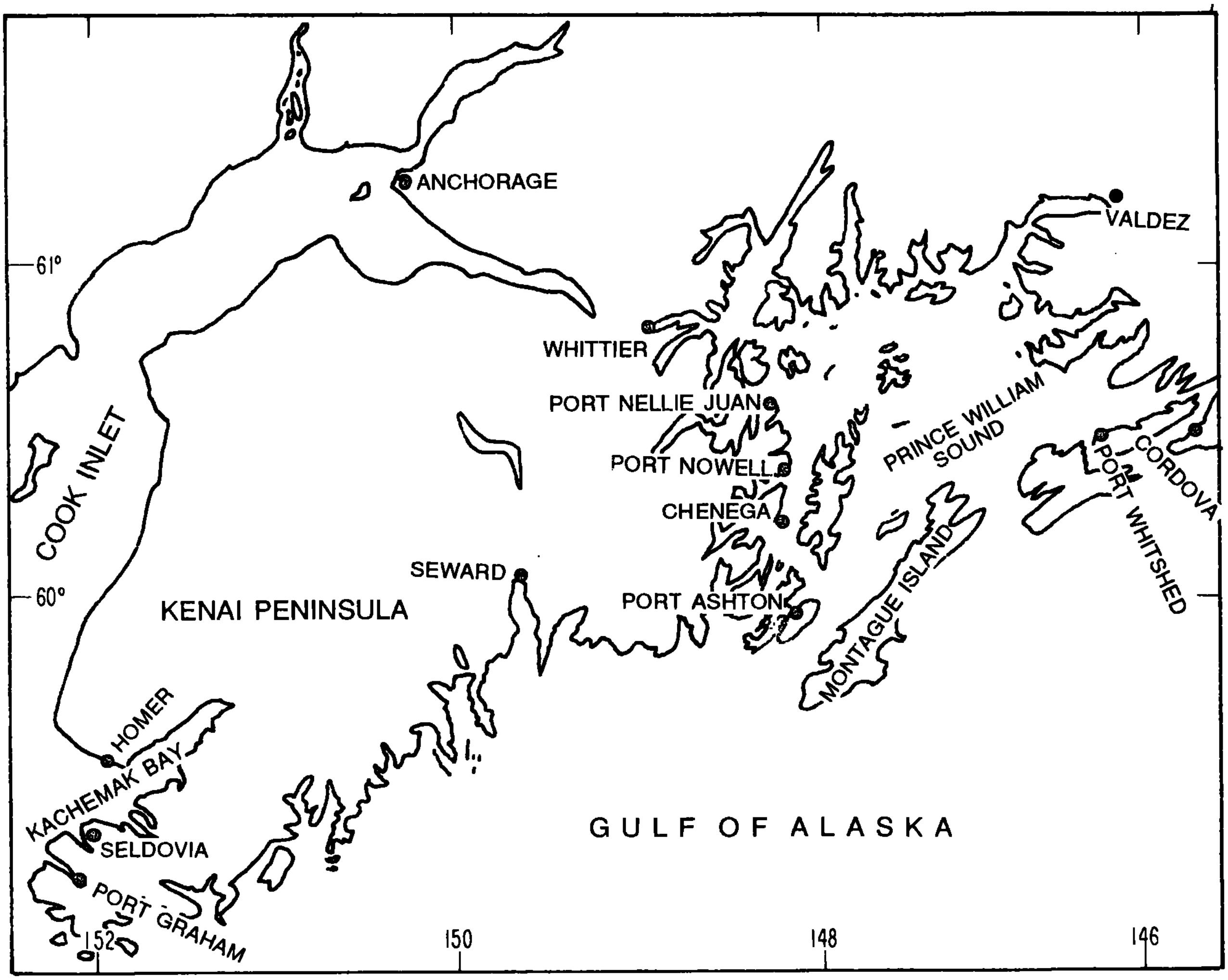


FIGURE 33.—Map of Gulf of Alaska.

be the date of the effects reported above for Sanak and Unga Islands, or there may have been a second flooding. The date of July 27 sometimes associated with this event is the Julian date for this second event, uncorrected for the International Date Line crossing.

1792. A severe earthquake collapsed huts at **Three Saints Bay (Old Harbor)** and caused the cliffs to collapse. A vessel entering the harbor encountered a severe storm and great difficulty from the unusual wave action. The land was further subsided, and the Russian inhabitants moved their settlement to Kodiak (Kisslinger and Davies, 1987 draft; Cox and Pararas-Carayannis, 1976). Note: Iida (1984) and Iida et al. (1967) list a tsunami affecting areas of the Ise Bay, Japan, not associated with a local earthquake on August 29, 1792, (Japanese local date) in daytime. It is possibly associated with this Alaskan shock.

1796, May 19. Erroneous report in Ponyavin (1965) of a tsunami accompanying the appearance of Bogoslof Island. Soloviev and Go (1974, p. 17) find no reference to a tsunami.

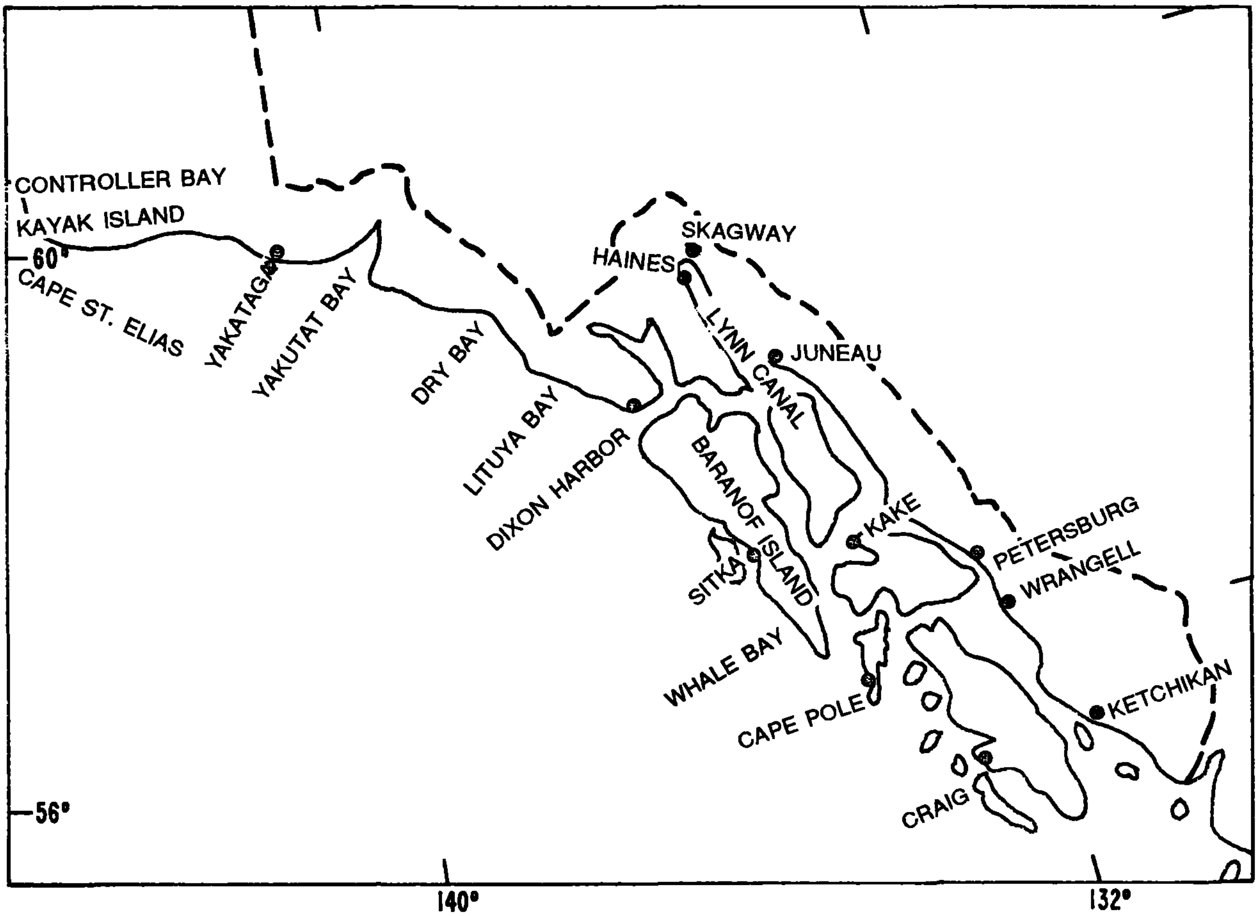


FIGURE 34.—Map of southeast Alaska.

1820, March 1 (or night of March 2-3). Owing to a large eruption of Pogromni volcano on the northernmost part of **Umnak Island**, ashes ejected into the air and were observed as far away as Unalaska and Unimak Islands. The shaking of the earth that accompanied the eruption caused the sea to become highly disturbed. (Soloviev and Go, 1974, p. 17; Kisslinger and Davies, 1987 draft). This was probably not a tsunami.

1824-Fall 1825. Apparently the eruption of Shishaldin volcano on **Unimak Island** at the end of the year 1824 continued to agitate the sea into autumn of the following year. (Soloviev and Go, 1974, p. 17). In the middle of March the sound of underground explosions was heard from Unalaska to the Alaskan Peninsula. The volcano ejected flames, ashes, and streams of water and rubble that inundated the southern coast of **Unimak Island** for 4 km.

1827, Aug. 8 and 9. This is an apparently confused entry by Dall (1870) of an earthquake on Copper Island and eruption of Pogromni volcano, which resulted in a tsunami drowning some swine on **Chernabura Island, Shumigan Islands.** However, Copper Island is in the Komandorski Islands at the western end of the Aleutian arc. There was no tsunami with that earthquake (Soloviev and Ferchev, 1961). There was a withdrawal of water far out into the bay during an eruption of Avacha (Avachinsky) volcano August 8 to 10 on Kamchatka and accompanying earthquakes, but Soloviev and Ferchev consider it to be a seiche. (oscillation of the surface of a lake or landlocked sea). However, it could not have affected the eastern Aleutians. The swine drowning report probably was a repeat of a similar report for the 1788 event. (Kisslinger and Davies, 1987 draft; Soloviev and Ferchev, 1961; Cox and Pararas-Carayannis, 1976; Iida et al., 1967)

1845, Summer. A collapsed glacier in **Yakutat Bay** created a wave in which "a hundred" natives perished. (Tarr, 1909, p. 67; Cox and Pararas-Carayannis, 1976) Apparently this is a misdated reference to the 1853-1854 Lituya Bay tsunami. Following the collapse of Fallen Glacier in 1905 Indian guides reported there had been two similar events in that vicinity, the more recent occurring about 60 years earlier (i.e., 1845). They reported that 100 Indians had been killed, all but one of them camped a few kilometers south of Haenke Island. The date is not accurate, and this event may have occurred at the same time as the events described below for 1853-1854.

Late 1853/Early 1854. Studies conducted in **Lituya Bay** by Miller (1960), in the period 1948 to 1953 uncovered evidence of a large wave that had occurred a century earlier. The evidence was discovered at a well-marked boundary in the forest that grew along the north and south shores of the bay. Above the boundary an old forest grew, while below it only young trees were discovered, as far as the zone of flood tides. It was determined that the wave had occurred between the middle of August 1853 and the beginning of May 1854 by the number of tree rings on the younger trees. The maximal known height of this boundary is 120 m above mean sea level; the maximal distance from the waterline is 750 m; the known area of the zone of destruction of forest is 3.5 km^2. The remaining traces of erosion show that the wave of 1958 was similar in destructive power to this earlier one. The origin of this wave is unknown, but probably was a rockslide on the south side of **Lituya Bay** near Mudslide Creek.

A Tlingit Indian story tells of a huge flood between 1850 and 1860 in which eight canoes filled with people were lost at **Lituya Bay**. This probably was the result of the 1853-54 tsunami, but cannot be proven. There is also a report in Miller (1960, p. 76) of a flood in **Dry Bay** that killed many people between 1850 and 1860. (Miller, 1960, p. 76-79; Cox and Pararas-Carayannis, 1976; Soloviev and Go, 1975, p. 202-203)

1854, January 27. An earthquake shortly after 8:00 A.M. lasted more than a minute in **Pavlovskaya Harbor (Saint Pauls Harbor)** on **Kodiak Island**. "At the first onset of the underground thunder on January 16th (the 27th, Gregorian calendar) the water in the harbor advanced and receded uncommonly at 2-and 3-minute intervals and there was a strong eddy." (Soloviev and Go, 1974, p. 17-18; Doroshin, translation, 1983; Kisslinger and Davies, 1987. Soloviev and Go (1974) give the Julian date of January 16, and Kisslinger gives the Gregorian date as January 28 (not correcting for the International Date Line.) The tsunami was also observed at Hilo, Hawaii.

1856, July 26. There was a volcanic eruption in Unimak Pass. It is described by Neville, the captain of the whaler *Alice Fraser*. Crossing **Unimak Pass** on his ship with six other whalers, he observed that as a result of the volcanic eruption, enormous masses of dense black smoke were rising over the conical peaks of the mountains on the adjacent islands. (Soloviev and Go, 1974, p. 18)

Sailing west and north of the eastern shore, the ships came out of the cloud of smoke. When they were near the northern base of the volcano, a prolonged dull rumble pealed out under them, and an underwater eruption occurred almost in the center of the flotilla. First the water churned and began to rise stormily in the form of disorderly waves. Then it rushed up, as if ejected from an enormous spring, forming a dazzling column of water of colossal height, which gradually disintegrated. Then a shaft of fire and smoke rose from the bottom upward with peals of thunder. Lava and stones from a walnut to a cannon ball in size were ejected and fell on deck. This lasted no more than an instant, and the eruption ended as quickly as it had begun. The water rushed into the abyss that had formed, forming a colossal whirlpool. The noise was like Niagara Falls. The ships rushed to safety, leaving the volcano in a state of regular alternations of relative calm and eruptions. None of these effects appear to be indicative of a tsunami. (Soloviev and Go, 1974, p. 18,19; Cox and Pararas-Carayannis, 1976)

1868, May 15. There was an earthquake on the Alaskan Peninsula. During this earthquake, the water in the port on the northern side of **Unga Island** was agitated. At some places, the level rose 6 m. This apparently refers to an elevation of the land and not a wave. (Soloviev and Go, 1974, p. 19; Tarr and Martin, 1912, p. 89; Perrey, 1875)

1868, August 14, 01:30. The Arica, Peru (now Chile), earthquake was recorded at **Kodiak** at 10:00 A.M. on the 14th. (Soloviev and Go, 1975, p. 90; Iida et al., 1967; Cox and Pararas-Carayannis, 1976). There were at least two great earthquakes at Arica on this date. The first occurred at about 4:45 P.M., August 13 local Chilean time and the second and possibly larger event at about 8:45 P.M.. The wave reported here relates to the second earthquake. These times given in the form of 16:45 and 20:45 are widely confused with UTC time, but are local times. The origin time of 01:30 UTC was derived from the time of the second event, 8:45 P.M. or 20:45 adjusted by four hours and 45 minutes for the 71° conversion to the Greenwich meridian.

1872, August 23, 18:02. Cox (1984) was able to locate a source region in the Aleutian Islands for a tsunami observed in Hawaii and on the West Coast. Neither the earthquake nor the tsunami was reported in Alaska owing to the sparse population in the area.

1874. At **Lituya Bay** a lower trimline of trees seen on old photographs suggests another giant wave occurred about midway between the 1853/1854 waves and 1894 when the photographs were taken. The height of the trimline was 24 m along a 7.5-km section of coastline. (Miller, 1960, p. 75) Dall (1883) noted "evidence of flooding and washing" in 1874. There are no reports of large earthquakes occurring in eastern Alaska during this period, but a landslide source is possible. (Dall, 1883, p. 203; Cox and Pararas-Carayannis, 1976; Soloviev and Go, 1975, p. 207)

1878, August 29. On **Unalaska Island**, **Makushin** was destroyed by an earthquake and "tidal" waves, but there is no specific mention of fatalities. (Kisslinger and Davies, 1987 draft; Soloviev and Go, 1974, p. 19; Cox and Pararas-Carayannis, 1976; Iida et al., 1967) Kisslinger and Davies quoting Mushketov and Orlov, 1893, report volcanoes and earthquakes affecting Umnak, Amukta, and "Chegak" (Chagulak) Islands, but do not mention the tsunami.

1880, September 29, 04:00. Strong earthquakes commencing at 6:00 P.M. September 28 (local date and time) caused the formation or renewal of a surface fracture on **Ukamak (now Chirikof) Island**. The sea rose several times as a body flooding the shore for a distance of about 55 m even though the tide was at low water on the west side of the island. The tide did not rise as high as it rose before the shocks because of the uplift. The southwestern side subsided, deepening creek channels and allowing salt water to enter. Heavy breakers appeared where they formerly were absent. Soloviev and Go (1975) suggest this is associated with the tsunami of October 26, 1880, near Sitka (See below) but these are separate events. (Kisslinger and Davies, draft; Soloviev and Go, 1975, p. 207; Sykes et al., 1980)

1880, October 26, 22:20. Two heavy earthquakes were felt in Sitka. The magnitude of the largest shock was 6.3. A large wave appeared after the first shock. Two Russian prospectors at **Whale Bay**, south of Sitka, reported a "tidal" wave of huge proportion running into Whale Bay. At **Redoubt Lake** on **Baranof Island** the water rose 1.8 m instantly and fell as quickly. The measurement was based on the height of drift left behind. (Monthly Weather Review, January 1881)

1883, August 27, 02:59. Small waves recorded between 6:00 and 11:00 P.M. were generated by the air waves from the explosion of Krakatau volcano. This is not considered to be a true tsunami. (Iida et al., 1967; Cox and Pararas-Carayannis, 1976)

1883, October 6. An eruption began of the Augustine volcano, which forms **Augustine Island** on the western part of Cook Inlet. At **Port Graham**, 90 km east of the volcano, a muffled explosion was heard at about 8:00 A.M. (The sound wave reached **Port Graham** about 6 minutes after the explosion.) A dense cloud of ash came from the peak, and a column of white steam that seemed to come from the sea near the volcano, rose at the same time as the ash. The sea was extremely agitated and churned so that it was impossible to approach or leave the island. Seven or eight Aleuts hunting otter on the island vanished.

About 25 minutes after the beginning of the eruption, a colossal wave estimated to be 7.6 to 9.1 m high, fell on **Port Graham** in the form of a wall of water. Houses were flooded. The first wave was followed, at about 5-and 10-minute intervals, by two other large waves whose heights were estimated at 5.5 and 4.6 m, respectively. Large, irregular waves occurred in the harbor all day. Kienle's (1986) travel time model predicts an arrival about 45 minutes after the generation of the wave.

The first wave carried all the fishing boats onshore, and then it carried them back out to the bay. In the end, the ships were run aground. Fortunately, it was full ebb time, which saved the settlement from destruction, since the height of the flood and ebb tide at these places is about 4.3 m.

A tsunami that also occurred on **Kodiak Island** may have been registered by the tide gage there. For many days following, from Port Graham one could see ashes being ejected from the volcano and flames in the darkness. (Soloviev and Go, 1974, p. 19-20; Cox and Pararas-Carayannis, 1976; Iida et al., 1967; Kienle, 1986; Tarr and Martin, 1912, p. 89). An erroneous date of October 8, 1883, is given in some accounts.

1899, September 4, 00:22. At about 13:03 P.M. September 3 (local "sun time") a catastrophic earthquake (magnitude 7.9) near **Cape Yakataga** caused the sea to recede from shore and fall to a full ebb tide in 20 minutes. The water crossing the reef in the bay was whipped into a mass of seething foam at **Yakutat**. The water in the bay began to run out toward the ocean heavily and went far below the lowest reported low-water mark. After a short while the water returned in a strong current and made a big swell on the beach. The houses in the Indian villages were nearly washed away as the water washed all around them. At **Cape Yakataga**, 167 km west of **Yakutat**, Captain Ben Durkee, commanding the schooner *Bellingham*, was 1.67 km off the coast. The first shock was plainly felt on the boat, which vibrated and shook as if it were on a rock. The sea ran out from the shore at the rate of 5 or 6.6 km an hour, and the schooner sailed out at the end of her anchor chain. The sea slowly returned and reached about half the proper height, according to the tide tables. Captain Durkee reached **Kayak** about 4:00 P.M., September 4, after a run in a heavy sea which taxed the schooner. (Cox and Pararas-Carayannis, 1976; Tarr and Martin, p. 70-71, 1912; Davison, 1936, p. 160)

1899, September 10, 21:40. There was a catastrophic magnitude 8.9 earthquake at the tip of Yakutat Bay. Large block dislocations occurred along the fault system. The earthquake caused many large collapses and slides, including the breakup and collapse of glacier tongues. The earthquake generated at least four separate tsunamis at **Yakutat Bay, Valdez, Katalla,** and **Lituya Bay**.

At **Russell Fjord** in **Yakutat Bay** (fig. 35) eight prospectors were camped at two places on the moraine. Five men at one camp barely escaped before a lake above their camp burst its containment sending its contents and thousands of tons of rocks onto the camp. This was followed almost immediately by a wall of water 6 m high rising in the bay. The wave was reported to have been preceded by "geysers" about a meter in diameter and 12-16 m high. The first wave was followed by a second wave 6-9 m high. All supplies at that camp were lost, but the men survived and were able to rejoin the other three prospectors. One small boat survived, along with a few provisions. They found a damaged native canoe, repaired it, and started for Yakutat 50 km away. The journey was very difficult as the bay was chocked with ice. They observed wave marks 18 m up the bluffs. There is no mention of native fatalities nor of the fate of the original owners of the canoe.

At **Yakutat**, the water became agitated after the earthquake, and at least until nightfall the level rose and fell 2.5-3 m (range) every 8-10 minutes.

(1899, September 10, continued)

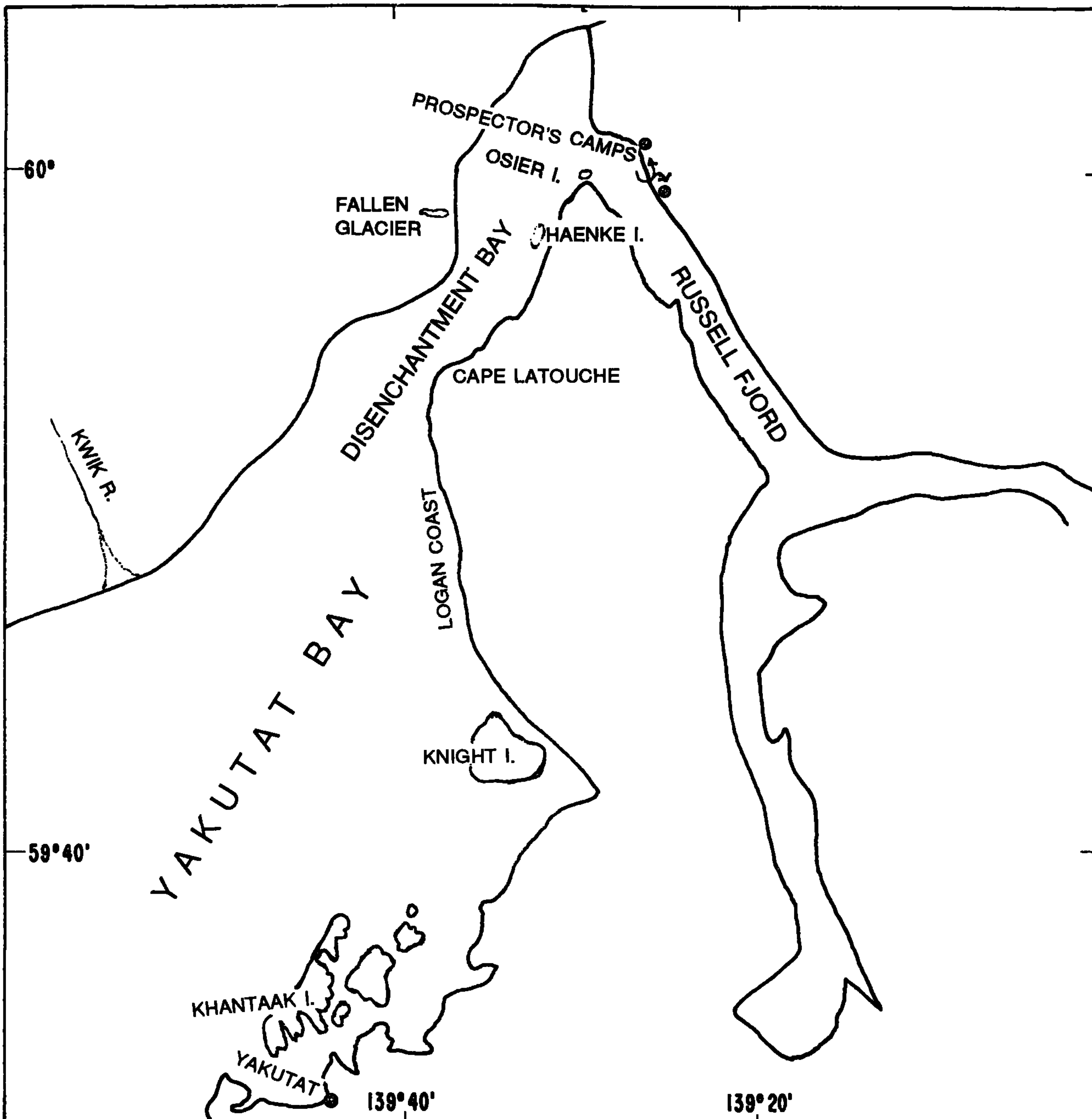


FIGURE 35.—Map of Yakutat Bay and Surrounding Area.

One eyewitness described flood tides that rolled in from the sea in three large waves at intervals of about 5 minutes. The water rose 4.5 m from the ebb tide mark. Eddies formed in the bay, in which trees, driftwood, and rubbish circled so rapidly that it was difficult to follow individual objects. The water foamed up and was covered with whitecaps on the whole expanse. Reaching the chute of a sawmill, the whirlpool tore it off and carried it away in an instant. Another eyewitness described stormily retreating water that returned soon afterward in a strong current and covered the shore. Everything around the Indian huts was flooded and washed away, and the huts themselves were nearly washed away.

An eyewitness in Yakutat reported the collapse of part of **Khantaak Island,** which had included part of an Indian graveyard. A high pole in the graveyard was carried upright some distance offshore and still protruded above the water some 1.2 to 1.5 m. The next day several people rowed a boat over the site and could see the tops of trees underwater. A similar collapse of the same island occurred during the 1958 earthquake and tsunami.

An investigation of the coast in 1905 showed clear traces of destruction by the tsunami on many sections of the coast, mainly near the line of the main fault of the earthquake. In the region of **Logan coast**, approximately between **Knight Island** and **Cape Latouche**, the bench and more deep-sea regions were completely flooded. On a high terrace, where a mature forest had grown until 1899, there remained a dense, almost impassable tangle of trees that had been uprooted, broken, twisted, and tossed about. They were entangled with trees remaining standing. All vegetation up to a height 12 m was destroyed. Even strong, 75 year-old trees were broken. Retreating, the water tossed about the trunks of felled trees on the lower terrace and on the new beach.

The tsunami was also destructive on the western shore of **Yakutat Bay**, near the entrance of **Disenchantment Bay**, west of the main fault. The water encroached 0.5 km on land, rose to a height of 9 m, and partly destroyed groves of poplars. Tree trunks were strewn along the edges of the flood zone at the boundaries of the surviving groves. Some willows between this line and the shore remained standing, but died; their branches and shoots were turned seaward by the retreating water, and the bark was torn off the trees. At the top of **Russell Fjord**, at **Cape Stoss**, the water passed over a sandy dike, joining the rocky island to the continent. Here, much driftwood remained on the elevated places for many hundreds of meters from the shore. There, and at other places on the coast, according to the Indians, large fields of strawberries were destroyed.

On the delta of the Kwik River in **Yakutat Bay**, the tsunami passed 0.5 km across the modern bar and lagoon to the old bar, on which grew a grove of poplars. Judging from the driftwood remaining, the water rose 4.5 m relative to the level of the beach, but the force of the waves was insufficient to fell the trees. From here to the entrance of **Disenchantment Bay**, driftwood lay everywhere, far beyond the reach of the highest regular waves.

At **Katalla**, a flood tide 1.25 m high rose upstream along the Bering River near the delta at **Katalla, Controller Bay**. This wave was probably generated by a slump in the area and was unrelated to the wave in Yakutat Bay.

At **Valdez**, "earthquake water waves" up to 2 m high were generated and rolled onshore. If this was a tsunami, it was generated separately from the waves at Yakutat and probably by a slump. (Tarr and Martin, 1912, p. 80; Cox and Pararas-Carayannis, 1976; Soloviev and Go, 1975, p. 210-213)

At **Lituya Bay**, a wave may have arisen and washed away the forest on the northeastern shore of **Crillon Bay** at a height of up to 60 m and to a lesser extent on some other sections of the coast of the bay. It is surmised that the wave was caused by a large avalanche that resulted from a catastrophic **Yakutat** earthquake and tsunami of September 10, 1899. Miller (1960) reports receiving an oral report that a flood wave was observed in **Lituya Bay** in 1899, and another report that a native village and saltery were destroyed in 1899, but he could not confirm them. This would be a separate tsunami generated within **Lituya Bay**. (Miller, 1960; Cox and Pararas-Carayannis, 1976; Soloviev and Go, 1975, p. 213)

1901, December 31, 09:03. Reid (1912) reported "[at] **Kenai** on Cook Inlet..[There was]... a volcanic eruption. Earthquake which accompanied it caused several tidal waves." From Reid's manuscript file are entries concerning a volcanic eruption of December 30 and 31, 1901, and an eruption

(1901, December 31, continued)
in late 1901 or early 1902 accompanied by a severe earthquake with "several tidal waves doing much damage." (Cox and Pararas-Carayannis, 1976) A magnitude 7.1 earthquake (Abe and Noguchi, 1983) occurred on December 31 at 09:03 UTC near Umnak Island and probably was the event Reid reports as having been recorded in Baltimore, Maryland on December 30, or 31. However, Umnak is about 1400 km from Kenai, and the earthquake is probably unrelated to the volcanic activity reported there. There was a second earthquake (magnitude 7.8) on January 1, 1902, at 05:20 UTC near Unimak Island (Richter, 1958, p. 710). Simkin, et al. (1981, p. 84) list eruptions for Redoubt volcano on January 18, 1902, but Redoubt volcano is 32 km inland. They list an eruption in 1902 for St. Augustine volcano. The 1902 eruption was not more closely dated, but it did have mudflows associated with it. From the information available it can not be determined whether the tsunamis were associated with either of the earthquakes or volcanic eruptions or was an erroneous report. (Soloviev and Go, 1974, p. 22; Iida et al., 1967)

1905, July 4. Dr. R. S. Tarr, a famous geologist of the 19th and early 20th century, was working in **Russell Fjord** when he saw a series of large waves. The water rose and fell 4.5-6 m for half an hour. There had not been an earthquake. Later, his Indian guides reported that a hanging glacier--now called Fallen Glacier--had slid into **Disenchantment Bay** 24 km away. When he had time to examine the site, he found that the entire glacier had slid out of its valley and tumbled 300 m down the steep slope to the bay. Alder bushes had been cleared from a 0.8-km swath by the slide, and the resulting tsunami broke branches to a height of 33 m at a distance of 0.8 km from the point of origin. At 4.8 km farther north near Turner Glacier, vegetation was killed to a height of 20 m. At **Haenke Island** waves reached 15 to 18 m on the north end and 35 m elsewhere. The Indians stated that this incident was the third time a glacier in that vicinity had fallen. The last time was about 60 years ago. (see 1845) (Soloviev and Go, 1975, p. 214; Miller, 1960, p. 66; Cox and Pararas-Carayannis, 1976)

1907, September 24, 12:58. A shock was felt at Skagway, Klukwan, and at the Point Sherman lighthouse in the region of Lynn Canal, and a small temporary change in the water level was noticed by a ship captain near **Haines**. It was recorded by the seismograph at Sitka. Soloviev and Go, (1975, p. 216-217) estimate the magnitude to be about 5.5 based on the Sitka record. (Tarr and Martin, 1912, p. 96.)

1908, February 14, 11:25. Steamer *Northwestern* rocked perceptibly near **Valdez**. The Sitka-Valdez cable was broken in seven places, and some of the cable was buried indicating a submarine landslide. The Seward cable was broken in four places. However, people on the dock at **Valdez** reported: "There was no marked sea wave." (Tarr and Martin, 1912, p. 97; Cox and Pararas-Carayannis, 1976; Soloviev and Go, 1975, p. 217)

1911, September 22, 05:01. A magnitude 6.9 earthquake occurred in Prince William Sound and on the Kenai Peninsula. A submarine cable was broken at **Fort Liscum** near **Valdez** some seconds after the shock. It was buried for a distance of 500 m. The cable was broken at this same location in 1908. There were large rockfalls at the top of the sound, and the water became agitated in **Port Wells (Bay)**. Tarr and Martin, 1912, report that the residents of Golden fled to their boats to escape the landslides and spent the night there. They also report that the floor of the bay (not the water itself) was violently disturbed, accounting for the large fish kill. This is a doubtful tsunami. (Tarr and Martin, 1912; p. 100; Soloviev and Go, 1974, p. 22; Gutenberg and Richter, 1954; Cox and Pararas-Carayannis, 1976)

1925, February 23, 23:54. There was a 6.0 magnitude earthquake at **Valdez** which caused part of the dock to collapse, tipping shoreward, after which an unusual wave tore up a section of the boardwalk on Water Street. The submarine cable was cut again. (Soloviev and Go, 1974, p. 22; Cox and Pararas-Carayannis, 1976; Coulter and Migliaccio, 1966, p. 69)

1927, October 24, 16:00. A magnitude 7.1 earthquake near the southeastern coast of Alaska apparently generated a wave observed in Hawaii, but were not reported as being observed in Alaska. Underwater cables were broken between **Petersburg** and **Wrangell**, between **Juneau** and **Skagway**, and between **Ketchikan** and **Wrangell** near **Wrangell**. (Cox and Pararas-Carayannis, 1976; Soloviev and Go, 1975, p. 218)

1929, March 7, 01:35. There was a 7.5 magnitude earthquake centered near the Fox Islands. Residents at Dutch Harbor, Unalaska, felt a severe tremor. A tsunami arose and was recorded by instruments in the Hawaiian Islands, but was not reported from Alaska. (Soloviev and Go, 1975, p.241; Iida et al., 1967; Cox and Pararas-Carayannis, 1976)

1936, October 27. There was an enormous wave in **Lituya Bay**. The following is from Miller (1960) and Soloviev and Go, (1975). Four people observed the event: fisherman Jim Huscroft and a companion in a cabin Huscroft had built 15 m above the bay on the western side of **Cenotaph Island** and two men on the small fishing ship *Mine* riding at anchor off the northern shore of the bay, near Fish Lake and 2 km west of the cabin.

According to the fishermen on the *Mine*, at about 6:20 A.M. local time, 2 hours before sunrise, a dull, continuous rumbling was heard on board the ship. It appeared to come from the mountains located beyond the top of the bay. Because of the darkness, they could not see what was happening. No tremors were felt. The tide was rising and was at about mean tide stage. The rumbling lasted until about until 6:50, when the first large wave appeared in the narrowest part of the bay. It was like a steep watery wall, stretching from shore to shore and having a possible height of 30 m. Seeing this wave, the fishermen weighed anchor and headed for **Cenotaph Island**. When the wave reached them 10 minutes later, they were situated 400 m northwest of **Cenotaph Island**, at a depth of 20 m. The arrival of the wave was not preceded by a drop in water level or other anomaly. The first wave lifted the ship about 15 m higher. Immediately after the passage of this wave, the water surface dropped below the normal level. A seining boat, riding at anchor off **Cenotaph Island** at a depth of 14.5 m, touched bottom. The first wave was followed by a second and third at about 2-minute intervals, and each successive wave was larger than the preceding one. After each of these waves, the surface of the water again fell below the normal level. Small waves were observed during the half hour after the passage of the third wave. All of the waves were directed toward the exit from the bay. After this, floating tree trunks and pieces of ice appeared around the ship.

The fishermen in the cabin were awakened at about 7:00 A.M. by a noise, like the droning of a hundred airplanes flying at low altitude, and found that a wave was approaching their cabin. Climbing to a high safe place, they saw three waves pass the island, growing in height, with a speed of about 37 km/hr. The maximal height of the waves was estimated at from 45 to 75 m. However, the height of the tree trimline on the island was only 7.3 m. The cabin was flooded washing away 50 barrels of salted salmon, and two frame out-buildings were destroyed. Subsequent geodetic, geographic, and geological investigations of the bay, done in 1937-53, made it possible to assess the height of rise of water along the coast of the bay. Trees were sheared and uprooted in the flood zone, and the soil was partly eroded. According to contemporary press accounts, the trees washed away by the water drifted 90 km south of the bay along the Pacific coast in the next several days. Some of the uprooted trees, according to witnesses, were left lying onshore with intact roots, branches, and bark. The largest determined rise of water, 150 m, occurred on the northeastern shore of **Crillon Bay**. The total flooded area of the shores of the bay (determined from the high tide line) was 3 km^2. The forest was not felled at the entrance to the bay, but the water flooded to 1 km from the shore, and the fishermen later gathered crabs and shellfish there. By all accounts, these waves arose at the top of **Crillon Bay**, but their cause cannot be reliably established. There are serious objections to all the hypotheses that have been advanced: a large subaerial or submarine slide or collapse, the calving of an iceberg from the tongue of the North Crillon Glacier, a sudden slide of the tongue of the

(1936, October 27, continued)
glacier, a breach in an ice-locked surface or sub-ice lake, etc. (Soloviev and Go, 1975, p. 221-223; Cox and Pararas-Carayannis, 1976; Miller, 1960)

1938, November 10, 20:19. A magnitude 8.3 earthquake occurred near the Alaskan Peninsula. A tsunami was recorded in Alaska at **Seward**, **Dutch Harbor**, and **Sitka** with a maximum amplitude of 0.1 m at **Sitka**.

Carte (1987), a geophysicist with the Alaskan Tsunami Warning Center, reports that he talked to a lady who lived in **Unga** during this quake. She told him minor flooding occurred there after the quake owing to a wave. Also, all the skiffs were washed away trapping the community people on the island. (Soloviev and Go, 1974, p. 23; Neumann, 1940; Cox and Pararas-Carayannis, 1976; Iida et al., 1967)

1944, December 7, 04:35. A 8.0 magnitude earthquake in Japan produced a tsunami with amplitude of 0.3 m at **Massacre Bay**, **Attu**, and 0.1 m at **Sweeper Cove**, **Adak**. (Cox and Pararas-Carayannis, 1976; Soloviev and Go, 1974, p. 112, 114; Iida et al., 1967)

1946, April 1, 12:29. A magnitude 7.3 earthquake occurred south of **Unimak Island**, causing one of the most destructive tsunamis ever to occur in the Pacific Ocean. The rise of water was 30.5 m in the **Aleutian Islands**, 17 m on the Hawaiian Islands, 9-10 m in the Marquesas Islands and the Juan Fernandez Islands, 3 m at Santa Cruz and Half Moon Bay, California, and not more than 1 m on Ayukawa, Japan . An important consequence of the tsunami--the realization that a tsunami warning system was needed-- resulted in the establishment of the Pacific Tsunami Warning Center in 1948. A second strong shock at 12:55 UTC was felt on **Unimak Island** before the wave arrived. However, Bodle (1946) found that the travel times of the tsunami fit the theoretical travel times for the earlier earthquake.

In the reinforced concrete Scotch Cap lighthouse on Unimak Island (fig. 36), five men were engaged in support operations connected with the maintenance of the 80,000-candlepower beam. Perched atop a building constructed 5 years earlier at a cost of $150,000 on a bluff 9.8 m above sea level, the new light was a total of 28 m above sea level. On a cliff behind the lighthouse a second building housed the Coast Guard radio direction-finding station and crew quarters.

Suddenly, at 1:30 A.M. an earthquake rocked the buildings for 30 or 40 seconds but caused no damage. About 27 minutes later, a second jolt was felt. Twenty-one minutes after the second shock, water began flooding the radio direction-finding station. Men off shift and asleep in their bunks were awakened and ran into the operations room where they were instructed to look for higher ground. Stumbling through ankle-deep water outside the structure, the men noted that the beacon from the lighthouse was no longer operating and believed the lighthouse had been destroyed.

The coming of daylight revealed the full extent of the damage. A concrete platform and a few pieces of broken concrete were all that remained of the 18-m structure (fig. 37). Debris had been deposited as high as 35 m above the sea, and a radio tower 32 m above the sea had been washed away. The tsunami had also completely destroyed the original **Scotch Cap** lighthouse built in 1903 and replaced by the newer structure in 1940. Even the direction-finding station on the bluff received damage, including a fire in the switch board, flooding of the fuel tank, and loosening of the antenna guy wires. Portions of the bodies of 3 of the 5 men who occupied the new lighthouse were recovered 3 weeks later. (Sanford, 1946)

The tsunami was recorded at **Yakutat Bay** with an amplitude of 0.2 m and at **Sitka** with an amplitude of 0.4 m. (Soloviev and Go, 1974, p. 23; Iida et al., 1967; Bodle and Murphy, 1948, p. 23; Cox and Pararas-Carayannis, 1976; Green, 1946).

At **Dutch Harbor, Unalaska,** a minor wave entered the harbor at 15:30 UTC that tore the ferry barges loose and demolished numerous pilings and some ferry installations. At **Ikatan** (now spelled **Akutan**) on **Unimak Island** several houses were swept away and considerable damage was done. At **Sanak**

FIGURE 36.—The lighthouse at Scotch Cap on Unimak Island, Alaska. constructed in 1940. The octagonal structure in the background is the former lighthouse constructed in 1903. Photo Credit: U.S. Coast Guard.

Island a 6.1 m wave arrived ten minutes after the shock. It demolished a carpentry shop and all of the equipment was lost. All the houses were gutted and dories were washed up to the school house where the population took refuge. Unusual high tides were reported from **King Cove** on the west end of the Alaskan Peninsula and 1.5 m waves with a period of one hour were observed at **Chignik**, further east. (Press release, Commander, *Alaskan Sea Frontier*, Kodiak, Alaska).

1946, November 1, 11:14. There was a magnitude 7.0 earthquake near the Aleutian Islands. Soloviev and Go (1974) report that at about the expected time, observers on the Hawaiian Islands supposedly noted a small rise in sea level. (Soloviev and Go, 1974, p. 23) Police dispatched to the southeast coast of Oahu reported at 5:00 A.M. that the sea had risen almost to the highway. However, Cox and Morgan (1977) report that this was 19 minutes earlier than the expected arrival time of the wave. The tide gage at Honolulu did not record any tsunami, nor were there any reports from Alaska or elsewhere. This is a doubtful tsunami. (Cox and Morgan, 1977, p. 51)

1949, August 22, 04:01. A 8.1 magnitude earthquake occurred in the region of the Queen Charlotte Islands. It is known that many collapses and slides took place, and cracks were formed in the ground. At **Ketchikan**, **Alaska**, a possible tidal wave

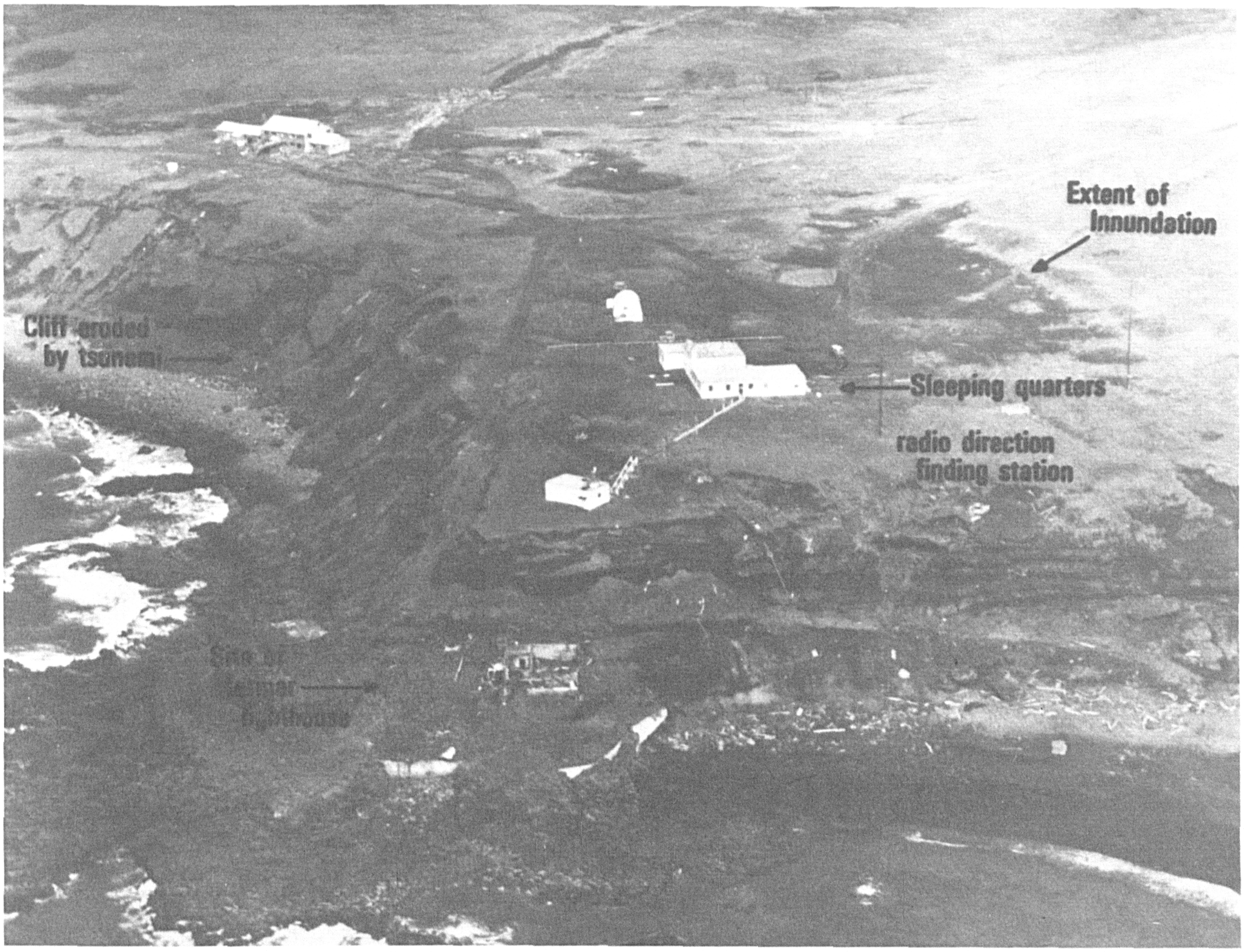


FIGURE 37.—The devastation at Scotch Cap after the tsunami of April 1, 1946. All that remains of the lighthouse is the foundation, a wall, and debris strewn over the bluff. Photo Credit: U.S. Coast Guard.

(1949, August 22, continued)
was reported as being 0.5 m high by Soloviev and Go (1974, p. 25), barely discernible at 0.1 m by Cox and Pararas-Carayannis (1976), and not reported by Murphy and Ulrich (1952). A weak tsunami with a height of 0.07 m and a period of 16 minutes may have been registered by the tide gage at **Sitka**. The tide gage at Hilo registered a tsunami 5.3 hours after the earthquake; the amplitude of oscillations was 0.10 m, the period was 20 minutes.

1949, September 27, 15:31. A magnitude 6.7 earthquake in the Gulf of Alaska produced a record at **Seward** caused by the shaking of the tide gage and not by a tsunami. (Zerbe, 1953; Cox and Pararas-Carayannis, 1976)

1952, March 4, 01:23. A magnitude 8.1 earthquake near Hokkaido, Japan produced a tsunami with an amplitude of 0.3 m at **Massacre Bay, Attu**; and 0.1 m at **Sweeper Cove, Adak**; **Dutch Harbor, Unalaska**; and **Sitka**. (Cox and Pararas-Carayannis, 1976; Iida et al., 1967; Soloviev and Go, 1974, p. 120)

1952, November 4, 16:58. A magnitude 8.2 earthquake off the Kamchatka Peninsula produced a tsunami that was observed in Alaska. At **Massacre Bay, Attu** the wave had an amplitude of 2.7 m and a period of about 17 minutes. This record was observed on the tide staff as the gage was not operating initially and the record was clipped. Low-lying areas were flooded. At **Sweeper Cove, Adak** the tsunami had an amplitude of about 1.1 m and slightly overflowed the banks of the harbor. At **Dutch Harbor, Unalaska** the schools were closed, and the people evacuated to higher ground, but the wave was only 0.6 m high. It was widely recorded elsewhere throughout Alaska with amplitudes of 0.3 m or less. (Zerbe, 1953; Cox and Pararas-Carayannis, 1976)

1953, November 25, 17:48. A magnitude 7.4 earthquake near Kashima, Japan, produced a tsunami recorded at **Massacre Bay, Attu** with an amplitude of 0.2 m (Cox and Pararas-Carayannis, 1976; Iida et al., 1967)

1956, March 30, 06:11. An explosive eruption of Bezymianny volcano in Kamchatka generated an air wave or tsunami that produced a small tsunami observed at **Massacre Bay, Attu**, with an amplitude of 0.3 m, and at **Sweeper Cove, Adak**, and **Dutch Harbor, Unalaska**, with an amplitude of 0.1 m. Although the volcano is about 75 km from the coast, the tsunami generated was observed at a number of places around the Pacific. It is uncertain whether the wave was generated near Kamchatka and traveled as a tsunami wave or was generated by air pressure in the vicinity of the gages. (Gorshkov, 1959; Iida et al., 1967; Cox and Pararas-Carayannis, 1976)

1957, March 9, 14:23. A magnitude 8.3 earthquake and tsunami occurred south of the **Andreanof Islands**. There were no casualties. Judging by the size of the area of the epicenters of the many aftershocks, the source of the earthquake was stretched out in an arc for more than 600 km, bounded on the west by Amchitka Pass and on the east by the Unimak Pass.

On **Adak Island**, the earthquake and tsunami caused severe damage. Roads were cracked. Several structures and two bridges were destroyed. According to reports, an 8-m wave was observed in **Sand Bay**. All structures at the fuel and oil dock were washed away up to the 4-m contour, and the oil pipelines were damaged. The rise of water was 2.7 m in **Sweeper Cove** at 15:50, UTC and the peak rise of water was 4 m. Two docks and a concrete mixer were destroyed on **Umnak Island**. On **Unimak Island** near **Scotch Cap**, where the lighthouse was washed out in 1946, a 12 m wave was reported. According to Cox and Pararas-Carayannis, (1976), its height was 15 m, and it may have been due to a local landslide since the travel times were too short to allow it to come from the earthquake epicenter. At **Dutch Harbor, Unalaska,** the wave was recorded with a height of 0.7 m; at **Women's Bay, Kodiak; Juneau**; and **Seward** all with an amplitude of 0.2 m; at **Yakutat Bay** with an amplitude of 0.3 m; and at **Sitka** with an amplitude of 0.4 m. At **Massacre Bay, Attu,** it was 0.6 m. It was recorded elsewhere in Alaska and was observed throughout the Pacific Basin.

Timely warnings disseminated by the Seismic Sea Wave Warning System minimized property damage and prevented loss of life. (Brazee and Cloud, 1959; Salsman, 1959; Cox and Pararas-Carayannis, 1976; Soloviev and Go, 1974, p. 25-30)

1958, July 10, 06:16 There was a magnitude 7.9 earthquake in southern Alaska. Its epicenter was established on the northern coast of Cross Sound, near Palma Bay. Earthquake-induced landslides, submarine slides, and icefalls caused at least six separate tsunamis. The most destruction occurred to the north, at **Lituya Bay** (fig. 38). Expeditions in 1958 and in 1959 determined that the earthquake was caused by the displacement on the Fairweather fault, from Palma Bay in the southeast to Nunatak Fjord in the northwest. The fault lies almost parallel to the Pacific coast, and separates the littoral piedmont zone from the Fairweather Range. The earthquake caused many rock avalanches and slides.

The most catastrophic events, unique in the history of strong earthquakes, occurred in **Lituya Bay**, which is the T-shaped bed of an ancient glacier that has been filled with water. The length of the bay is 11 km, its width at the main external part is up to 3 km, and its maximal depth is about 200 m. The outer part of the bay, separated from the sea by La Chausse Spit, first crosses a coastal plain, then a piedmont. The shores here are

(1958, July 10, continued)

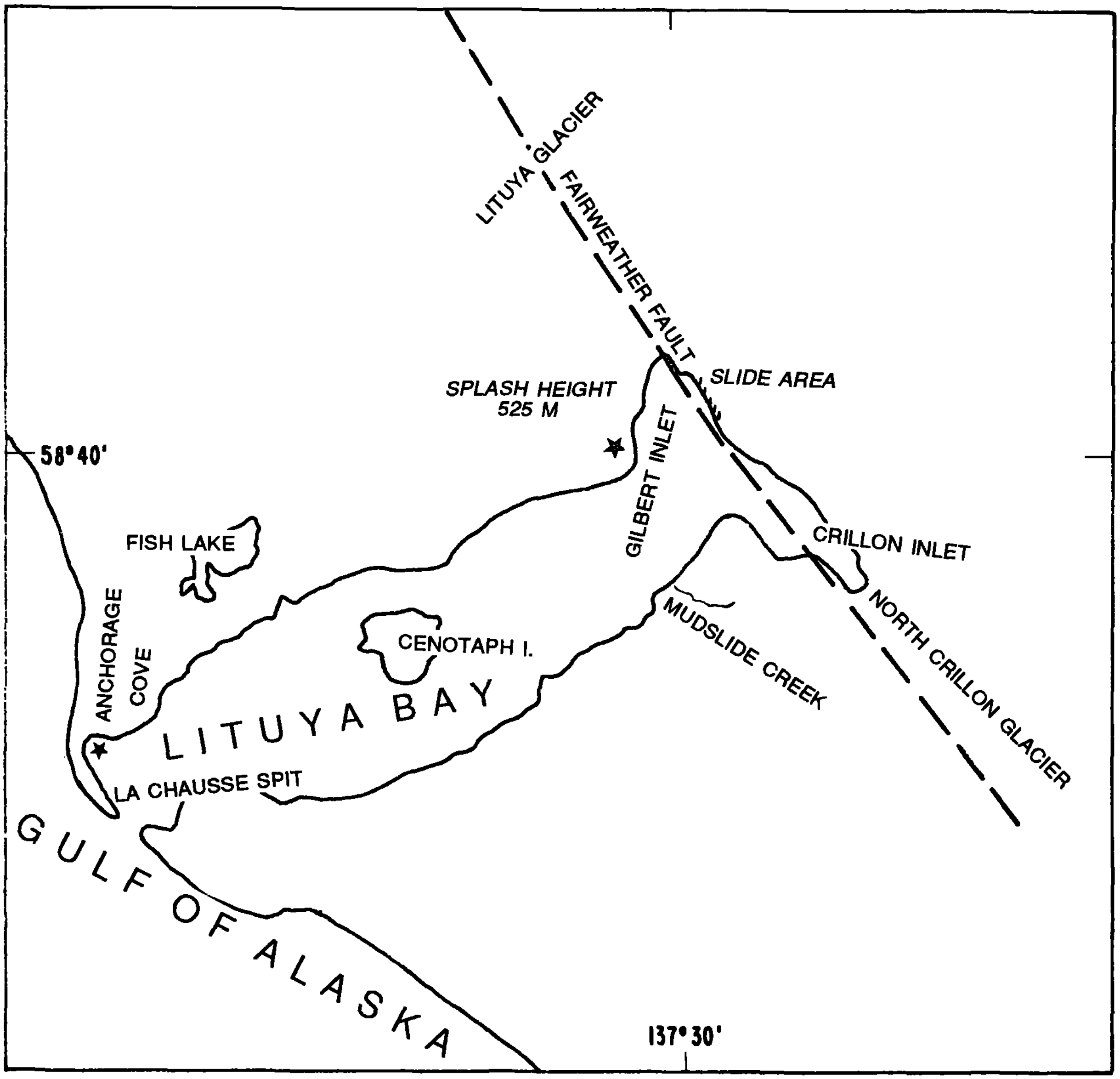


FIGURE 38.—Map of Lituya Bay.

comparatively flat, and until 1958, were covered with dense forest. The inner part of the bay is part of the Fairweather Canyon. Here, the bay is like a fjord, and its steep walls rise to a height of 650 to 1800 m. The depth is greatest in this area. Two large glaciers, the Lituya and North Crillon, lying in the Fairweather Canyon, feed the internal part of the bay on both sides.

At the time of the earthquake ebb tide had begun in the bay, but the water level was still 0.3 m above the mean level. The earthquake caused about 300 million m^3 of rock to collapse into **Gilbert Bay** from the northeast shore. The water was pushed from the bay by the collapsing mass, and surged up on the opposite shore, reaching a colossal height of 525 m. The movement of the water was so fast that it uprooted a whole forest in the

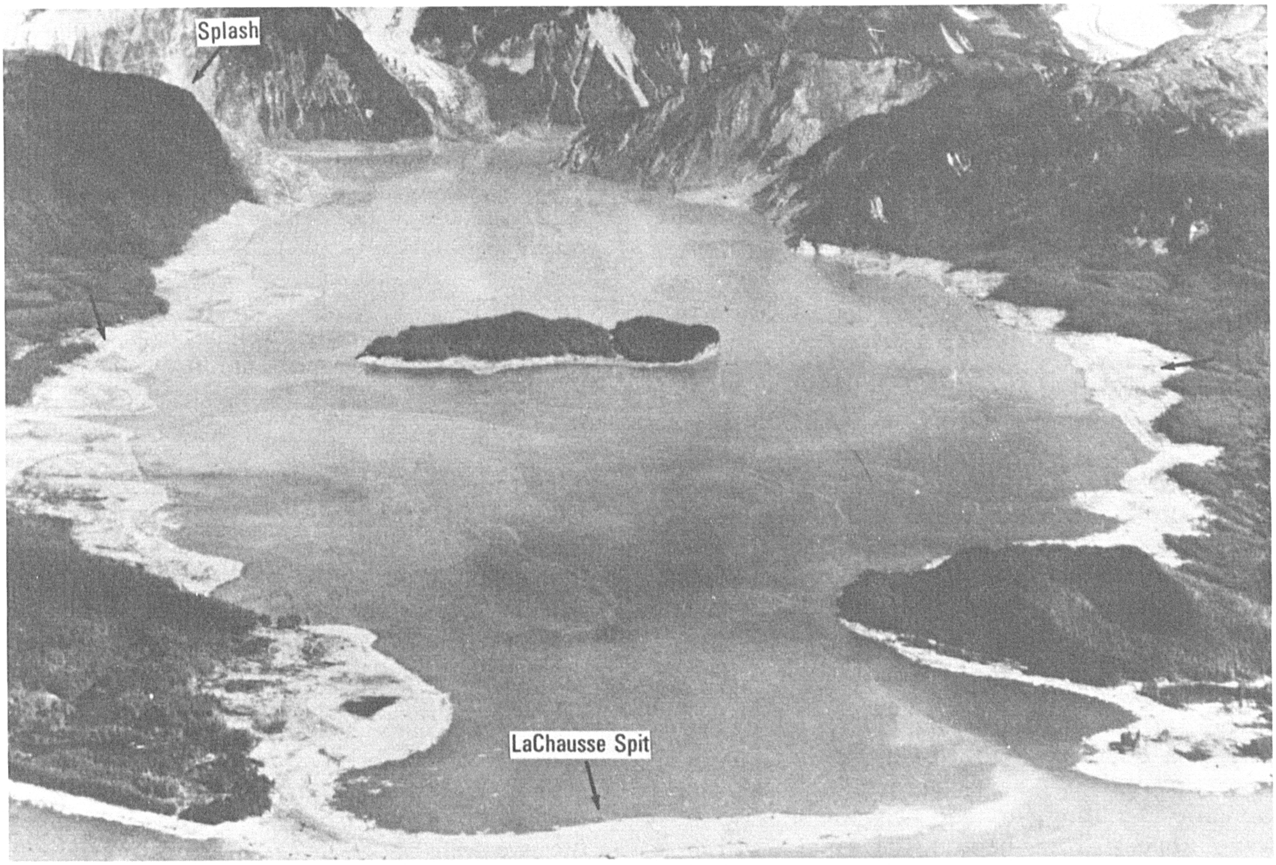


FIGURE 39.—Lituya Bay following the tsunami of July 9, 1958. A rockslide at top left at the head of the bay generated a splash indicated by an arrow. The tsunami cleared trees and left a white rim around the bay. Note Cenotaph Island in the center of the bay with a swath of trees destroyed by the tsunami. Photo Credit: National Oceanic and Atmospheric Administration.

flood zone and stripped the bark and branches from the trees (fig. 39). Besides this gigantic splash, the collapse of this huge mass caused a wave which crossed the entire **Lituya Bay** from **Gilbert Bay** to the sea with a velocity of 150-200 km/hr, (that is, with the speed of gravity waves) and devastated the shores of the **Lituya Bay**. Three fishing launches in the bay were caught by the wave; one of them, the *Sunmore* sank, drowning fishermen Orvile Wagner and his wife Mickey from Idaho Inlet; the other crews were saved. The surviving fishermen gave the following account (Miller, 1960):

Howard G. Ulrich and his 7-year-old son entered **Lituya Bay** at 20:00 on July 9 in the launch *Edrie* and cast anchor at a depth of 9 m in a small inlet off the southern shore. In the evening, Mr. Ulrich was awakened by vigorous rocking of the launch and went out on deck. The launch was being shaken vigorously and tossed up. Collapses were occurring in the mountains at the top of the bay, and avalanches were descending. About 2 1/2 minutes after the earthquake, a deafening crack was heard coming from the top of the bay. Soon after, a wave, like the moving tongue of a glacier, appeared from **Gilbert Bay**. When the wave was between the top of **Lituya Bay** and **Cenotaph Island**, it was like a precipitous wall of water, perhaps 30 m high extending from shore to shore. The wave was breaking as it came around the island, but on the south side it had a smooth, even crest. The wave approached the launch about 2 1/2 to 3

(1958, July 10, continued)
minutes after it was generated. Its front was steep and had a height of 15-20 m. Until the arrival of the wave, no drop in level or any other disturbance was observed, except that the launch vibrated from the continuing earthquake. The wave lifted the launch, and the anchor chain snapped, although it was completely slack. The boat was carried forward, and would have been tossed across the spit, but then a reverse current carried it back to the center of the bay. The width of the wave crest was apparently 7.5-15 m, and its back slope was considerably flatter than the front. After the passage of the gigantic wave, the water surface returned almost to its normal level, but whirlpools and surges arose from one shore to the other. Steep sharp-pointed waves up to 6 m high were observed moving in all directions. The agitation in the bay abated in 25-50 minutes.

Other witnesses, the Swansons, on the launch Badger entered the bay at 21:00 and cast anchor at the northern shore of **Anchorage Bay** at a depth of 7 m. In the evening they were aroused by a strong vibration of the launch. Coming up top, Swanson saw a wave appear from behind the cape, cutting off **Gilbert Bay**, and strike the southern coast of the bay in the region of **Mudslide Creek** where a maximum height of 200 m occurred. As the wave passed **Cenotaph Island**, it cleared trees to a height of about 49 m and rose somewhat toward the shore. The wave passed the island about 2.5 minutes after its appearance and reached the launch in another 1.5 minutes.

Moving on the crest, with the stern forward and sinking in the water, the launch was lifted up and thrown across La Chausse Spit. Immediately behind the spit, in the sea, the crest collapsed, and the launch hit bottom and sank. The Swansons were able to transfer to a small boat and were soon picked up by the fishing trawler *Luman*.

On the morning of the 10th, Don Miller (1960) flew over **Lituya Bay** in a small airplane. **Gilbert** and **Crillon Bay** and the entire inner part of **Lituya Bay**, on a stretch of 4.5 km, were packed with floating ice blocks, and some ice rafts were strewn with rock debris and boulders and all kinds of rubbish. Logs and other vegetation, as well as chunks of ice, floated over the rest of the surface of the bay and in the sea up to a 9-km radius from the entrance to the bay. The absence of ice on the shore, except on the northeast shore of **Gilbert** and **Crillon Inlets**, is a significant indication that the glaciers were not involved in the initial splash or surge of water. (Miller, 1960, p. 59)

It was noted that the tongue of the **Lituya Glacier** had retreated about 400 m and cracked along a stretch of about 100 m. The delta on the northeast side had disappeared and on the southwest side was much smaller. The glaciers appeared to have been "washed" by the waves, but otherwise, the position and shape of the glaciers was not changed.

A fresh scarp, from which rock continued to collapse, was found at the site of the above-mentioned huge slide. The main effect of the wave was the total destruction of vegetation in the littoral belt. On this flight and in subsequent land studies, it was established that the maximal height at which the forest was washed away was 520 m on the western shore of **Gilbert Bay**, directly opposite the collapse. This was due to the initial splash or surge rather than a true tsunami. The maximal width of the devastated zone was 360 m at a height of 32 m near **Fish Lake**. The total area on which forest was washed away was 10 km^2, while the total flooded area was apparently 13 km^2. The soil cover, on the average at least 0.3 m deep, was washed away in the flood zone, that is, a total of at least 30 million m^3 of loose deposits were washed off. All the shellfish colonies in the littoral area were destroyed. The few structures and geodetic markers on the shore were washed away.

The part of the slope of **Gilbert Bay** that split off, according to rough estimates, represents a prism having a triangular cross-section with sides of 914 and 731 m, a maximal thickness of 90 m, and a center of gravity at a height of 609 m. Only 2% of the potential energy of this mass was converted into the energy of the wave that crossed the mouth of **Lituya Bay**. According to the wave model generated in the laboratory, the wave that developed in

Gilbert Bay should have been reflected first from the southern shore of **Lituya Bay** in the region of **Mudslide Creek**, then from the northern shore, and possibly, once again from the southern shore, and then should have passed out to sea.

At **Yakutat Bay** Mrs. Jeanne Walton, President of the Bellingham Canning Company, Mr. Robert Tibbs, a Federal Aviation Administration employee, his wife, and Mr. John Williams, postmaster of Yakutat and his wife had gone to **Turner Point** on **Khantaak Island** about 3 km northwest of **Yakutat** in two boats to pick berries. Sometime after 9:00 P.M. the Williams decided to leave. A few minutes after waving good-by to the remaining party, they noticed the trees swaying. Looking back to where the three had been standing, they saw a wave approaching. The wave was so high they were unable to see the trees on the part of **Khantaak Island** they had just left, which was now 0.8 to 1.6 km behind them. Mr. Williams increased the speed of the boat to a maximum of 40 km/hr attempting to outrun the wave. The wave overtook them before they could cover the remaining distance, but by then it was quite small and harmless.

This was also observed by a resident at **Yakutat** from which an estimate of 4.6 to 6.1 m could be given for the initial height of the wave. The wave was estimated to be 0.9 m at the Bellingham Cannery dock at **Yakutat**, breaking mooring lines there. Two later swells of nearly equal height again tore loose the mooring lines. The three who had remained on Khantaak Island were not found, although their badly damaged boat surfaced. A section of the point about 45 by 320 m had slumped into the water leaving a 1.1 m cliff. The water was 27 m deep over what formerly had been land. A harbor light disappeared, and 36 m of the north end of the island also disappeared. This is a second tsunami generated by the earthquake-induced slumping. Several other independently generated tsunamis are described below.

In **Disenchantment Bay** two men were about 0.4 km from the Turner and Haenke glaciers when their canoe quivered from the earthquake. Then they were tossed for an hour by 6-m waves radiating from the glaciers from where many tons of ice fell into the water. A second party of three was camped onshore between **Haenke** and **Osier Islands**. After the earthquake, two of the men reached their boat and spent several hours riding the swells. The third man tried to save the camping gear, but lost much to 1.5-m waves (Davis and Sanders, 1960).

At **Dry Bay** a collapse at the mouth of the Alsek River caused a wave 1-2 m high that spread upriver.

In **Glacier Bay**, rocks crashed down the steep beaches, resulting in small waves no more than 0.5-1.0 m high. Similar waves were observed in **Dixon Harbor** several minutes after the earthquake.

The tectonic dislocations in the source of the earthquake, and possibly the wave emerging from **Lituya Bay**, caused a small tsunami, which was registered on remote tide gages. Thus, slight, anomalous waves were registered by the tide gage at **Sitka**. These began at 23:25, 70 minutes after the earthquake, with oscillations 0.03 m in height, and they lasted several hours; the maximum amplitude, 0.05 m, was observed at 2:00 A.M. on the 10th; the period of oscillations was 18 minutes. At **Yakutat**, the tide gage registered waves with an amplitude (range ?) of up to 0.20 m and a period of 27 minutes immediately after the earthquake. The Alaska communication system had six cable breaks in the Haines-Skagway area and one at Wrangell probably due to submarine slumping. At Hilo, Hawaii, the tsunami was registered 6.7 hours after the earthquake with an amplitude of 0.10 m and a period of 15 minutes. (Soloviev and Go, 1975, p. 225, 230; Cox and Pararas-Carayannis, 1976; Iida et al., 1967; Roberts, 1961)

1958, November 6, 22:58. A magnitude 8.1 earthquake in the south Kuril Islands produced a tsunami that was recorded at **Massacre Bay, Attu,** with an amplitude of 0.2 m and at **Sweeper Cove, Adak,** with an amplitude of less than 0.1 m. (Cox and Pararas-Carayannis, 1976; Iida et al., 1967)

1958, November 12, 20:23. A magnitude 7.0 earthquake in the south Kuril Islands may have been recorded at **Massacre Bay, Attu,** and **Sweeper Cove, Adak.** The maximum amplitude of 0.2 m at **Attu** and 0.1 m at **Adak** are near the detection threshold, and these are doubtful recordings. (Cox and Pararas-Carayannis, 1976; Brazee and Cloud, 1960; Iida et al., 1967)

1959, May 4, 07:16. A magnitude 8.0 earthquake in the north Kuril Islands was recorded at **Massacre Bay, Attu,** with an amplitude of 0.2 m. (Eppley and Cloud, 1961; Cox and Pararas-Carayannis, 1976; Iida et al., 1967)

1960, May 22, 19:11. The great Chilean earthquake with a magnitude of 8.6 generated a wave that was recorded at **Massacre Bay** (more than 1.7 m), **Sweeper Cove** (1.1 m), **Seward** (0.7 m), **Women's Bay** (0.7 m), **Yakutat** (0.8 m), **Dutch Harbor** (0.7 m), **Sitka** (0.5 m), and **Skagway** (0.2 m). The wave was observed at **Kake, Juneau,** and **Ketchikan.** (Symons and Zetler, 1960; Cox and Pararas-Carayannis, 1976; Iida et al., 1967, Soloviev and Go, 1975, p. 154) Cox and Pararas-Carayannis (1976) reported "some cracking of the ice was noted in the afternoon," but do not give a location. At **Cape Pole** (55.9° N, 133.8° W), a log boom was broken by a strong current associated with this tsunami. The runup there was about 1 m. At **Craig** (55.4° N, 133.1° W), a buoy was moved by the tsunami. (Carte, 1987)

1963, October 13, 05:17. A magnitude 8.1 earthquake in the south Kuril Islands generated a wave at **Massacre Bay, Attu,** with an amplitude of 0.2 m. (Cox and Pararas-Carayannis, 1976; Iida et al., 1967)

1964, March 28, 03:36. The Prince William Sound earthquake (magnitude 8.4) was one of the largest shocks ever recorded on the North American Continent, and it was the most destructive in Alaska's history. The epicenter was located between Crescent Glacier and Unakwik Inlet. This earthquake, in addition to generating a major tsunami of record size along much of the Pacific coast of North America, caused several local tsunamis that were responsible for locally heavy damage in various arms and inlets of **Prince William Sound.** The tsunami caused at least 106 fatalities in Alaska, of which 71 to 82 were due to the local slump-generated tsunamis. The 11 fatalities at **Seward** have been ascribed to the first wave (Cox, 1972) and 13 fatalities were ascribed to the later main tsunami (Grantz et al., 1964). Cox (May 25, 1988) now believes both the slump generated and main tsunamis were probably responsible for the 11 to 13 fatalities. It also generated seiches in rivers, harbors, channels, lakes, and swimming pools as distant as the United States Gulf Coast States. Total tsunami damage amounted to about $84 million in Alaska.

The major tsunami of the Prince William Sound earthquake was generated by broad crustal warping along a northeast-southwest trending hinge line. This hinge line runs roughly parallel to the southeast coast of Kodiak Island; passes across Narrow Cape and seaward of Cape Chiniak; turns north and passes across the eastern portion of the Kenai Peninsula and the western portion of Prince William Sound; swings east in the area of the epicenter; and passes just south of Valdez, terminating near the Copper River. South and east of this hinge zone, an area stretching from Kodiak Island to Kayak Island was uplifted as much as 15.1 m according to United States Coast and Geodetic Survey bathymetric surveys. The seaward limits of the uplifted zone have not been definitely established, but the zone includes most of Prince William Sound and the continental shelf from Kayak Island to Sitkinak Island. The zone of uplift probably includes portions of the continental slope and may extend seaward as far as the Aleutian trench; it is roughly equivalent to the zone of aftershocks. North and west of the hinge line, an area that includes most of Kodiak Island and the Chugach Mountains subsided by amounts up to more than 2.1 m.

The area of generation of the major tsunami is roughly equivalent to the area of uplift. Within the generating area, the complex motion of the water was compounded by waves generated by local slides and, particularly within **Prince William Sound,** by complex local patterns of diffraction, refraction, and reflection.

In many of the harbors and bays along the south and east coast of the Kenai Peninsula and the northern shore of Prince William Sound, subaqueous landslides occurred and generated highly destructive local waves. The principal destructive local waves occurred at **Seward**, **Valdez**, and **Whittier** (fig. 40, 41).

FIGURE 40.—Surge wave left 2 x 12-inch (52 x 31-cm) plank in tire at Whittier, March, 1964. Photo Credit: U.S. Geological Survey.

Living spruce trees up to 24 inches (60.9 cm) in diameter and between 88 and 101 feet (26.7-30.6 m) above sea level were broken and splintered near Shoup Bay by the surge-wave generated by an underwater landslide in **Port Valdez** (fig. 41).

FIGURE 41.—Sruce trees splintered near Shoup Bay by the surge-wave generated by an underwater landslide in Port Valdez, Prince William Sound, March 28, 1964. Photo Credit: U.S. Geological Survey.

At Seward, a community of about 2,300 population, a section of the waterfront about 1070 m long and as much as 91 m wide, including all waterfront facilities from the Standard Oil Company dock north to the San Juan dock, slid into Resurrection Bay shortly after the earthquake started and while the shaking was still intense. The slide drew water out from the shoreline and created one or two boil-like disturbances at distances estimated from less than 0.1 km to perhaps 0.8 km from the shore; waves spread from these disturbances in all directions. Oil from waterfront fuel storage tanks that had been ruptured by the earthquake immediately ignited, and the waves spread fire along the waterfront.

The ground that slid into Resurrection Bay was water-soaked alluvium having an offshore slope of 30° to 35°. The wave generated by the slide caused much damage to the railroad yards (Grantz et al., 1964). About 20 minutes later, a wave reached a maximum height of about 9 m at **Lowell Point**. This wave, the first of the major tsunami series, struck **Seward**, destroying the Alaska Railroad docks, washing out railroad and highway bridges, and piling railroad rolling stock into giant windrows of wreckage (fig. 42). It spread flaming petroleum over the waterfront, igniting the rolling stock, the electrical generation plant, and some residences. This wave also swept many dwellings from the area of the small boat harbor, and washed boats into the lagoon north of **Seward** (fig. 43) and onto the tidal flats at the head of **Resurrection Bay** (fig. 44). The 11 to 13 fatalities at **Seward** were probably caused by both the local tsunami and the main tsunami. (Cox, May, 1988)

(1964, March 28, continued)

FIGURE 42.—Damage to port facilities and rail yards at Seward resulting from the March 28, 1964, tsunami. Photo credit: National Oceanic and Atmospheric Administration.

Local waves were generated by slides in two separate areas of **Port Valdez**: one at the town of **Valdez** having a population of about 1,200 and the other near the mouth of Shoup Bay. The wave generated near Shoup Bay by large submarine slides of portions of the terminal moraine of Shoup Glacier that occupies the mouth of the bay, deposited driftwood at an elevation of 51.5 m above lower low water near the site of the Cliff Mine, and splashed silt and sand as much as 67 m above lower low water at the same place (Plafker and Mayo, 1965). Waves from this source washed the Middle Rock Light in

FIGURE 43.—March 28, 1964, tsunami damage at Seward showing overturned ships and torn-up dock strewn with logs and scrap metal. Photo Credit: National Oceanic and Atmospheric Administration.

FIGURE 44.—Damage at the north end of Resurrection Bay near Seward from March 28, 1964, tsunami. Note boat surrounded by logs and other debris. Photo Credit: U.S. Department of the Interior.

Valdez Inlet off the 10.7-m reinforced concrete pedestal on which it was mounted. It also accounted for one fatality and a cabin being swept away at Anderson Bay directly opposite Shoup Bay.

The town of Valdez (fig. 45) was situated on the edge of an outwash delta consisting of unconsolidated silty sand and gravel. This delta lies at the head of the deep, steep-sided fjord of Port Valdez. Before the earthquake, the offshore slope of the delta face was about 15°. During the earthquake, the shaking caused failure of the unstable, water-saturated material, and a slice, about 1220 m long and 183 m wide, slid into the sea and carried the dock area and portions of the town with it. The slide generated a wave that slammed into the waterfront within 2 to 3 minutes of the onset of the earthquake. In a report to the owners, the captain of the SS *Chena*, which was unloading cargo at the **Valdez** dock at the time of the earthquake, stated that his ship was raised about 9.1 m and heeled over 50° to 70° by the first wave. This wave demolished what was left of the waterfront facilities, caused the loss of the fishing fleet, and penetrated about 2 blocks into the town. Thirty-two people lost their lives in the slide and the subsequent waves. This death toll includes three on board the SS *Chena*, one of whom died of a heart attack and two killed by falling cargo. The crew watched 28 men, women, and children struggle in vain to get off the collapsing dock. According to Cox (in Weller, 1972) only one of all the fatalities

FIGURE 45.—Aerial view of Valdez coastline following tsunami of March, 1964. Photo Credit: U.S. Department of the Interior.

could have been saved--a resident who had left **Valdez** in a small boat after the first wave. The whole town subsided owing to compaction of the soil. Water Street subsided 2.7 m. Heavy trucks were washed inland, and boats were beached. As at Seward fires broke out at the tank farm located near the shore (fig. 46).

FIGURE 46.—Tank fire at the Union Oil tank farm, Valdez, Alaska, following tsunami of March 28, 1964. Photo Credit: Earthquake Engineering Research Institute.

Slides of unconsolidated water-soaked alluvium around the head of Passage Canal generated waves that destroyed much of the **Whittier** waterfront before the earthquake ended. According to witnesses, three waves struck **Whittier**, the second one causing most of the damage. One of the waves, probably the one that caused the major damage in **Whittier**, reached a height of 31.7 m above mean lower low water on the shore opposite **Whittier** at Passage Canal. The waves destroyed two saw mills; the Union Oil Company tank farm, wharf, and buildings; the Alaska Railroad depot; many frame dwellings; and the railroad ramp handling towers at the Army pier. They also caused severe damage to the small boat harbor. As at **Seward** and **Valdez**, fire broke out at the tank farm and contributed to the destruction. The tsunami killed 12 people directly at **Whittier**, a community of 70 people. An indirect victim, a baby washed from its mother's arms, was later found alive in a snow bank. It died shortly thereafter, and is counted here in the overall total. The locally generated waves dissipated, the tsunami did not reach above the extreme high water line. A wave generated by an underwater landslide near Whittier in **Blackstone Bay** produced a large wave that surged to 24.2 m.

Major waves were noted at other localities within **Prince William Sound** minutes after the earthquake. Although the wave action at some of these places may have been generated locally, it is probable that most of he disturbances noted were caused by the tectonic warping and were part of the major tsunami. Because of the many islands, inlets, and passages in western **Prince William Sound**, the waves built to great heights and caused much damage in many places. At **Chenega**, a village of 76 people, 23 people were killed, 19 of 20 houses were washed away, and the water reached a school, which was located 27.4 m above sea level. At **Port Nellie Juan**, the dock was destroyed, and three lives were lost. In this general area, maximum heights reached by the tsunami ranged from 15 to 21 m, although the maximum at **Port Nellie Juan** was much lower. At **Port Nowell**, a wave that reached about 12 m above sea level washed away two cabins and killed their owner. **Port Ashton**

(March 28, 1964, continued)
sustained little damage, although one person was drowned.

In many **Prince William Sound** localities, the water reached the highest level close to the time of high tide, which occurred between 10:00 and 11:00 UTC. At **Cordova**, the tsunami caused extensive damage to the docks and floated away some houses near the waterfront. Here, the maximum height reached by the tsunami was about 6.1 m. At **Port Whitshed**, near **Cordova**, 10 cabins were washed away; one person, who had returned to his cabin believing the danger had ended, was drowned. (Spaeth and Berkman, 1972, p. 224, 228) At **Craig**, the runup was 0.3 m above high water (highest runup was 2.4 m at 10:09 UTC). Since the tsunami arrived near the time of low tide, no flooding occurred. There was a strong wind with the highest wave (4.9 m) at 11:00 P. M. A 4.8-m runup was noted at a camp site near **Craig**.

At the **Cape St. Elias Lighthouse**, a member of the United States Coast Guard was drowned by the initial wave, and the other three men stationed there barely escaped. The Coast Guardsman had been photographing sea lions when the earthquake triggered a rockfall that broke his leg. The other crewmen were attempting to carry him back to the base when the tsunami struck about 40 minutes after the earthquake. Beyond Cape St. Elias, damage in Alaska was limited to the following: the loss of three houses at **Klawak** when drifting logs knocked their pilings out; a barge in the northeast section of **Meares Passage** (55.3° N, 133.2° W) that was first beached allowing the crew to escape before being carried back to sea and cracked in half; (Carte, 1987); a dock which collapsed at **Sitka**, and minor disruptions of floats and log rafts at the logging camps in the **Ketchikan** area. The Big Salt Lake northeast of **Klawak** was flooded. (Carte, 1987) The nearest tide gage to the epicenter to survive the tsunami was at **Yakutat Bay**. It recorded a maximum rise of 1.2 m beginning at 10:07 UTC, near the time of the predicted high tide. The **Sitka** tide gage recorded a 2.4-m rise on the second wave of the tsunami beginning at 06:24 UTC.

Outside the **Prince William Sound** area and **Seward**, the only Alaskan area to sustain heavy tsunami damage was the **Kodiak Island** group.

The Alaska Peninsula and the Aleutian Islands were shielded by the **Kodiak Island** group from the direct action of the tsunami. In **Shelikof Strait**, as in **Cook Inlet**, maximum amplitudes were on the order of 1.5 m. Maximum amplitude in the **Aleutian Islands**, as recorded on tide gages, was under 1 m.

The city of Kodiak and Kodiak Naval Station were the only places in Alaska that received warning of the tsunami. The United States Fleet Weather Central at Kodiak Naval Station, which participates in the Seismic Sea Wave Warning System by maintaining a tide station and by serving as a dissemination agency, provided this local warning.

The earthquake, strongly felt at the Fleet Weather Central, put the tide gage and all communication circuits available (except telephone), out of commission, and caused damage to hangars.

There was not sufficient time for the Pacific Tsunami Warning System to issue effective warnings in Alaska, a fact that led to the establishment of the Alaskan Regional Tsunami Warning System in 1967. Locally generated warnings of several types were effective in reducing the fatalities.

At 04:10 UTC after a report of a 9.1-m tsunami was broadcast from an Air Force installation at Cape Chiniak, the Commanding Officer of the Fleet Weather Central, failing to reach the Naval Station Officer of the Day, called the Armed Forces Radio Station to broadcast a warning. The broadcast resulted in an smooth, orderly, prompt, and complete evacuation of the Naval Station and Federal Aviation Agency personnel on Woody Island. Reports indicate that the evacuation of the city of Kodiak, which also heard the broadcast, was reasonably prompt, but it was not as complete or as well carried out. This difference was undoubtedly due to the emergency procedures that had been prepared in advance for the Naval Station. Sirens were sounded in **Kodiak**, and police cruisers patrolled the lower parts of the city giving out warnings. People were slow to respond to the warnings, and many were caught by the first wave. Fortunately, the first wave was not violent, and all were able to walk out of the area. Despite repeated warnings of subsequent waves many fishermen stayed in the harbor area trying to save their boats. Some succeeded and were able to ride out the later waves. Most of the 15 fatalities at **Kodiak** and nearby **Spruce Cape** and **Kalsin Bay** were among fishermen trying to save their boats.

About 10 minutes after the warning was issued, the tsunami, similar in appearance to a swiftly rising flood, arrived at the Fleet Weather Central. By 04:35 UTC, the first wave had crested at 6.7 m above the tide staff zero, giving a rise of about 4.8 m on the first wave. The highest crest in the tsunami reached about 9 m above the tide staff zero, and the maximum range (crest to trough) was about 10.6 m.

The personnel at Fleet Weather Central continued to supply information of the tsunami to the Honolulu Observatory under extreme handicap. With all radio circuits in the tower building inoperative, a telephone message was passed to a remote Navy radio station for relay via Naval Communication Station San Francisco, giving information on the first crest. At 04:47 UTC, all electric power in the tower was lost, owing to flooding of the main power station. Auxiliary power was supplied at 05:03 UTC, and an additional message was sent to the Honolulu Observatory, giving more detail on the first wave. Since there was doubt about the delivery of the first two messages, a third message was sent over Coast Guard circuits at 07:26 UTC, shortly after the Coast Guard Radio Station NOJ, located in the tower building, returned to operation and contacted Ketchikan. This message gave details on crest heights and arrival times.

The **Kodiak Naval Station** sustained heavy damage from the tsunami and minor damage from the earthquake. Estimates of about $10 million tsunami damage by Public Works, Kodiak Naval Station (Tudor, 1964) include complete destruction of the cargo dock and heavy damage to roads and bridges, the central power plant and the Holiday Beach generator, the microwave installation, the runway ends and shoulders, the marginal pier, the public works maintenance shop, the hobby shop, and the bowling alley. Because of the warning, there were no military fatalities or serious injuries.

The tsunami caused 19 deaths in and near the city of **Kodiak**. These included 8 dead at **Kodiak**, 3 at **Kaguyak**, 6 at **Kalsin Bay**, 1 at **Old Harbor**, and 1 at **Spruce Cape** (Lowell, 1965). The low-lying areas of the **Kodiak** waterfront suffered extreme damage (fig. 47). All float docks in the area that were protected by breakwaters were broken up and cast ashore or were washed away. All wharves and piers on the waterfront were destroyed, except for the City dock. A preliminary Civil Defense survey listed 58 structures in a 5-block section of the business district as demolished or so badly damaged as to make demolition necessary. Seven more structures in the same 5-block area were so badly damaged as to make their salvage questionable, and an additional 23 were damaged. Overall, Civil Defense estimated damage to **Kodiak** at $31,279,000 (Tudor, 1964). This includes damage of $2,165,000 to harbor facilities: $19,346,000 to business and industry; $5,400,000 to public property; $2,440,000 to the fishing fleet, and $1,928,000 to dwellings. Commander Alfred Stroh, Civil Engineer Corps, United States Navy, reported 158 dwellings destroyed and 20 severely damaged (Stroh, 1964). The Alaska Division of Public Health (Preliminary Report of Earthquake Damage to Environmental Health Facilities and Services in Alaska, 1964) lists 71 business firms that were heavily damaged or destroyed.

The city of **Kodiak** was fortunate in that it had about 30 minutes of warning before the arrival of the first crest. The first wave was a gentle flood followed by a gradual ebb. The second wave advanced as a cresting 9.1-m wall of water that thundered through the channel and pushed 45 to 90 metric ton boats over the breakwater as far as three blocks into the city.

Small villages in the area also sustained heavy damage. The nine houses and the Russian Orthodox Church that comprised

(March 28, 1964, continued)

FIGURE 47.—Damage at Kodiak from March 28, 1964 tsunami. Photo Credit: National Oceanic and Atmospheric Administration.

Kaguyak were swept away. After the earthquake the natives were alert for a possible tsunami. On seeing a swell approach, they shouted warnings to each other. Since the first wave was a slow rise of water, all were able to escape. The second wave was also rather gentle. Lulled into a false sense of safety, some people returned to their boats and houses. The fourth wave was 9 to 12 m, and three people of a total population of 45 were drowned.

All of the 35 houses in **Old Harbor** were floated from their foundations; however, 6 or 7 probably were salvageable. The old school and the new school sustained minor damage, and the church was undamaged. The 200 residents were alerted by the earthquake and short-wave radio to expect a tsunami. The last of the people evacuated after the second wave, and the third and fourth waves were the most destructive. The single fatality occurred on nearby **Sitkalidak Island**.

Ouzinkie had 5 houses, a grocery store, and a cannery destroyed. The natives had evacuated to higher land after noticing that the water offshore was acting strangely.

At **Afognak**, 4 houses, the community hall, and a grocery were washed away and destroyed. Several other houses moved on their foundations, and most of the 26 automobiles in the town sustained water damage. The residents had heeded radio warnings and the early wave activity and spent the night on higher ground. (Spaeth and Berkman, 1972, p. 38-110; Iida et al., 1967; Cox and Pararas-Carayannis, 1976; Soloviev and Go, 1974, p. 34)

At **Homer**, waves were observed within 5 to 10 minutes after the earthquake arriving from both the **Cook Inlet** and **Kachemak Bay** side. Their early arrival would have to have been from a locally generated tsunami although the source has not been determined. The first wave from the **Cook Inlet** side was 2.7 m high, and the water withdrew before the main crest. Inside **Kachemak Bay** waves were formed while the earthquake was in progress. A series of 14 waves were observed having a height of up to 1.2 m. Waves were observed on the south shore of **Kachemak Bay** at **Peterson Bay** where the "tide" came and went for at least 15 hours. A 9.0-m wave hit **Perl Island**, 54 km south of Seldovia, at 8:40 P.M. Some damage to the harbor at **Seldovia** was caused by an 11:15 P.M. wave estimated at 1.2 m above high tide. **Halibut Cove**, due east of the Homer Spit, reported a 7.2 m-wave at 11:35 P. M. At **Homer**, a 6-m wave washed over the base of the spit and covered the floor of the new Porpoise Room Restaurant. The water rose to a height of 1.2 m in the Salty Dawg Saloon. It also covered the floor of the Land's End Hotel (Waller, 1971; von Huene and Cox, 1972)

It is noteworthy that most (71 to 81) of the fatalities occurred due to locally generated submarine landslide tsunamis which gave the victims little or no chance to take evasive action and that almost all of the remainder lost their lives trying to save a boat or personal property during recessions between waves.

1965, February 4, 05:01. A magnitude 8.2 earthquake in the Rat Islands, Aleutian Islands, caused a tsunami that was observed in Hawaii, Japan and elsewhere in the Pacific as well as Alaska. At **Sweeper Cove** on **Adak Island**, the sea level fell 0.4 m in 15 minutes. At **Massacre Bay** on **Attu Island**, the level rose 1.6 m relative to the normal position. It was recorded with an amplitude of less than 0.1 m at **Sitka** and 0.1 m at **Dutch Harbor**.

On the southern coast of **Shemya Island**, the height of rise of the water was estimated at 10.7 m. Here, the warehouse was flooded, and a part of the coastal road was washed out. Slight damage from the tsunami was reported from **Amchitka Island**.

Hwang et al. (1972), surmising an instantaneous ellipsoid elevation of the bottom at the source of the earthquake, calculated the spread of the resulting tsunami over the Pacific Ocean. A distinct radiation pattern followed a line orthogonal to the Aleutian arc, passing between Japan and the Hawaiian Islands. (Soloviev and Go, 1974, p.31; Cox and Pararas-Carayannis, 1976; Von Hake and Cloud, 1967)

1965, March 30, 02:27. A 7.4 magnitude earthquake, felt on Amchitka and Adak Islands, caused a tsunami registered by tide gages on **Attu Island** with an amplitude of 0.1 m. (Von Hake and Cloud, 1967; Cox and Pararas-Carayannis, 1976; Soloviev and Go, 1974 , p.31)

1965, July 2, 20:59. A magnitude 6.5 earthquake on Umnak Island caused a tsunami with an amplitude of <0.1 m on **Unalaska Island**. (Soloviev and Go, 1974, p.31; Cox and Pararas-Carayannis, 1976; von Hake and Cloud, 1967)

1966, October 17, 21:42. A magnitude 8.0 earthquake in Peru generated a tsunami that was recorded at **Snug Harbor, Kenai; Massacre Bay, Attu; Kodiak;** and **Sweeper Cove, Adak**, all with an amplitude of less than 0.1 m. (Cox and Pararas-Carayannis, 1976; von Hake and Cloud, 1968; Soloviev and Go, 1975, p. 158; Iida et al., 1967).

1968, April 1, 00:42. A 7.5 magnitude earthquake in Bungo Strait, Japan, produced a tsunami recorded at **Attu** with an amplitude of <0.1 m. (Cox and Pararas-Carayannis, 1976; Coffman and Cloud, 1970)

1968, May 16, 00:49. A magnitude 7.9 earthquake off the east coast of Honshu, Japan, produced a tsunami with 0.2-m height at **Attu**, and <0.1 m at **Adak, Dutch Harbor, Unalaska** and **Sitka**. (Cox and Pararas-Carayannis, 1976; Coffman and Cloud, 1970)

1968, August 1, 20:19. A magnitude 7.3 earthquake on Luzon in the Philippine Islands generated a <0.1-m tsunami at **Attu, Alaska.** (Soloviev and Go, 1974, p. 224; Cox and Pararas-Carayannis, 1976)

1969, August 11, 21:27. A magnitude 7.8 earthquake in the Hokkaido, Japan-Kuril Islands region, generated a 0.1-m tsunami at **Attu, Alaska**. (Cox and Pararas-Carayannis, 1976; von Hake and Cloud, 1971)

1969, November 22, 23:10. A magnitude 7.3 earthquake near the east coast of Kamchatka generated a 1.1-m tsunami at **Attu**, a 0.9-m tsunami at **Shemya**, and a 0.3-m tsunami at **Adak, Alaska.** (Cox and Pararas-Carayannis, 1976; von Hake and Cloud, 1971; Soloviev et al., 1986)

1971, May 2, 06:08. A magnitude 6.8 earthquake in the Andreanof Islands, Aleutian Islands, produced a 0.03 m wave at **Adak, Alaska**. (Cox and Pararas-Carayannis, 1976; Coffman and von Hake, 1973)

1971, July 14, 06:11. A magnitude 7.9 earthquake in New Ireland produced a 0.03-m wave at **Attu, Alaska.** (Cox and Pararas-Carayannis, 1976; Coffman and von Hake, 1973; Soloviev et al., 1986)

1971, July 26, 01:23. A magnitude 7.9 earthquake in New Ireland produced a 0.03-m wave at **Adak** and at **Attu, Alaska.** (Cox and Pararas-Carayannis, 1976; Coffman and von Hake, 1973)

1971, November 6, 12:00. The underground nuclear explosion "Cannikin" on Amchitka produced 0.1-m waves at **Square Bay** and 0.05-m waves at **Constantine Harbor**, both on the north shore of **Amchitka**. These bays have natural periods of about 20 minutes, and the explosion excited these natural periods beginning about 6 and 10 minutes, respectively, after the explosion. The energy appeared to be trapped as edge waves on the shelf, since they were not recorded on the south side of the island nor at Rat Island about 110 km away nor on deep water gages. (Olsen et al., 1972)

1971, December 15, 08:30. A magnitude 7.8 earthquake off the east coast of Kamchatka generated a 0.03-m wave at **Adak**, a 0.09-m wave at **Attu**, a 0.09-m wave at **Shemya**, and a <0.01-m wave at **Unalaska**. (Cox and Pararas-Carayannis, 1976; Coffman and von Hake, 1973)

1972, July 30, 21:45. A magnitude 7.6 earthquake in southeast Alaska produced a 0.1-m wave at **Juneau** and a 0.08-m wave at **Sitka, Alaska.** (Cox and Pararas-Carayannis, 1976; Coffman and von Hake, 1974)

1973, February 28, 06:38. A 7.2 magnitude earthquake in the Kuril Islands generated a tsunami that reached a maximum height of 1.5 m on Shumshu Island. There is evidence of this tsunami on the **Attu, Alaska**, tide record with a maximum amplitude of 0.1 m and on the **Shemya, Alaska**, record with a maximum amplitude of 0.08 m. (Coffman and von Hake, 1975; Cox and Pararas-Carayannis, 1976; Soloviev et al., 1986)

1973, June 17, 03:55. A magnitude 7.4 earthquake on Hokkaido, Japan, produced a 0.06-m wave at **Attu, Alaska.** (Cox and Pararas-Carayannis, 1976; Coffman and von Hake, 1975)

1975, June 10, 13:47. A Kuril Islands magnitude 7.0 earthquake generated a tsunami that was possibly recorded at **Sitka** and **Adak** with an amplitude (zero to peak) of 0.03 m. This value may actually be the tsunami range (twice the amplitude; peak to trough), as tsunami range is the unit most commonly reported in *United States Earthquakes*. (Coffman and Stover, 1977)

1975, November 29, 14:48. The magnitude 7.2 Hawaiian earthquake that generated a locally damaging tsunami also produced a measurable amplitude of 0.05 m in **Yakutat**, and 0.1 m in **Sitka**. (Coffman and Stover, 1977; Tilling, et al., 1976; Cox and Morgan, 1977)

1979, February 28, 21:27. A magnitude 7.1 earthquake in southeastern Alaska generated a 0.15-m wave at **Yakutat**. An amplitude of 30 cm is reported in *United States Earthquakes*, 1979, but this is believed to be the range. (Stover and von Hake, 1981)

1985, March 3, 22:47. A magnitude 7.8 earthquake near the coast of central Chile produced a tsunami that was widely recorded around the Pacific. It was recorded in Alaska with wave heights of 0.08 m at **Sand Point, Shumagin Island**; 0.06 m at **Adak**, 0.03 m at **Seward**, 0.02 m at **Kodiak**, and observed at **Yakutat**. (International Tsunami Information Center, 1985)

1986, May 7, 22:47. A magnitude 7.6 earthquake caused minor damage on Adak and Atka and generated a small tsunami that was widely recorded throughout the Pacific. In Alaska it had an amplitude of 0.35 to 0.88 m at **Adak**, 0.05 to 0.12 m at **Unalaska**, and 0.05 m at **Sand Point**. (International Tsunami Information Center, 1986)

1987, November 17, 08:47. A magnitude 6.9 earthquake in the Gulf of Alaska produced a wave of <0.1 m at **Yakutat**. (Carte, 1987; Preliminary Determination of Epicenters, Monthly Listing, November, 1987)

1987, November 30, 19:23. A magnitude 7.6 earthquake about 75 km south of Cape Yakataga in the Pacific plate produced a tsunami observed at **Yakutat** where boats slowly rose and fell without damage. It was recorded at **Yakutat** with a maximum amplitude of 0.5 m and at **Sitka** with an amplitude of 0.1 m. It was recorded at **Seward**, but intermittent power outages made it impossible to determine the amplitude. (Carte, 1987; Preliminary Determination of Epicenters, Monthly Listing, November, 1987)

1988, March 6, 22:36. A magnitude 7.6 earthquake in the Gulf of Alaska caused a seaquake which caused $5,000 damage to the ships *Exxon Boston* and *Exxon New Orleans* located at 57° 38' N and 142° 45' W. It generated a tsunami with amplitudes of 0.19 m at **Yakutat**, 0.06 m at **Sitka** and 0.04 m at **Kodiak**. (Preliminary Determination of Epicenters, March, 1988)

(Alaska tables begin on next page.)

TABLE 4. TSUNAMI DATA FOR ALASKA

ORIGIN DATA: DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	TSUNAMI DATA: MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOT-ION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1788 07 21	54.0N	Gulf of Alaska	4	E	3.0	Alaska Peninsula	OBS					Effects uncertain.
	160.0W				4.0	Pavlof Vilage, Kodiak	OBS					
	8.0					Sanak Island	OBS					Waves pass over the island drowning swine.
						Three Saints Bay, Kodiak	OBS					Ship cast on shore, several huts destroyed.
						Unga Island, Shumagin Is.	OBS					Water rose 117 m (?) and many natives drowned.
1788 07 27		Gulf of Alaska				Sanak Island	OBS					Julian date uncorrected for international date line effect for 8/06 event below.
1788 08 06		Gulf of Alaska	2	E		Unga Island						The effects reported for this location given above for 07-21 event are also associated with this date as a possible second earthquake and tsunami.
1792		Gulf of Alaska				Three Saints Bay	OBS					Agitated and anomalous waves following strong earthquake.
1796 05 19		E. Aleutian Islands		V		Unimak Island						Erroneous report of a tsunami accompanying eruption of Bogoslof volcano.
1820 03 01		E. Aleutian Islands	2	V&T	0.5	Umnak Island						Eruption of Pogromni volcano caused highly disturbed sea. Probably not a tsunami.
1824-25	54.8N 164.0W	E. Aleutian Islands	2	V	0.5	Unimak Island						Eruption of Shishaldin volcano caused sea to be agitated until fall. Presumably, underwater explosion carried rubble 4 km inland.
1827 08 08		Alaskan Peninsula				Chernabura Island						Some swine reportedly drowned, probably a confused entry for an earthquake in Komandoski Is. and the eruption on Kamchatka in 1827 and the swine drowning of 1788.
1845 Summer		Yakutat, Alaska	3	L	3.0	Yakutat Bay	OBS					"100" natives perished near Haenke I. Date uncertain. Possible erroneous date for 1853-54.
1853-1854		Lituya Bay, Alaska	3	L	4.0	Lituya Bay	120.0					Tsunami in bay cleared trees to a height of 120 m. The people in 8 canoes reportedly perished at Lituya Bay. The report of many drowned at Dry Bay between 1850 and 1860 is probably associated with this tsunami.
1854 01 15		Aleutian Islands	1	E								Erroneous date (Julian) for 01 27 tsunami.
1854 01 27		Gulf of Alaska		E		St. Pauls Harbor	OBS	03.0	R			Water in harbor advanced and receded. Possibly associated with 1853-54 above. (See also Hawaii section.)
1856 07 26		E. Aleutian Islands	1	V		Unimak Island	OBS					Submarine volcanic eruption. Water agitated.
1868 05 15		Alaskan Peninsula	3	E	2.5	Unga Island	OBS					Water agitated.
1868 08 14	01:30 18.6S 71.0W (PAL) 8.5	N. Chile	4	E	4.3 3.5	Kodiak Island	OBS				22.0	Recorded on tide gage. Earlier great earthquake and tsunami on August 13 at 21:30 not mentioned. (See also West Coast, Hawaii, and Samoa sections.)
1872 08 23	18:02 52.0N 170.0W (Cox)	Fox Is., Aleutian Is.	4									Observed on West Coast and Hawaii, not reported in Alaska. (See also Hawaii and West Coast.)
1874		Lituya Bay, Alaska	3	L	4.0	Lituya Bay	24.0					Washing and flooding.

ORIGIN DATA					TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOTION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1878 08 29	53.6N 166.4W	E. Aleutian Islands	3	E	1.0 1.5	Makushin, Unalaska	OBS					Village destroyed by earthquake and tsunami.
1880 09 29	04:00 55.8N 155.6W 6.3 (DNAG)	Alaskan Peninsula	1	E		Chirikof Island	OBS					Water inundated land 55 m at low tide.
1880 10 26	22:20 57.0N 136.0W 6.3 (DNAG)	S. Alaska	3	E		Whale Bay	OBS		R			Huge wave ran into bay.
						Redoubt Lake, Baranof Is.	1.8					
1883 08 27	02:59 6.7S 105.4E	S. Java Sea (Krakatau)	4	V	4.5	Kodiak Is.	0.1					Atmospheric pressure wave from Krakatau eruption generated small water waves recorded on tide gage. This is not considered to be a true tsunami. (See also Hawaii and West Coast)
1883 10 06	59.4N 153.4W	Alaskan Peninsula	4	V	3.0 3.0	Augustine Island						Volcanic eruption generated tsunami.
						Kodiak Island	OBS					
						Port Graham	9.1	05.0	R		00.4	Flooded houses and ships run aground.
1899 09 04	00:22 60.0N 142.0W (DNAG) 7.9 (Abe)	Gulf of Alaska	3	E		Cape Yakataga	OBS		F			Tide from shore pulled ship to limit of anchor chain.
						Yakutat	OBS		F			Water ran out of bay below lowest tide and returned as a swell flooding an Indian village.
1899 09 10	21:40 60.0N 140.0W (DNAG) 8.9 (Abe) 25	Gulf of Alaska	4	E&L	3.0	Katalla, Controller Bay	1.2					Probably a slump-generated wave.
						Lituya Bay	60.0					Local tsunami, date not certain. Native village and saltery destroyed.
						Logan Coast	12.0					Mature trees uprooted to a height of 12 m.
						Russell Fjord	18.0		R			Eight prospectors narrowly escaped local tsunami caused by collapse of glacier.
						Valdez	2.0					Local tsunami.
						Yakutat	1.5	08.0				Water became agitated.
						W. shore Yakutat Bay	9.0	08.0				Water inundated 1/2 km.
						Yakutat Bay	3.0					Sawmill damaged, huts flooded. Part of Khantaak Island with Indian graveyard slid into the bay.
1901 12 31	09:03 51.4N 171.0W (DNAG) 7.1 (Abe)	Kenai, Cook Inlet	1	V&E		Kenai						Several waves causing much damage reported, but reports confused.
1905 07 04	59.5N 139.8W	S. Alaska	4	L		Disenchantment Bay	35.0					Fallen Glacier collapsed. Loose deposits and bushes cleared off the land.
						Russell Fjord	6.0					
1907 09 24	12:58 5.5 (S&G)	S. Alaska	2	E		Haines	OBS					Small temporary change in water level noted.
1908 02 14	11:25 61.0N 146.2W (EQH) 6.0	Gulf of Alaska	1	E		Valdez	OBS					Steamer rocked. Submarine cable cut and buried. Not noticed at Valdez dock.
1911 09 22	05:01 60.5N 149.0W 6.9 (DNAG)	Gulf of Alaska	1	E	0.5	Port Wells (Bay)	OBS					Landslides into the bay, water agitated, fish killed. Cables cut and buried. Doubtful tsunami.
1925 02 23	23:54 60.0N 146.0W (1SS) 6.0	Gulf of Alaska	3	E	1.0	Valdez	OBS					Boardwalk torn up by wave; cable broken.
1927 10 24	16:00 57.5N 137.0W 7.1 (DNAG)	S. Alaska	1	E		Wrangell, Petersburg, Juneau, Skagway, Ketchikan						Cables broken, wave recorded in Hawaii. Not observed in Alaska.
1929 03 07	01:35 51.0N 170.0W (DNAG) 7.5 55	E. Aleutian Islands	4	E								Recorded in Hawaii. Not observed in Alaska.

ORIGIN DATA					TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOT-ION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1936 10 27	58.6N 137.1W	S. Alaska	4	L		Lituya Bay	150.0	02.0	R		00.2	Two small buildings destroyed. Three km² of land inundated. Many trees uprooted. 50 barrels of salted salmon washed away.
1938 11 10	20:19 55.5N 158.0W 8.3 25	Alaska Peninsula (DNAG)	4	E		Dutch Harbor, Unalaska	0.1	60.0		10-22:30	02.2	
						Seward	0.1	75.0			01.5	
						Sitka	0.1	100.0		10-22:40	02.4	
						Unga	OBS					Minor flooding, skiffs washed away. (See also Hawaii and West Coast sections.)
1944 12 07	04:35 34.0N 137.1E 8.0 30	Ryukyu Trench, Japan (Iida)	4	E	3.0	Massacre Bay, Attu	0.3	10.0	F		05.4	(See also Hawaii, West Coast, and Samoa sections.)
					2.5	Sweeper Cove, Adak	0.1	12.0			06.4	
1946 04 01	12:29 52.8N 163.5W 7.3 25	E. Aleutian Islands (DNAG)	4	E		Chignik	1.5					
						Dutch Harbor, Unalaska	OBS		R	01-15:30		Minor damage to pilings.
						Ikatan (Akutan)	OBS					Several houses washed away. Considerable damage.
						Sanak Island	6.1				00.2	Houses gutted; carpentery shop destroyed.
						Sitka	0.4	08.0			02.9	
						Unimak Island	35.0					Scotch Cap lighthouse destroyed, 5 deaths resulted. (See also Hawaii, West Coast, and Samoa sections.)
						Yakutat	0.3	06.0				
1946 11 01	11:14 51.5N 174.5W 7.0 40	Aleutian Islands (DNAG)	1	E								Not reported in Alaska; doubtful report in Hawaii.
1949 08 22	04:01 53.6N 133.3W 8.1	British Columbia, Canada (DNAG)	4	E		Ketchikan	0.1					(See also Hawaii section.)
						Sitka	<0.1	16.0				
1949 09 27	15:31 59.8N 149.0W 6.7 50	Gulf of Alaska (DNAG)		E		Seward	OBS					Probably "gage shaking."
1952 03 04	01:23 42.2N 143.9E 8.1 45	SE. Hokkaido, Japan (Iida)	4	E	2.0	Dutch Harbor, Unalaska	0.1	33.0				(See also Hawaii, West Coast, Samoa, and Pacific Territories sections.)
					2.0	Massacre Bay, Attu	0.3	18.0				
						Sitka	0.1	16.0				
						Sweeper Cove, Adak	0.1	21.0				
1952 11 04	16:58 52.8N 159.5E 8.2 30	Kamchatka Peninsula, USSR (Iida)	4	E	4.0	Dutch Harbor, Unalaska	0.6	58.0	R	04-20:25	03.5	
						Juneau	0.1	75.0				
						Massacre Bay, Attu	1.5	17.0				
						Seward	0.1	60.0		04-23:15	06.3	
						Sitka	0.3	90.0		04-23:13		
						Skagway	OBS			05-00:40		
						Sweeper Cove, Adak	1.1	48.0	R	04-19:27	02.5	Low-lying areas flooded.
						Women's Bay, Kodiak I.	0.2	62.0	R	04-22:43	05.8	(See also Hawaii, West Coast, Samoa, and Pacific Territories sections.)
						Yakutat	0.3	50.0		04-23:20	06.4	
1953 11 25	17:48 34.0N 141.7E 7.4 60	Kashima, Japan (Iida)	4	E	1.0 1.5	Massacre Bay, Attu	0.2	13.0			04.2	(See also Hawaii section.)
1956 03 30	06:11 55.0N 160.5E	Kamchatka Peninsula, USSR (PCT)	4	V		Dutch Harbor,Unalaska	0.1	27.0				Explosion of Bezymianny volcano generated a tsunami or air wave recorded on tide gages. (See also Hawaii, West Coast, and Pacific Territories sections.)
						Massacre Bay, Attu	0.3	20.0			01.8	
						Sweeper Cove, Adak	0.1	18.0			02.1	
1957 03 09	14:23 51.5N 175.7W 8.3 33	Central Aleutian Is. (DNAG)	4	E	3.5	Dutch Harbor, Unalaska	0.7	27.0	R	09-15:45	01.4	
						Juneau	0.2					
						Massacre Bay, Attu	0.6	07.0	R	09-15:30	01.1	
						Sand Bay, Adak	8.0					Fuel dock structures and pipelines washed away.
						Scotch Cap, Unimak I.	15.0					High wave possibly due to local landslide.
						Seward	0.2					
						Sitka	0.4	10.0		09-19:16	04.9	
						Sweeper Cove, Adak	4.0					Structures and two bridges destroyed.
						Umnak Island	OBS					2 moorages and a concrete mixer destroyed.
						Women's Bay, Kodiak I.	0.2	13.0		09-16:32	02.2	(See also Hawaii, West Coast Samoa and Pacific Territories sections.)
						Yakutat Bay	0.3	09.0		09-19:12	04.8	

ORIGIN DATA			V	C	TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOT-ION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1958 07 10	06:16 58.4N 136.3W 7.9	S. Alaska (DNAG)	4	E&L	-2.0	Disenchantment Bay	6.0					Ice fell from glacier, camping gear lost.
						Dixon Harbor	1.0					
						Dry Bay	2.0					Collapse at the mouth of Alsek River caused a 1 - 2 m wave to spread up river.
						Glacier Bay	1.0					Landslide induced waves of 0.5 to 1.0 m.
						Haines-Skagway, Alaska	OBS					6 underwater cables broken.
						Khantaak I., Yakutat Bay	6.1					Local submarine slump caused 3 deaths and wrecked a boat.
						Lituya Bay	525.0		R			2 boats were wrecked, and 2 deaths resulted. 30 million m^3 of soil and loose material washed away. Ten km^2 of forest swept away. Shellfish colonies destroyed, and a few structures destroyed. The 525 m value for the runup is a surge and not a true tsunami. (See text.)
						Sitka	<0.1	18.0		10-07:25	01.2	
						Yakutat	0.9	27.0			00.0	Mooring lines torn loose. (See also Hawaii section.)
						Wrangell, Alaska	OBS					Underwater cable broken.
1958 11 06	22:58 44.3N 148.5E 8.1 80	S. Kuril Islands, USSR (Iida)	4	E	2.0	Massacre Bay, Attu	0.2	40.0			03.0	(See also Hawaii, West Coast, Samoa, and Pacific Territories sections.)
						Sweeper Cove, Adak	<0.1	15.0			02.0	
1958 11 12	20:23 44.2N 148.8E 7.0	S. Kuril Islands, USSR (Iida)	2	E	2.0	Massacre Bay, Attu	0.2	40.0			02.6	Doubtful recording.
						Sweeper Cove, Adak	<0.1	15.0				(See also Hawaii section.)
1959 05 04	07:16 53.4N 159.8E 8.0 74	N. Kuril Islands, USSR (ISS) (PAS)	4	E		Massacre Bay, Attu	0.2	31.0			01.7	(See also Hawaii section.)
1960 05 22	19:11 39.5S 74.3W 8.6 33	S. Central Chile (PAL)	4	E	4.5	Cape Pole	OBS					Log boom broken.
					4.0	Craig	OBS					Buoy was moved.
						Dutch Harbor, Unalaska	0.7	33.0		23-14:50	19.6	
						Juneau	OBS					
						Kake	OBS			23-14:00		
						Ketchikan	OBS					
						Massacre Bay, Attu	1.7	45.0	R	23-15:30	20.3	
						Seward	0.7	48.0	R	23-14:40		
						Sitka	0.5	27.0	R	23-13:33	18.4	
						Skagway	0.2	80.0		23-15:00		
						Sweeper Cove, Adak	1.1	50.0	R	23-14:40	19.5	Record clipped; not extrapolated.
						Womens Bay, Kodiak	0.7	70.0		23-14:25	19.2	(See also Hawaii, West Coast, Samoa, and Pacific Territories sections.)
						Yakutat	0.8	30.0	R	23-14:18	19.1	
1963 10 13	05:17 43.8N 150.0E 8.1	Kuril Islands, USSR (Iida)	4	E	2.0	Massacre Bay, Attu	0.4					(See also Hawaii, West Coast, Samoa, and Pacific Territories sections.)
1964 03 28	03:36 61.1N 147.5W 8.4 23	Gulf of Alaska- Alaska Peninsula (DNAG)	4	E	4.5	All Alaska						$84 million in damage, 106 deaths.
						Afognak Island	OBS					Damage to villages and boats.
						Blackstone Bay	24.2					Wave generated by underwater landslide.
						Cape St Elias	OBS				00.7	Damage to villages and boats. One death.
						Cape Yakataga	3.7				00.7	
						Chenega	27.4					Village totally destroyed, 23 deaths, $100,000 damage.
						Cook Inlet	1.5					
						Cordova	6.1					1.7 million dollars in damage.
						Craig	2.4					
						Dutch Harbor, Unalaska	0.4	36.0	R	28-06:06	02.5	
						Halibut Cove	7.2					
						Homer	6.0				00.1	Buildings flooded.
						Juneau	1.1	81.0	R	28-06:49	03.2	
						Kachemak Bay	OBS					Waves observed.
						Kaguyak	9.2		R			Village totally destroyed, 3 deaths, $50,000 damage.
						Kalsin Bay	OBS					6 deaths.
						Kenai Peninsula	OBS					Damage to waterfront and boats.
						Ketchikan	0.6	29.0	R	28-06:25	02.8	
						Klawak	OBS					3 houses lost.
						Kodiak	6.1		R		00.8	8 deaths, $31.3 million damage including 5 blocks of the business district destroyed.
						Kodiak Naval Station	5.3					$10.3 million damage including total destruction of cargo dock and heavy damage to roads and bridges.

ORIGIN DATA DATE TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PERIOD (MIN)	1ST MOTION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1964 03 28 (continued)					Massacre Bay, Attu	0.4	72.0	R	28-07:27	03.8	
					Meares Passage	OBS					Barge beached & broken.
					Old Harbor	9.2				00.8	Village nearly destroyed, $150,000 damage, 1 death on Sitkaledak Island nearby.
					Ouzinkie	OBS					$500,000 damage.
					Passage Canal	31.7					Opposite shore from Whittier.
					Perl Island	9.0					
					Peterson Bay	OBS					Tide came and went for 15 hrs.
					Port Ashton	OBS					1 death.
					Port Nellie Juan	15.0					3 deaths, dock destroyed.
					Port Nowell	12.0					1 death.
					Port Whitshed	OBS					1 death, 10 cabins washed away.
					Seldovia	1.2					$500,000 damage mostly to boats. Wave amplitude may include tide.
					Seward	9.2		F			Disastrous to town, waterfront, boats and railroad. $14.6 million in damage. Section of waterfront slid into bay. 11-13 deaths due to combined effect of local and main tsunamis.
					Shelikof Strait	1.5					
					Sitka	2.4	50.0	R	28-05:06	01.5	Dock collapsed.
					Sitkalidak Island	OBS					1 death.
					Spruce Cape	OBS					1 death.
					Sweeper Cove, Adak	0.3	54.0	F	28-07:00	03.4	
					Valdez Inlet	67.0					Middle Rock light washed away. A cabin at Anderson Bay was washed away killing 1 person.
					Valdez	9.1					Disastrous to town, waterfront, and boats. $15 million in damage. Large section of land slid into sea. 30 deaths.
					Whittier	13.1					$10 million in damage. 13 deaths. 2 saw mills, oil tank farm, railroad depot, wharf and building destroyed.
					Women's Bay	6.1				00.8	$10.3 million in damage.
					Yakutat Bay	1.2	07.0	R	28-05:00	01.4	(See also Hawaii, West Coast, Samoa, and Pacific Territories sections.)
1965 02 04 05:01 51.3N 178.6W 8.2 (DNAG) 36	W. Aleutian Islands	4	E	3.0	Amchitka	OBS					Minor flooding damage.
					Dutch Harbor, Unalaska	0.1				02.0	
					Kodiak Island	<0.1					
					Massacre Bay, Attu	1.6				03.0	
					Shemya Island	10.7					Warehouse and road flooded.
					Sitka	0.1					
					Sweeper Cove, Adak	0.4				00.6	(See also Hawaii and Samoa sections.)
1965 03 30 02:27 50.3N 177.9W 7.4 (DNAG) 20	W. Aleutian Islands	4	E	-1.0	Attu	0.1					(See also Hawaii and Samoa sections.)
1965 07 02 20:59 53.0N 167.6W 6.5 (DNAG) 40	E. Aleutian Islands	4	E	-1.0	Dutch Harbor, Unalaska	<0.1					(See also Hawaii and Samoa sections.)
1966 10 17 21:42 10.7S 78.8W (PAL) 8.0 40	Peru	4	E	1.0	Adak	<0.1					(See also Hawaii, West Coast, Samoa, and Pacific territories sections.)
				1.5	Kodiak	<0.1					
					Massacre Bay, Attu	<0.1					
					Sitka	<0.1					
					Snug Harbor	<0.1			18-18:30	20.8	
					Sweeper Cove, Adak	<0.1					
1968 04 01 00:42 32.3N 132.5E 7.5 (Iida) 30	Shikoku, Japan	4	E		Attu	<0.1					(See also Samoa section.)
1968 05 16 00:49 40.7N 143.6E 7.9 (Iida) 0	Honshu, Japan	4	E	2.0	Adak	<0.1					(See also Hawaii, West Coast, Samoa, and Pacific Territories sections.
				-0.5	Attu	0.2					
					Dutch Harbor, Unalaska	<0.1					
					Sitka	<0.1					
1968 08 01 20:19 16.5N 122.2E (ISC) 7.3 (USE) 36	E. Luzon Island, Philippines	4	E		Attu	<0.1					(See also Hawaii, Samoa, and Pacific Territories sections.)
1969 08 11 21:27 42.7N 147.6E 7.8 (Iida) 30	Hokkaido, Japan Kuril Islands	4	E	1.0	Attu	0.1					(See also Hawaii, Samoa, and Pacific Territories sections.)

ORIGIN DATA			V	C	TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOT-ION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1969 11 22	23:10 57.7N 163.6E 7.3 51	Kamchatka, USSR (ISC) (USE)	4	E		Adak Attu Shemya Island Unalaska	<0.1 0.3 0.3 <0.1					(See also Hawaii, Samoa, and Pacific Territories sections.)
1971 05 02	06:08 51.4N 177.2W 6.8 38	Andreanof Islands (DNAG)	2	E		Adak	<0.1					
1971 07 14	06:11 5.5S 153.9E 7.9 43	New Ireland (ISC) (USE)	4	E		Attu	<0.1					(See also Hawaii, Samoa, and Pacific Territories sections.)
1971 07 26	01:23 4.9S 153.2E 7.9 43	New Ireland (ISC) (USE)	4	E		Adak Attu	<0.1 <0.1					
1971 11 06	12:00 51.5N 179.1W 7.4 21	Central Aleutian Is. (AEC)	4	E		Constantine Harbor	<0.1	20.0	R		00.2	Waves generated by undersea nuclear explosion "Cannikin".
						Square Bay, Amchitka	0.1	20.0	R		00.1	Waves generated by undersea nuclear explosion "Cannikin".
1971 12 15	08:30 56.0N 163.2E 7.8 39	Kamchatka, USSR (ISC) (USE)	4	E		Adak Attu Shemya Island Unalaska	<0.1 <0.1 <0.1 <0.1					(See also Hawaii and Pacific Territories sections.)
1972 07 30	21:45 56.8N 135.9W 7.6 0	SE Alaska (DNAG)	4	E		Juneau Sitka	0.1 <0.1	10.0 10.0	R			
1973 02 28	06:38 50.5N 156.6E 7.2 62	Kamchatka-Kuril Is. (ISC) (USE)	4	E		Attu Shemya	0.1 <0.1	20.0				
1973 06 17	03:55 43.0N 146.0E 7.4 40	Hokkaido, Japan- Kuril Islands, USSR (Iida)	4	E	1.0	Attu	<0.1					(See also Hawaii and Pacific Territories sections.)
1975 06 10	13:47 42.8N 148.2E 7.0 0	Hokkaido, Japan- Kuril Islands, USSR (Iida)	4	E	1.0	Adak Sitka	<0.1 <0.1					Doubtful recording. Doubtful recording. (See also Hawaii and Pacific Territories sections.)
1975 11 29	14:48 19.3N 155.0W 7.2 8	Hawaii (Cox)	4	E		Sitka Yakutat	0.1 <0.1					(See also Alaska, West Coast, Samoa, and Pacific Territories sections.)
1979 02 28	21:27 60.7N 141.6W 7.1 16	Gulf of Alaska (DNAG)	2	E		Yakutat	0.2					
1985 03 03	22:47 33.2S 72.0W 7.8 33	Valparaiso, Chile (PAL)	4	E		Adak Kodiak Island	<0.1 <0.1					Doubtful record, looks like background noise. (See also Hawaii section.)
						Sand Point Seward Yakutat	<0.1 <0.1 OBS					
1986 05 07	22:47 51.5N 174.8W 7.6 19	W. Aleutian Islands (ISC)	4	E		Adak Sand Point Unalaska	0.4 <0.1 0.1	12.0				(See also Hawaii, West Coast, Samoa, and Pacific Territories sections.)
1987 11 17	08:47 58.6N 143.3W 6.9 10	Gulf of Alaska (PDE)	4	E		Yakutat	<0.1					
1987 11 30	19:23 58.7N 142.8W 7.6 10	Gulf of Alaska (PDE)10	4	E		Seward	<0.1					The gage was out intermittently throughout the tsunami.
						Sitka Yakutat	0.1 0.5					Boats bumped together. (See also Hawaii and West Coast sections.)
1988 03 06	22:36 57.0N 143.0W 7.6 10	Gulf of Alaska (PDE)	4	E		Yakutat Sitka Kodiak	0.2 <0.1 <0.1					

TABLE 5. TSUNAMI DATA FOR NON UNITED STATES AREAS AFFECTED BY TSUNAMIS GENERATED IN ALASKA

ORIGIN DATA			VALID	CAUSE	TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA			MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PERIOD (MIN)	1ST MOTION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1946 04 01	12:29 52.8N 163.5W 7.3 (DNAG) 25	E. Aleutian Islands	4	E		Iquique, Chile	OBS					Boats damaged.
						Isla Juan Fernandez, Chile	OBS					Some damage.
1957 03 09	14:23 51.5N 175.7W 8.3 (DNAG) 33	Central Aleutian Islands	4	E	3.5	Hakodate, Japan	OBS					32 houses and 18 boats damaged.
1964 03 28	03:36 61.0N 147.5W 8.4 (DNAG) 23	Gulf of Alaska-Alaska Peninsula	4	E	4.5	British Columbia, Canada	OBS					$10 million in damage.
						Sanriku coast, Japan	OBS					Damage to oyster and pearl harvest.
1965 02 04	05:01 51.3N 178.6W (DNAG) 8.2 36	W. Aleutian Islands	4	E	3.0	Sanriku coast, Japan	0.4					Minor flooding.
						Tohoku district, Japan	OBS					Damage to planted shell.
						Wakayama Pref., Japan	OBS					Pearl raft damaged.

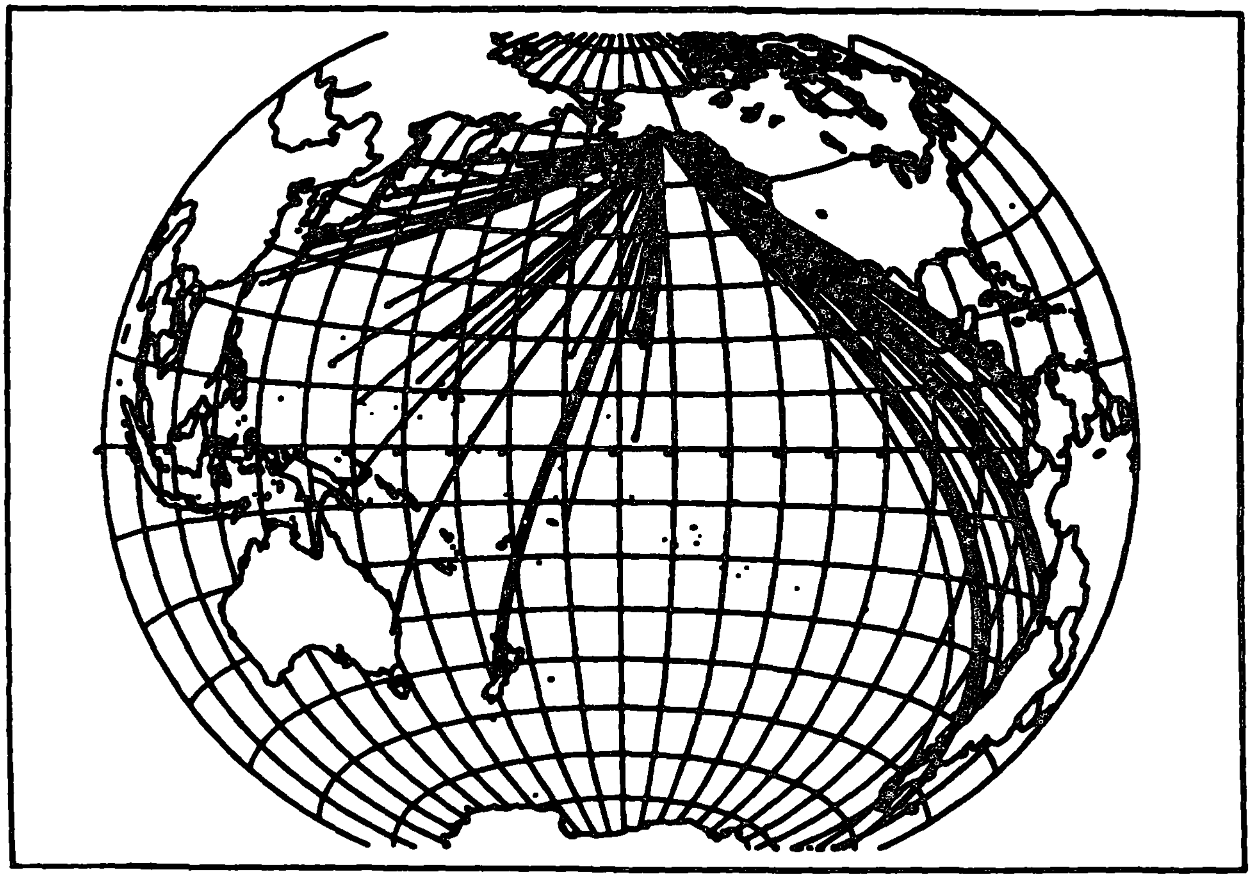
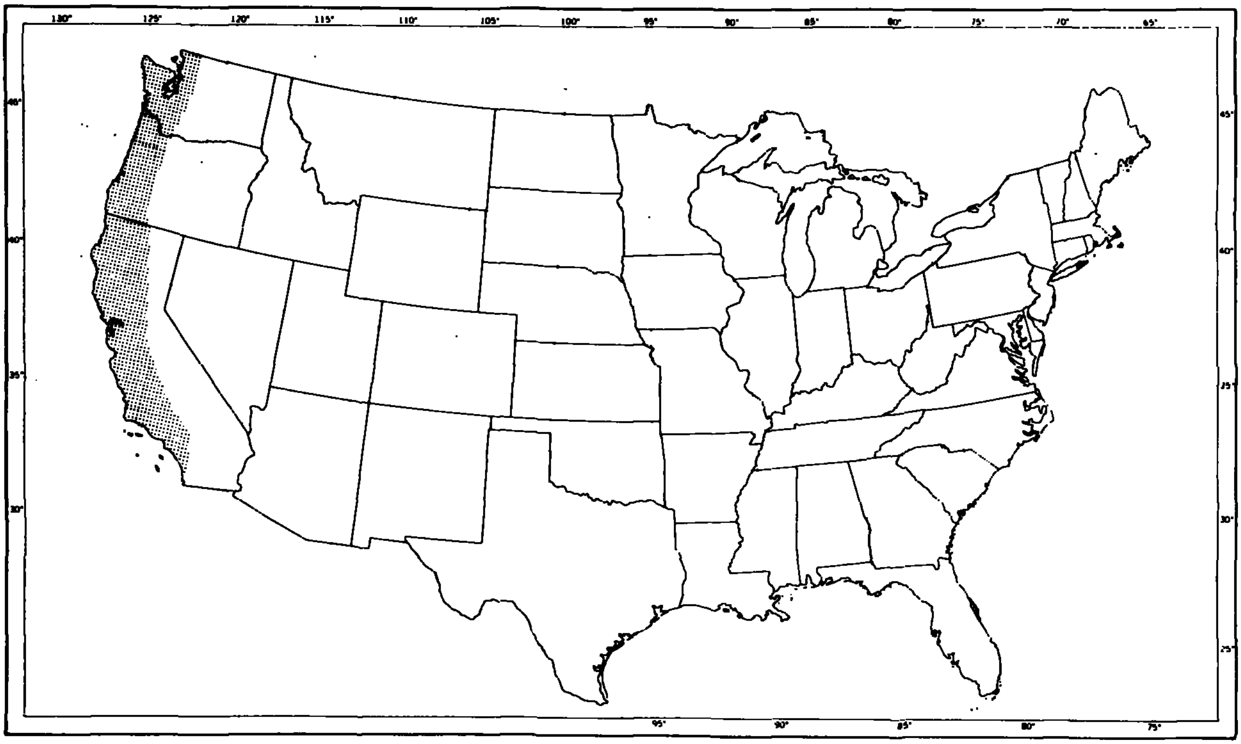


FIGURE 48.—Areas in the Pacific Basin that experienced tsunamis resulting from earthquake of March 27, 1964 in the Gulf of Alaska.

4. WEST COAST OF THE UNITED STATES



4.1 BACKGROUND INFORMATION

The pre-1940 data for the west coast of the United States appears incomplete with a number of questions unresolved. This is mainly because the limited effects of tsunamis in areas of low population drew little attention and reports remain scattered. Most of the data prior to 1940 were obtained from the tide gages at San Diego and San Francisco in California. Additional tide gages along the California coast came into existence after 1940.

4.2 EARLY HISTORY OF CALIFORNIA

In 1542 Juan Rodriguez Cabrillo made the first exploration of the California coast. Although he died in an accident in the Santa Barbara Islands, his pilot, Bartolome Ferrelo, completed the voyage as far north as Cape Mendocino. In 1579 Francis Drake, captain of the English ship, *Golden Hind*, landed in the area of San Francisco (at what is now Drake's Bay) and claimed the land for England. Many ships, including Spanish ships from the Philippines en route to Mexico, visited the California coast over the next 60 years. In 1602 Sebastian Vizcaino surveyed Monterey Bay as a possible site for a Spanish settlement. Thus, the possibility of a tsunami being observed was limited until the first permanent settlement was made in the latter part of the 18th century.

The first settlement was not made until 1769 when the mission at San Diego was established by Father Junipero Serra. By 1823 the evangelical Franciscan priests established 21 missions extending from San Diego to Sonoma, north of San Francisco Bay. Spanish settlements were of three types; missions administered by the church, presidios which were military garrisons, and pueblos which were civilian settlements. The first pueblos were established at San Jose in 1777, Los Angeles in 1781, and Santa Anna in 1798. Juan Bautista de Anza selected a settlement site at Yerba Buena (now San Francisco) in 1776, and a presidio and mission were established at about the same time. Thus, the coastal areas south of San Francisco were populated since the early part of the 19th century and many contemporary documents exist from that area.

The Russians established Fort Ross near Bodega Bay in 1812, but abandoned it in 1841 with the decline in the fortunes of the Russian American Company. It was reinhabited in the 1870's by American settlers. American smugglers and traders had been active along the coast since the early part of the nineteenth century. American trappers reached San Gabriel in 1826 and settlers arrived in 1841. California was added to the United States in 1848 following the war with Mexico.

In 1848, gold was discovered at Sutter's Mill, and so began the largest mass migration of people the West had ever known. In 1849 alone, an estimated 90,000 people arrived in California to dig for gold.

Many of the '49ers stayed to settle in small towns on the coast, or to form new towns. San Luis Obispo was thus established in 1850 near some older missions. Santa Cruz was named in 1866, although the mission it was built around was founded in 1791. Santa Monica was incorporated in 1886, and the city of San Pedro in 1888. Two years later the town of Coronado was formed, and Newport Beach was settled in 1906, the year of the infamous San Francisco earthquake.

4.3 EARLY HISTORY OF OREGON

Meriwether Lewis and William Clark spent the winter of 1805-06 at the site of Fort Clatsop by the mouth of the Columbia River. In 1811 John Jacob Astor established a fur trading post at Fort Astoria, which he sold to the British Canadian North West Company in 1813. In 1843, 900 settlers arrived. Oregon, like Washington, has a rather short recorded history. The Pacific coasts of Washington, Oregon, and northern California remain sparsely populated because of a rugged coastline.

Although the Pacific coast states have a history of habitation ranging from about 200 years in the south to more than 100 years in the north, the history of tsunamis is rather sparse. Observed tsunamis have been harmless or have caused minor damage, except for the 1964 Gulf of Alaska tsunami which killed 16 and caused $12 million in damage on the West Coast.

Tide gages were established at San Diego, San Francisco and Astoria in 1854. The first on the Pacific Basin, these tide gages have helped extend the record to include waves that would not otherwise have been noticed. The historical record contains descriptions of phenomena other than tsunamis, exaggerations, and misdated and mislocated events. For example, storm surges, seaquakes, and seiches have been described as tsunamis. Several of the reports of the most severe historical tsunamis have, on close examination of contemporary records, proved to be exaggerations or meteorological phenomena.

Interest in constructing nuclear power plants in coastal areas has belatedly spurred an interest in tsunamis on the West Coast. California has a history of only a few nondestructive local tsunamis, but the history is too short to rule out entirely a risk to coastal activities from this source.

4.4 EARLY HISTORY OF WASHINGTON

Spanish explorers Bruno Heceta and Juan Francisco de la Bodega y Quadra landed north of the Columbia River in 1775 and claimed the land for Spain. Many other explorers undertook voyages in the following years including Captain Cook in 1778, Captain Gray, an American who explored the Columbia River, and Captain Vancouver, an English explorer. The search for a Northwest Passage around the North American Continent was one goal of the voyages.

The Spanish settled Neah Bay in 1791, but abandoned it five months later. Spain abandoned its claim on the Oregon Territory including Washington in 1818. In 1818 Great Britain and the United States agreed to joint occupancy of the Oregon Territory which continued until 1846 when the present boundary was adopted. There were no permanent Caucasian settlements in the State until 1810, and so historical records of this area date back less than 200 years. However, there are Indian legends of large earthquakes and of large disturbances of the sea (Heaton and Snavely, 1985).

4.5 TECTONIC SETTING OF CALIFORNIA

The Pacific plate is not being subducted beneath the continental plate along the California coast as is occurring in the Gulf of Alaska, the Aleutian Islands, and South America. Instead, the two plates are sliding past each other in a complex system of faults, the most famous being the San Andreas. Here, the major fault movement is horizontal rather than vertical. Also, 93% of the earthquakes have epicenters on land rather than offshore.

However, a few areas are experiencing compressional forces offshore, and therefore have the potential for tsunami generation. The first of these areas is in southern California, near the "Big Bend" in the San Andreas fault. In the area offshore of Point Arguello, the Hosgri fault zone and the Santa Lucia Bank area have each produced at least two compressional motion earthquakes. The best documented local tsunami in southern California, the 1927 Point Arguello tsunami, was generated in this area (McCulloch, 1985).

Another potential source area for locally generated tsunamis lies along the major geologic boundary between the Santa Barbara Channel and the adjoining Transverse Ranges. Here, seismically active northeast-dipping reverse faults separate the rocks beneath the Santa Barbara Channel to the south from the elevated and folded rocks of the Transverse Ranges to the north. Two large earthquakes of estimated magnitude larger than 7.0 occurred in this area on December 21, 1812. The epicenters for these quakes have tentatively been placed along the Pitas Point-Ventura fault and its westward extension. (McCulloch, 1985) Other potentially tsunamigenic faults, such as the Santa Inez, the Malibu, and the Ventura faults, lie offshore in this area. (Benioff, 1965)

Fourteen locally generated tsunamis have been reported in the region offshore Point Arguello and the Santa Barbara Channel since 1812. With the possible exception of the 1812 Santa Barbara and the 1927 Point Arguello tsunamis, these locally generated tsunamis have posed little hazard to the West Coast. (McCulloch, 1985)

A third area where vertical offset of the seafloor may be possible lies to the south at Huntington Beach and Newport Beach, where 3 m of uplift may occur along the Palos Verdes Hills fault. However, the shallow depth of the water in this area would be an important factor in limiting the height of a wave if one were generated. (McCulloch, 1985)

A fourth area along the coast of California that is capable of generating tsunamis is the Mendocino scarp. This scarp may be considered a transverse fault with a substantial dip-slip component. However, activity on this fault is limited to a short segment adjacent to the coast and is induced by movements of the San Andreas fault. (Benioff, 1965)

In general, these offshore faults are not long enough to produce sufficient slip amplitude and rupture length to generate earthquakes substantially larger than the November 4, 1927 shock.

4.6 TECTONICS OF CASCADIA SUBDUCTION ZONE

The coastline of Washington and Oregon is situated along a convergent plate margin. The oceanic Juan de Fuca, Gorda, and Explorer plates are moving northeast at a rate of 2-4 cm/yr, and are being thrust under the overriding North American plate along the Cascadia subduction zone. Such underthrusting is usually accompanied by shallow, large-magnitude earthquakes capable of generating large tsunamis. However, the seismic processes of the Cascadia subduction zone may be different from those of other subduction zones as the geologic evidence seems to suggest. Two explanations are possible. Since the amounts of total uplift along the Washington and Oregon coasts are less than in other areas, the recurrence interval may be considerably longer than for other such zones. A second explanation is that the subduction may be aseismic. (West et al., 1987)

The oceanic lithosphere in the Pacific Northwest is about 10 million years old. This youthfulness gives the area several characteristics that distinguish it from other subduction zones. For example, there is no significant bathymetric trench offshore. The average heat flow is high compared to other plate boundary areas. The Benioff-Wadati seismicity zone, while definite, stops at a much shallower depth than in other subduction zones. The coastal area historically has had low seismicity. Although this may be taken as evidence for aseismic slip, an alternative explanation is that stress is accumulating uniformly over a wide locked zone. "Evidence for active convergence at the rate of 4 cm/year exists for the 1200-km Cascadia subduction zone. If the Cascadia subduction zone is locked, a sequence of great earthquakes (M_w 8) or a giant earthquake (M_w 9) would be necessary to fill this gap...Large and potentially destructive local tsunamis would be expected if large subduction events do occur." (Heaton and Hartzell, 1987)

However, the geologic and geomorphic data indicate, according to West et al. (1987), that the "seismogenic process of the Cascadia subduction zone are different than other zones in the form of longer recurrence intervals for large magnitude thrust earthquakes or that (earthquakes) are of lower maximum magnitude."

An argument against a large magnitude earthquake occurring in the area suggests that the young age of the oceanic crust and the high temperatures at the subducting boundary cause movement to take place as aseismic creep. (Heaton and Hartzell, 1987)

4.7 LANDSLIDE GENERATED TSUNAMIS ON THE WEST COAST OF THE UNITED STATES

McCulloch (1985) estimated that the runup height of a landslide-generated tsunami off the coast of California would be about 1 m. This proposed modest runup is due to the absence of large rivers to supply new sediments to the shelf, the absence of a trench off the coast, the rather small angle of the slope of the margin compared to the slopes of the trench wall, and the reduced depth to the bottom of the slope compared to trench depths. If this 1-m approximation is valid, it suggests that tsunamis generated by landslides pose no threat to nearby coastal areas.

4.8 POTENTIAL FOR REMOTE-SOURCE TSUNAMIS ON THE WEST COAST OF THE UNITED STATES

Historically, tsunamis generated in Chile and Alaska are more likely to cause high runup on the west coast of the United States than those generated elsewhere. The most prominent seismic gap (area within a seismic belt in which no great earthquake has occurred in a significantly long period of time relative to areas around it) in the Pacific Basin lies offshore at the Chile-Peru border, near the "Great Bend" in the South American coastline. This area has produced two earthquakes that caused devastating tsunamis in the last century--one in 1868 and the other in 1877. Both were observed on the West Coast, and, in addition, caused severe damage in Hawaii and flooding as far away as Japan.

The west coast of the conterminous United States is not as vulnerable to tsunamis produced in the Chile area as it is to those in the Alaska area because of the directional nature of the waves. Tsunamis generated in Chile are directed toward the northwest (i.e., Japan). The areas in Alaska where tsunamis have occurred that affected the West Coast are: the tip of the Alaskan Peninsula, the Gulf of Alaska, and to a lesser degree, the Aleutian Islands. When seismic gaps are filled by the occurrence of large earthquakes, destructive tsunamis may be generated.

Those areas have the most apparent potential for generating a large earthquake and therefore a large tsunami that could cause damage on the west coast of the United States. One of the Alaskan seismic gaps still open in 1988 is near the tip of the Alaskan Peninsula in the Shumagan Islands area, and has the potential for generating a destructive tsunami that could impact the West Coast.

Of cities on the West Coast, Crescent City, California, has incurred the most severe damage from tsunamis. According to some sources, the offshore bathymetry appears to focus the waves toward that city. This bathymetry includes a ridge about 650 km northwest of Crescent City on which Cobb Seamount is located. A second seamount is located about 150 to 250 km west-northwest of the city. These features focused the waves from the 1964 Alaskan tsunami, and caused the tsunami to approach the city from the southwest. (Roberts and Chien, 1964)

The May 1960 tsunami, which was generated off the coast of Chile, also had its highest runup heights on the West Coast in Crescent City. In this tsunami the Mendocino Escarpment appeared to focus the wave toward Crescent City.

The coastal area of the State of Washington appears to be relatively safe from remote-source tsunamis, but still incurred $1 - 2 million dollars in property damage from the great 1964 tsunami generated in the Gulf of Alaska, the only reported tsunami damage for the State. Its protection results from the geometry of the continental shelf in that area. Also, because high storm waves are common there, a tsunami of less than a meter in height and occurring before high tide would probably go unobserved. The coastal areas are also only sparsely populated and developed.

Most of the locations mentioned in the following descriptions are shown in figures 49, 50, and 51.

4.9 DESCRIPTION OF TSUNAMI EVENTS

1812. Several strong earthquakes generated waves that covered the ground where the plaza (not further identified) now is in **San Francisco**. This information was reported by Holden (1887) as communicated to him by J.R. Jarboe, Esq. citing Senora Juana Briones. This is a third-hand report of events that were supposed to have happened 70 years earlier and attributed to a woman who was at least 84 years old (born in 1796). It is the only report of a tsunami in **San Francisco** in 1812. There is no mention in contemporary mission records of earthquakes in San Francisco in 1812. (Grauzinis et al., unpublished manuscript). Iida et al. (1967) suggested that this report is possibly a mislocated account of the same event that produced the December 21 waves at Santa Barbara, but Wood (1916) cited these waves as evidence for displacement on a fault across San Francisco Bay rather than a more seaward fault. This is a doubtful tsunami report. (Soloviev and Go, 1975, p. 200, 202; McCulloch, 1985)

1812, December 21, 19:00. A major earthquake on December 8 destroyed the Mission San Juan Capistrano. Jacoby, et al. (1988) place the epicenter of the Dec. 8, 1812 shock on the San Andreas fault. Two more earthquakes on December 21, the largest with a magnitude estimated at 7.7 occurred at about 11:00 A. M., destroyed the Mission Purisima Concepcion and damaged the Mission and Presidio of Santa Barbara and Mission San Buenaventura (Ventura).

Information on a tsunami from the December 21 earthquake has become distorted over the years to include exaggerated reports of waves of up to 15 m at **Gaviota**, 9 to 10.5 m at **Santa Barbara**, and 3.5 m or more at **Ventura**. The wave heights for **Gaviota** were derived from an account of "an old trader" in the *San Francisco Bulletin* of March 16, 1864, 52 years after the event, which reported "the sea was seen to retire all at once and return in an immense wave, which came roaring and plunging back, tearing over the beach fit to crack everything to pieces. This wave penetrated the lowlands of the gulches a mile from shore." This report, in turn, was converted into the 15-m height by using a topographic map. Contemporary sources from the Missions at Santa Barbara and Ventura make scant mention of disturbances of the ocean. An entry in the book of the Mission San

(1812, December 21, continued)

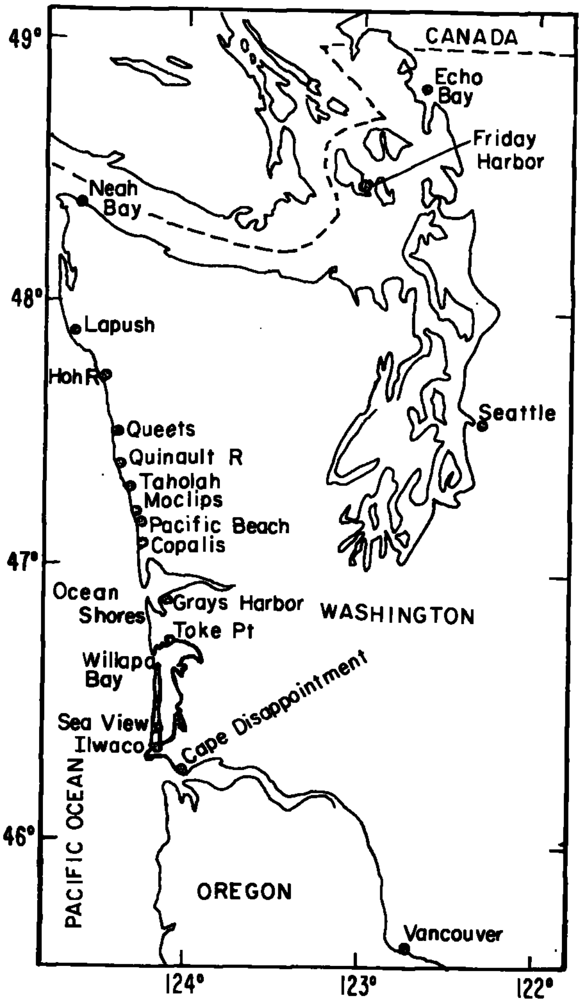


FIGURE 49.—Map of the State of Washington

Buenaventura of January 9, 1813 reported that the church has been evacuated "because of the horrible tremblors or terremotos which they had experienced most strongly and because the sea was so greatly disturbed by the earthquakes that by chance it was feared that its waters would inundate the mission." (Grauzinis et al., unpublished manuscript) In 1948, Mr. Frank Orr, a Ventura lawyer, wrote that he had recently talked to Mrs. Myrtle Francis who had settled in Ventura in 1873 and she related the account of an old Indian who was living in Ventura at the time of the tidal wave. He reported that the chapel of San Miguelito was damaged by the tidal wave of 1812. The chapel was 4.5 m above sea level, and this accounts for the published

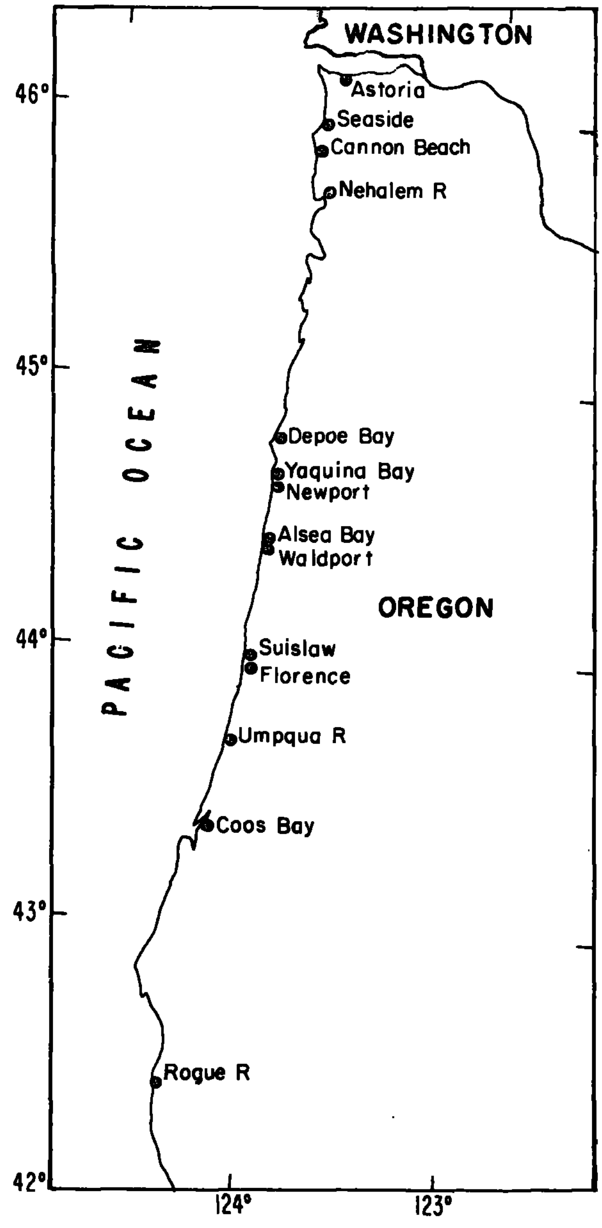


FIGURE 50.—Map of the State of Oregon

wave height at Ventura. However, the contemporary mission report does not directly mention a tsunami, but only a disturbed ocean and a fear of a tsunami.

Trask (1856) reported on information he had collected from native inhabitants and older foreign residents on the earthquake and

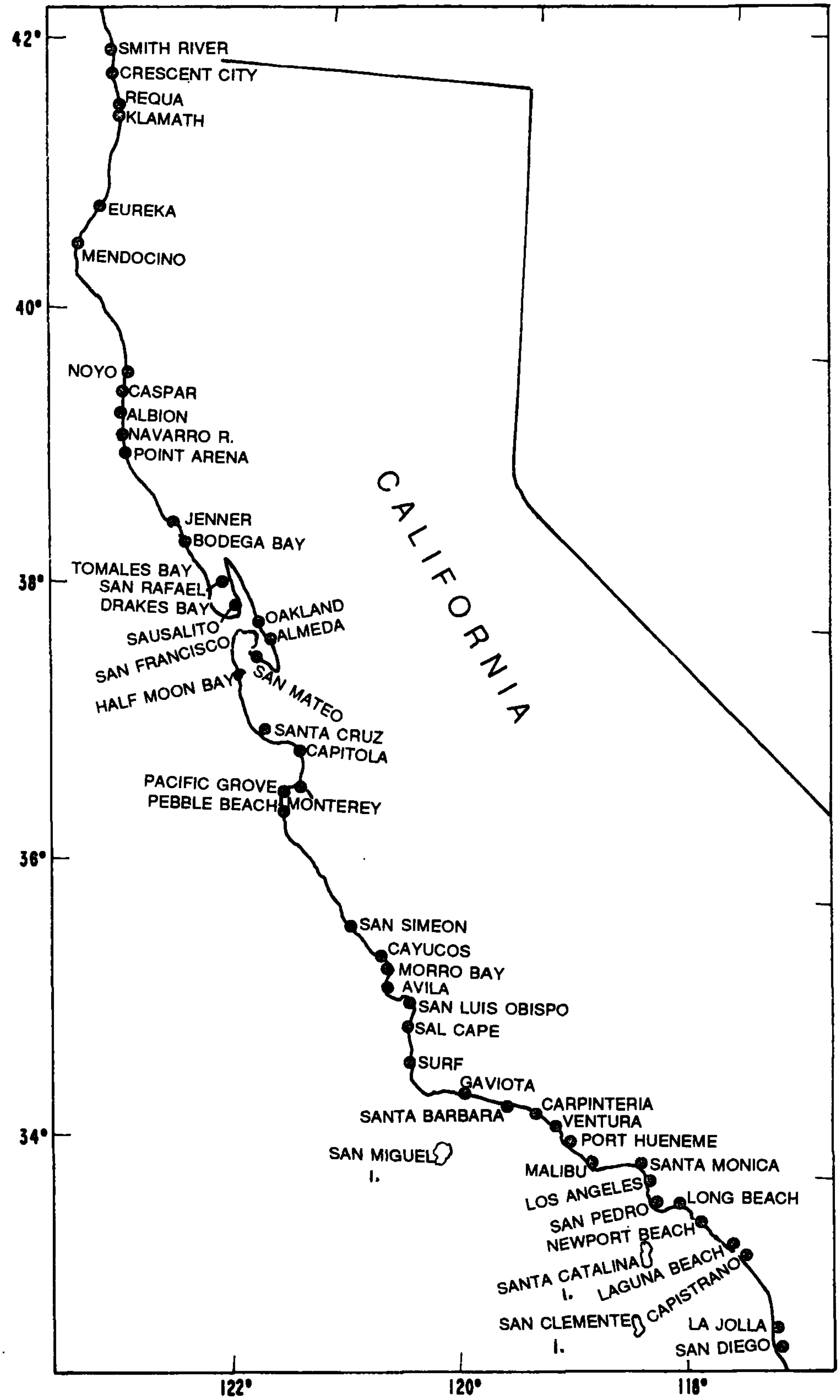


FIGURE 51.—Map of the State of California

(1812, December 21, continued)
tsunami: "A Spanish ship which lay at anchor off San Buenaventura 38 miles from Santa Barbara, was much injured by the shock, and leaked to the extent that it became necessary to beach her, and remove most of her cargo."

Later, regarding the **Bay of Santa Barbara**, Trask (1856) quotes an unknown source: "The sea was observed to recede from the shore during the continuance of the shocks, and left the harbor dry for a considerable distance, when it returned in five or six heavy rollers, which overflowed the plain on which **Santa Barbara** is built. The inhabitants saw the recession of the sea, and being aware of the danger on its return, fled to the adjoining hills near the town to escape the probable deluge."

Trask (1856) continues: "The sea, on its return flowed inland little more than half a mile, and reached the lower part of town, doing but trifling damage, destroying three small adobe buildings."

In an article regarding the history of earthquakes in the January 17, 1857 *Los Angeles Star*, a local authority reported that "on Dec. 21, 1812 an American ship, engaged in smuggling, was laying anchored off a canyon at the Ranch Refugio, in Santa Barbara county. The sea became violently agitated by the earthquake, and the captain let go his cable, the vessel was drifted ashore and up the canyon, the receding waters bringing her back to her proper element."

The ship mentioned by Trask was probably not a Spanish ship nor was it at San Buenaventura. Instead it was an American smuggling ship at El Refugio, near Gaviota that was collecting otter skins and trading with the missions. This illegal activity might account for the lack of mention of the ship in the contemporary mission reports. On the other hand there were several Indian encampments near the beach at Santa Barbara. The Padres kept careful records of Indian births and deaths, and the lack of any mention of effects at these sites is a strong limitation to the report of the height of any wave at Santa Barbara.

Even though the contemporary record does not describe a tsunami or runup, and the later reports are possibly exaggerated and occasionally confused, it is likely that there was a moderate tsunami. Grauzinis et al. (unpublished manuscript) conclude that the data would be reasonably supported by runup elevations of about 3.5 m at **El Refugio** where an American ship was anchored, and less than 3 m at **Santa Barbara** and **Ventura**. (Grauzinis et al., unpublished manuscript; Soloviev and Go, 1975 p. 200; McCulloch, 1985; Marine Advisers, 1965; Iida et al., 1967; Wood, 1916; Heck, 1947, Toppozada et al. 1981.) According to Long (1988) the predicted tide at **Santa Barbara** and **Ventura** was about 0.8 m above mean sea level at 10:00 A.M. which would make the height of the tsunami at **Santa Barbara** and **Ventura** about 2.0 m. The Marine Advisers' report and the Grauzinis et al. manuscript are sources for much more detailed information for this event. Note that a single wave was observed in Hookena, Hawaii probably in late December and is possibly a tsunami generated by this earthquake.

1840, January 16-18. Bancroft's *History of California* (1886) reported that a magnitude 6.3 earthquake at **Santa Cruz** threw down several houses and the church towers, besides causing a wave that carried away a large quantity of roofing material 182 m from the shore. Similar accounts have been carried in numerous catalogs and histories. Louderback (1944), in examining original records, found that sea waves on January 16 and 17 carried off roofing material that was 200 varas (168 m) inland. On January 18 the church tower fell owing to the abundance of water and the weakness of the ground on which it was built. There was no mention of an earthquake. This is probably a meteorological wave, not a tsunami. (Iida et al., 1967; Soloviev and Go, 1975, p. 202; Louderback, 1944)

1851, May 15, 16:10. Perhaps the largest of mild shocks on March, April, and May 15, 17, 28 at **San Francisco** and **Salinas** which may have been accompanied by marine flooding. (Toppozada et al. 1981; Soloviev and Go, 1975, p. 202; quoting Perrey, 1872; the only source for the report of flooding.)

1851, November 13. An earthquake at 7:00 P.M. at **San Francisco Bay** produced motion of the waters of the bay. This was possibly a seiche or a seaquake, not a tsunami. (Iida et al., 1967; McCulloch, 1985; Soloviev and Go, 1975, p. 202; Townley and Allen, 1939)

1853, November. An earthquake in the Kuril Islands, USSR, produced a tsunami that penetrated far inland at Simushir Island in the Kuril Islands. The tsunami was possibly recorded on the newly installed tide gage at **San Diego**. (Soloviev and Ferchev, 1961; Iida et al., 1967; Joy, 1968; Bache, 1856)

1854, May 31. A local tsunami reportedly occurred on the coast of southern California at 4:50 A.M., following three shocks at **Santa Barbara**. The sea was very agitated. Perrey (1853) is the sole source for this report. It may have been either a seiche or an erroneous report. However, the report may refer to one of two small tsunamis reported by Bache (1856) to have been recorded by the **San Diego** tide gage between July 1, 1853, and December 23, 1854. (Joy, 1968; Townley and Allen, 1939; Soloviev and Go, 1975, p. 203; Iida et al., 1967)

1854, July 24. The tidal observer at **San Diego** noted that "Water rose and fell nearly 0.3 m in 10 minutes--currents set up also, harbor calm." The source is unknown. (Agnew, 1979; Cassidy, 1862; McCulloch, 1985)

1854, October 26. An earthquake at **San Francisco** and **Benicia** occurred near midnight. A sea wave or "swell in the bay" followed the shock or shocks. Ships were shaken vigorously. (McCulloch, 1985; Soloviev and Go, 1975, p. 203; Iida et al., 1967; Townley and Allen, 1939). These were possibly seiches. (Joy, 1968)

1854, November 1. At 10:00 on **Angel Island** near **San Francisco**, the water suddenly rose about 0.6 m (several feet) with enormous waves lasting about one half hour. A local earthquake was not reported. Alternate dates are November 10 and December 1. (Soloviev and Go, 1975, p. 203, 204; Townley and Allen, 1939; Iida et al., 1967; Joy, 1968)

1854, December 23, 00:00. A magnitude 8.3 earthquake in Tokkaido, Japan, generated a 21-m tsunami at Osatsu, Shima Peninsula, Japan. The earthquake and tsunami destroyed 8,300 houses and killed 1,000 people in Japan. (Iida, 1984) New tide recorders had been installed at San Francisco and San Diego, California, and Astoria, Oregon. The earthquake produced a wave recorded with amplitude of <0.1 m at **San Diego**, 0.1 m at **San Francisco**, and recorded at **Astoria** with a small amplitude. (McCulloch, 1985; Agnew, 1979; Iida et al., 1967; Soloviev and Go, 1974, p. 62) This is the first recording of a tsunami recognized as such at the time and identified as coming from a remote source. Bache (1856) used the travel time to compute the average depth of the Pacific Ocean.

1854, December 24, 08:00. A magnitude 8.4 earthquake in Nankaido, Japan, generated a maximum wave of 28 m at Kochi, Japan. The earthquake and tsunami killed more than 3,000 people. The tsunami washed away 15,000 houses in Japan. It produced a wave with 0.1 m amplitude at **San Francisco** and at **San Diego** and was recorded feebly at **Astoria, Oregon**. (McCulloch, 1985; Agnew, 1979; Iida et al., 1967; Soloviev and Go, 1974, p. 70; Townley and Allen, 1939; Joy, 1968). The marigrams are reproduced in Soloviev and Go (1974).

1855, March 19, 21:50. An earthquake at 4:30 P.M. in the area of **Humboldt Bay**, California caused the discharge of water in the rivers to change. The water in **Humboldt Bay** was agitated for an hour. (Soloviev and Go, 1975, p. 204; Townley and Allen, 1939). This is a doubtful tsunami.

1855, July 11, 04:15. A magnitude 6.3 earthquake at Los Angeles at 8:00 P.M. caused movement of water at **San Juan Capistrano**. Two large waves surged on shore at **Point San Juan** after the last of four shocks. (Toppozada et al. 1981, Soloviev and Go, 1975, p. 204; McCulloch, 1985; Iida et al., 1967; Townley and Allen, 1939; Joy, 1968)

1855, October 21. A strong earthquake at **San Francisco** at 7:45 P.M. was preceded by several minutes of much commotion in the water of the bay. Ships riding at anchor were reportedly dragged by a current before the shocks. This is a doubtful tsunami. (Soloviev and Go, 1975, p. 204; Townley and Allen, 1939)

1856, February 15, 13:25. A magnitude 5.5 earthquake at 5:25 A.M. at San Francisco caused the water in **San Francisco Bay** to rise, keep a high level for 5 minutes, then fall 0.6 m below normal level. (Toppozada et al. 1981, Soloviev and Go, 1975; p. 204; Iida et al., 1967; Townley and Allen, 1939)

1856, August 23. A magnitude 7.8 earthquake off the coast of Japan produced a 3.5 m tsunami in Japan that washed away 93 houses and drowned 26 people in Japan. It was recorded on the **coast of California**. (McCulloch, 1985; Agnew, 1979; Joy, 1968)

A note was published in the *West American Scientist*, Vol. 2, page 62, 1886 which is quoted here in its entirety: "Mr. S. Haley, of Los Angeles, who was Captain of the *Sea-bird* in 1856, mentions the occurrence in that year of an earthquake in Japan which caused a tidal wave that in less than three days struck the **California coast**, destroying twenty-six vessels along our shores. The waters of **San Diego bay** rose over twelve feet above high-water mark." This report was made thirty years after the event. The 1856 tsunami was not reported observed in Hawaii, and it is doubtful that it could have had such an effect on the West Coast. This could be an exaggerated report, and/or an erroneous date.

1859, September 24. An earthquake at 3:00 A.M. at **San Francisco** and **Half Moon Bay** caused the water in the bay to retreat beaching the schooner, *Black Warrior*, which was later damaged with the rapid return of the water. **Half Moon Bay** reported that water receded 4.6 m and returned suddenly, but Iida et al. (1967) suggested that this distance may be exaggerated, and that the event may not be a local one but a report of the October 5 Chilean tsunami. A date of October 18 and a time of 6:00 A.M. is given by Perrey. (Soloviev and Go, 1975, p. 204; Iida et al., 1967; McCulloch, 1985; Townley and Allen, 1939) Townley and Allen list as their source the *Sacramento Union* newspaper of September 28, 1859, and therefore, neither the October 5 or October 18 date is possible.

1861, May 4. A light shock was felt near **San Francisco**. It was noted during this week that the ebb tide dropped 30-45 cm below the lowest mark. May 5 is an alternate date for this event. (Toppozada et al., 1981, Soloviev and Go, 1975; p. 204, 205; Townley and Allen, 1939)

1862, May 27, 20:00. An magnitude 5.8 earthquake at San Diego caused a small tsunami in San Diego Bay. This event is the only locally generated tsunami that has affected **San Diego**. It was associated with an earthquake that caused the most intense shaking known in San Diego. The tide gage was being repaired at the time, and so there is no quantitative record of the event, but an eyewitness account by tidal observer Andrew Cassidy (1862) has been preserved. At the time of the earthquake, Cassidy was on the beach at La Playa. He wrote that: "The water in the Bay did not appear to be much agitated notwithstanding the sea runup on the beach between 3 and 4 feet (0.9 and 1.2 m), and immediately returned to its usual level." This probably refers to the horizontal distance along the beach; the wave height would have been much less. It is possible that one of the earthfalls noted by Cassidy along the bank might have generated the wave. (Toppozada et al., 1981, Agnew, 1979; McCulloch, 1985)

1865, October 8, 20:46. A destructive earthquake (magnitude 7.0) at 12:45 P.M. near **Santa Cruz** caused a high flood tide and then a strong ebb tide at the moment of the earthquake. Soloviev and Go (1975) report that the effect of the earthquake on the water of Mission Bay and on Long Bridge was terrifying. However, the location now called Mission Bay is in San Diego and far from the source region. The location of Long Bridge is also not known. Soloviev and Go (1975) incorrectly give the date as October 4. (Toppozada et al., 1981, Lawson et al., 1908; Townley and Allen, 1939; Soloviev and Go, 1975, p. 205)

1868, April 3, 02:24. A magnitude 7.5 earthquake in Hawaii generated a tsunami with waves up to 20 m high that washed away 108 houses and drowned 47 residents in Hawaii. On the West Coast it had an amplitude of 0.1 m at **San Diego** and an amplitude of <0.1 m at **San Francisco.** (McCulloch, 1985; Agnew, 1979; Joy, 1968)

1868, June 13? An earthquake-generated wave on the Pacific coast was reported in the *San Francisco Bulletin* of June 13, but there was no report of an earthquake. (Townley and Allen, 1939).

1868, August 13, 21:30. The magnitude 8.5 Arica, Peru, (now Chile) earthquakes occurring at about 4:45 and 8:45 P.M. local time on August 13 generated tsunamis that reached 21 m locally, killed more than 25,000, and destroyed several cities and settlements along the Peru-Chile coast. At Arica, Peru, the U.S.S. *Wateree* was carried 400 m inland and was abandoned. The earthquake generated waves on the Pacific coast of 0.3-m amplitude at **San Diego** and 0.2 m at **San Francisco** on August 14th. A runup of 18 to 21 m reported for **San Pedro** is considered by Gutenberg and Richter (1954) to be a mistake. Joy (1968) reports heights of 1.8 m at **San Pedro** and **Wilmington** on the basis of local newspapers, and these are more likely the correct heights. McCulloch (1985) lists tsunamis recorded at **San Diego** on August 13 with a height of 0.8 m (after Agnew, 1979) and on August 14 with a height of 0.3 m (after Iida et al., 1967). This probably represents a single recording with confusion between origin date and observation date and between range and amplitude. (Iida et al., 1967; McCulloch, 1985; Soloviev and Go, 1974, p. 90)

1868, October 21, 15:53. At about 7:53 A.M. a magnitude 7.0 destructive earthquake on the Hayward fault produced a fault scarp 32 km long with about 0.9 m horizontal offset and apparently a slight downthrow. It caused the following effects at sea. Two sailors in a small boat were rowing between Cape Fort and Mill House toward **San Francisco Bay**. Suddenly the water trembled, and its surface rippled; at the same time, a booming rumble was heard from the depths. Three high waves appeared on the previously calm surface of the water and fell on the boat and broke on shore. A tide gage on **Government Island** registered an unusual rise of water, but none was noticed on the gage at Cape Fort nor was a rise of water reported by other vessels in the harbor. Lawson et al., 1908, (p. 438) report "At Cliff House nothing unusual took place with the exception of a decided commotion in the ocean and an impetus given to an everyday wave which sent it well inland, say 15-20 feet (4.6 to 6.1 m) above the usual mark." Later Lawson et al. report that a tidal wave did not accompany the earthquake. At **Santa Cruz** the water rushed up river against the current 2 or 3 seconds after the shock. (Toppozada et al., 1981, Soloviev and Go, 1975 p. 205, 206; Lawson et al., 1908)

1869, February 13. A light shock at 4:30 A.M. at San Francisco was recorded on the **Fort Hornet** tide gage. (Soloviev and Go, 1975, p. 207)

1869, June 2. Papers speak of recent earthquakes at Santa Cruz and Gilroy and that earthquake waves were recorded by the **Fort Point** tide gage. (Townley and Allen, 1939).

1872, August 23, 18:02. A tsunami generated by an earthquake in the Fox Islands, Aleutian Islands, was recorded at **San Diego**, and **San Francisco**, **California**, and **Astoria, Oregon**, but not in Alaska. Cox (1984) was able to determine the source of the tsunami using time differences of the arrival of the tsunami at the West Coast gages and at Hawaii. This is the earliest instrumentally located earthquake. The amplitude at all three stations was less than 0.1 m. (McCulloch, 1985; Soloviev and Go, 1975, p. 207; Cox, 1984a Joy, 1968)

1872, September 16. Oscillations of the tsunami type were recorded at **Astoria**, **San Francisco**, and **San Diego**. They were possibly caused by an aftershock of the above earthquake 1885 or by another remote source. (Soloviev and Go, 1975, p. 207)

1877, April 16. At 6:00 A.M. a minor earthquake in San Luis Obispo Bay may have generated a tsunami that was observed to be 3.6 m high at **Cayucos** and **Anaheim Landing**. The event may have been confused with the Chilean tsunami of May 10, 1877. (Soloviev and Go, 1975, p. 207; Joy, 1968) Soloviev and Go (1975) give the date as April 19, but cite only Joy (1968) as their source who gives the April 16 date, referencing Angel (1883).

1877, May 10, 00:59. A magnitude 8.3 earthquake in Chile produced a 24-m tsunami that caused extensive damage along the Peru-Chile coast. The tsunami also produced fatalities in Hawaii and Japan. Six waves with amplitudes of 0.2 m were recorded at **San Francisco**, 1-m waves were reported at **Wilmington** and **San Pedro** (suburbs of Los Angeles), and three waves were recorded at **Gaviota** with a maximum rise of 3.7 m. (McCulloch, 1985; Iida et al., 1967; Soloviev and Go, 1975, p. 108, 117; Joy, 1968)

1878, January 15. Cox and Morgan (1977) discuss observations of a tsunami in Hawaii on January 20, 1878 that they believe originated in the Aleutian Islands. They mention an item from the *Pacific Commercial Advertiser* (February 2, 1878) containing a report from San Francisco concerning "a great tidal wave" or extraordinary swell" that was observed "five days earlier" (January 15th?) at Los Angeles. According to the report the wave destroyed or badly damaged wharves at **Carpinteria, More's Landing, Ventura,** and **Santa Barbara.**

In the *San Diego Union* newspaper edition of January 16, 1878, an article entitled "The Storm," reports that beginning about 6:00 P.M. at San Buenaventura (now Ventura) heavy swells began striking the wharves strongly and, at times, was overtopping it. At about 9:00 A.M. the outer 90 meters of the wharf gave way. It was the third time in a year that the wharf had been destroyed. There was heavy rain and wind over large parts of the state. The wharves at Carpentaria, 19 to 24 km east of Santa Barbara, and at More's Landing, 11 km west of Santa Barbara, were also destroyed. At Santa Barbara an old wharf was destroyed and its debris damaged 60 m of the new wharf. There is little doubt that these were meteorologically generated waves and are a possible source for the waves observed in Hawaii five days later.

1878, November 22. A wave 2 m high was reported at **Wilmington.** Waves did some damage in **San Luis Obispo Bay, Surf, Sal Cape, Port Harford(?), Pismo Beach, Avila, Morro Bay, and Cayucos.** (Soloviev and Go, 1975, p. 207; Angel, 1883). Joy (1968) believes this to be a misdated report for the May 10, 1877, or August 13, 1868, tsunamis. An earthquake was not reported in California on this date.

1879, August 10. A strong shock at San Fernando at 1:15 P.M., and a minor shock at Los Angeles generated a tsunami at **Santa Monica.** Details are not available. (Soloviev and Go, 1975, p. 207; McCulloch, 1985; Iida et al., 1967; Townley and Allen, 1939; Joy, 1968)

1883, August 27, 02:59. The explosion of the Krakatau volcano in Indonesia generated a 30-m tsunami in the Sunda Strait that destroyed all the towns and villages and killed 36,000 people. The explosion was heard 4,800 km away. It also caused an atmospheric pressure wave that was recorded on the tide record with a <0.1-m amplitude at **San Francisco.** (McCulloch, 1985; Iida et al., 1967; Soloviev and Go, 1974, p. 255; Joy, 1968)

1884, January 25. A local tsunami was reported to have occurred on the coast near San Francisco. This is an error and relates to long-period earthquake waves from a remote source recorded on instruments at the Astronomic Observatory at San Francisco. (Soloviev and Go, 1975, p. 207; Townley and Allen, 1939)

1884, November 12. The tide gage at **Sausalito (San Francisco Bay)** recorded movements of the water from 8:00 until 11:00 A.M. with a height of 0.1 m. The water movements may have been caused by an underwater earthquake. (Soloviev and Go, 1975, p. 209)

1885, November 19. The record of the tide gage at **San Francisco** from 1:00 to 8:00 P.M. shows waves with a period of about 35 minutes apparently from a remote earthquake. (Soloviev and Go, 1975, p. 209; McCulloch, 1985; Iida et al., 1967) This event may also be related to the storm-related flooding described below.

1885, November 24. A tide at about 11:00 A.M. was reportedly 0.2 to 0.3 m higher than any measured since **Eureka** was settled. At about 11:00 A.M. wind that had been blowing steadily and hard for several days stopped just before the sea began to rise. At about 12:00 noon, water began to pour into the foot of First, Second, Third, and Fourth Streets flooding many houses. Warehouses were flooded, destroying 32 tons of salt. Two feet of water flooded Vance's mill and people in low-lying areas were forced to evacuate. Damage to the Eel River and Eureka Railroad was estimated to be $20,000. (*Humboldt Beacon*) At Crescent City an unusually high gale had been blowing for several days, and it was near full moon. Tides were higher than normal. Much damage was done to the wharf, and many houses were flooded. A log 75 cm across and 9 m long was washed inside a saloon. The above description was compiled from an article by Evelyn McCormick in the *Humboldt Historian*, November-December 1985 and from transcripts she provided from the *Daily Times-Telephone* of Eureka, the *Weekly Times* of Eureka, and the *Humboldt Standard* of Eureka. The description seems to be related to high tides and a storm surge rather than a tsunami, although a series of minor earth tremors occurred in the area in the middle of November.

1887, July 8. Distinct waves (possibly caused by an earthquake) were recorded by the Coast Guard at **Sausalito** between 4:00 and 7:30 P.M. (Soloviev and Go, 1975, p. 209) Townley and Allen (1939) report that a sharp but minor earthquake was recorded at 10:15 P.M. on July 6 at Mount Hamilton. These two reports may refer to the same event with an error in date and time in one of the reports.

1895, March 30. Joy (1968) lists as a dubious local tsunami report a sensational newspaper account of uplift of 18 m on March 8 and other effects on **San Miguel Island** near Santa Barbara. The dateline of the article was March 10. On March 30 another disturbance (landslide?) occurred that wrecked a small schooner there. A third disturbance occurred on nearby Flag Island in July. (Townley and Allen, 1939; Joy, 1968)

1895, October 14. A local tsunami or heavy storm waves reportedly occurred on the northern California coast. The tide gage record at **Sausalito** showed irregularities for 18 hours. (Soloviev and Go, 1975, p. 209)

1896, June 15, 10:33. The great Sanriku earthquake in Japan (magnitude 7.6) produced a tsunami of 38.2-m height at Sherahama, Ryori Bay. The earthquake and tsunami destroyed more than 11,000 houses and killed more than 26,000 people. (Iida, 1984) A wave of 0.08-m amplitude was recorded at **Sausalito** near **San Francisco**. At **Santa Cruz** a 1.5-m wave destroyed the protective dike. The wave rose far upriver and did severe damage to a ship moored to the pier. (Soloviev and Go, 1974, p. 83; McCulloch, 1985; Iida et al. 1967; Davison, 1936)

1896, December 17. There are numerous reports that at **Santa Barbara**, a "tidal wave", the strongest in the entire history of the city, surged on the coastal boulevard and washed away a section of the embankment and the thoroughfare. The waves washed away the asphalt covering, the solid masonry, and the iron frame with a total area of 4.5 m^2 and a depth of 2.5 m. A large sandy hill was washed out to sea. (Soloviev and Go, 1975, p. 209; Iida et al., 1967; Joy, 1968) However, an account of this same event in the December 17, 1896, edition of the *Daily Independent* of Santa Barbara indicated that the erosion was caused by an abnormally high tide: "The flood tide this morning was one of the highest ever known in this city, and the boulevard suffered considerable damage... The tide will be unusually high for the rest of the week." (McCulloch, 1985) This is a meteorological and tidal event, not a tsunami.

1899, December 25, 12:25. A magnitude 7.0 earthquake in southern California apparently was caused by a shift along the San Jacinto fault on its highest mountainous section, several kilometers southeast of San Jacinto, where many large cave-ins occurred. A large wave broke on the sea coast without doing any damage. The San Jacinto fault is about 75 km inland and could not have generated the tsunami directly. The wave, if it is related to the earthquake, would have to be due to seiche or a submarine landslide. (Soloviev and Go, 1975, p. 213, 214)

1902, February 26. An earthquake-generated tsunami in El Salvador-Guatemala produced much damage and 185 deaths. The wave was also observed in **San Diego**. Details are not available. (McCulloch, 1985; Iida et al., 1967; Soloviev and Go, 1975, p. 185-186) There were strong earthquakes on January 18 and on February 26. This latter event seems to be the only one that caused a tsunami. A magnitude 8.3 event on April 18 caused the coast in the region of Ocos, Mexico, to subside 1 m. A mistaken year of 1912 and dates of February 2 and 21 appear in the literature.

1904, March 30. An earthquake in the State of Washington caused water to rise in **Grays Harbor** and in the mouths of the **Queets, Quinault, Wishkah** and **Hoh Rivers.** (Soloviev and Go, 1975, p. 214) This description possibly refers to the strong earthquake at Vancouver on March 16, 1904, which was widely felt in western Washington.

1906, January 31, 15:36. A magnitude 8.2 earthquake off the coast of Ecuador produced a 5-m local tsunami that destroyed 49 houses and killed 500 people in Colombia. It was recorded at **San Diego** and **San Francisco.** (McCulloch, 1985; Iida et al., 1967; Agnew, 1979; Joy, 1968)

1906, April 18, 13:12. A catastrophic earthquake (magnitude 7.8) destroyed San Francisco. Everywhere on the high steep coast from Mendocino Cape to Cabo Delgade, on a stretch of many kilometers, slopes collapsed into the sea. On the lower coast between Shelter Cove and Point Arena, bedrocks and loose material slipped into the sea, and the water was turbid for several days after the quake. At **San Francisco**, a tide gage, located 3 km east of Cape Fort, registered a drop in water level of a little more than 10 cm 9 minutes after the earthquake. The period of the oscillations was 16 minutes. This interval of time corresponds to the calculated time of travel of the tsunami from the underwater section of the San Andreas fault between Bolinas Bay and Mussel Rock. There were no traces of vertical displacement of the flanks of the fault south of Mussel Rock. In the region of Bolinas Bay and to the north, the eastern flank subsided 0.3-0.6 m. Apparently, one of the flanks of the fault subsided slightly under the water as well. After this disturbance, the tide gage record shows oscillations with a period of about 40 minutes, which is equal to the period of the transverse seiches of **San Francisco Bay**. One report noted that a change in sea level after the earthquake was noticed visually. In the mouth of the **Navarro River**, situated between Albion and Point Arena, several minutes after the earthquake, a section of low-lying flat coast, 4 hectares (10 acres) in area was flooded according to a second-hand report. (Toppozada et al. 1981, Soloviev and Go, 1975, p. 214; Lawson, et al., 1908; Iida et al., 1967)

1906, August 17, 00:40. The Valparaiso, Chile, earthquake (magnitude 8.6) generated a 1.5-m tsunami that was locally damaging and caused damage in Hawaii. It produced a wave of 0.1-m height at **San Diego** and an 0.04 m wave at **San Francisco.** A second great earthquake occurred 30 minutes earlier in the Aleutian Islands but did not generate an observable wave at San Francisco. The travel times show that the tsunami recorded came from the Chile source. (Richter, 1958; McCulloch, 1985; Iida et al., 1967; Soloviev and Go, 1974, p. 128; McAdie, 1907)

1906, November 6. The American Schooner *Stanley*, situated at the center of a cyclone at 46° 9" N, 125° 32" W felt a sudden shock at 8:00 A.M. which lasted 2 to 3 seconds. Soon afterward, the captain saw three mountainous waves approaching from the southwest. When they fell on the ship, the schooner began to pitch and roll violently; its bow dipped into the water, and the ship almost sank. The dangerous seas lasted one hour and 30 minutes. (Soloviev and Go, 1975, p. 216; McAdie, 1907; Lawson, et al., 1908, p. 373). These were probably meteorological waves.

1910, November 21. The tide gage at **San Francisco** registered tsunami-like waves beginning between 4:00 and 5:00 A.M. but they were of meteorological origin, hypothetically caused by a rapid drop in pressure of 2 mm over a period of one hour and a rapid rise by the same amount and period of time. (Soloviev and Go, 1975, p. 217)

1917, May 1, 18:27. A magnitude 8.0 earthquake in the Kermadec Islands located in the south Pacific produced a 12-m tsunami in the Samoa Islands according to Heck (1947). Pararas-Carayannis and Dong (1980) do not mention a tsunami observed in Samoa in May. Iida et al. (1967) state that the Samoa report was confused with the June 26th tsunami. However, a reexamination of the marigrams at Honolulu and San Francisco reveals that both recorded the event clearly and at the expected time. The waves were well defined at **San Francisco** and **La Jolla**. (McCulloch, 1985; Agnew, 1979; Iida et al., 1967; Soloviev and Go, 1975, p. 10-11; Heck, 1947; Joy, 1968)

1917, June 26, 05:50. A magnitude 8.3 earthquake in the Tonga Islands produced a 12-m tsunami in Samoa and destroyed several villages. The tsunami was recorded on the west coast of the United States. (McCulloch, 1985; Soloviev and Go, 1975, p. 11; Agnew, 1979; Iida et al., 1967; Joy, 1968)

1918, September 7, 17:16. A magnitude 8.3 earthquake in the south Kuril Islands, USSR, produced a 12-m local tsunami that caused damage in the Kuril Islands and in Japan, and it killed 24 people. It was observed in **San Francisco**. (McCulloch, 1985; Iida et al., 1967; Agnew 1979; Soloviev and Ferchev, 1961; Joy, 1968)

1919, April 30, 07:17. A magnitude 8.3 earthquake in the Tonga Islands produced a tsunami that had a maximum wave height of 2.5 m locally and was recorded **at San Francisco** and **San Diego**. (McCulloch, 1985; Iida et al., 1967; Agnew, 1979; Soloviev and Go, 1975, p. 13; Joy, 1968)

1922, November 11, 04:33. A magnitude 8.3 earthquake in north-central Chile produced a 9-m local tsunami that inundated parts of several Chilean cities and killed more than 100 people. It was recorded with 0.2 m at **San Diego** and 0.3 m at **San Francisco**. (McCulloch, 1985; Soloviev and Go, 1975, p. 135-136; Iida et al., 1967; Agnew, 1979; Joy, 1968)

1923, Jaunary 22, 09:04. A magnitude 7.2 earthquake offshore of **Cape Mendocino, California**, produced a tsunami that was recorded with an amplitude of 0.02 to 0.03 m. (Toppozada et al. 1981, Marine Advisers, 1965; McCulloch, 1985)

1923, February 3, 16:01. A magnitude 8.3 earthquake off the east coast of Kamchatka, USSR, generated an 8-m tsunami that caused damage in Kamchatka and in Hawaii. A 0.2-m wave was recorded at **San Diego** and a 0.1-m wave was recorded at **San Francisco**. (McCulloch, 1985; Iida et al., 1967; Agnew, 1979; Joy, 1968)

1923, April 13, 15:30. A magnitude 7.2 earthquake off the east coast of Kamchatka generated a 20-m wave that caused some damage on Kamchatka and on the east coast of Korea. A wave of 0.1-m height was recorded at **San Diego**, and a 0.2-m wave was recorded at **San Francisco**. (McCulloch, 1985; Iida et al., 1967; Agnew, 1979; Joy, 1968) Soloviev and Ferchev (1961) report that several vessels were set adrift in **Los Angeles**' harbor.

1923, September. A sudden rise of water in California resulted in destruction at **Jose de Cado**. (Soloviev and Go, 1975, p. 217) This location is not listed in available gazetteers. This probably refers to San Jose del Cabo, Baja California, Mexico. Wave is of possible meteorological origin or from the Kanto, Japan, earthquake and tsunami of September 1.

1925, October 4. A wave beginning at 4:15 A.M. of possible meteorological origin was

(1925, October 4, continued)
measured at 0.34 m at **Long Beach**. It was also observed at Hawaii. A small and poorly located earthquake occurred at 03:45 at 10°N, 103°W (ISS, 1925, p. 256) or at 03:44 at 0.5°N, 106°W (Neumann, 1926) on the East Pacific Rise. The expected arrival times for waves originating from these locations would be respectively three hours and two hours earlier than the reported time at **Long Beach**. However, a submarine volcanic source may be possible. (McCulloch, 1985; Soloviev and Go, 1975, p. 217; Iida et al., 1967)

1927, January 1, 08:17. A magnitude 5.7 earthquake occurred in the Imperial Valley on the border of the USA and Mexico. An aftershock with about the same magnitude occurred 57 minutes later and was followed by a multitude of aftershocks. Montandon (1928) adds the following to his description of this earthquake: "At **San Pedro**, the port of Los Angeles, sea waves carried off part of the new embankment; the damage was estimated at 3 million dollars." (Toppozada et al., 1981; Soloviev and Go, 1975, p. 217) Since the Imperial Valley is about 150 km from the coast and 225 km from San Pedro, and since the earthquake was of moderate size, it could not have directly caused a tsunami. If these reports are related, then the wave must have come from seiches or a submarine landslide.

1927, November 4, 13:51. A magnitude 7.3 earthquake occurred on the edge of the shelf on the northern boundary of the Murray fault zone. A tsunami arose which was observed on the coast of California and was registered on the Hawaiian Islands. A Southern Pacific employee from **Surf** reported a wave about 1.8 m high, which began with the crest. A railroad employee at **Port San Luis** (Avila) observed a fall and rise in water level of 1.5 m followed by oscillations in level for an hour. According to the lighthouse attendant in the same port, a 1.2-m rise occurred, followed by a similar drop, without subsequent substantial oscillations. An observer at **Pismo Beach** compared the tsunami with large storm waves. The tsunami was registered by the tide gages at **Fort Point, San Francisco, San Diego,** and **La Jolla.** On the **Fort Point** record, the oscillations began with a slow drop in level at 7:00 A.M. Then more rapid oscillations began with a period of about 15 minutes and maximum amplitudes of 2 cm. The sign of the first onset of the tsunami of the record at **La Jolla** is not definite. The oscillations had a period of 15 minutes, a maximum amplitude of 3 cm, and lasted about 13 hours. (Toppozada et al., 1981; Soloviev and Go, 1975, p. 219, 220) This is perhaps the best documented and authenticated locally generated tsunami ever to occur on the West Coast. (Marine Advisers, 1965; Byerly, 1930; Iida et al., 1967; Joy, 1968; McCulloch, 1985)

1928, June 17, 03:19. A magnitude 7.8 earthquake off the coast of southern Mexico generated a tsunami that caused minor damage locally and killed 4 people. The wave that was recorded with a 0.1-m height at **La Jolla** and <0.1 m at **San Francisco.** (McCulloch, 1985; Soloviev and Go, 1975, p. 190; Iida et al., 1967)

1930, August 31, 00:41. A magnitude 5.2 earthquake in Santa Monica Bay generated a tsunami with an amplitude of 0.6 m at **Santa Monica**. It was possibly a seiche or a landslide-generated tsunami. The epicenter was 71 km from Redondo submarine canyon. (McCulloch, 1985; Soloviev and Go, 1975, p. 220; Joy, 1968)

1931, October 3, 19:13. A magnitude 7.9 earthquake in the Solomon Islands generated a 9-m tsunami locally that was also recorded at **Santa Barbara** and doubtfully recorded at **San Diego**. (McCulloch, 1985; Iida et al., 1967; Soloviev and Go, 1974, p. 308; Joy, 1968)

1933, March 2, 17:31. The magnitude 8.3 Sanriku, Japan, earthquake generated tsunami runups of as much as 29 m, destroyed 5,851 structures in Japan, and 3,064 people were killed or missing. It was measured with a 0.2 m height at **San Francisco** and **Los Angeles**, and with less height at **Santa Monica** and **La Jolla**. (McCulloch, 1985; Iida et al., 1967; Joy, 1968)

1933, March 11, 01:54. The 6.3 magnitude earthquake at **Long Beach** was reported to have been accompanied by a tsunami. The waves had an amplitude of 10 cm and a period of 19 minutes and were observed in the **Long Beach** region, but these data may be unreliable. Joy (1968) states that there was ground motion recorded on the tide gage. There was a questionable recording at **La Jolla.** (Marine Advisers, 1965; Soloviev and Go, 1975, p. 220; McCulloch, 1985) Records are uncertain according to Iida et al. (1967).

1934, August 21. "Enormous waves rolled onto the coast of **California** from **Malibu Beach** to **Laguna Beach.** At **Newport Beach,** waves reached a height of 9-12 m. The crests rolled 270 m inland, that is, 3 m above ordinary tides. Part of the city was flooded to a depth of a meter. Many houses were damaged. Four people were trapped at the entrance to the harbor at the western pier and were injured. Debris weighing thousands of tons was tossed onshore. Waves flooded the moorage at **Balboa** and detached a two-story, 25 room home from its foundations. The residents took to the streets screaming. Part of the pavement on the central avenue connecting the rich quarters, situated on **Balboa Peninsula,** with the center of the city, was washed away, and the residents of this region found themselves isolated for a time. Tidal waves were observed at 25 minute intervals. At the time, an earthquake with an intensity of 3 degrees was recorded." At **Long Beach** on the same day, or later on September 5, the outer part of the breakwater, with a large dance hall was destroyed. The earthquake was not felt anywhere except at **Balboa.** There was no wind, and the cause of the waves is unknown. (Soloviev and Go, 1975, p. 221) The earthquake is not mentioned in *United States Earthquakes,* 1934, or in Hileman et al., 1973. (Heck, 1947; Neumann, 1936; Hileman, et al., 1973) The waves were probably meteorological in origin.

1938, March 22, 15:22. A magnitude 6.3 earthquake off the coast of Queen Charlotte Islands, British Columbia, Canada, was recorded weakly at Santa Monica (Neumann, 1940). Iida et al. (1967) carry this as a doubtful tsunami, partly because they mistakenly list the arrival time as 3:00 which was derived from Neumann's reported travel time of 3 hours. Cox (1982b) examined the marigram for **Santa Monica** and found small oscillations similar to those on the marigrams from San Francisco and Honolulu, and found similar oscillations not distinguishable from background. He concludes that a tsunami was not generated. (Cox, 1982b, Soloviev and Go, 1975, p. 223)

1938, May 19, 17:08. An earthquake of magnitude 7.6 generated a 2- to 3-m tsunami in the Strait of Macassar, Indonesia, that caused some damage locally and killed 16 people. It reportedly (McCulloch, 1985) generated a wave with a height of less than 0.1 m at Santa Monica. Cox (1982a) believes that the record "represents no more than the normal background at Santa Monica" and could not find evidence of a tsunami from the marigrams of San Francisco, San Diego, Honolulu, or King Cove (Unalaska). (Cox, 1982a; Iida et al., 1967)

1938, November 10, 20:19. A magnitude 8.3 earthquake at Shumagin Islands, Alaskan Peninsula, was observed weakly in Alaska and Hawaii as well as at **Santa Monica.** (McCulloch, 1985; Iida et al., 1967)

1941, February 9, 09:44. A magnitude 6.6 earthquake occurred off the coast of northern California. There was an overall intensification of seiches in the harbor 14 hours later in San Francisco and San Diego; 36 hours later, the same occurred at Port Hueneme. There were no changes at La Jolla. (Soloviev and Go, 1975, p. 224; Marine Advisers, 1965) The length of time that elapsed between the earthquake and the seiche activity makes it unlikely that the seiches were associated with this earthquake. In any case it is not a tsunami.

1943, April 6, 16:07. A magnitude 8.3 earthquake north of Santiago, Chile, generated a small tsunami that was damaging locally. It was registered with heights of 0.1 m at **San Diego** and **Terminal Island, California.** (Soloviev and Go, 1974, p. 148; Iida et al., 1967; Joy, 1968)

1944, April 8 to August 19, 1953. Landslides occurred in terrace scarps underlain by bedded unconsolidated deposits in the Reed Terrace area near Kettle Falls, Columbia River Valley, Washington. Narrow

(1944, April 8 to August 19, 1953, cont.)
segments of the scarp on slopes averaging about 23° suddenly gave way and slid into **Franklin D. Roosevelt Lake**. Debris came down from a maximum height of 63.6 m above water. Waves were generated by at least 11 different slides; the largest wave rose to a maximum height of 19.7 m on the opposite shore and was observed 10 km up the lake where boats and barges broke loose from the dock. Observed velocity of one series of waves was about 75 km per hour. (Miller, 1960, p. 66)

1944, December 7, 04:35. A magnitude 8.0 earthquake near Honshu, Japan, produced a 10-m wave that destroyed more than 3,000 houses and killed nearly 1,000 people in Japan. It was recorded with an amplitude of less than 0.1-m at **San Diego** and **Terminal Island**. (McCulloch, 1985; Iida et al., 1967; Joy, 1968)

1946, April 1, 12:29. A magnitude 7.8 earthquake in the Aleutian Islands generated a 30-m tsunami on Unimak Island that destroyed Scotch Cap Lighthouse. In California the tsunami caused a rise above normal tides of, 2.6 m at **Half Moon Bay**, 2.6 m at **Bolinas**, 2.4 m at **Arena Cove**, 1.5 m at **Morro Bay**, 1.5 m at **Santa Cruz**, 1.4 m at **Noyo**, 1.3 m at **San Luis Obispo**, and 1.2-m rise at **Avila**. The *Santa Cruz Sentinel* reports confirm the unusual heights at **Santa Cruz**, and at **Half Moon Bay, California**. At **Charleston, Oregon**, near **Coos Bay**, 3 meter waves were observed, and 1.8 m waves were observed at **Clatsop Spit, Oregon**, at the mouth of the Columbia River. The wave was 1.5 m at **Newport** and 1.0 m (range) at **Siuslaw River**. Other localities reported runups of less than 1.0 m.

At **Noyo River, California**, 100 fishing boats were thrown 1.8 m up bank. At **Half Moon Bay** where $1,000 in damage occurred waves swept into the unoccupied Coast Guard barracks loosening the building from its foundation. A house was flooded to the window sills (figs. 52 and 53). At nearby **Princeton** huge boulders weighing up to 70 kilograms were washed as far as the highway and some residences were flooded. Water was about 1 m deep on the road. A shack had a wall cave in, and it was moved 0.6 m from its foundation. Also, at nearby **Granada** a 10 m boat was washed onto the highway. At **Bolinas, California**, just north of the entrance to San Francisco Bay, a Coast Guard dock was loosened and part of a wooden wharf was broken. A small island was submerged. Several row boats were capsized and sunk. At **San Luis Obispo, California**,

FIGURE 52.—Photo by Howard Anderson shows water height of 14.8 ft (4.5 m) at Half Moon Bay, California after the tsunami of April 1, 1946. High water reached window sills. Photo Credit: Magoon Private Collection.

FIGURE 53.—Photo by Howard Anderson shows water receding at Half Moon Bay, California, after the tsunami of April 1, 1946. Photo Credit: Magoon Private Collection.

a tanker tore loose from its mooring, but, as it had its power up, it steamed away to safety. At **San Pedro, California**, one tender and two cargo vessels broke their moorings. At **Santa Cruz, California**, cars were pushed into houses, and garages, chicken houses, and cow sheds were swept inland. An 8 m boat was swept off the beach 300 m into the lagoon. Two boats were washed across the highway leading to the army post at Pillar Point. Two men were walking on Cowell's Beach at **Santa Cruz** when a large wave hit them washing one off his feet. A second wave tore him from his companion's grasp and washed him out to sea. (*San Francisco Chronicle*, April 2, 1946; Davies, April 2, 1946; McCulloch, 1985; Iida et al., 1967; Soloviev and Go, 1974, p. 23; Joy, 1968; O'Brien, 1946). The destruction caused by this tsunami in Hawaii led to the creation of the Pacific Tsunami Warning System.

1946, December 20, 19:19. A magnitude 8.1 earthquake at Nankaido, Japan, generated a 6-m wave that swept 1,400 houses out to sea and killed about 2,000 people. Wave heights of 0.2 m at **Crescent City** and less than 0.1 m at **San Francisco** were recorded. (McCulloch, 1985; Iida et al., 1967)

1949, July 27. A landslide occurred in a terrace scarp underlain by bedded unconsolidated deposits near the mouth of Hawk Creek near Lincoln, Columbia River Valley, Washington. A narrow segment of the scarp on a slope averaging about 31° suddenly gave way and slid into the lake. Debris came down from a maximum height of 103 m above the level of **Franklin D. Roosevelt Lake.** A wave rose 19.7 m on shore opposite the slide. (Miller, 1960, p. 66)

1951, February 23. A debris slide in bedded unconsolidated deposits and talus on the east side of the Columbia River Valley north of Kettle Falls, Washington, fell from a maximum height of several hundred meters above the level of **Franklin D. Roosevelt Lake.** A wave was generated, but no height was recorded. (Miller, 1960, p. 66)

1952, March 4, 01:23. A magnitude 8.1 earthquake on Hokkaido Island, Japan, produced a 6-m tsunami that swept away 90 houses and 448 vessels. It killed 33 people in Japan. On the West Coast it produced a tsunami of 0.4 m at **Los Angeles** and 0.3 m at **San Francisco** and lower readings elsewhere. (McCulloch, 1985; Iida et al., 1967)

1952, November 4, 16:58. A magnitude 8.2 earthquake off the east coast of Kamchatka generated 13-m waves locally. In California the amplitude of the wave was 1.4 m at **Avila**, 1.0 m at **Crescent City**, and less than 1 m elsewhere on the West Coast. (McCulloch, 1985; Spaeth and Berkman, 1972; Iida et al., 1967; Zerbe, 1953; Joy, 1968)

1956, March 30, 06:11. A gigantic explosion of Bezymianny volcano on Kamchatka, USSR, produced a shock wave or air wave that struck the coastal waters of Kamchatka. It created a tsunami or air wave that was widely recorded, including a wave of 0.1 m at **Avila.** (McCulloch, 1985; Iida et al., 1967)

1957, March 9, 14:23. The tsunami generated in the Aleutian Islands by a magnitude 8.3 earthquake generated a 12-m tsunami on Unimak Island that caused minor damage locally, extensive damage in Hawaii, and some damage in Japan. At **San Diego** a surprising wall of water about 1 m high arrived at about 10:30 P.M. (about 9 hours after the first arrival) and swept in smashing a boat slip at Shelter Island. The wave had a velocity of about 46 km/hr in the harbor. It set adrift the former submarine chaser *Halcyon* and broke a 25 m boat loose from the pier and drove it into a small schooner, *Sea Starr*, on which a couple and two small children were sleeping. They were jarred but uninjured. The tide gage recorded only a 0.2 m wave (Salsman, 1959). It caused minor damage at **La Jolla.** The largest amplitude was 0.7 m at **Crescent City.** The tsunami was recorded at many places along the Pacific coast. (McCulloch, 1985; Iida et al., 1967; Salsman, 1959; Joy, 1968)

1958, November 6, 22:58. A magnitude 8.1 earthquake in the south Kuril Islands, USSR, produced a locally damaging 5.0-m tsunami, amplitudes of up to 5.0 m in Japan, and an amplitude of less than 0.1 m at **Port Hueneme** and 0.2 m at **San Francisco.** (McCulloch, 1985; Iida et al., 1967; Wiegel, 1970)

1960, May 22, 19:11. A magnitude 8.6 earthquake off the coast of Chile caused $550 million damage in Chile and 1,000 deaths;

(1960, May 22, continued)
about $24 million damage in Hawaii (oral communication, Hawaii Office of Civil Defense) and 61 deaths; $50 million damage in Japan and 199 deaths; and about $500,000 to $1,000,000 in damage on the west coast of the United States. Local runups measured as much as 25 m and runups in Japan were more than 6 m. The largest wave height in California was measured at the **Crescent City** tide gage was 1.7 m. Iida et al. (1967) give 3.7 m, but the tide gage as reproduced in Berkman and Symons (1964) gives the 1.7 m amplitude. Waves of 1.5 m were observed at **Stenson Beach**. The amplitude was more than 1.4 m at **Santa Monica.** The amplitude at **Port Hueneme** was 1.3 m and 1.2 m at **Pacifica.** The tsunami was recorded widely along the Pacific coast with amplitudes less than 1 m. Two vessels valued at $30,000 were lost at **Crescent City**. Major damage was reported in the **Los Angeles** and **Long Beach** harbors. An estimated 300 small craft were set adrift and about 30 sunk including a 24 m yacht which smashed into bridge piers partially disabling the bridge. The Yacht Center lost 235 boat landing slips and 110 more were destroyed at the Colonial Yacht Anchorage and the Cerritos Yacht Anchorage for a loss of $300,000. A skin diver, Raymond Stuart, was missing and presumed drowned at Cabrillo Beach, but no death certificate was found. In the harbor currents estimated to be 22 km/hr snapped and washed out pilings. Many thousands of liters of gasoline and oil spilled from the overturn of the boats prompting fears of a fire. Several buoys and navigational aids were swept away at **Terminal Island**. The Coast Guard landing including the tide gage was washed 5.6 km to sea but was rescued. A mess boy fell 6 m from the bridge of the first ship to attempt to leave the harbor the next day. The ship returned to harbor so his injuries could be treated at the hospital. The accident was blamed on rough seas.

At **San Diego**, ferry service was interrupted after one passenger-laden ferry smashed into the dock at Coronado knocking out eight pilings. A second ferry was forced 1.5 km off course and into a flotilla of anchored destroyers. More than 80 m of dock were destroyed. A 100 ton dredge rammed the concrete pilings supporting the Mission Bay bridge tearing out a 21 m section. A 45 m bait barge smashed eight slips at the Seaforth Landing before breaking in half and sinking. The currents swept 12 and 30 m floats from the San Diego Harbor Masters Pier on Shelter Island and swept away two sections of dockage at the Southwest Yacht Club at Point Loma.

At **Santa Monica** the water fell so low that the bottom of the breakwater was nearly exposed. Eight small craft snapped mooring lines but were taken in tow. One surge swept more than 91 m up the beach flooding a parking lot just off the Pacific Coast Highway.

At **Santa Barbara** a drifting oil exploration barge repeatedly rammed the new dredge causing at least $10,000 in damage. An additional $10,000 was done elsewhere including damage to 40 small craft set adrift there. (Soloviev and Go, 1975 p. 154; Iida et al., 1967; Talley and Cloud, 1962; Joy, 1968)

1963, October 13, 05:17. A magnitude 8.1 earthquake in the south Kuril Islands produced a 4-m wave locally. The tsunami had a height of 0.5 m at **Crescent City**. (McCulloch, 1985; Iida et al., 1967)

1964, March 28, 03:36. The Prince William Sound earthquake (magnitude 8.4) in the Gulf of Alaska generated a tsunami that caused $84 million in damage and 107 deaths in Alaska. Runups exceeded 16 m in Alaska. The damage in western Canada was about $10 million and on the west coast of the United States the damage was nearly $12 million. It caused less than $100,000 in damages in Hawaii and some damage and 26 deaths in Japan. It was the largest tsunami ever to hit the West Coast. The largest runups for California were: **Crescent City** (4.3 m), **Fort Bragg** (3.8 m range?), **Martins Beach** (3.0 m), **Capitola** (2.1 m), **Noyo** (2.0 m), **Humboldt Bay** (1.9 m), **Arena Cove** (1.8 m), **Santa Cruz** (1.5 m), **Avila** (1.6 m), **San Rafael** (1.5 m), **Moss Landing** (1.4 m), **Pacifica** (1.4 m), **Monterey** (1.4 m), **San Francisco** (1.1 m), **Tomales Bay** (1.0 m), and **Santa Monica** (1.0 m). The largest runups for Washington were: **Wreck Creek**

(4.5 m), **Sea View** (3.8 m), **Moclips** (3.4 m), **Ocean Shores** (2.9 m), **Cape Disappointment** (1.7 m), **Ilwaco** (1.4 m); and for Oregon: **Umpqua River** (4.3 m), **Siuslaw River** (3.7 m), **Nehalem River** (3.5 m), and **Coos Bay, Yaquina Bay** and **Depoe Bay** (3.5 m). Other areas on the West Coast reported runups of 1 m or less or did not report the amplitude of the runup. It was recorded 160 km up the Columbia River at **Vancouver, WA** with an amplitude of 2 cm. (McCulloch, 1985; Iida et al., 1967; Magoon, 1965; Wilson and Tørum, 1972)

The following account of this event is taken largely from Spaeth and Berkman (1972): Some damage was done on Lake Union, **Seattle, Washington**, by seiching caused by the earthquake vibration. The disturbance caused minor damage to the gangway of the USCGS Ship *Patton* and snapped a mooring line on the USCGS Ship *Lester Jones*. Minor damage was also caused to several pleasure craft, houseboats, and floats that broke their moorings.

Four bulletins were issued by the Honolulu Observatory during the tsunami. The first was received in most areas at 05:36 UTC (9:36 P.M., March 27, local time). The second was received at 06:42 UTC (10:42 P.M., March 27, local time). The warning bulletin (bulletin number three) was received around 7:13 UTC (11:13 P.M., March 27, local time), and the final bulletin advising that the emergency had ended was received around 11:30 UTC (3:30 P.M., March 28, local time).

Three of these bulletins were received by the Washington State Department of Civil Defense. At 06:42 UTC, the second advisory was received by the Washington State Department of Civil Defense, giving an estimated arrival time for Neah Bay of 07:30 UTC. By 07:18 UTC, all coastal counties had been advised that the tsunami warning had been received. Damage in Washington included the destruction of one small bridge at **Copalis**, one at **Boone Creek**, and one at **Joe Creek** (fig. 54), near Pacific Beach. At the **Wreck Creek** State Highway Bridge the approach fill material eroded and debris was deposited on the bridge deck and highway near that bridge. The total damage to bridges was $75,000. The Iron Springs Resort at **Boone Creek** had five hundred dollars damage. The town of **Copalis** incurred $5,000 in damage. About 1.6 km of ocean shore bulkhead was taken out at **Moclips**. Minor damage of $6,000 and $12,000, respectively, was reported to beach front

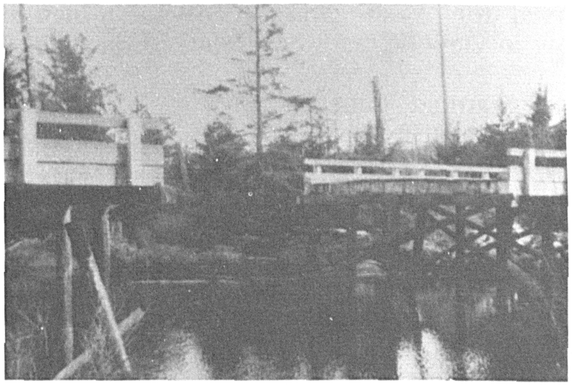


FIGURE 54.—Two spans and middle pile bent on bridge at Joe Creek, Washington, are lost due to the tsunami of March 28, 1964. Right side of bridge has been deflected from original position. Photo Credit: U.S. Department of the Interior.

houses at **Moclips** and **Pacific Beach**. Four mobile campers were overturned. A sheriff's car was lost in the **Ocean Shores** and **Pacific Beach** area. There were two injuries, a broken foot and an injured arm and two non-fatal heart attacks. (Spaeth and Berkman, 1972; Wilson and Tørum, 1972) At **Lapush** several boats and a floating dock broke loose from moorings, and the approach channel to United States Coast Guard boat house may have been decreased in depth due to the deposit of sediments. One boat was wrecked at **Westport**. At **Ocean Shores** debris was deposited in the streets in the vicinity of the Central Motel Office and on streets and yards in the vicinity of the breach in the sand dune dike. At **Taholah** several skiffs and fish nets valued at $1,000 were lost in the inlet at the mouth of Quinault River. Large logs commonly found on the shore contributed to the damage by acting as battering rams and added to the debris needing to be cleaned up. (Hogan et al., 1964)

The tsunami struck the outer coast of Washington between 07:15 UTC and 07:55 UTC. The acting director of the office of Emergency Services for Gray County, C. Tab

(1964, March 28, continued)
Murphy, reported one home totally destroyed, a second home partially destroyed and three houses with water damage, nine trailers damaged, and eight cars lost in **Grays Harbor County**. The total damage figure given for Washington of $104,500 may be low in view of the above reported damage.

The warning bulletin, filed at 06:37 UTC, was received by the Oregon State Civil Defense Agency at 07:00 UTC and immediately disseminated to the coastal areas. United States Coast Guard stations along the coast reported that the initial wave arrived between 07:30 UTC and 08:00 UTC. The Coast Guard stations reported heights ranging up to 4.3 m at **Umpqua River**, 3.7 m at **Siuslaw River**, and 3.0 to 3.5 m at **Nehalem River, Depoe Bay, Yaquina Bay**, and **Coos Bay**.

The Oregon State Civil Defense Agency reported that four children camping with their parents on **Depoe Beach** near **Newport** were crushed by logs moved by the unexpected high water. Damage estimates, supplied by Oregon State Civil Defense, are: Bandon, negligible; **Cannon Beach**, $230,000; Chetco, negligible; Coos Bay, negligible; **Depoe Bay**, $5,000; **Florence**, $50,000; Port Orford, negligible; **Rogue River**, $3,000; **Seaside** area, $276,000; Tillamook, negligible; **Umpqua**, $5,000; Warrenton, negligible; **Waldport-Alsea** area $160,000; and **Yaquina**, $5,000 for a total of about $734,000.

Much of the damage in Oregon occurred away from the ocean front. For example, in **Seaside**, all damage occurred along the banks of the Necanicum River and Neawanna Creek (fig. 55). At the north end of town, the wave overflowed the banks of Neawanna Creek, damaging four house trailers and 10 to 12 houses and washing out a railroad trestle over the creek. Along the Necanicum River, flooding occurred in the downtown section of **Seaside** in the area bounded by Broadway, Downing Street, Second Avenue, and the river. The Fourth Avenue Bridge was washed out, and the Avenue G Bridge was so badly damaged that it had to be closed. Logs and debris were scattered over all the

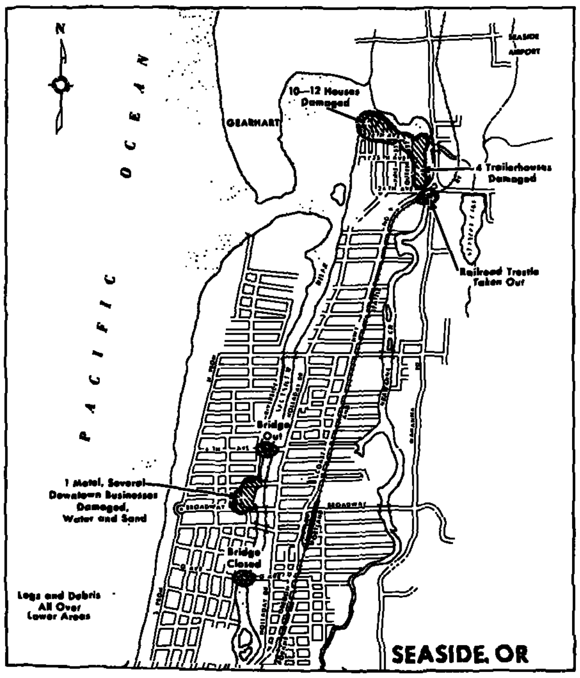


FIGURE 55.—The location of major damage at Seaside, Oregon, from the tsunami of March 28, 1964. Credit: Coast and Geodetic Survey Report.

low-lying areas. Schein (1988), an eyewitness of the event, reports: "The wave picked up giant logs and carried them upstream until they hit fixed objects, often a well-secured house. One log, probably 30 feet long and six to eight feet in diameter, had pushed a car onto its side against a single story house, caving in the wall. Some houses were lifted off their footings and set down nearby, while others had the front and back walls pushed out by the wave."

Much the same pattern of damage occurred at **Cannon Beach** where the wave penetrated up Elk Creek, washing out the old Highway 101 Bridge and damaging the new one. "Just north of downtown Cannon Beach, the main road into town crosses Ecola Creek and just beyond, a motel unit sat next to the bridge. These two structures were carried upstream 0.3 km and set in a pasture still near each other. Both were in one piece and upright." (Schein, 1988).

The *first advisory bulletin* issued by the Honolulu Observatory was received by the California Disaster Office at 05:36 UTC.

The second advisory was received at 06:44 UTC and disseminated via the California State Department of Justice Teletype System to all sheriffs, chiefs of police, and civil defense directors of coastal counties and cities at 07:03 UTC. The California Disaster Office received the warning at 07:13 UTC and relayed it to the coastal counties and cities at 07:25 UTC. Some discrepancy exists in these reported dissemination times, since all coastal jurisdictions reports stated that bulletin number 2 was received at 07:08 UTC, and the warning bulletin was received at 07:50 UTC.

The tsunami reached record heights along the coast of northern California and was disastrous at **Crescent City**. The large amplitude of the waves (4.3 m) at **Crescent City** was probably due to focusing caused by bottom topography. J.A. Roberts and Chen-Wu Chien (1964) have ascribed this focusing primarily to the topography in the area of Cobb Seamount, about 667 km northwest of Crescent City, and have prepared refraction diagrams to illustrate this theory.

California had a longer time to prepare for the onslaught of the tsunami than the other Pacific Coast States, but owing to much larger wave amplitudes and lack of proper response and knowledge among the public, the death and damage totals were much larger than at any other place, except Alaska. The California Disaster Office reported 11 killed (including one fatality at Klamath) and 35 injured (14 hospitalized) in **Crescent City**, and between $7,939,000 and $8,789,000 damage in the State. An additional $1 million in **Marin County**, which was not included in the California Disaster Office estimate, brought the total damage in California to about $10 million.

At **Crescent City** where the bulk of the damage occurred, the county sheriff immediately contacted county and city civil defense authorities upon receipt of the advisory at 07:08 UTC. The low-lying and coastal areas were warned, and evacuation began immediately. Evacuation was reasonably prompt but not complete. The first two waves caused minor flooding in the business district, and many people returned to the area to clean up their places of business. Since past experience showed that **Crescent City** normally experienced one or two surges with minor flooding during a tsunami, this premature return to the evacuation area was the cause of most of the fatalities. The third and fourth waves caused most of the destruction and the casualties; they caught the people who returned to the area after the second wave, and others who had failed to evacuate. Seven people, including the owner and his wife, returned to the Long Branch Tavern to remove the money from the building. Since everything appeared normal, they stopped to have a beer and were trapped by the third wave. Five of the seven were drowned when the boat in which they were attempting to escape was sucked into Elk Creek by the recession and was smashed against the steel grating of the bridge over the mouth of the creek.

About 30 blocks were devastated in **Crescent City**. The California Disaster Office reported damage (excerpted from a report of the California Department of General Services) as follows: 54 residences, total loss; 13 residences, major damage; 24 residences, minor damage; 21 commercial fishing boats, lost; 12 house trailers, total loss; 172 business houses, severely damaged or destroyed. Estimated cost to replace and repair: public property, $473,000; private utilities, $68,000; private property, $6,873,000. Total estimated cost was $7,414,000. The streets of **Crescent City** were strewn with rubble from demolished buildings and logs that were swept in from the beaches (figs. 56 and 57). Automobiles were heaped in scattered piles (fig. 58), and stock from damaged stores was scattered throughout the area. The third wave picked up a gasoline tank truck, parked at the Texaco station, and slammed it through the garage door of the Nickols' Pontiac Building. An electrical junction box just inside the door was knocked loose by the impact, and a fire ignited. The fire destroyed the building and spread to the Texaco tank farm where it burned for 3 days (fig. 59).

The greatest height reached by the tsunami at **Crescent City** was 6.3 m above mean lower low water or at least 4.3 m above tide stage. This height was determined from the water

(1964, March 28, continued)
marks on the flag pole near the harbor master's office at citizens' dock.

Crescent City was not the only place where the inhabitants placed themselves in jeopardy. Newspapers estimated that 10,000 people jammed beach areas at San Francisco to watch the tsunami arrive. In San Diego, an attempt was made to evacuate the beach areas, but curious citizens created a problem. Had large-amplitude waves struck these places, the casualty lists would have been much longer.

FIGURE 56.—Photograph taken in Crescent City, California following the tsunami of March 28, 1964, showing an intersection filled with houses washed from their foundations. Photo Credit: U.S. Army Corps of Engineers.

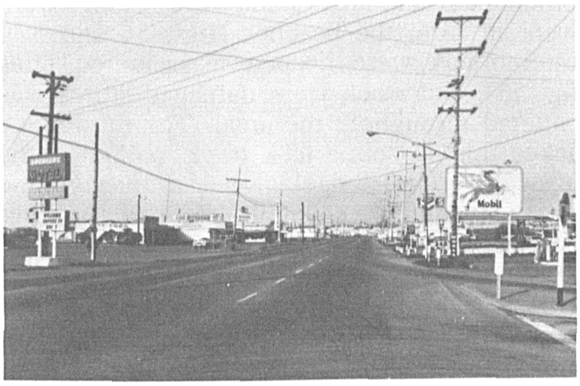


FIGURE 57.—Photograph showing the same location as Figure 56 following the cleanup after the tsunami. Photo Credit: U.S. Army Corps of Engineers.

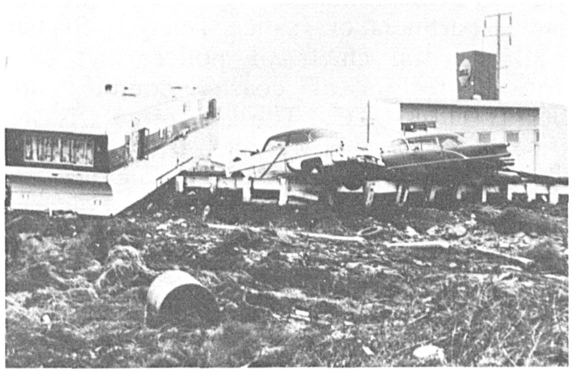


FIGURE 58.—Automobiles and trailer washed onto fence by tsunami of March 28, 1964, in Crescent City, California. Photo Credit: U.S. Army Corps of Engineers.

FIGURE 59.—Destruction and fire at Texaco Gas Station and tank farm taken following the tsunami on March 28, 1964, at Crescent City, California. Photo Credit: U.S. Army Corps of Engineers.

Reaction by county and city civil defense organizations varied considerably. In Humboldt County the second advisory issued by the Honolulu Observatory was received at 07:08 UTC at the County sheriff's office. All agencies were mobilized by 07:18 UTC, evacuation of all persons in danger areas was completed by 07:40 UTC, and road blocks were established under the direction of the sheriff's office to guarantee and enforce against any return to the threatened area. San Francisco attempted to evacuate ocean beaches immediately upon receipt of the advisory, but efforts were unsuccessful. Los Angeles County made no attempt to evacuate waterfront areas.

The tsunami did not spare other areas of the California coast. Mendocino County reported that about 100 fishing boats in **Noyo** harbor sustained damage with 10 being sunk. A dredge in the harbor was carried upstream about 0.4 km and grounded on a sandbar. Estimates of the damage ranged from $250,000 to $1 million. One man fishing for eels on **Klamath River** was drowned, and $4,000 damage was done to boats and the dock. In **Marin County**, about $77,000 worth of damage was done to small boats and berthing facilities, mostly in Loch Lomond Harbor in **San Rafael**. There was $100,000 damage in **Sausalito**. On **Tomales Bay**, $6,000 damage was done to Lawson's Pier. Los Angeles County Civil Defense reported $100,000 to $200,000 damage to six small-boat slips, pilings, and the Union Oil Company fuel dock; $75,000 damage owing to scouring action on the harbor sides in **Los Angeles County Harbor**; and 8 docks with a value of $100,000 destroyed in **Long Beach** Harbor. Only minor damage was reported elsewhere in the State. (Spaeth and Berkman, 1972)

At **Bolinas** on the afternoon of March 28, one hour after high tide, a man was swept from Duxberry Reef by a surge and drowned more than 12 hours after the initial wave arrived. (Cox in Weller, 1972)

1965, February 4, 05:01. A magnitude 8.2 earthquake in the Rat Islands, Aleutian Islands generated a tsunami that was widely recorded throughout the Pacific Basin and was recorded with an amplitude of 0.3 m at **Crescent City, California** and 0.08 m at **Santa Monica, California**. (Soloviev and Go, 1974, p. 319; Von Hake and Cloud, 1967)

1966, October 17, 21:42. A magnitude 8.0 earthquake in Peru generated a 3.0-m local tsunami that caused some damage. The tsunami was recorded at **Crescent City** with an amplitude of 0.1 m and elsewhere in California with amplitudes of less than 0.1 m. (Soloviev and Go, 1975, p. 154-160; Iida et al., 1967; McCulloch, 1985; Joy, 1968)

1968, May 16, 00:49. A magnitude 7.9 earthquake east of Honshu, Japan, generated a 5.0-m tsunami that flooded houses, destroyed more than 100 ships, and killed more than 50 people in Japan. It was recorded on the United States West Coast with a maximum amplitude at **Crescent City, California** of 0.6 m, 0.2 m at **Santa Monica, California** and **Newport, Oregon**, 0.1 m at **Long Beach, California**, and less elsewhere. (McCulloch, 1985; Coffman and Cloud, 1970; Joy, 1968)

1971, July 26, 01:23. A magnitude 7.9 earthquake in the Bismarck Sea near New Ireland northeast of New Guinea generated a 3.4-m local tsunami that caused some damage; it was recorded at **Crescent City** with an amplitude of 0.07 m and **Los Angeles**, with an amplitude of 0.05 m. (Coffman and von Hake, 1973).

1974, October 3, 14:21. A magnitude 8.1 earthquake near Lima, Peru, caused loss of life and devastation of the city. At the Port of Callao, Peru, a 0.9-m wave was generated. It was recorded at **Crescent City, California**, with an amplitude of 0.08 m. (Soloviev et al., 1986; Coffman and Stover, 1976)

1975, November 29, 14:48. A magnitude 7.2 earthquake in Hawaii generated an 8.0-m tsunami in Hawaii. On the West Coast the largest wave amplitudes were 0.4 m at **Port San Luis** and 0.21 m at **Bodega Bay** 0.2 m at **Imperial Beach** and 0.1 m at **La Jolla**, all in California. Readings were less elsewhere in California. About $2,000 in damage was caused to two docks on **Santa Catalina Island, California**. (McCulloch, 1985; Spaeth, 1977; Soloviev et al., 1986)

1977, June 22, 12:09. A 7.2 magnitude earthquake in the Tonga trench area generated a 0.3-m tsunami at Suva, Fiji. The tsunami was registered on tide gages at **Long Beach** and **Port San Luis, California** with amplitudes of 0.12 m, at **San Diego** with an amplitude of 0.09 m and **Los Angeles** with amplitude of 0.05 m. (Spaeth, 1979)

1986, May 7, 22:47. A magnitude 7.6 earthquake in the western Aleutian Islands generated a tsunami with the highest runup of 0.4 m recorded at Adak, Alaska. The tsunami was widely recorded throughout the Pacific Basin including locations along the shores of the west coast of the United States. The amplitudes at **Crescent City, California** and at **Neah Bay** and **Toke Point, Washington**, were all less than 0.1 m. (Preliminary Determination of Epicenters, Monthly Listing, May 1987).

1987, November 30, 19:23. A magnitude 7.6 earthquake about 75 km south of Cape Yakataga, Alaska, on the Pacific plate produced a 0.5-m local tsunami. Small waves were recorded at the **Presidio, San Francisco, California**. (Preliminary Determination of Epicenters, Monthly Listing, May 1987)

1988, March 6, 22:36. A magnitude 7.6 earthquake in the Gulf of Alaska generated a tsunami with a maximum amplitude of 0.2 m at Yakutat in Alaska. A reading of 0.025 m was obtained at **San Francisco** (Carte, 1987).

(West Coast tables begin on next page.)

TABLE 6. TSUNAMI DATA FOR THE WEST COAST OF THE UNITED STATES

ORIGIN DATA		VALID	CAUSE	TSUNAMI DATA							
DATE TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PERIOD (MIN)	1ST MOTION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1812	N. California				San Francisco, CA	OBS?					Possible misdated report of December 21 waves at Santa Barbara.
1812 12 21 19:00 34.2N 119.7W (DNAG) 7.7	S. California	4	E	1.0 1.5	El Refugio, CA	3.5					Ship at anchor drifted to shore and up canyon.
					Santa Barbara, CA	2.0		F			Estimated runup.
					Ventura, CA	2.0					Estimated runup. (See also Hawaii section.)
1840 01 16-18	S. California	1	M		Santa Cruz, CA	OBS					Church tower collapsed, flooding of probable meteorological origin.
1851 05 15 16:10 37.8N 122.4W (TOP)	California		E		Salinas, CA	OBS					
					San Francisco, CA	OBS					Mild shocks March, April, and May 15, 17, and 28 accompanied by marine flooding.
1851 11 13	N. California	1			San Francisco Bay, CA	OBS					Possible seiche.
					Santa Barbara, CA	OBS					Possible seiche.
1853 11	Kuril Islands				San Diego, CA	OBS?					
1854 05 31	S. California	1			Santa Barbara, CA	OBS					Sea agitated.
					San Diego, CA	OBS?					Possibly recorded.
1854 07 24	S. California	2		-2.0	San Diego, CA	0.3	10.0	R			Currents set up in a calm harbor.
1854 10 26	N. California	1			Benicia, CA	OBS					Seawave possibly observed.
					San Francisco, CA	OBS					Seawave possibly observed.
1854 11 01	N. California	1			San Francisco, CA	0.6					The water rose 0.6 m (several feet) with high waves in calm weather in the vicinity of Angel Island, San Francisco Bay.
1854 11 10	N. California										Alternate date for 1854, November 1.
1854 12 01	N. California	1									Alternate date for 1854, November 1.
1854 12 23 00:00 34.0N 137.9E (Iida) 8.3	Enshunada, Japan	4	E	4.0	Astoria, OR	OBS					
				3.0	San Diego, CA	<0.1				13.8	
					San Francisco, CA	0.1	35.0		23-12:22	12.6	
1854 12 24 08:00 33.1N 135.0E 8.4 (Iida)	Nankaido, Japan	4	E	4.0	Astoria, OR	<0.1					
				3.0	San Diego, CA	0.1					
					San Francisco, CA	0.1			23-21:55	12.0	
1855 03 19 21:50 41.0N 125.0W 6.0	N. California	2	E		Humboldt Bay, CA	OBS					Water in bay agitated for an hour.
1855 07 11 04:15 34.1N 118.1W 6.3 (DNAG)	S. California	2	E		San Juan Capistrano, CA	OBS					Two large waves surged on shore.
1855 10 21	N. California	1			San Francisco, CA	OBS					Surface of sea was agitated and dragged ships riding at anchor. Doubtful tsunami.
1856 02 15 13:25 37.6N 122.3W (TOP) 5.5	N. California	4	E	-1.0	San Francisco, CA	0.6					Water rose and stayed high for 5 minutes.
1856 08 23 40.5N 143.5E (Iida) 7.8	SE Hokkaido Island, Japan	4	E	2.0	California coast	OBS					
				2.0	San Diego, CA	3.6					Exaggerated report and/ or erroneous date.
1859 09 24	N. California?	2	E	1.5	Half Moon Bay, CA	4.6		F			Schooner damaged.

ORIGIN DATA					TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOT-ION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1861 05 04		N. California	1			San Francisco, CA	OBS					Tide dropped 30-45 cm below lowest low tide during the week.
1861 05 05		N. California	1									Alternate date for 05-04.
1862 05 27	20:00 32.7N 117.2W 5.8 (TOP)	S. California	2			San Diego, CA	1.2		R			0.9 to 1.2 m runup. Possibly innundation rather than runup.
1865 10 04		San Francisco, CA	1			Santa Cruz, CA	OBS					Alternate date for 10-08 below.
1865 10 08	20:46 37.2N 121.9W 7.0 (DNAG)	San Francisco, CA	2	E		Santa Cruz, CA	OBS		R			High flood tide and strong ebb tide.
1868 04 03	02:24 19.2N 155.3W (Cox) 7.5	Hawaii	4	E	4.1	San Diego, CA	0.1	30.0				(See also Hawaii section.)
					3.4	San Francisco, CA	<0.1					
1868 06 13?		S. California	1			Pacific Coast	OBS					"Earthquake wave" reported by San Francisco paper. Very doubtful tsunami.
1868 08 13	21:30 18.6S 71.0W 8.5 (PAL)	N. Chile	4	E	4.3	Astoria, OR	0.1				18.8	(See also Hawaii, Alaska, and Samoa sections.)
					3.5	San Diego, CA	0.3	16.0			11.9	
						San Francisco, CA	0.2	21.0			12.9	
						San Pedro, CA	1.8					
						Wilmington Beach, CA	1.8	20.0				
1868 10 21	15:53 37.7N 122.1W (DNAG) 7.0	N. California	1			Government Island, CA	OBS		R			Registered on tide gage.
						San Francisco Bay, CA	4.5		R			6.0 m surge on shore at Cliff House.
						Santa Cruz, CA	OBS		R			Water rushed up river.
1869 02 13		N. California				Fort Hornet, CA	OBS					Earthquake recorded on tide gage.
1869 06 02		N. California	1			Fort Point, CA	OBS					Earthquake waves recorded on tide gage.
1872 08 23	18:02 52.0N 170.0W (Cox)	Fox Islands, Aleutian Islands	4	E	0.5	Astoria, OR	<0.1					(See also Hawaii and Alaska sections.)
						San Diego, CA	<0.1					
						San Francisco, CA	<0.1					
1872 09 16		Fox Islands, Aleutian Islands?	2			Astoria, OR	OBS					Oscillations recorded.
						San Diego, CA	OBS					Oscillations recorded.
						San Francisco, CA	OBS					Oscillations recorded.
1877 04 16		N. California/ S. California	1			Anaheim Landing, CA	3.6					This is possibly a confused report for May 10 below.
						Cayucos, CA	3.6					
1877 05 10	00:59 19.6S 70.2W 8.3 (PAL)	N. Chile	4	E	4.0	Gaviota, CA	3.7					(See also Hawaii and Samoa sections.)
					3.5	San Francisco, CA	0.2				13.5	
						San Pedro, CA	1.0					
						Wilmington, CA	1.0					
1878 01 15		California		M?		Carpinteria, CA	OBS					Wharves damaged or destroyed by meteorological waves.
						More's Landing, CA	OBS					Wharves damaged or destroyed by meteorological waves.
						Santa Barbara, CA	OBS					60 m of new wharf destroyed by meteorological waves.
						Ventura, CA	OBS					90 m of wharf destroyed by meteorological waves.
1878 11 22		Chile ?	1			Avila, CA	OBS					Some damage, unspecified location. Possible misdated report for May 10, 1877, or August 13, 1868.
						Cayucos, CA	OBS					
						Morro Bay, CA	OBS					
						Pismo Beach, CA	OBS					
						Port Harford(?), CA	OBS					
						Sal Cape, CA	OBS					
						San Luis Obispo Bay, CA	OBS					
						Surf, CA	OBS					
						Wilmington, CA	2.0					
1879 08 10		S. California	1			Santa Monica, CA	OBS					
1883 08 27	02:59 6.7S 105.4E	S. Java Sea (Krakatau)	4	V	4.5	San Francisco, CA	<0.1					Air pressure wave recorded on marigram. (See also Alaska and Hawaii sections.)

ORIGIN DATA: DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	TSUNAMI DATA: MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PERIOD (MIN)	1ST MOTION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1884 01 25		N. California				San Francisco, CA	OBS					Erroneous report.
1884 11 12		N. California	2		-3.0	Sausalito, CA	0.1					Oscillation recorded on tide gage.
1885 11 19		Unknown	2	E?	1.0	San Francisco, CA	OBS					Record on tide gage.
1885 11 24		N. California	1	M		Eureka, CA Crescent City, CA	OBS OBS					Some flooding. Meteorological waves and high tides but not a tsunami.
1887 07 08		N. California	1			Sausalito, CA	OBS					Distinct waves.
1895 03 30		S. California	1	L		San Miguel I., CA	OBS					Small schooner wrecked, dubious report.
1895 10 14		N. California	1			Sausalito, CA	OBS					Irregularities continued for 18 hours.
1896 06 15	10:33 39.6N 144.2E 7.6	Sanriku, Japan	4	M?	4.0 3.8	San Francisco, CA Santa Cruz, CA Sausalito, CA	0.2 1.5 <0.1	20-30.0			10.6	Dike & ship destroyed. (See also Hawaii and Samoa sections.)
1896 12 17		Santa Barbara, CA		L?	1.5	Santa Barbara, CA	2.5					Wave was a true "tidal wave" and not a tsunami at all.
1899 12 25	12:25 33.8N 177.0W 7.0	S. California (DNAG)	1			S. California	OBS					Large wave; uncertain tsunami.
1902 02 26	13.5N 89.5W	El Salvador-Guatemala (PCT)	4	E		San Diego, CA W. coast of United State	OBS OBS					Date probably inaccurate, as large earthquake occurred in this region on January 19 and April 19, 1902 but none on this date. Large waves broke on coast.
1904 03 30		Washington-Oregon	2	E		Grays Bay, WA Hoh River, WA Queets River, WA Quinault River, WA Wishkah River, WA	OBS OBS OBS OBS OBS					Water rose in the bay. Water rose in mouth of river. Water rose in mouth of river. Water rose in mouth of river. Water rose in mouth of river. Possibly refers to March 16, 1904 earthquake felt strongly at Victoria, B.C. and widely over western Washington.
1906 01 31	15:36 1.0N 81.5W 8.2	Colombia-Ecuador (DNAG) (Abe)	4	E	1.0 3.0	San Diego, CA San Francisco, CA	OBS OBS					(See also Hawaii section.)
1906 04 18	13:12 37.7N 122.5W 7.8	N. California (DNAG) (Abe)	4	E	0.1 -2.0	Navarro River, CA San Francisco, CA	OBS 0.1	 16.0	 F		 0.8	Flooding of low-lying areas. Slight drop in water level.
1906 08 17	00:40 33.0S 72.0W 8.6 25	Central Chile (PAL) (Abe)	4	E	2.0 2.0	San Diego, CA San Francisco, CA	0.1 <0.1	22.0 59.0			13.8 15.0	(See also Hawaii section.)
1906 11 06	46.0N 125.0W	Washington/Oregon		M?		Off Wash.–Ore. Coast	OBS					Ship nearly lost to large waves; waves of probable meteorologic origin.
1910 11 21		N. California		M	-1.5	San Francisco, CA	OBS					Waves recorded at San Francisco probably meteorologically induced.
1917 05 01	18:27 29.2S 177.0W 8.0	Kermadec Islands South Pacific (ISS) (G&R)	2	E	1.0	La Jolla, CA San Francisco, CA	OBS OBS					(See also Hawaii and Samoa sections.)
1917 06 26	05:50 16.0S 171.0W 8.3	Samoa Islands (ISS) (G&R)	4	E	3.0 3.0	West Coast	OBS					(See also Hawaii and Samoa sections.)
1918 09 07	17:16 45.5N 152.0E 8.3 33	Kuril Islands (USSR) (Iida)	4	E	3.6	San Francisco, CA	OBS				09.5	(See also Hawaii and Samoa sections.)

ORIGIN DATA					TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOT-ION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1919 04 30	07:17 21.2S 172.5W (ISS) 8.3 (G&R)	Tonga Islands	4	E	1.0	San Diego, CA	OBS					(See also Hawaii and Samoa sections.)
						San Francisco, CA	OBS					
1922 11 11	04:33 28.5S 70.6W 8.3 (PAL) 25	N. Central Chile	4	E	3.0	San Diego, CA	0.2	15.0			13.0	(See also Hawaii and Samoa sections.)
					2.5	San Francisco, CA	0.3	15.0			13.8	
1923 01 22	09:04 40.8N 124.1W (DNAG) 7.2	N. California	2	E	-2.0	Cape Mendocino, CA	<0.1					Recorded on tide gage.
1923 02 03	16:01 54.0N 161.0E (Iida) 8.3	Kamchatka Peninsula, USSR	4	E	3.0	San Diego, CA	0.2	10.0			10.0	(See also Hawaii and Samoa sections.)
						San Francisco, CA	0.1	16.0			10.0	
1923 04 13	15:30 56.5N 162.5E 7.2 (Iida)	Kamchatka Peninsula, USSR	4	E	4.0	Los Angeles, CA	OBS					Vessels set adrift in harbor.
						San Diego, CA	0.1	43.0			14.3	
						San Francisco, CA	0.2	20.0			11.5	(See also Hawaii section.)
1923 09		California (?)		M		Jose de Cado, CA(?)	OBS					Sudden rise in water caused destruction. Location of Jose de Cado is unknown but probably refers to San Jose del Cabo in Baja, California, Mexico. Possibly meteorologic in origin or associated with Kanto, Japan, earthquake and tsunami of September 1.
1925 10 04		California	1	M	-1.0	Long Beach, CA	0.3					Wave of possible meteorological origin. (See also Hawaii section.)
1927 01 01	08:17 32.5N 115.5W 5.7 (EQH)	California	1	E		San Pedro, CA	OBS					Sea wave carried off part of embankment, damage estimated at $3 million. Uncertain connection to to inland earthquake.
1927 11 04	13:51 34.9N 120.7W 7.3 (DNAG)	N. to S. California	4	E	1.0 1.0	La Jolla, CA	<0.1	15.0			00.9	Registered on tide gage.
						Pismo Beech, CA	OBS					
						Port San Luis (Avila), CA	1.5	15.0	F			
						San Diego, CA	OBS					Registered on tide gage.
						San Francisco, CA	<0.1	12.0	F	04-15:00	01.2	Registered by tide gage. (See also Hawaii section.)
						Surf, CA	1.8		R			
1928 06 17	03:19 16.3N 97.7W (DNAG) 7.8	S. Mexico	4	E	1.0	La Jolla, CA	0.1					(See also Hawaii and Samoa sections.)
					1.0	San Francisco, CA	<0.1					
1930 08 31	00:41 33.9N 118.6W 5.2 (EQH) 5	S. California	1	L?	-1.0 -0.5	Santa Monica, CA	0.6					
1931 10 03	19:13 10.6S 161.7E (ISS) 7.9 (G&R)	Solomon Islands	4	E	1.0	San Diego, CA	OBS?					(See also Hawaii section.)
					2.5	Santa Barbara, CA	0.6					
1933 03 02	17:31 39.1N 144.7E 8.3 (Iida) 10	Sanriku, Japan	4	E	3.0	La Jolla, CA	<0.1	11.0				(See also Hawaii and Samoa sections.)
					3.5	Los Angeles, CA	0.2	14.0			11.5	
						San Francisco, CA	0.2	11.0			10.5	
						Santa Monica, CA	<0.1			03-04:30		
1933 03 11	01:54 33.6N 118.0W 6.3 (DNAG) 16	S. California	1	E	-2.0	Long Beach, CA	<0.1	19.0				Uncertain recording.
						La Jolla, CA	OBS					Questionable recording.
1934 08 21		S. California	1	M		Balboa, CA	OBS	25.0				Flooding and wave damage probably not related to earthquake of same date.
						Laguna Beach, CA	OBS					
						Long Beach, CA	OBS					Questionable damage reports.
						Malibu Beach, CA	OBS					
						Newport Beach, CA	12.0					High waves and damage reported probably not due to true tsunami.

DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUNUP/AMP (M)	PERIOD (MIN)	1ST MOTION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
ORIGIN DATA					TSUNAMI DATA							
1938 03 22	15:22 52.2N 131.9W 6.3 16	Canada (DNAG)	1	E		California coast	OBS					Cox believes tsunami report to be only background oscillations.
1938 05 19	17:08 0.5S 119.2E 7.6	N. Molucca Islands, Indonesia (ISS) (G&R)	4	E	1.5	Santa Monica, CA	<0.1					Doubtful recording. Probably only background oscillations.
1938 11 10	20:19 55.5N 158.0W 8.3 25	Alaska Peninsula (DNAG)	4	E		Santa Monica, CA	0.1	35.0		12-01:20	05.0	(See also Alaska and Hawaii sections.)
1941 02 09	09:44 40.9N 125.4W 6.6	N. to S. California (EQH)		E		Port Hueneme, CA	OBS					Seiches observed 36 hours after the earthquake.
						San Diego, CA	OBS					Harbor seiches 14 hours following earthquake.
						San Francisco, CA	OBS					Seiches in harbor 14 hours following earthquake. No tsunami was observed.
1943 04 06	16:07 30.8S 72.0W 8.3 33	N. Central Chile (PAL)	4	E		San Diego, CA	0.1					(See also Hawaii section.)
						Terminal Island, CA	0.1					
1944-1953		Columbia River Valley, Washington	4	L		Franklin D.Roosevelt Lake WA	19.7					Series of 11 landslides from April 8, 1944 to August 19, 1953 at Reed Terrace with a maximum height of 63.6 m produced by tsunamis on the lake. Largest wave rose to height of 19.7 m on opposite side of the lake.
1944 12 07	04:35 34.0N 137.1E 8.0 30	Ryukyu Trench, Japan (Iida)	4	E	3.0	San Diego, CA	<0.1	14.0			13.9	(See also Alaska, Hawaii, and Samoa sections.)
					2.5	Terminal I., CA	<0.1	16.0				
1946 04 01	12:29 52.8N 163.5W 7.8 25	E. Aleutian Islands (DNAG)	4	E		Alameda, CA	0.3	13.0			05.8	
						Arena Cove, CA	2.4					Given as height by O'Brien (1946) and also as 4.3 m above MLLW.
						Avila, CA	1.2	16.0		01-18:05		
						Bolinas, CA	OBS	10.0		01-18:50		Height obove MLLW given by O'Brien (1946) as 2.6 m above MLLW. Small island submerged and several row boats sunk. Part of wharf broken and pier loosened at Coast Guard Station. Minor damage.
						Caspar Beach, CA	OBS					
						Charleston (Coos Bay), OR	3.0			01-18:20		
						Clatsop Spit, OR	1.8					Mouth of Columbia River. Height given by O'Brien (1946). Also given as 3.7 m above MLLW.
						Crescent City, CA	0.9	12.0	R	01-17:07	04.6	Bay drained; water returned as a wall. High surf for next 26 hours.
						Depoe Bay, OR	0.9		F			
						Drakes Bay, CA	2.6			01-19:00		Height (runup?) given by O'Brien (1946). Also given as 2.5 m above MLLW.
						Granada, CA	OBS					10 m boat washed on highway.
						Half Moon Bay, CA	2.6	11.0		01-18:45		Wave swept into unoccupied Coast Guard barracks and loosened it from its foundation. $1,000 in damage.
						La Jolla, CA	0.2	10.0		01-18:40	06.2	
						Los Angeles, CA	0.4	06.0				
						Morro Bay, CA	1.5			01-20:30		Height (runup?) given by O'Brien also given as 2.4 m above MLLW.
						Muir Beach, CA	OBS			01-19:45		Wave reported by O'Brien (1946) as 4.8 m above MLLW.
						Navarro River, CA	OBS					Water rose to top of pier.
						Neah Bay, WA	0.2	10.0	R	01-17:00	04.5	
						Newport OR	1.5		R			
						Noyo, CA	1.4			01-18:00		100 fishing boats thrown 1.8 m up bank and some damage to pier. Height (runup) given by O'Brien as 3.4 m above MLLW.
						Pacific Grove, CA	OBS					Dressing rooms in municipal swimming pool on beach flooded 1 m.(3.1 m above MLLW)
						Port Hueneme, CA	0.8	14.0		01-18:23	05.9	
						Princeton, CA	OBS					Large boulders washed as far as the highway. Houses flooded.
						San Diego, CA	0.2	07.0		01-19:15		
						San Francisco, CA	0.3	15.0			05.5	

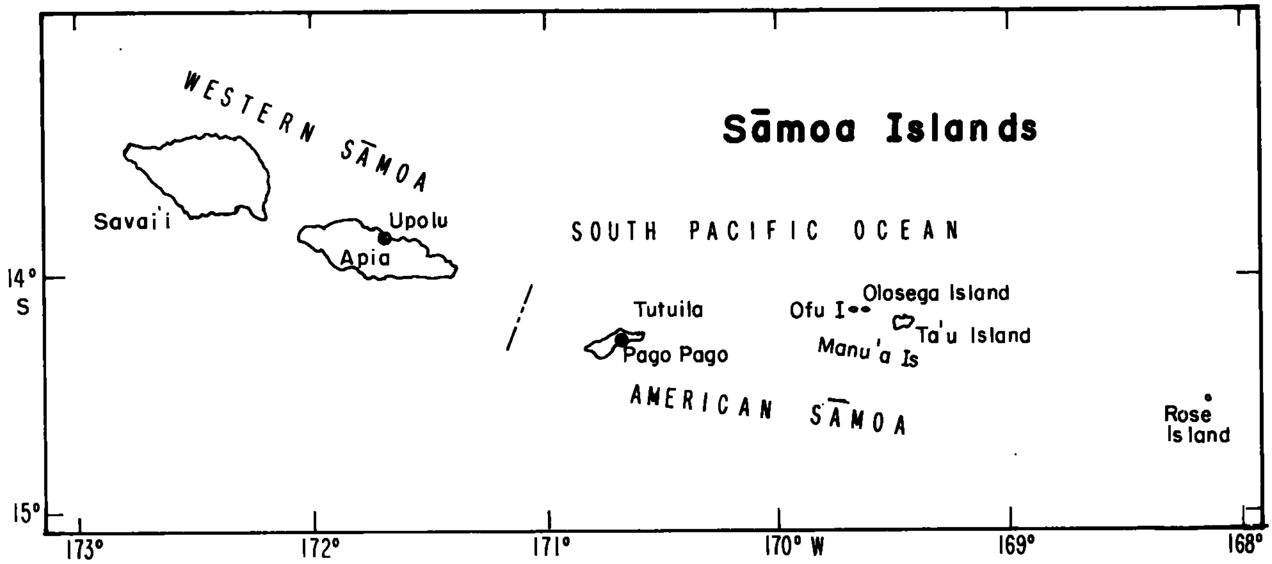
ORIGIN DATA					TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER- IOD (MIN)	1ST MOT- ION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1946 04 01 (continued)						San Luis Obispo, CA	1.3	11.0	R	01-18:05	05.6	Tanker torn from mooring lines.
						San Mateo, CA	0.1	16.0			06.3	
						San Pedro, CA	OBS					One tender and two cargo ships broke mooring lines.
						San Simeon, CA	OBS					
						Santa Cruz, CA	1.5			01-18:15		Man drowned; cars pushed against houses. Garages, chicken house, and cowshed swept inland; 8 m boat washed 300 m off beach and into lagoon. Waves swept 12 m up bay. Fishermen terrified. Wave height given as 4.6 m by Santa Cruz Sentinel and as 3.8 m above MLLW by O'Brien (1946).
						Siuslaw River, OR	1.0					Range? (See also Alaska, Hawaii, Samoa, and Pacific sections.)
1946 12 20	19:19	Nankaido, Japan	4	E	2.4	Crescent City, CA	0.2	14.0			13.0	(See also Hawaii section.)
	33.0N					San Francisco, CA	<0.1	12.0				
	135.6E											
	8.1	(Iida)										
	20											
1949 07 27		Columbia River Valley, Washington	4	L		Franklin D.Roosevelt Lake WA	19.7					Debris slide at Hawk Creek from 103 m above lake level. Largest wave rose 19.7 m on opposite side of lake.
1951 02 23		Columbia River Valley, Washington	4	L		Franklin D.Roosevelt Lake WA	OBS					Debris slide on east side of Columbia River from 60 m (several hundred feet) above lake level.
1952 03 04	01:23	SE. Hokkaido, Japan	4	E	2.0	Crescent City, CA	0.2	25.0				(See also Hawaii, Alaska, Samoa, and Pacific Territories sections.)
	42.2N				2.0	La Jolla, CA	<0.1	10.0				
	143.9E					Los Angeles, CA	0.4	33.0				
	8.1	(Iida)				Neah Bay, WA	<0.1	32.0				
	45					Oceanside, CA	<0.1	10.0				
						San Francisco, CA	0.3	27.0				
1952 11 04	16:58	Kamchatka Peninsula,	4	E	4.0	Alameda, CA	0.5					(See also Hawaii, Alaska, Samoa, and the Pacific Territories sections.)
	52.8N	USSR				Astoria, OR	0.1					
	159.5E					Avila, CA	1.4	18.0			09.0	
	8.2	(Iida)				Crescent City, CA	1.0	18.0			08.0	
	30					Friday Harbor, WA	0.1					
						La Jolla, CA	0.1				09.6	
						Los Angeles, CA	0.5	19.0			09.6	
						Neah Bay, WA	0.2					
						Port Hueneme, CA	0.7	12.0			09.0	
						San Diego, CA	0.4	20.0			09.6	
						San Francisco, CA	0.5	18.0			08.7	
						San Pedro, CA	0.3				09.5	
						Santa Monica, CA	0.7				09.6	
						Seattle, WA	OBS					
1956 03 30	06:11	Kamchatka Peninsula,	4	V		Avila, CA	0.1	23.0				Explosions of Bezymianny volcano induced wave. May not be a true tsunami. (See also Hawaii, Alaska, and the Pacific Territories sections.)
	55.0N	USSR										
	160.5E	(PCT)										
1957 03 09	14:23	Central Aleutian	4	E	3.5	Alameda, CA	0.2	12.0		09-20:32	06.2	
	51.5N	Islands				Anaheim Bay, CA	0.4	24.0		09-21:05	06.7	
	175.7W					Astoria, OR	<0.1					
	8.3	(DNAG)				Avila, CA	0.5	18.0		09-20:08	05.8	
	33					Bodega Harbor, CA	0.3	30.0		09-19:42	05.3	
						Crescent City, CA	0.7	14.0		09-19:33	05.2	
						La Jolla, CA	0.3	14.0		09-20:58	06.6	Minor damage.
						Long Beach, CA	0.3	40.0		09-21:00	06.6	
						Los Angeles, CA	0.5	28.0		09-21:20	07.1	
						Neah Bay, WA	0.2	13.0		09-19:21	05.0	
						Newport Bay, CA	0.1	21.0		09-21:00	06.6	
						Port Hueneme, CA	0.5	15.0		09-20:54	06.5	
						San Diego, CA	0.2	18.0		09-21:15	06.9	Pier, moorings, and ship damage. Wall of water 1 m high reported at Shelter I.
						San Francisco, CA	0.3	11.0			05.9	
						San Pedro, CA	0.2	13.0			07.0	(See also Alaska, Hawaii, Samoa and Pacific Territories sections.)
						Santa Monica, CA	0.5	15.0		09-20:59	06.6	
1958 11 06	22:58	S. Kuril Islands, USSR	4	E	2.0	Port Hueneme, CA	<0.1	12.0			10.5	(See also Hawaii, Alaska, Samoa, and Pacific Territories sections.)
	44.3N					San Francisco, CA	0.2					
	148.5E											
	8.1	(Iida)										
	80											
1960 05 22	19:11	S. Central Chile	4	E	4.5	All West Coast						$500,000-$1,000,000 damage.
	39.5S				4.0	Alameda, CA	0.3	100.0	R	23-19:50	15.6	
	74.5W					Alamitos Bay, CA	0.6	36.0	R	23-09:34	14.4	
	8.6	(PAL)				Astoria, OR	0.2	90.0	F	23-12:40	17.5	
	33					Bodega Bay, CA	0.3					
						Crescent City, CA	1.7	84.0	R	23-10:40	15.5	Two ships were destroyed ($30,000).
						Echo Bay, WA	OBS			23-17:05	21.9	
						Friday Harbor, WA	0.1	33.0	R	23-16:30	21.3	

ORIGIN DATA		VALID	CAUSE	TSUNAMI DATA							
DATE TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	V A L I D	C A U S E	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOT-ION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1960 05 22 (continued)					Grays Harbor, WA	0.3					
					Half Moon Bay, CA	OBS					Boat washed ashore. 3.5 m above MLLW.
					La Jolla, CA	0.5	21.0	R	23-08:50	13.6	
					Long Beach, CA	0.7	40.0	R	23-09:27	14.3	$500,000-$1,000,000 in damage in Long Beach and Los Angeles harbors. 300 small craft ripped from moorings and 30 sunk. 24 m yacht smashed into bridge loosening its superstructure.
					Los Angeles, CA	0.8	46.0	R	23-09:18	14.1	One drowned at Cabrillo Beach and one injured.
					Moss Landing, CA	0.8					
					Monterey, CA	0.8					
					Neah Bay, WA	0.4	52.0	R	23-12:25	17.2	
					Pacifica, CA	1.2					
					Pacific Grove, CA	0.9					
					Port Hueneme, CA	1.3	20.0	R	23-09:15	14.1	
					San Diego, CA	0.7	57.0	R	23-09:12	14:0	80 m of dock destroyed. bridge damaged, barge sunk, 8 slips destroyed.
					San Francisco, CA	0.4	72.0	R	23-10:13	15:0	
					San Pedro, CA	0.5	26.0	R	23-09:18	14.1	
					Santa Barbara, CA	OBS					Total of $20,000 damage to 40 small craft and dredge.
					Santa Cruz, CA	0.9					
					Santa Monica, CA	1.4	46.0	R	23-09:22	14.2	8 small craft snapped lines, innundation 91 m, parking lot flooded.
					Shelter Cove, CA	0.6					
					Stinson Beach, CA	1.5					
					Terminal I., CA	0.9	45.0	R	23-09:30	14.3	
					Willapa Bay, WA	0.6					
					Wilson Cove, CA	0.6	38.0	R	23-08:54	13.7	(See also Alaska, Hawaii, Samoa, and Pacific Territories sections.)
1963 10 13 05:17 43.8N 150.0E 8.1 (Iida)	Kuril Islands, USSR	4	E	2.0	Crescent City, CA	0.5					(See also Alaska, Hawaii, Samoa, and Pacific Territories sections.)
1964 03 28 03:36 61.1N 147.5W 8.4 (DNAG) 23	Gulf of Alaska-Alaska Peninsula	4	E	4.5	All West Coast	OBS					16 deaths and $12 million total damage including $105 thousand damage in Washington and $734 thousand in Oregon.
					Alameda (NAS), CA	0.8	42.0	R	28-09:06		
					Alamitos Bay, CA	0.4	37.0	R	28-09:36	05.0	
					Albion River, CA	OBS					2.7 m above MLLW. Bores observed 2 km up river from mouth.
					Arena Cove, CA	1.8					
					Astoria, OR	0.4	20.0	R	28-07:56		
					Avila, CA	1.6	15.0	R	28-08:44	05.1	
					Bodega Bay, CA	0.8					
					Bolinas, CA	OBS					1 drowned. Damage in city: $50,000; private: $180,000.
					Boone Creek, WA	OBS					Bridge damaged. $500 damage at Iron Springs Resort. $400 damage to culvert.
					Cannon Beach, OR	OBS					Bridge and motel unit moved 0.3 km inland, $230,000 damage.
					Cape Disappointment, WA	1.7					
					Capitola, CA	2.1					
					Coos Bay, OR	3.5					
					Copalis, WA	OBS					Small bridge destroyed. and $5,000 damage in town. 4 mobile campers overturned. Debris in streets.
					Crescent City, CA	4.3	29.0	R	28-07:39	04.1	$7.4 million damage, 54 houses destroyed, 172 businesses damaged or destroyed, 21 fishing boats lost, 11 deaths and 35 injured. Runup was 6.3 m above MLLW.
					Depoe Bay, OR	3.5					$5,000 in damage. 4 children killed while camping on beach.
					Drakes Beach, CA	OBS					2.4 m above MLLW
					Florence, OR	OBS					$50,000 in damage.
					Fort Bragg, CA	3.8					Range? Noyo?
					Friday Harbor, WA	0.4	19.0	R	28-08:30		
					Grays Harbor, WA	OBS					8 automobiles lost, 9 trailers damaged, 5 houses destroyed or damaged.
					Half Moon Bay, CA	OBS					3.1 m above MLLW.
					Hoh River mouth, WA	0.5					
					Humboldt Bay, CA	1.9					
					Ilwaco, WA	1.4					Minor damage.
					Jenner Beach, CA	OBS					3.0 m above MLLW.
					Joe Creek, WA	OBS					Bridge damaged.
					Klamath River, CA	OBS					1 killed. $4,000 damage to boat dock and boats at Requa. 1.1 km above mouth. $200 damage to dock and boats 2.6 km above river mouth at Chinook trailer court.
					La Jolla, CA	0.3	33.0	R	28-09:24	05.8	
					Lapush, WA	1.6					Boat wrecked.
					Long Beach Harbor, CA	OBS	29.0	R	28-09:24	05.8	8 docks destroyed with value of $100,000.
					Los Angeles County Harbor, CA	0.5				05.8	$75,000 damage to harbor sides.
					Los Angeles, CA	0.6					$200,000 damage to six boat slips, fuel dock damaged.

ORIGIN DATA					TSUNAMI DATA						
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PERIOD (MIN)	1ST MOTION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1964 03 28 (continued)						Marin County, CA	OBS					$1 million damage.
						Martins Beach, CA	3.0					
						Mendocino County, CA	OBS					$1 million in damage.
						Moclips, WA	3.4					Bulkhead washed out, $6,000 damage to 8 houses, road damaged.
						Monterey, CA	1.4					Small boats broken loose. $1,000 damage.
						Moss Landing, CA	1.4					$200 in damage.
						Muir Beach, CA	OBS					2.7 m above MLLW
						Neah Bay, WA	0.7	22.0	R	28-07:18	03.7	
						Nehalem River, OR	3.5					
						Newport, OR	0.3					
						Newport Bay, CA	0.5	24.0	R	28-09:26	05.8	
						Noyo, CA	2.0					100 fishing boats damaged, 10 sunk, $250,000-$1,000,000 damage.
						Oakland, CA	OBS					
						Ocean Shores, WA	2.9					Debris in streets and yards.
						Pacifica, CA	1.4					$200 damage.
						Pacific Beach, WA	OBS					$12,000 damage to houses, 1 injured.
						Pacific Grove, CA	0.9					
						Pebble Beach, CA	OBS					4.5 m above MLLW.
						Point Arena, CA	OBS					3.7 m above MLLW.
						Rincon I., CA	0.9	17.0	R	28-09:17		
						Rogue River, OR	OBS					$3,000 in damage.
						Russian Gulch, CA	OBS					3.4 m above MLLW.
						Salmon Creek Beach, CA	OBS					3.6 m above MLLW. Fisherman lost catch.
						San Diego, CA	0.6	09.0	R	28-09:50	06.2	
						San Francisco, CA	1.1	39.0	R	28-08:42	05.1	
						San Rafael, CA	1.5					$77,500 damage to boats and berthing facilities.
						Santa Cruz, CA	1.5					Dredge and cabin cruiser sunk ($100,000)
						Santa Monica, CA	1.0	39.0	R	28-09:15	05.7	
						Sausalito, CA	1.2					$100,000 damage to floating structures and boats at Clipper Yacht Harbor
						Seaside, OR	OBS					Damage in city: $41,000; Private: $235,000. 4 trailers, 10-12 houses, 2 bridges damaged.
						Seattle, WA	0.1	48.0	R	28-09:12		
						Sea View, WA	3.8					
						Siuslaw River, OR	3.7					
						Smith River, CA	OBS					4.1 m above MLLW, $6,000 damage to floating structures
						Taholah, WA	0.7					$1,000 damage. Skiffs destroyed, fish nets lost.
						Tomales Bay, CA	1.0					$6,000 damage to pier.
						Trinidad, CA	OBS					5.4 m above MLLW
						Umpqua River, OR	4.3					$5,000 in damage.
						Vancouver, Washington	<0.1					Amplitude recorded at about 2 cm 160 km from mouth of Columbia River.
						Van Damme State Park, CA	OBS					2.6 m above MLLW, wave progressed 450 m up Big River.
						Waldport-Alsea, OR	OBS					Port facilitites damaged, $160,000 total damage
						Westport, WA	OBS					One boat was wrecked.
						Wreck Creek, WA	4.5					Debris deposited on bridge. $500 damage.
						Yaquina Bay, OR	3.5					$5,000 damage. (See also Alaska, Hawaii, Samoa, and Pacific Territories sections.)
1965 02 04	05:01 51.3N 178.6W 8.2 (DNAG) 36	W. Aleutian Islands	4	E	3.0	Crescent City, CA	0.3					
						Santa Monica, CA	<0.1					
1966 10 17	21:42 10.7S 78.8W 8.0 (PAL) 40	Peru	4	E	1.0	Avila, CA	<0.1					(See also Alaska, Hawaii, Samoa, and Pacific Territories sections.)
					1.5	Crescent City, CA	0.1	15.0		18-09:45	12.1	
						Long Beach, CA	<0.1					
						Los Angeles, CA	<0.1					
						Neah Bay, WA	<0.1					
						Newport Bay, CA	<0.1					
						Rincon Island, CA	<0.1					
						San Diego, CA	<0.1	33.0		18-07:49	10.1	
						San Francisco, CA	<0.1					
1968 05 16	00:49 40.7N 143.6E 7.9 (Iida) 0	Honshu, Japan	4	E	2.0	Alameda, CA	<0.1					(See also Alaska, Hawaii, Samoa, and Pacific Territories sections.)
					-0.5	Avila, CA	<0.1					
						Crescent City, CA	0.6					
						La Jolla, CA	<0.1					
						Long Beach, CA	0.1					
						Los Angeles, CA	<0.1					
						Neah Bay, WA	<0.1					
						Newport Bay, CA	<0.1					
						Newport, OR	0.2					
						Rincon I., CA	<0.1					
						San Diego, CA	<0.1					
						San Francisco, CA	<0.1					
						Santa Monica, CA	0.2					
1971 07 26	01:23 4.9S 153.2E (ISS) 7.9 (PDE) 43	New Ireland	4	E		Crescent City, CA	<0.1					(See also Hawaii and Pacific Territories sections.)
						Los Angeles, CA	<0.1					

ORIGIN DATA					TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER- IOD (MIN)	1ST MOT- ION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1974 10 03	14:21	Peru	4	E		Crescent City, CA	<0.1					(See also Hawaii, Samoa,
	12.3S											and Pacific Territories
	77.8W											sections.)
	8.1	(PAL)										
	13											
1975 11 29	14:48	Hawaii	4	E		Bodega Bay, CA	0.2					(See also Alaska, Hawaii,
	19.3N					Imperial Beach, CA	0.2					Samoa and Pacific Territor-
	155.0W					La Jolla, CA	0.1					ies sections.)
	7.2	(Cox)				Long Beach, CA	<0.1					
	8					Los Angeles, CA	<0.1					
						Port San Luis, CA	0.4					
						San Diego, CA	<0.1					
						San Francisco, CA	<0.1					
						Santa Catalina Island, CA	OBS					$2,000 damage to two docks.
1977 06 22	12:09	Tonga Trench	4	E		Long Beach, CA	0.1					(See also Hawaii and Samoa
	22.9S					Los Angeles, CA	<0.1					sections.)
	175.7W	(ISC)				Port San Luis, CA	0.1					
	7.2	(BRK)				San Diego, CA	<0.1					
	69											
1986 05 07	22:47	W. Aleutian Islands	4	E		Crescent City, CA	<0.1		F			(See also Alaska, Hawaii,
	51.5N					Neah Bay, WA	<0.1					Samoa, and Pacific Ter-
	174.8W					Toke Point, WA	<0.1					ritories sections.)
	7.6	(ISC)										
	19											
1987 11 30	19:23	Gulf of Alaska	4	E		Presidio, S. F., CA	<0.1					Small waves recorded.
	58.7N											(See also Alaska and
	142.8W											Hawaii sections.)
	7.6	(PDE)										
	10											
1988 03 06	22:36	Gulf Of Alaska	4	E		San Francisco, CA	<0.1					(See also Alaska section.)
	57.0N											
	143.0W											
	7.6	(PDE)										
	10											

5. AMERICAN SAMOA



5.1 BACKGROUND INFORMATION

American Samoa consists of Tutuila Island (the location of the capital of American Samoa, Pago Pago); Aunuu Island; the Manu'a Group of Tau, Olosega, and Ofu Islands; Rose Island (uninhabited); and Swains Island. Western Samoa, which is much larger and about five times more populous, has the islands of Savai'i; 'Upolu (with the capital of Western Samoa, Apia); Apolima; and Manono.

Samoa was probably first discovered in the first millennium B.C. by voyagers from the Melanesian Islands to the west. It was not discovered by Westerners until 1722, when the Dutch navigator Jacob Roggeveen sailed through the islands without landing. Louis Antoine de Bouginville, a French explorer, rediscovered the islands in 1768 and named them the Navigators Islands in recognition of the natives' skill with their boats. In 1787 La Perouse, another French explorer, visited the islands. His second in command and 11 other men were killed by the Samoans while they were ashore searching for fresh water. In 1791 Captain Edward Edwards of the *Pandora* visited the islands twice while searching for the mutineers from the *Bounty*.

The first permanent settlers were John Williams and Charles Barff, missionaries from London, who lived on Savai'i Island in 1830. In 1836 Captain Cuthbert of the British Whaler *Elizabeth* discovered Pago Pago Harbor and the Rev. A. W. Murray, another missionary from London, soon settled there.

The United States Navy made a scientific investigation of the islands in 1839 and by 1850 England, Germany, and the United States were represented by commercial agents in Apia. In 1872 American interest in a trans-Pacific shipping route led Commander Richard Meade of the USS *Narragansett* to negotiate for the use of Pago Pago Harbor with a local chief. In 1899 Britain, Germany, and the United States agreed on a division of the islands. Britain withdrew its claim in the islands in exchange for concessions by the Germans elsewhere. The United States Navy was the administrator of the islands comprising American Samoa from 1900 to 1951 when the islands came under the jurisdiction of the Department of the Interior. Swains Island was added to the Samoa territory in 1925 after having been under British administration. After World War I, New Zealand administered Western Samoa until its independence in 1962.

The geology of Samoa is similar to that in Hawaii, as it is a series of volcanic peaks decreasing in age from Rose Island in the east to Savai'i Island in the west. As in

Hawaii, this series of peaks is probably the result of a fixed "hot spot" of material rising from the Earth's mantle over which the Pacific Ocean crust is moving in an easterly direction. Savai'i still has active volcanoes, and Matavanu has erupted as recently as 1905. The Samoan Islands lie just north and east of the highly seismic Tonga trench and represent a structure cutting across that subduction zone. The Tonga trench bends sharply to the west at this end.

The islands are protected by coral reefs, which decrease the effect of tsunamis. However, remote-source tsunamis have caused damage in American Samoa. A runup height of about 2.4 m resulted at Pago Pago from the Chilean tsunami in 1960. Samoa has incurred damage from three additional tsunamis generated in Chile, two generated in the Aleutian Islands, and one generated in the Kamchatka Peninsula.

At least two local tsunamis also have caused property damage in these islands. The 1917 event produced wave runup heights reported to have been about 12 m, but this is not substantiated in local records. It caused minor damage in Pago Pago and elsewhere. Pago Pago, which has a triangular-shaped harbor, is particularly vulnerable to tsunamis.

A seismic observatory has been in operation at Apia since 1902, and tide gages have operated there since at least 1917. The tide gage at Pago Pago was installed in 1948.

The following description of the effects of tsunamis is primarily for American Samoa, but includes effects in Western Samoa where they augment the data from American Samoa. Most of the locations mentioned in the following descriptions are shown in figure 60.

5.2 DESCRIPTION OF TSUNAMI EVENTS

1837, November 7, 12:51. An earthquake in Chile at 8:05 A.M. caused a tsunami that was observed at **Pago Pago, Tutuila Island**, (now American Samoa). (Hitchcock, 1911; Pararas-Carayannis and Dong, 1980; Iida et al., 1967). Waves observed at Apia, Western Samoa, had a maximum amplitude of about 0.4 m (Soloviev and Go, 1974, p. 67)

1866, September 12. An underwater volcanic eruption that caused a disturbance of the sea originated about 3 km from the Island of Olosega and 8 km from Tau. "The destruction continued all that day and through part of the next." A column of thick smoke rose to a height of 600 m. The seas heaved violently, and high waves around the center of the eruption continued for 3 days. The sea was extremely disturbed. Explosions continued for a month. (Soloviev and Go, 1975, p. 8)

1868, August 13, 21:30. The magnitude 8.5 Arica, Peru (now Chile), earthquakes occurring at about 4:45 and 8:45 P.M. local time generated tsunamis that reached 21 m locally, killed more than 25,000, and destroyed several cities and settlements along the Peru-Chile coast. The USS *Wateree* was carried 400 m inland and was abandoned. The tsunami destroyed settlements in Apia, 'Upolu Island (now Western Samoa), where a 3-m wave was reported (Iida et al., 1967). The wave arrived at 2:30 A.M. and was associated with the first great earthquake. It may have caused damage in American Samoa, but there are no available reports of it being observed there. (Pararas-Carayannis and Dong, 1980; Soloviev and Go, 1974, p. 93; Iida et al., 1967)

1877, May 10, 00:59. A magnitude 8.5 earthquake in Chile produced a 24-m tsunami in Chile that caused extensive damage along the Peru-Chile coast. The tsunami also produced fatalities in Hawaii and Japan and devastation throughout the Pacific. Lomnitz (1970) reports damage in Samoa from this event. It was observed at Apia as a 0.9-m wave (Iida et al., 1967; Soloviev and Go, 1974, p. 111 and 116). It may have been observed in the islands that now comprise American Samoa, but there are no reports available of its being observed there. (Pararas-Carayannis and Dong, 1980)

1883, March 24. According to Soloviev and Go (1975) a strong hurricane was raging in the Samoa Islands. Some accounts suggest an earthquake occurred at the same time. Ships at anchor broke loose. Two tidal waves appeared. The *New York Times* reports, "Captain Pearson, commander of the *Wachusett*, in a report from Apia, Samoa

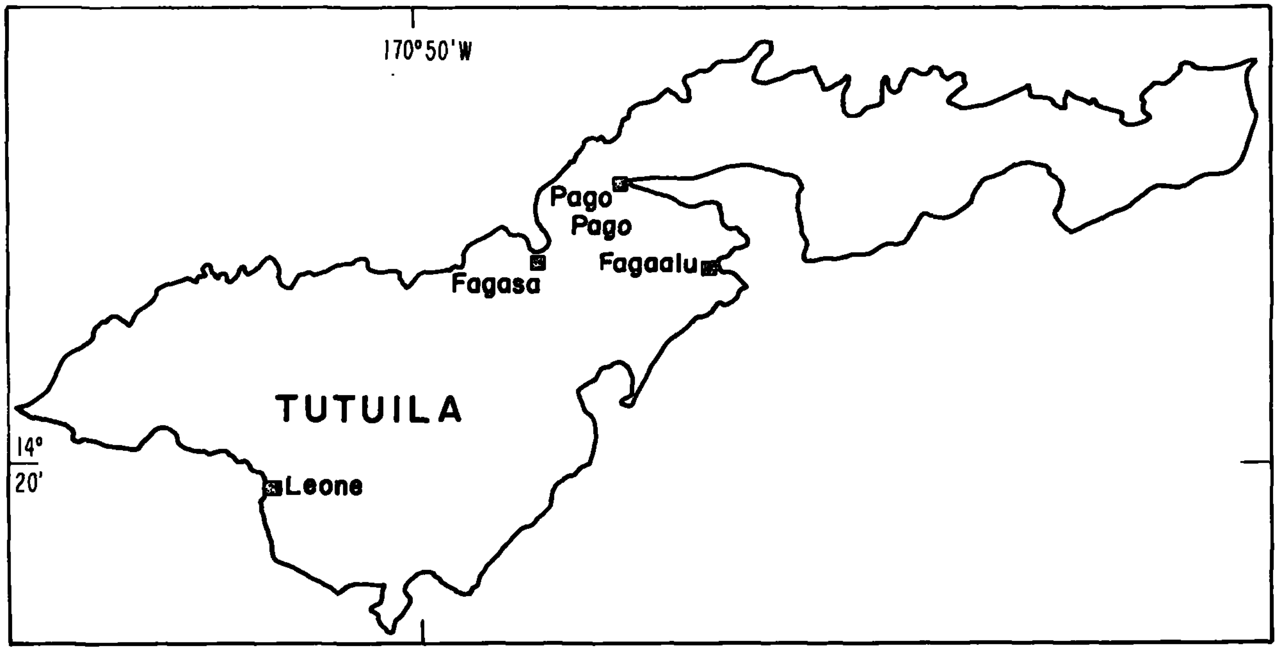


FIGURE 60.—Location map of Tutuila Island.

Islands, gives a description of a storm accompanied by shocks of earthquakes, which occurred in the Samoa group on the night of March 24. The east end of the Island of Savai'i was visited by a tidal wave, which swept away all houses within a quarter of a mile (0.4 km) of the beach for a distance of 15 miles (25.5 km) along the shore." This is probably a meteorological event, but Soloviev and Go (1974, p. 10) believed the destruction was too severe to be due entirely to the storm alone. (Pararas-Carayannis and Dong, 1980)

1896, June 15, 10:33. A letter from William Churchill, Consul General of the United States at Apia, Samoa, to the Hydrographer of United States Navy dated September 2, 1896, contains the following information as given in Pararas-Carayannis and Dong, (1980): Along the north coast of Savai'i (Western Samoa) after the tide had run ebb for about 1 hour, the water ceased to fall, and great waves were seen outside the reef. There was a slow rise during all the remainder of the ebb period. The great waves continued at long intervals. The tide at the time had a maximum height of 1.7 m above mean low water.

"No damage was done by the strange tide except the carrying adrift of a few canoes beached not quite high enough. But considerable alarm was manifested over the unusual circumstance." (Pararas-Carayannis and Dong, 1980) The date was given as the latter part of June. The June 15th date is the date of the great Sanriku, Japan, tsunami that killed 27,000 in Japan and caused damage in Hawaii.

1907, October 6. The Matavanu volcano on Savai'i Island began erupting on August 4, 1905. The flows occasionally generated small tsunamis in Western Samoa by avalanching material into the sea on the following dates: November 28, 1906; June 8, 19, 27, 1906; July 9, 25, 1907. Waves inundated the shore for a distance of 90 to 110 m. (Pararas-Carayannis and Dong, 1980; Soloviev and Go, 1974, p. 10).

According to Anderson (1910), the largest and most important tsunami that was caused by the Matavanu volcano eruption occurred on October 6, 1907, at about 5:30 P.M. local time. It was just at the time of high water, but the sea was smooth. The wave was 3.0 to 3.6 m high; it came from the northeast around the lave-point (Matautu?) as the others had done. A houseboat was wrecked, a buggy in it smashed, and several boats were damaged; while, at a house a few score yards off, a 1700-liter tank of water was lifted bodily from its foundation and carried across

(1907, October 6, continued)
the road. The wave was noticed, but of smaller size, in some of the other islands. (There is no indication as to whether or not these islands included the islands of American Samoa.) At Apia the tsunami had a height of only 0.3 to 0.6 m. It was probably caused by lava falling into the sea or by a steam explosion, but the exact cause was uncertain. Activity continued into 1911. (Pararas-Carayannis and Dong, 1980; Soloviev and Go, 1975, p. 10)

1915, February 11. Pararas-Carayannis and Dong (1980) quote the *New York Times* as follows: "Not only a hurricane, but with it an earthquake and a tidal wave swept the **Manu'a Islands** of the American Samoa group. Three persons were killed. One of these was beheaded by flying wreckage. Entire villages disappeared. Those of which traces remain were ruined. All shipping was either destroyed or badly damaged. Three-fourths of the cocoa palms on which the islands depend for nourishment and their commerce on copra, were leveled, and all the remainder were injured." Pararas-Carayannis and Dong continue: "No seismic activities were recorded for that period in that vicinity. It is not known whether the 'tidal wave' reported in the *New York Times* was indeed a tsunami generated by a local earthquake or high surge caused by the hurricane. The absence of any information on an earthquake or a tsunami elsewhere in the Samoa Islands suggests that the latter was the case."

1917, May 1, 18:27. A magnitude 8.0 earthquake occurred in the Kermadec Islands. Heck (1947) reports a 12.2-m wave at Samoa. A pronounced wave was recorded at Honolulu and on the west coast of the United States. The reference to the above statement was given by the International Seismological Summary, 1913-1934, but no mention of a tsunami was found in the volume containing the earthquake data for May, 1917. Searches were carried out in the local newspapers *O le Fa'atonu* from Pago Pago; and *Samoa Times* from Western Samoa for 1917, but newspaper articles relating to a 12.2-m wave or any indication of a tsunami could not be found for May. (Pararas-Carayannis and Dong, 1980)

Iida et al. (1967) report that a tsunami was observed in the Samoa Islands and that a 12-m height reported by Heck (1947) is probably confused with height of the June 25 (local date) tsunami. (Iida et al., 1967; Soloviev and Go, 1974, p. 10)

"No record of this tsunami from Apia gage was found. No other reference has been located thus far giving the actual height of the tsunami. The absence of any information in local papers is indeed strange, considering the magnitude and location of the earthquake." (Pararas-Carayannis and Dong, 1980)

1917, June 26, 05:50. A magnitude 8.3 earthquake that occurred about 250 km southwest of Apia was the most severe known to Samoa. Rocks rolled down the mountains, trees were uprooted, and pilings of houses were torn off, but there was no loss of life. Heck (1947) reported: "There was a 40-foot (12.2 m) tidal wave."

Mayor (1924) states the following: "The only unusual disturbance appears to have been due to the earthquake wave on the night of June 25, 1917, when the harbor-water suddenly sank about 3 feet (0.9 m) above high tide, oscillating several times with decreasing amplitude." It is not known to which harbor he is referring, but it is assumed to be **Pago Pago**. (Pararas-Carayannis and Dong, 1980)

Apia Observatory (1980) gives the following: "Destructive tsunami on south coast. At Apia Harbour, the wave arrived at about 05:55 UTC; maximum range about 80 cm; period about 18 minutes."

The *Samoa Times* of June 30, 1917, reports the following: "In **Tutuila** a small tidal wave swept in through **Pago Pago** destroying many Samoa houses. Most of those living in **Pago Pago** took to the hills. (Pararas-Carayannis and Dong, 1980)

The following is the account from the *O le Fa'atonu* of July 1917 from American Samoa given in Pararas-Carayannis and Dong (1980): "The fear experienced from the violence of the tremors is not to be compared with that experienced by the subsequent tidal wave. A few minutes after the quake ceased, the water began to leave **Pago Pago** Bay rapidly, falling about 6 feet (1.8 m). The return of the water resembled a small tidal wave at the head of the bay, and there the water may have reached a height of 6 to 8 feet (1.8 to 2.4 m) above normal. Injuries did not occur. There was damage of minor importance, the most important being the damage to two large churches, which were partly demolished--the Mormon Church in **Pago Pago** and the Catholic Church in **Leone**. Many of the natives around the bay sought refuge in the mountains where they remained until morning."

1918, September 7, 17:16. A magnitude 8.3 earthquake in the Kuril Islands produced a tsunami that was recorded at Apia with a maximum amplitude of 0.2 m and a period of 20 minutes. (Iida et al., 1967) Reports from American Samoa newspapers can not be found for this event. (Pararas-Carayannis and Dong, 1980)

1919, April 30, 07:17. A magnitude 8.3 earthquake in the Ha'apai Islands, Tonga Islands, caused cave-ins there and cave-ins and landslides in Samoa. Mayor (1924) reports: "It may also be of interest to state that the Tonga earthquake of April 30, 1919, produced quite similar oscillations of sea-level in **Pago Pago** harbor." *O le Fa'atonu* reported that the quake was also followed by tidal waves in **Tutuila**. The water receded about 6 feet (1.8 m) below the low water mark, and when it returned it attained a height of 6 or 8 feet (1.8 m or 2.4 m) above high water. Indication of where the tidal waves occurred on the Island of Tutuila was not provided. (Pararas-Carayannis and Dong, 1980) [Note similarity of wording with account of June 26, 1917 event.] It had an amplitude of 0.2 m at Apia (Iida et al., 1967; Heck, 1947; Soloviev and Go, 1975, p. 13)

1920, August. Heck (1947) included a reference to an earthquake and tidal wave at **Pago Pago** on this date. His reference was based on a vocal report by Mr. Mayor that "Recently at **Pago Pago** an earthquake was followed in half an hour by a wave." However, no primary sources from local newspapers have recorded this event. The seismic register at the Apia Observatory (1980) did not mention any tsunami nor were there any outstanding local earthquakes in or near the month of August. (Pararas-Carayannis and Dong, 1980) Iida et al. (1967) conclude that this is probably a re-entry for the April 30, 1919, event above, and Soloviev and Go (1975, p. 13) believe it to be mistaken for the September 20, 1920, event that follows.

1920, September 20, 14:39. A magnitude 8.0 earthquake occurred in the area of New Hebrides. Iida et al. (1967) report waves arrived at Apia at about 19:00. The tide gage record from the Apia Observatory is not available. Reports concerning this tsunami were not found in the *O le Fa'atonu* from American Samoa or the *Samoa Times* from Western Samoa. No other locality in the Pacific reported a tsunami from the earthquake. It is doubtful that this was a true tsunami. (Pararas- Carayannis and Dong, 1980; Soloviev and Go, 1974, p. 306)

1922, November 11, 04:33. A magnitude 8.3 earthquake in north-central Chile produced a 9-m local tsunami that inundated parts of several Chilean cities and killed more than 100 people. According to the reports from Western Samoa, the first sea wave reached Apia at 18:36 UT. The amplitude was 0.9 m at **Pago Pago**. Iida et al. (1967) indicate slight damage in **Pago Pago**. However, other sources were not found to verify this. Reports were not found in the *Samoa Times* of Western Samoa nor in the *O le Fa'atonu* of American Samoa. (Pararas-Carayannis and Dong, 1980; Iida et al., 1967; Soloviev and Go, 1975, p. 135)

1923, February 3, 16:01. A magnitude 8.3 earthquake in Kamchatka produced a tsunami of 6 to 8 m locally. The tsunami was recorded as a small wave at Apia. Pararas-Carayannis and Dong (1980) cite the *Samoa Times* report that a tidal wave was recorded by the tide gage, but the rise and fall of the water was small. Other information for Western Samoa or American Samoa could not be found. (Iida et al., 1967)

1926, March 16, 17:37. A magnitude 6.0 earthquake occurred in the Tonga Islands on this date. Heck (1947) reports that a tidal wave had swept over Palmerston Island about 250 km from Apia, which had devastated the island. The reported wave was said to have occurred about 3 months prior to June 30. The tide records from Apia are available, but did not record a tsunami. (Iida et al., 1967; Soloviev and Go, 1975, p. 13-14; Pararas-Carayannis and Dong, 1980). The effects at Palmerston may have been due to earlier hurricanes in the area. Evidence of a tsunami being recorded in Samoa for this event is not available, and one would not be expected from an earthquake so small.

1928, June 17, 03:19. A magnitude 7.8 earthquake offshore at Oaxaca, Mexico, produced waves that destroyed a warehouse. About three prominent cycles appeared on the Apia marigram 14.7 hours later with 20 minute periods. Other sources of information could not be located concerning the effects of this event in Samoa. (Pararas-Carayannis and Dong, 1980; Iida et al., 1967; Soloviev and Go, 1975, p. 190)

1932, June 3, 10:37. A magnitude 7.9 earthquake offshore at Jalisco, Mexico, caused a tsunami in which some people and small buildings were carried out to sea. The Apia Observatory tide gage recorded this event at about 10:45 A. M. local time. The period was 20-25 minutes, and the amplitude was about 0.03 m. A report was not found in *O le Fa'atonu* of American Samoa. The *Samoa Times* of Western Samoa for 1932 was not available. (Pararas-Carayannis and Dong, 1980; Iida et al., 1967)

1933, March 2, 17:31. An extremely destructive (magnitude 8.3) earthquake and tsunami occurred at Sanriku, Japan. It was recorded at Apia but not reported from American Samoa. (Iida et al., 1967; Pararas-Carayannis and Dong, 1980)

1944, December 7, 04:35. A magnitude 8.0 earthquake and tsunami at Kii, Japan, wrecked over 3,000 houses and killed nearly 1,000 people in Japan. Newspaper accounts cannot be found in *O le Fa'atonu*, and *Samoa Times* is not available for this year. However, a small tsunami was recorded by the Apia tide gage. Prominent weak waves, 0.03 m in amplitude, began at 11:00 A.M. (local time) with a period of 20 minutes. The waves may have lasted until 09 hours. (Apia Observatory, 1980; Pararas-Carayannis and Dong, 1980) The time does not appear correct and should be about 3:00 A.M. That also makes the statement about the waves' duration more reasonable.

1946, April 1, 12:29. A magnitude 7.8 earthquake in the Aleutian Islands generated a 30-m tsunami on Unimak Island that destroyed Scotch Cap Lighthouse. The tsunami was disastrous to Hawaii, and was recorded at Apia with an amplitude of 1.2 m and observed at **Pago Pago** with an amplitude of 0.8 m (Pararas-Carayannis and Dong, 1980). According to records of Apia Observatory the first sea wave arrived at Apia at 21:43 UTC as a recession. The period was 25 minutes. There is also a reflection from the California coast, arriving at Apia at April 2nd 02:08 U.T.C. causing an apparent period of 10-15 minutes. Apia record is available. (Apia Observatory, 1980; Pararas-Carayannis and Dong, 1980)

An article from the *Honolulu Advertiser* dated April 19, 1946, states: "Several huts in the village of **Pago Pago, Samoa**, were washed away by the tidal wave according to officers of the *MV Honda Knot*, which arrived at Pearl Harbor Wednesday from Samoa...In that port, the officers said, the rise and fall (range) of the harbor as the wave struck was about 5 feet (1.5 m)." (Pararas-Carayannis and Dong, 1980)

Information has not been obtained concerning this tsunami from any other locality in American Samoa. (Pararas-Carayannis and Dong, 1980; Iida et al., 1967)

1948, September 8, 15:09. A magnitude 7.8 earthquake in the Tonga Islands generated a tsunami of less than 0.1 m with a period of 17 minutes at **Pago Pago**. This information is probably taken from a record made on the newly-installed tide gage. Reports from *O le Fa'atonu* could not be located. The *Samoa Times* for this year was not available at the University of Hawaii Library. (Pararas-Carayannis and Dong, 1980; Iida et al., 1967; Soloviev and Go, 1975, p. 14)

1952, March 4, 01:23. A magnitude 8.1 earthquake on Hokkaido Island, Japan, produced a 6-m tsunami that swept away 90 houses and 448 vessels. It killed 33 people in Japan. A minor trace of a tsunami was recorded at **Pago Pago**. (Pararas-Carayannis and Dong, 1980)

1952, March 9, 17:04. An aftershock with a magnitude of 7.0 in southeast Hokkaido, Japan, caused a minor tsunami recorded at Hachinohe, Japan, with a maximum amplitude of 0.15 m. It was recorded at two other Japanese stations. Pararas-Carayannis and Dong (1980) report that it was recorded as a minor trace at **Pago Pago**. This is surprising for a tsunami having such a small amplitude in the source region. (Pararas-Carayannis and Dong, 1980)

1952, March 17, 03:58. A swarm of earthquakes occurred off the south coast of Hawaii. The largest earthquake with a magnitude of 4.5 produced a local tsunami that inundated about 183 m to the school yard at Kalapana. The wave would have to have been 3 m high. However, it was not recorded at Hilo or elsewhere in Hawaii (Cox and Morgan, 1977). A minor trace of a tsunami was recorded at **Pago Pago**. (Pararas-Carayannis and Dong, 1980)

1952, March 19, 10:57. An earthquake that occurred east of Mindanao, Philippine Islands, with a magnitude of 7.7 caused a minor trace of a tsunami recorded at the tide gage of **Pago Pago**. (Pararas-Carayannis and Dong, 1980). Although it was also recorded at Yap Island and Guam, there are no reports that the wave was observed in the Philippines.

1952, May 13, 19:32. A magnitude 6.9 earthquake in Costa Rica caused a tsunami that was recorded at Puntarenas with an amplitude of less than 0.1 m. Pararas-Carayannis and Dong (1980) report that it was recorded at **Pago Pago** as a minor trace. This seems doubtful given the small waves in the source region and an earthquake focal depth of 100 km.

1952, July 13, 11:59. A magnitude 7.0 earthquake in the New Hebrides was reported by Zerbe (1953) to have produced a wave recorded at one station, believed to be Canton. Iida et al. (1967) could not find oscillations of a tsunami character, and therefore concluded that a tsunami was not generated. Pararas-Carayannis and Dong (1980) report a minor trace of a tsunami was recorded at the tide gage of **Pago Pago** that was attributed to the earthquake that occurred on this date in the New Hebrides.

1952, November 4, 16:58. The magnitude 8.2 Kamchatka tsunami with waves up to 13 m in Kamchatka affected many areas around the Pacific. The *Samoa Bulletin* from Western Samoa dated November 7, 1952, reports: "The tidal wave which Western Samoa experienced last Tuesday afternoon could have caused serious damage along Apia's foreshore if it had happened 4 hours later. The incoming tide was well below its high water level at 3:42 P. M. when the first effects of the tidal wave were recorded on the tide gage at the Apia Observatory at Mulinu'u. The third surge was the first of a series of spectacular movements of the sea. Shortly after 4 o'clock, (P.M.) the inner harbour became almost empty, then back came the sea swirling toward the shore in a rush which sprayed water over the sea wall, and inundated low-lying areas...The highest reading of the tide at the Observatory was recorded at 8:50 P.M. when the oscillations were still quite large, and the tide was at its maximum height." (Pararas-Carayannis and Dong, 1980) Waves were estimated to have been 0.7 m at the wharf, and about 0.9 m on the tide record. Elsewhere in Western Samoa damage reported included the destruction of a school and other buildings at Fagaloa Bay. (Zerbe, 1953)

Newspapers from American Samoa were not available for the years 1952 and 1953. A copy of the tide gage record showing the tsunami at Pago Pago for this date is available. However, information about this tsunami in Samoa is meager (Pararas-Carayannis and Dong, 1980). Zerbe (1953) gives the amplitude at **Pago Pago** as 0.9 m with a period of 18 minutes. Iida et al. (1967) state that there was some damage.

1953, September 14, 00:27. The magnitude 6.8 earthquake at Kandavu Passage of the Fiji Islands generated a 3-m wave at Suva, Fiji.

(1953, September 14, continued)
Soloviev and Go (1975, p. 17) report a 2-m wave. Apparently, submarine landslides that cut cables were responsible at least for some of the effects. A 0.1-m tsunami was recorded at **Pago Pago**. (Iida et al., 1967; Pararas-Carayannis and Dong, 1980)

1957, March 9, 14:23. A magnitude 8.3 earthquake in the Aleutian Islands generated a 12-m tsunami on Unimak Island that caused minor damage locally. The tsunami also caused extensive damage in Hawaii, some damage in Japan, and considerable damage around the Pacific.

The following information from Pararas-Carayannis and Dong (1980) was obtained from the Director of Public Works, Pago Pago. "**Pago Pago** Harbour: The first motion was a recession of the water at 12:48, although north shore people said it advanced. At the Pago (sic) end of the harbour the sea went over the road which is 4 feet (1.2 m) above mean tide. **Fagasa**, the small bay on the north coast, had waves about 5 feet (1.5 m) higher than normal high tide. There were about 11 large sea waves over a period of 1 hour and 50 minutes. The first three waves were about 14 minutes apart." By the time of the arrival of the 9th and 10th waves, the arrivals were about 8-9 minutes apart; the waves were smaller and faster. "The harbour kept on oscillating for approximately 5 hours. At 6 P.M. there was still a slight disturbance, but the north shore **Fagasa** port showed fairly rough waters. There is no record as to how long Fagasa oscillated."

Reports were not made anywhere else in Tutuila or in Manu'a. (Pararas-Carayannis and Dong, 1980). Iida et al. (1967) give the amplitude at **Pago Pago** as 0.3 m and period of 18 minutes. Salsman (1959) gives the recorded amplitude as 0.2 m.

There was minor damage in Western Samoa. A stone causeway was demolished at Safa'i on the north shore of Savai'i. At Ta'elefaga on the north coast of 'Upolu the sea inundated 23 m into the village, washing into huts. A canoe and its occupant were swept into one hut. (Pararas-Carayannis and Dong, 1980)

1958, November 6, 22:58. The magnitude 8.1 earthquake at Iturup, south Kuril Islands, generated a tsunami of 3 - 4 m locally and less than 0.1 m at **Pago Pago**. (Iida et al., 1967; Pararas-Carayannis and Dong, 1980)

1960, May 22, 19:11. A magnitude 8.6 earthquake off the coast of Chile caused heavy damage in Chile, Japan, and the United States. (See sections on Hawaii and on the West Coast for additional details.) This was undoubtedly one of the largest tsunamis ever recorded in the Samoa group. The following was extracted mainly from the report by Keys (1963).

The marigram at **Pago Pago** showed that the first wave arrived at about 8:35 P.M. Observers reported about 10 wave crests and troughs with the third and fifth considered to be the largest and the period estimated to be about 20 minutes. Berkman and Symons (1964) give the amplitude on the marigram as 0.8 m.

Up the bay 727 m farther, peak amplitudes of 0.8 to 2.1 m were recorded above the normal tide, which was on the ebb and approaching low water. The subsequent trough was about 1.2 to 1.5 m.

About 800 m up from the bay, five waves were observed of which the fourth was the largest. The maximum amplitude here was estimated at 1.2 to 1.5 m.

A tidal disturbance was not noticed at Tafuna because it was screened by an offshore reef.

At **Pago Pago** village, which is located at the extreme west end of the harbor, the tsunami reached its greatest heights in Samoa. The amplitude was about 2.4 m and damage estimated at $50,000 resulted. One house was lifted and moved about 3 m inland, and another was washed into the bay by the outgoing wave. A school, substantially constructed on concrete piers, was rotated about 0.3 m, and nearly all structural members were sprung.

At **Faga'alu**, the sea rose no more than 0.8 m. Reports of activity were not obtained from other coastal villages. It seems evident that **Pago Pago** Harbor was the only location where the tsunami was observed. (Pararas-Carayannis and Dong, 1980; Iida et al., 1967)

1963, February 13, 08:50. A magnitude 7.3 earthquake that occurred in north Taiwan generated a 0.2-m local tsunami that was recorded at the tide gage at **Pago Pago** as a minor trace. (Pararas-Carayannis and Dong, 1980)

1963, March 30. Although earthquake data are not available for this day, a minor tsunami was reportedly recorded at the tide gage at **Pago Pago**. (Pararas-Carayannis and Dong, 1980)

1963, October 13, 05:17. A magnitude 8.1 earthquake in the Kuril Islands generated a 4.4-m wave locally and less than 0.1-m tsunami at **Pago Pago**. (Iida et al., 1967; Pararas-Carayannis and Dong, 1980)

1963, October 20, 00:53. A magnitude 6.7 earthquake in the Kuril Islands reportedly produced runup heights of 15 m at Urup in the Kuril Islands. A small tsunami of less than 0.1 m was recorded at **Pago Pago**. (Iida et al., 1967) The *Samoa News* from Pago Pago reported that a tidal wave alert was given early that night, but other detail was not provided. (Pararas-Carayannis and Dong, 1980)

1964, March 28, 03:36. The Prince William Sound, Alaska, earthquake with a magnitude of 8.4 generated a tsunami that caused $84 million in damage and 106 deaths in Alaska. (See sections on Alaska, West Coast, and Hawaii for additional details.) A tide gage record for **Pago Pago** shows that the tsunami arrived at 13:51 UTC and had an amplitude of 0.2 m and a period of 20 minutes. (Iida et al., 1967; Pararas-Carayannis and Dong, 1980)

1964, June 16, 04:01. An earthquake with a magnitude of 7.5 in Niigata, Japan, produced a tsunami with maximum amplitude of 5.8 m there. The tsunami was reportedly recorded at the tide gage at **Pago Pago** (Pararas-Carayannis and Dong, 1980). Because Niigata is on the Sea of Japan side of Honshu and the only stations in Japan that reported the event were on the Sea of Japan, it seems unlikely that the event could have been recorded at Pago Pago.

1965, January 24, 00:11. A magnitude 7.6 earthquake in Indonesia generated a destructive tsunami locally that was reportedly recorded at the tide gage of **Pago Pago**. (Pararas-Carayannis and Dong, 1980; Soloviev and Go, 1974, p. 287) It seems doubtful that the tsunami could have been recorded there since the epicenter was in the western end of the Ceram Sea (west of New Guinea) with many islands blocking the tsunami from the Pacific, and no other station reported a tsunami.

1965, February 4, 05:01. A magnitude 8.2 earthquake in the Rat Islands, Aleutian Islands, generated a 10-m tsunami at Shemya. The tsunami also was recorded in Japan and Hawaii. (Iida et al., 1967) It was recorded on the tide gage at **Pago Pago** as a minor trace. (Pararas-Carayannis and Dong, 1980)

1965, March 30, 02:27. A second earthquake in the Aleutian Islands with a magnitude of 7.4 generated a 0.2-m tsunami that was recorded on the tide gage at Attu. (Iida et al., 1967) Pararas-Carayannis and Dong (1980) report that it was recorded at **Pago Pago** as a minor trace.

1965, July 2, 20:59. A magnitude 6.5 earthquake near Unalaska in the Aleutian Islands generated a tsunami that was recorded on the tide gage at Dutch Harbor with an amplitude of 0.1 m. (Iida et al., 1967) Pararas-Carayannis and Dong (1980) report that it was recorded at **Pago Pago**, but this seems doubtful given the small size of the wave in the source region and the lack of reports from any other station.

1965, August 11, 22:32. A magnitude 7.0 earthquake in the New Hebrides generated a tsunami that was recorded at the tide gage at Tongoa Island, New Hebrides, with an amplitude of 2.5 m. (Iida et al., 1967) Pararas-Carayannis and Dong (1980) report that it was recorded at **Pago Pago** as a minor trace.

1966, October 17, 21:42. A magnitude 8.0 earthquake near Peru generated a minor tsunami widely recorded in the Pacific. It

(1966, October 17, continued)
had an amplitude of 0.1 m at **Pago Pago**. (Iida et al., 1967; Pararas-Carayannis and Dong, 1980)

1966, December 28, 08:18. A magnitude 7.8 earthquake near the coast of northern Chile generated a minor tsunami that was observed in Hawaii and at **Pago Pago** with an amplitude of 0.06 m at both locations. (Von Hake and Cloud, 1968; Pararas-Carayannis and Dong, 1980)

1966, December 31, 18:23. A magnitude 7.5 earthquake in the Santa Cruz Islands caused a small tsunami of 2 m in the New Hebrides and 0.03 m at **Pago Pago**. (Pararas-Carayannis and Dong, 1980; Iida et al., 1967)

1968, April 1, 00:42. A magnitude 7.5 earthquake in Shikoku, Japan, produced a 1.2-m wave locally and was reported to have been recorded on the tide gage at **Pago Pago** as a minor trace. (Pararas-Carayannis and Dong, 1980)

1968, May 16, 00:49. A magnitude 7.9 earthquake off Honshu, Japan, caused a tsunami of maximum 5.1-m rise of water at Shiogama, but did little damage. It was recorded with an amplitude of 0.08 m in **Pago Pago**. (Pararas-Carayannis and Dong, 1980; Soloviev and Go, 1974, p. 130-140, 352)

1968, August 1, 20:19. A magnitude 7.3 earthquake in Luzon, Philippines, generated a minor tsunami that was recorded at Guam, Hawaii, Alaska, Japan, and **Pago Pago** as a minor trace. (Pararas-Carayannis and Dong, 1980)

1969, August 11, 21:27. A magnitude 7.8 earthquake in the Kuril Islands generated a tsunami with a rise of 5 m at Shikotan Island. It was recorded in **Pago Pago** as a minor trace. (Pararas-Carayannis and Dong, 1980; Soloviev et al., 1986)

1969, November 22, 23:10. A magnitude 7.1 earthquake on the east coast of Kamchatka generated a tsunami that caused minor damage locally. Waves were 12-15 m high. It was recorded in **Pago Pago** as a minor trace and at other Pacific Basin locations. (Pararas-Carayannis and Dong, 1980; Soloviev et al., 1986)

1971, July 14, 06:11. A magnitude 7.9 earthquake in New Ireland generated a 2-m wave at Rabaul, New Britain. (New Ireland and New Britain are part of the Bismarck Archipelago north east of New Guinea.) A 0.06-m tsunami was reported from **Pago Pago**. (Pararas-Carayannis and Calebaugh, 1977; Pararas-Carayannis and Dong, 1980)

1973, January 30, 21:01. A magnitude 7.3 earthquake near the coast of Michoacan, Mexico, produced a minor tsunami with a maximum amplitude of 0.58 m at Manzanillo, Mexico. It caused a 0.11-m tsunami at **Pago Pago**. Pararas-Carayannis and Dong (1980) give the amplitude at **Pago Pago** as 0.22, which is possibly the range rather than the amplitude. (Soloviev et al., 1986)

1973, June 17, 03:55. A magnitude 7.4 earthquake near Hokkaido, Japan, produced a tsunami with a height of 3.0 m in Japan that sank several fishing boats. It had an amplitude of about 0.05 m at **Pago Pago**. (Soloviev et al., 1986, Pararas-Carayannis and Dong, 1980, Coffman and von Hake, 1975)

1974, October 3, 14:21. The magnitude 8.1 earthquake at Lima, Peru, generated a tsunami of 0.92-m amplitude at La Punta, Peru, and in the Pacific Basin. A 0.16-m amplitude wave was recorded at **Pago Pago**. Information about the event was not found in the local newspapers. (Pararas-Carayannis and Dong, 1980; Soloviev et al., 1986)

1975, November 29, 14:48 The magnitude 7.2 earthquake on the Island of Hawaii generated a 7.9-m wave at Halape, Hawaii. It killed two people and was widely recorded around the Pacific. It generated a minor tsunami recorded with amplitudes (range?) of 0.11 m at **Pago Pago** and 0.17 m at Apia. (Pararas-Carayannis and Dong, 1980)

1975, December 26, 15:57. A magnitude 7.8 earthquake, about 120 km south of Samoa at the northern end of the Tonga-Fiji arc, generated a minor tsunami in the Samoa Islands. A 0.38 m tsunami was recorded at **Pago Pago**, and, a 0.08 m tsunami was recorded at Apia. The tsunami did not cause damage. (Pararas-Carayannis and Dong, 1980; Soloviev et al., 1986; Coffman and Stover, 1977)

1977, April 2, 07:15. A magnitude 7.6 earthquake in the Tonga trench region caused a minor tsunami that was recorded with a maximum amplitude of 0.02 m at Apia and a maximum amplitude of 0.08 m at **Pago Pago**. (Coffman and Stover, 1979; Pararas-Carayannis and Dong, 1980; Soloviev et al., 1986)

1977, June 22, 12:09. A magnitude 7.2 earthquake in the Tonga trench generated a tsunami having a maximum height of 0.04 m at Apia and 0.08 m at **Pago Pago**. (International Tsunami Information Center, Tsunami Reports, 1977, No. 9; Pararas-Carayannis and Dong, 1980; Soloviev et al., 1986; Coffman and Stover, 1979)

1977, October 10, 11:54. The magnitude 7.2 earthquake in the Tonga Islands caused a minor tsunami of 0.03 m at **Pago Pago**. (International Tsunami Information Center, Tsunami Reports, 1977, No. 16; Pararas-Carayannis and Dong, 1980; Soloviev et al., 1986; Coffman and Stover, 1979)

1979, March 14, 11:07. A magnitude 7.6 earthquake centered near the Pacific coast of Mexico generated a tsunami. It was recorded with a wave amplitude of 0.005 m and a period of 1.5 hours on an underwater gage at a depth of 3,210 m about 980 km from the epicenter. It was recorded as far away as Japan, and in **Pago Pago**, American Samoa with a 0.07-m amplitude. (Soloviev et al., 1986; Pararas-Carayannis and Dong, 1980)

1981, September 1, 09:30. A magnitude 7.5 earthquake in the Tonga trench caused destruction on the southwestern coast of Samoa. A tsunami was recorded at **Pago Pago** with an amplitude of 0.12 m. Noticeable damage occurred on the southwest coasts of the islands of Western Samoa. In Western Samoa at the village of Taga on Savai'i Island, two large guest houses collapsed, and the road was blocked with rocks and logs. Food, clothing, household goods, and a fishing boat were swept out to sea. Minor damage was also reported on the Island of Manono, Western Samoa. Waves hit some houses and carried off household goods. (Stover, 1984; International Tsunami Information Center, March, 1982; Soloviev et al., 1986)

1982, December 19, 17:44. A magnitude 7.5 earthquake south of the Tonga Islands produced a small tsunami. It was recorded widely around the Pacific, including a wave with an amplitude of 0.05 m at **Pago Pago**. (De Rycke, 1982)

1985, September 19, 13:18. A magnitude 7.9 earthquake along the coast of Mexico generated a tsunami that was damaging locally and was recorded with an amplitude of 0.12 m at **Pago Pago**. (Pararas-Carayannis, 1985)

1986, May 7, 22:47. A magnitude 7.6 earthquake near Adak in the Aleutian Islands had a maximum amplitude of 0.88 m at Adak and was widely recorded around the Pacific. It had an amplitude of 0.01 m at **Pago Pago**. (Pararas-Carayannis, 1986)

1986, October 20, 06:46. A magnitude 7.9 earthquake in the Kermadec Islands produced a tsunami that was recorded at **Pago Pago** with a wave amplitude of 0.05 m. (Person, 1986)

1987, October 6, 04:19. A magnitude 7.3 earthquake in the Tonga Islands produced a tsunami that was recorded at **Pago Pago** with a wave amplitude of 0.12 m. The tsunami was not reported elsewhere. (Tsunami Newsletter, December, 1987; PDE Monthly Listing, October 1987)

TABLE 7. TSUNAMI DATA FOR AMERICAN SAMOA

ORIGIN DATA					TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOT-ION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1837 11 07	12:51 42.5S 74.0W 8.5	S. Central Chile (PAL)	4	E&L	3.0 3.0	Pago Pago, Tutuila I.	OBS					(See also Hawaii section.)
1866 09 12		Manu'a Islands, Samoa	1	V		American Samoa	OBS					Waves generated by volcanic eruption.
1868 08 13	21:30 18.6S 71.0W 8.5	N.Chile (PAL)	4	E	4.3 3.5	American Samoa	OBS?					3-m waves observed in Apia, Western Samoa; therefore, some unreported effects probably occurred in American Samoa. (See also Hawaii and West Coast sections.)
1877 05 10	00:59 19.6S 70.2W 8.5	Chile (PAL)	4	E		American Samoa	OBS?					No reports of effects in American Samoa but reported as 0.9-m wave at Apia, W. Samoa. (See also Hawaii and West Coast sections.)
1883 03 24		Samoa Islands	2	E		American Samoa	OBS?					Houses on Savai'i washed away. Storm and earthquake reported to cause disturbed waves in W. Samoa. Not reported from American Samoa.
1896 06 15	10:33 39.5N 144.0E 7.6	Sanriku, Japan (Iida)	4	E	4.0 3.8	American Samoa	OBS?					Observed in W. Samoa where canoes were set adrift; not reported from American Samoa. (See also West Coast and Hawaii sections.)
1907 10 06		Savai'i, Samoa	4	V		American Samoa	OBS?					The largest of 7 waves generated by volcanic activity on Savai'i over the preceding year. None reported observed in American Samoa.
1915 02 11		Manu'a Islands, American Samoa	1	E		Manu'a Is.	2.4					Probably meteorological in origin. Several fatalities and damage reported.
1917 05 01	18:27 29.2S 177.0W 8.0	Kermadec Islands (ISS) (G&R)	2	E	1.0	American Samoa	OBS?					Substantiation for reported 12-m wave not found. (See also West Coast and Hawaii sections.)
1917 06 26	05:50 16.0S 171.0W 8.3	Samoa Islands (ISS) (G&R)	4	E	3.0 3.0	Pago Pago, Tutuila I.	2.1		F			Many houses destroyed, church damaged.
						Leone, Tutuila I.	OBS					Church damaged. (See also West Coast and Hawaii sections.)
1918 09 07	17:16 45.5N 152.0E 8.3 33	Kuril Islands (Iida)	4	E	3.6	American Samoa	OBS?					Recorded in Apia, W. Samoa, with 0.2-m amplitude. Not in American Samoa. (See also West Coast and Hawaii sections.
1919 04 30	07:17 21.5S 172.5W 8.3	Tonga Islands (ISS) (G&R)	4	E	1.0	Pago Pago, Tutuila I.	2.1		F			(See also West Coast and Hawaii sections.)
1920 08			1	E		Pago Pago, Tutuila I.						Probable erroneous entry for 04/30/1919 or 09/20/1920.
1920 09 20	14:39 20.6S 168.8E 8.0	New Hebrides Islands (ISS) (G&R)	4	E	1.0	American Samoa	OBS?					Waves reported from Apia, W. Samoa. Not reported from American Samoa.
1922 11 11	04:33 28.5S 70.0W 8.3 25	N. Central Chile (PAL)	4	E	3.0 2.5	Pago Pago, Tutuila I.	0.9	20.0				Unconfirmed report of slight damage. (See also West Coast and Hawaii sections.)
1923 02 03	16:01 54.0N 161.0E 8.3	Kamchatka Peninsula, USSR (Iida)	4	E	3.0	American Samoa	OBS?					Recorded at Apia, Western Samoa but not reported observed in American Samoa. (See also West Coast and Hawaii sections.)
1926 03 16	17:37 16.0S 171.0W 6.0	Tonga Islands (ISS) (G&R)	1	M	2.5	American Samoa	OBS?					Palmerston I. devastated by wave in spring 1926. No indication of wave on Apia records. Wave is probably meteorological in origin and unrelated to earthquake on this date.

ORIGIN DATA			V	C	TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOTION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1928 06 17	03:19 16.3N 97.7W 7.8	S. Mexico (DNAG)	4	E	1.0 1.0	American Samoa	OBS?					Three waves recorded at Apia. Not reported for American Samoa. (See also West Coast and Hawaii sections.)
1932 06 03	10:37 19.8N 103.0W 7.9	Central Mexico (DNAG)	4	E	 2.0	American Samoa	OBS?					Recorded at Apia with 3-cm amplitude, but not reported for American Samoa. (See also Hawaii section.)
1933 03 02	17:31 39.1N 144.7E 8.3 10	Sanriku, Japan (Iida)	4	E	3.0 3.5	American Samoa	OBS?					Recorded at Apia but not reported from American Samoa. (See also West Coast and Hawaii sections.)
1944 12 07	04:35 34.0N 137.1E 8.0 30	Ryukyu Trench, Japan (Iida)	4	E	3.0 2.5	American Samoa	OBS?					Recorded at Apia with 3-cm in amplitude, but not reported American Samoa. (See also Alaska, Hawaii, and West Coast sections.)
1946 04 01	12:29 52.8N 163.5W 7.8 25	E. Aleutian Islands (DNAG)	4	E	5.0 4.0	Pago Pago, Tutuila I.	0.8					Several huts washed away. (See also Alaska, Hawaii, and West Coast sections.)
1948 09 08	15:09 21.0S 174.0W 7.8	Tonga Islands (ISS) (G&R)	4	E	1.0	Pago Pago, Tutuila I.	<0.1	17.0				(See also Hawaii section.)
1952 03 04	01:23 42.2N 143.9E 8.1 45	SE. Hokkaido, Japan (Iida)	4	E	2.0 2.0	Pago Pago, Tutuila I.	OBS					Minor trace. (See also Alaska, Hawaii, West Coast, and Pacific Territories sections.)
1952 03 09	17:04 41.7N 143.5E 7.0 20	SE. Hokkaido, Japan (Iida)	4	E		Pago Pago, Tutuila I.	OBS?					Dubious report.
1952 03 17	03:58 19.1N 155.0W 4.5	Hawaii (Cox)	4	E		Pago Pago, Tutuila I.	OBS					Minor trace. (See also Hawaii section.)
1952 03 19	10:57 9.4N 125.1E 7.7	Mindanao, Philippine Islands (ISC) (PAS)	4	E		Pago Pago, Tutuila I.	OBS					Minor trace. (See also Pacific Territories section.)
1952 05 13	19:32 10.3N 85.3W 6.9 64	Costa Rica-Panama (DNAG)	2	E		Pago Pago, Tutuila I.	OBS?					Doubtful report.
1952 07 13	11:59 18.7S 170.3E 7.0	New Hebrides (ISC) (PAS)	2	E		Pago Pago, Tutuila I.	OBS					Minor trace.
1952 11 04	16:58 52.8N 159.5E 8.2 30	Kamchatka Peninsula, USSR (Iida)	4	E	4.0	Pago Pago, Tutuila I.	0.9	18.0	F	05-02:41	09.7	Some damage, few details. (See also Alaska, Hawaii, West Coast, and Pacific Territories sections.)
1953 09 14	00:27 18.3S 178.2E 6.8 60	Fiji Islands (ISC) (PAS)	4	E&L	1.0	Pago Pago, Tutuila I.	0.1					(See also Hawaii section.)
1957 03 09	14:23 51.5N 175.7W 8.3 33	Central Aleutian Islands (DNAG)	4	E	3.5	Pago Pago, Tutuila I.	1.2	22.0	R	09-23:29	09.1	Road flooded. Tide gage recorded amplitude of 0.2 m. (See also Alaska, Hawaii, West Coast and Pacific Territories section.)
						Fagasa, Tutuila I.	1.5	14.0				
1958 11 06	22:58 44.3N 148.5E 8.1 85	S. Kuril Islands, USSR (Iida)	4	E	2.0	Pago Pago, Tutuila I.	<0.1	22.0			09.9	(See also Alaska, Hawaii, West Coast, and Pacific Territories sections.)
1960 05 22	19:11 39.5S 74.5W 8.6 33	S. Central Chile (PAL)	4	E	4.5 4.0	Pago Pago, Tutuila I.	2.4	18.0	R	23-07:33	12.4	$50,000 damage to houses and school. Tide gage recorded an amplitude of 0.8 m. (See also Alaska, Hawaii, West Coast, and Pacific Territories section.)
						Faga'alu, Tutuila I.	0.8					

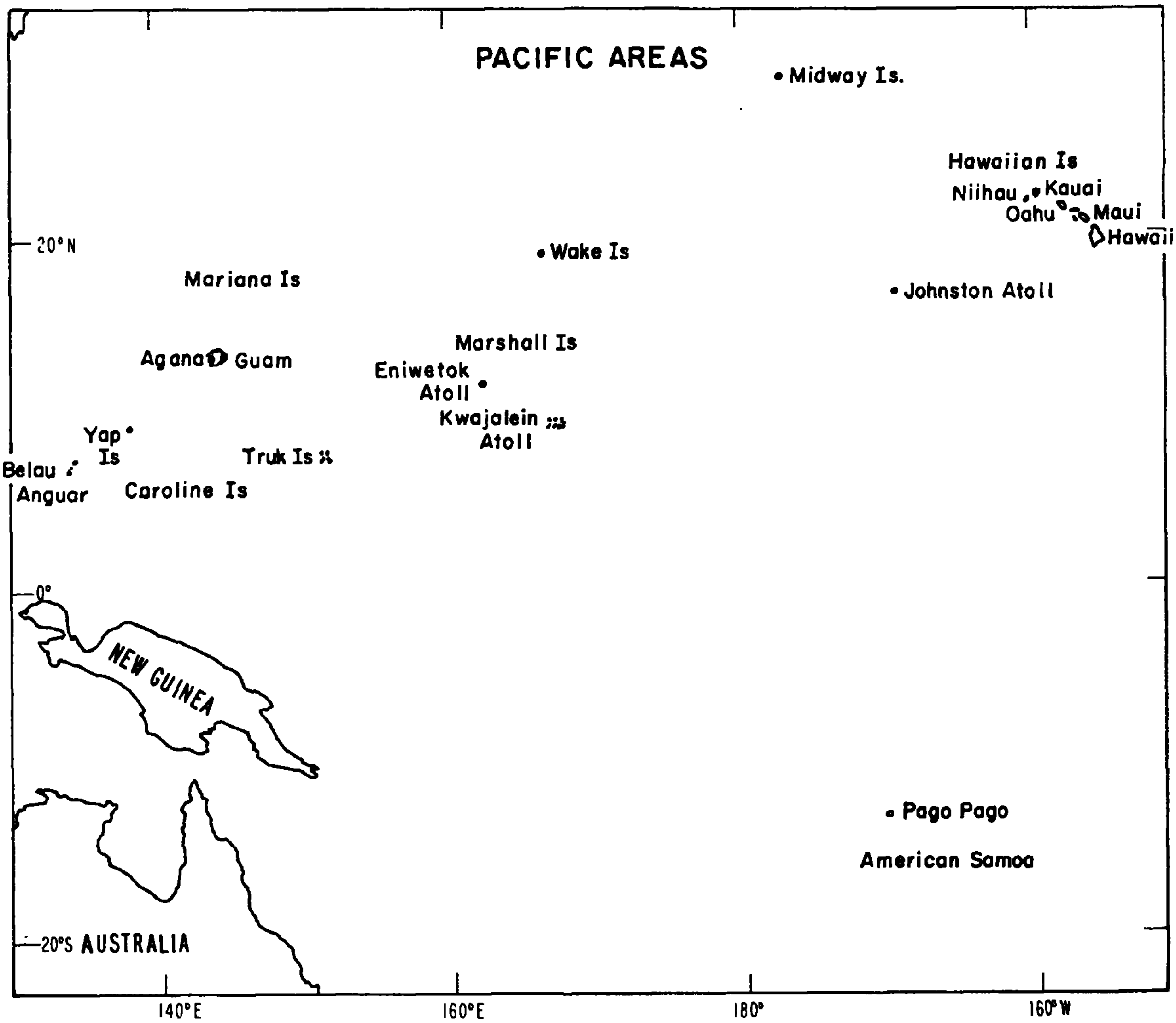
DATE (ORIGIN DATA)	TIME / LAT./LONG. / MAGNITUDE / DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT (TSUNAMI DATA)	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOTION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1963 02 13	08:50 24.4N 122.1E 7.3 53	E. Taiwan-Ryukyu Islands (ISC) (CGS)	4	E		Pago Pago, Tutuila I.	OBS					Minor trace.
1963 03 30						Pago Pago, Tutuila I.	OBS					Trace of a tsunami. No earthquake data.
1963 10 13	05:17 43.8N 150.0E 8.1	Kuril Islands, USSR (Iida)	4	E	2.0	Pago Pago, Tutuila I.	<0.1	14.0			09.6	(See also Alaska, Hawaii, West Coast, and Pacific Territories sections.)
1963 10 20	00:53 44.1N 150.1E 6.7 0	Kuril Islands, USSR (Iida)	4	E	2.0	Pago Pago, Tutuila I.	<0.1	18.0			09.8	(See also West Coast, Hawaii, and Pacific Territories section.)
1964 03 28	03:36 61.1N 147.5W 8.4 23	Gulf of Alaska-Alaska Peninsula (DNAG)	4	E	4.5	Pago Pago, Tutuila I.	0.2	20.0	R	28-13:51	10.3	(See also Alaska, Hawaii, West Coast, and Pacific Territories sections.)
1964 06 16	04:01 38.7N 139.2E 7.5 40	NW. Honshu Island, Japan (Iida)	4	E	2.0	Pago Pago, Tutuila I.	OBS?					Doubtful report.
1965 01 24	00:11 2.4S 126.0E 7.6 6	Ceram Island, Indonesia (ISC) (PAS)	4	E	4.0	Pago Pago, Tutuila I.	OBS?					Doubtful report.
1965 02 04	05:01 51.3N 178.6W 8.2 36	W. Aleutian Islands (DNAG)	4	E	3.0	Pago Pago, Tutuila I.	0.1					Minor trace. (See also Alaska and Hawaii sections.)
1965 03 30	02:27 50.3N 177.9W 7.4 20	W. Aleutian Islands (DNAG)	4	E	-1.0	Pago Pago, Tutuila I.	OBS?					Minor trace. (See also Alaska and Hawaii sections.)
1965 07 02	20:59 53.0N 167.6W 6.5 40	E. Aleutian Islands (DNAG)	4	E	-1.0	Pago Pago, Tutuila I.	OBS?					Minor trace, doubtful report. (See also Alaska and Hawaii sections.)
1965 08 11	22:32 15.8S 167.1E 7.0 31	New Hebrides Islands (ISC) (PAS)	4	E	1.5	Pago Pago, Tutuila I.	OBS					Minor trace.
1966 10 17	21:42 10.7S 78.8W 8.0 40	Peru (PAL)	4	E	1.0 1.5	Pago Pago, Tutuila I.	0.1					(See also Alaska, Hawaii, West Coast and Pacific Territories sections.)
1966 12 28	08:18 25.5S 70.6W 7.8 32	N. Chile (PAL)	4	E	0.5	Pago Pago, Tutuila I.	<0.1					(See also West Coast and Pacific Territories section.)
1966 12 31	18:23 11.9S 166.4E 7.5 73	Santa Cruz Islands (ISC) (PAS)	4	E		Pago Pago, Tutuila I.	<0.1					
1968 04 01	00:42 32.3N 132.5E 7.5 30	Shikoku, Japan (Iida)	4	E	1.0	Pago Pago, Tutuila I.	OBS					Minor trace. (See also Alaska section.)
1968 05 16	00:49 40.7N 143.6E 7.9 0	Honshu, Japan (Iida)	4	E	2.0	Pago Pago, Tutuila I.	<0.1					(See also Alaska, Hawaii, West Coast and Pacific Territories sections.)
1968 08 01	20:19 16.5N 122.2E 7.3 36	E. Luzon Island, Philippines (ISC)	4	E	2.0	Pago Pago, Tutuila I.	OBS					Minor trace. (See also Alaska, Hawaii, and the Pacific Territories sections.)

ORIGIN DATA					TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOT-ION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1969 08 11	21:27 42.7N 147.6E 7.8 30	Hokkaido, Japan-Kuril Islands, USSR (Iida)	4	E	1.0	Pago Pago, Tutuila I.	OBS					Minor trace. (See also Alaska, Hawaii, and the Pacific Territories sections.)
1969 11 22	23:10 57.7N 163.6E 7.1 51	Kamchatka, USSR (ISC)	4	E		Pago Pago, Tutuila I.	OBS					Minor trace. (See also Alaska, Hawaii, and the Pacific Territories sections.)
1971 07 14	06:11 5.5S 153.9E 7.9 43	New Ireland, Bismarck Archipelago (ISC)	4	E		Pago Pago, Tutuila I.	<0.1					(See also Alaska, Hawaii, and Pacific Territories sections.)
1973 01 30	21:01 18.4S 103.2W 7.3 32	S. Mexico (DNAG)	4	E		Pago Pago, Tutuila I.	0.1					(See also Hawaii section.)
1973 06 17	03:55 43.0N 146.0E 7.4 40	Hokkaido, Japan-Kuril Islands, USSR (Iida)	4	E	1.0	Pago Pago, Tutuila I.	<0.1					(See also Alaska and Hawaii sections.)
1974 10 03	14:21 12.3S 77.8W 8.1 13	Peru (PAL)	4	E		Pago Pago, Tutuila I.	0.2	19.0	R			(See also West Coast, Hawaii, and Pacific Territories sections.)
1975 11 29	14:48 19.3N 155.0W 7.2 8	Hawaii (COX)	4	E		Pago Pago, Tutuila I.	0 1					(See also Alaska, Hawaii, West Coast and Pacific Territories sections.)
1975 12 26	15:57 16.2S 172.5W 7.8 33	Tonga-Kermadec Islands (ISC) (USE)	4	E		Pago Pago, Tutuila I.	0.4					
1977 04 02	07:15 16.8S 172.0W 7.6 33	Tonga Trench (ISC) (USE)	4	E	-2.0	Pago Pago, Tutuila I.	<0.1			04-07:45	00.5	
1977 06 22	12:09 22.9S 175.7W 7.2 69	Tonga Trench (ISC) (BRK)	4	E		Pago Pago, Tutuila I.	<0.1					(See also West Coast and Hawaii sections.)
1977 10 10	11:54 25.9S 175.4W 7.2 24	Tonga Trench (ISC) (USE)	2	E	-3.0	Pago Pago, Tutuila I.	<0.1				00.9	
1979 03 14	11:07 17.5N 101.5W 7.6 15	S. Mexico (DNAG)	4	E		Pago Pago, Tutuila I.	<0.1					
1981 09 01	09:30 15.1S 173.1W 7.5 20	Tonga Trench (ISC)	4	E		Pago Pago, Tutuila I.	0.1					
1982 12 19	17:44 24.2S 176.0W 7.5 40	S. Tonga Islands (ISC)	4	E		Pago Pago, Tutuila I.	<0.1					(See also Hawaii section.)
1985 09 19	13:18 18.1N 102.8W 7.9 18	Mexico (DNAG)	4	E		Pago Pago, Tutuila I.	0.1					(See also Hawaii section.)
1986 05 07	22:47 51.5N 174.8W 7.6 19	W. Aleutian Islands (ISC)	4	E		Pago Pago, Tutuila I.	<0.1					(See also Alaska, Hawaii, West Coast, and Pacific Territories sections.)

ORIGIN DATA: DATE / TIME / LAT./LONG. / MAGNITUDE / DEPTH (KM)	AREA	VALID	CAUSE	TSUNAMI DATA: MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOT-ION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1986 10 20 06:46 28.1S 176.4W 7.9 29	Kermadec Islands (ISC)	4	E		Pago Pago, Tutuila I.	<0.1					(See also Hawaii section.)
1987 10 06 04:19 17.9S 172.2W 7.3 16	Tonga Islands (PDE)	4	E		Pago Pago, Tutuila I.	0.1			06-05:10		

6. UNITED STATES POSSESSIONS AND CURRENT AND FORMER TRUST TERRITORIES IN THE PACIFIC OCEAN

(excluding American Samoa)



6.1 BACKGROUND INFORMATION

The approximately 2,000 islands including the Marianas, Caroline and Marshall Islands archipelagoes are collectively known as Micronesia. They were discovered by sixteenth and seventeenth century explorers and traders but were largely ignored except for Guam, the largest of the islands. Guam was discovered by Magellan in 1521. Spanish missionaries arrived in 1688 making it one of the first Pacific Islands inhabited by Europeans. In 1885 many of the Marshall and Caroline Islands were claimed by

Germany. Spain sold its claim to these and other islands to Germany in 1898 at the time of the Spanish American War. As a result of the War, the United States took possession of Guam. At the outbreak of World War I, Japan occupied the German islands and was given a League of Nations mandate to the islands following the war. The United States occupied the islands during and at the end of World War II and continued to administer the islands as United Nations trust territories. In 1986 the Marshall Islands became the Republic of the Marshall Islands and the eastern part of the Caroline Islands became the Federated States of Micronesia. Both are independent in free association with the United States which retained defense and aid responsibilities. Palau Islands in the western end of the Caroline archipelago obtained local self government as the Republic of Belau but, for now, remains part of the Trust Territories. The United States retains control of Kwajalein Atoll as a missile range site for 30 years under agreement with the Federated States of Micronesia. The northern Mariana Islands elected commonwealth status with the United States. Guam, Wake Island, and Johnston Atoll which had been U. S. Territories since the end of the nineteenth century remain as unincorporated territories.

Due in part to the small area of the islands other than Guam, tsunamis refract around them rather than build up on the shores. The observed amplitudes are small. This and the sparsity of historical records for most of the area limits the tsunami history to the period of instrumental observations for the most part. There are reported observations of tsunamis from tide gages at Truk and Yap, two of the four states comprising the Federated States of Micronesia in the Caroline Islands; at Anguar Island, Republic of Belau (Palau) in the western Caroline Islands: Enewetak (formerly Eniwetok) and Kwajalein Atolls in the Republic of the Marshall islands; at Guam, Wake Island and Johnston Atoll. The stations were installed in 1940 at Johnston, in 1946 at Kwajalein, 1948 at Apra Harbor, Guam, 1950 at Wake Island; and 1953 on Moen Island, Truk. The tide gage installation dates for Angaur Island, Palau and Enewetak were not located.

6.2 DESCRIPTION OF TSUNAMI EVENTS

1819. A tsunami was reported from an explosive eruption of Asuncion volcano in the Mariana Islands but no other details are given. (Soloviev and Go, 1974, p. 189; Iida et al., 1967; Heck, 1947)

1849, January 24. A strong earthquake at 2:30 or 2:56 P.M. in the Mariana Islands caused extensive damage on Guam. The earthquake generated a tsunami on **Guam** that was also and reported in the **Caroline Islands**. Heavy aftershocks continued into March and caused new damage and fear among the inhabitants that the island would be swallowed by the sea. Soloviev and Go (1974) quote the following: "One of the eyewitnesses, who was on board a ship riding in the bay gave the following account of the effects of the main earthquake and the tsunami in **Umatac Bay**: (southwest coast of **Guam**). 'I had never before experienced anything like it. The tremor lasted about a minute and continued at night with seven shocks, much less strong. The last of them occurred at dawn on January 25.

" 'The first, main earthquake began with an exceptional trembling of the water, which was then transmitted to the land. The displacements of the ground were so large that all stone and brick buildings suffered to some extent, and many completely collapsed.

" 'One of my boats was taking on a supply of water in the mouth of the river. It was caught by the flood tide, and almost tossed onto the trees. Barrels and other objects were carried 1/2 km (1/4 mile) or more from shore to open sea. When the wave rolled back, hundreds of fishes were left on the dried bottom. The shore near the river dropped about 3 1/2 m (12 feet). The wave entrained the ship with such force, that it could not hold to its anchors. The water ran up onto the island in an east-west direction. A mild northeasterly wind was blowing.'"

"In the **Inarajan region** (southeast coast), a woman was caught up by the wave near the Talofofo River, and never reappeared. "People arriving from **Satawan Island (Caroline Islands)** related that this island was flooded by a wave." (Soloviev and Go, 1974, p. 189-190; Iida et al., 1967)

1892, May 16. A strong earthquake at about 9:10 P.M. cracked walls and shook tile from roofs on Guam. The sea retreated as far as the reefs but returned slowly to the shoreline at **Agana** and an unspecified amount further in the San Antonio quarter. (Soloviev, 1974, pp. 191-192)

1903, February and continuing. A series of earthquakes occurred on **Guam** and the level (of the sea?) rose 15 cm. (Soloviev and Go, 1974, p. 192)

1906, July 1. Heck (1947) lists a sea wave occurring on this date in the **Marshall Islands.** Both Soloviev and Go (1974, p. 192) and Iida et al. (1967) state that Heck's source, Mitteilungen, Petermann (1906), does not mention a sea wave. No earthquake was located by Gutenberg (1956) in the area. This is a doubtful tsunami.

1912, October 31, 17:24. A magnitude 6.7 earthquake occurred south of the Yap Islands where it was felt. The surf made an unusual sound although the weather was calm. (Soloviev and Go, 1974, p. 192)

1912, December 6. An earthquake (similar to that of October 31 above) was felt and heard in the **Yap Islands** at about 3:11 P.M. Immediately after the earthquake a wave was seen at sea. The quake was not reported by seismological stations in the area. (Soloviev and Go, 1974, p. 192)

1925, December 22. At about 4:00 P.M. sea waves devastated the **Yap Islands** causing high casualties and destruction. The underwater cable between Guam and the Yap Islands was cut. These were meteorological waves. (Soloviev and Go, 1974, p. 192)

1952, March 4, 01:23. A magnitude 8.1 earthquake on the southeast shore of Hokkaido, Japan, generated a damaging tsunami there and was recorded with amplitudes of 0.2 m at **Angaur Island, Palau Islands** and with amplitudes of less than 0.1 m at **Guam, Kwajalein, Wake**, and **Yap Islands.** (Zerbe, 1953; Iida et al., 1967; Soloviev and Go, 1974, p. 343)

1952, March 19, 10:57. A magnitude 7.7 earthquake occurred east of Mindanao, Philippines. A tsunami was recorded with an amplitude of 0.3 m on **Angaur Island, Palau Islands**, less than 0.1 m on **Guam** at **Tarague and Apra Harbor,** and on the **Yap Islands.** (Murphy and Cloud, 1954; Soloviev and Go, 1974, p. 222; Iida et al., 1967)

1952, November 4, 16:58. A magnitude 8.3 earthquake on Kamchatka produced a 13 m tsunami there that was widely observed throughout the Pacific Ocean. It had amplitudes of 0.3 meters at **Wake**; 0.2 m at **Enewetak, Johnston Island**, and **Kwajalein**; 0.1 m at **Guam** and **Truk**, and less than 0.1 m on the **Yap Islands.** (Iida et al., 1967; Zerbe, 1953)

1956, March 30, 06:11. Possible air waves from a gigantic explosion of Bezymianny volcano on Kamchatka were recorded on tide gages in Alaska, Hawaii, and other places. It was recorded at **Johnston, Wake,** and **Truk Islands** with amplitudes of less than 0.1 m. (Iida et al., 1967)

1957, March 9, 14:23. A magnitude 8.3 earthquake generated a 12 m wave in the Aleutian Islands and caused damage there, in Hawaii, Japan and elsewhere around the Pacific Ocean. The tsunami had an amplitude of 0.4 m at **Wake,** 0.3 m at **Kwajalein** and **Enewetak,** and 0.1 m at **Johnston Island** and less than 0.1 m at **Guam** and **Truk Islands.** (Salsman, 1959)

1958, November 6, 22:58. A magnitude 8.1 earthquake in the south Kuril Islands, USSR, generated a 3 to 4 meter wave locally and was recorded at **Wake** with an amplitude of 0.1 m and at **Kwajalein** with an amplitude of less than 0.1 m. (Iida et al., 1967)

1960, May 22, 19:11. A magnitude 8.6 earthquake in Chile caused a tsunami that produced extensive damage there and in Hawaii and Japan. It was recorded at **Johnston** and **Wake Islands** with amplitudes of 0.5 m, at **Kwajalein** with an amplitude of 0.4 m, at **Enewetak** and **Guam** with amplitudes of 0.2 m, and was observed on **Truk Island.** (Berkman and Symons, 1964; Iida et al., 1967)

1963, October 13, 05:17. A magnitude 8.1 earthquake in the Kuril Islands, USSR, generated a 4.4 m wave there and a tsunami with amplitudes of 0.2 m at **Kwajalein**, 0.1 m at **Wake Island** and **Truk**, and less than 0.1 m at **Johnston Island** and **Guam** (Iida et al., 1967)

1963, October 20, 00:53. A magnitude 6.7 earthquake in the Kuril Islands, USSR, produced a 15 m tsunami at Urup and was recorded with amplitudes of less than 0.1 m at **Kwajalein** and **Truk**. (Iida et al., 1967)

1964, March 28, 03:36. A 8.4 magnitude earthquake in the Gulf of Alaska produced a destructive tsunami in Alaska and on the West Coast of the United States. It was recorded with amplitudes of 0.2 m at **Kwajalein** and **Johnston Island** and less than 0.1 m at **Guam**, **Enewetak**, **Truk**, and **Wake Island**. (Spaeth and Berkman, 1972; Iida et al., 1967)

1966, October 17, 21:42. A magnitude 8.0 earthquake off the Peruvian coast generated a small tsunami there that was recorded with amplitudes of less than 0.1 m at **Guam** and **Wake Island**. (Iida et al., 1967; Soloviev and Go, 1975, p. 154-160)

1966, December 28, 08:18. A magnitude 7.8 earthquake near the northern coast of Chile generated a small tsunami that was recorded locally and at **Wake Island** with an amplitude less than 0.1 m. (Soloviev and Go, 1975, p. 160; Von Hake and Cloud, 1968)

1968, May 16, 00:49. A magnitude 7.9 earthquake near Honshu, Japan generated a destructive tsunami there that was recorded at **Guam**, **Johnston**, **Kwajalein**, **Truk**, and **Wake Islands** all with amplitudes less than 0.1 m. (Coffman and Cloud, 1970; Soloviev and Go, 1974, p. 355)

1968, August 1, 20:19. A magnitude 7.3 earthquake near Luzon, Philippine Islands generated a minor tsunami recorded at **Guam** and **Wake Island** with amplitudes of less than 0.1 m. (Coffman and Cloud, 1970)

1968, August 5, 16:17. A magnitude 6.5 earthquake in Japan was reported by Coffman and Cloud (1970) to have produced a tsunami recorded at **Wake Island** with an amplitude of 0.03 m. However, Iida (1984) gives this event a validity of 0 since the tsunami was not recorded in Japan.

1969, August 11, 21:27. A magnitude 7.8 earthquake near Hokkaido, Japan produced a tsunami with an amplitude of 5 m in the Kuril Islands, USSR and was recorded at **Wake Island** and **Kwajalein** with an amplitude of 0.1 m. (Soloviev et al., 1986; ITIC Newsletter, October, 1969)

1969, November 22, 23:10. A magnitude 7.1 earthquake near Kamchatka produced a 12 to 15 m wave that caused some damage there and was recorded at **Wake Island** with an amplitude of less than 0.1 m.

1970, January 10, 1970, 12:07. A magnitude 7.3 earthquake near Mindanao, Philippine Islands generated a small tsunami which was recorded at **Malakale, Palau, Caroline Islands** with an amplitude of less than 0.1 m. (ITIC Newsletter, June, 1970; Soloviev et al., 1986; Coffman and von Hake, 1972)

1971, July 14, 06:11. A magnitude 7.9 earthquake near New Ireland caused fatalities and considerable damage and generated a 2.0 m tsunami at Rabaul, New Ireland. It was recorded at **Kwajalein** with an amplitude of 0.1 m and at **Truk** and **Wake Island** with amplitudes of less than 0.1 m. (Soloviev et al., 1986; Coffman and von Hake, 1973)

1971, July 26, 01:23. A second 7.9 magnitude earthquake occurred near New Ireland. It also generated a damaging wave at Rabaul. It was recorded at **Kwajalein** with an amplitude of 0.1 m and at **Truk** and **Wake Islands** with amplitudes of less than 0.1 m. (Coffman and von Hake, 1973; Soloviev et al., 1986)

1971, December 15, 08:30. A magnitude 7.8 earthquake near Kamchatka produced a minor local tsunami and was recorded at **Guam** and **Wake** with amplitudes of less than 0.1 m. (Soloviev et al., 1986)

1972, December 2, 00:20. A magnitude 7.4 earthquake near Mindanao, Philippines Islands caused a minor tsunami recorded at **Truk, Guam,** and **Yap Islands** all with amplitudes less than 0.1 m. (Soloviev et al., 1986; Coffman and von Hake, 1974)

1974, October 3, 14:21. A magnitude 7.6 earthquake near Peru generated a minor tsunami there that was recorded with an amplitude of less than 0.1 m at **Wake Island.** (Spaeth, 1976; Soloviev et al., 1986)

1975, June 10, 13:48. A magnitude 7.0 earthquake near the Kuril Islands, USSR, caused a minor local tsunami and was recorded with amplitudes of less than 0.1 m at **Kwajalein, Truk,** and **Wake Islands.** (Spaeth, 1977; Soloviev et al., 1986)

1975, October 31, 08:28. A magnitude 7.6 earthquake in the Philippine Trench generated a tsunami that caused damage and one fatality on Samar Island. It was recorded at **Yap, Truk,** and **Wake Islands** all with amplitudes of less than 0.1 m. (Spaeth, 1977; Soloviev et al., 1986)

1975, November 29, 14:48. A magnitude 7.2 earthquake on the southern shore of the Island of Hawaii caused two fatalities and damage there. It was recorded at **Johnston, Wake,** and **Kwajalein Islands** all with amplitudes of less than 0.1 m. (Spaeth, 1977; Soloviev et al., 1986)

1978, March 24, 19:48. A magnitude 7.7 earthquake in the Kuril Islands, USSR, produced a minor tsunami that was recorded at **Wake** with an amplitude of less than 0.1 m. (Soloviev et al., 1986)

1979, December 12, 07:59. A magnitude 7.7 earthquake in Ecuador produced a minor tsunami that was recorded at **Johnston Island** with an amplitude of less than 0.1 m. (Stover and von Hake, 1981)

1986, May 7, 22:47. A magnitude 7.6 earthquake in the Aleutian Islands generated a tsunami with an amplitude of 0.3 to 0.9 m at Adak, Alaska and was recorded at **Johnston, Wake, and Truk Islands** all with amplitudes less than 0.1 m. (Pararas-Carayannis, August, 1986)

TABLE 8. TSUNAMI DATA FOR OTHER UNITED STATES POSSESSIONS AND CURRENT AND FORMER TRUST TERRITORIES IN THE PACIFIC OCEAN

ORIGIN DATA			VALID	CAUSE	TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA			MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PERIOD (MIN)	1ST MOTION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1819		Mariana Islands		V		Mariana Is.	OBS?					Tsunami generated from explosive eruption of Asuncion volcano.
1849 01 24		Mariana Islands		E		Guam	3.5		R			Extensive damage. 1 swept away. Island flooded.
						Satawan I., Caroline Is.	OBS					
1892 05 16		Guam		E		Agana, Guam	OBS		F			Sea retreated.
1903 02		Guam		E		Guam	OBS?					Level (of sea?) rose 0.15 m.
1906 07 01		Marshall Islands		?		Marshall Islands	OBS?					Doubtful tsunami.
1912 10 31	17:24	Caroline Islands		E		Yap, Caroline Islands	OBS					Unusual surf noise.
	7.0N											
	138.0E	(G&R)										
	6.9	(Abe)										
1912 12 06		Yap, Caroline Islands		E		Yap, Caroline Islands						Wave observed at sea.
1925 12 22		Yap, Caroline Islands		M		Yap, Caroline Islands	OBS					Island devastated. High casualties. Underwater cable between Guam and Yap was cut. Believed to be meteorological waves.
1952 03 04	01:23	SE. Hokkaido, Japan	4	E	2.0	Angaur I. Palau Is.	0.2	15.0				(See also Alaska, Hawaii, West Coast, and Samoa sections.)
	42.2N				2.0	Apra Harbor, Guam	<0.1	21.0				
	143.9E					Kwajalein, Marshall Is.	<0.1	20.0				
	8.1	(Iida)				Wake Island	<0.1	14.0				
	45					Yap, Caroline Is.	<0.1	23.0				
1952 03 19	10:57	E. of Mindanao,	4	E		Apra Harbor, Guam	<0.1					(See also Samoa Section.)
	9.4N	Philippines				Tarague, Guam	<0.1					
	125.1E	(ISS)				Angaur I., Palau Is.	0.3				01.8	
	7.7	(PAS)				Yap, Caroline Is.	<0.1				01.8	
	SH											
1952 11 04	16:58	Kamchatka Peninsula,	4	E	4.0	Enewetak, Marshall Is.	0.2	09.0			05.4	(See also Alaska, Hawaii, West Coast and Samoa sections.)
	52.8N	USSR				Guam, Marianas	0.1	21.0			05.4	
	159.5E					Johnston Island	0.2					
	8.3	(Iida)				Kwajalein, Marshall Is.	0.2	14.0			06.0	
	30					Truk, Caroline Is.	0.1	14.0			05.8	
						Wake Island	0.3	07.0			04.2	
						Yap, Caroline Is.	<0.1	14.0			06.1	
1956 03 30	06:11	Kamchatka Peninsula,	4	V		Johnston Island	<0.1	11.0			07.2	Possibly air waves or tsunami from explosion of Bezymianny Volcano. (See also Alaska, Hawaii, and West Coast sections.)
	55.0N	USSR				Truk, Caroline Is.	<0.1	14.0				
	160.5E	(PCT)				Wake Island	<0.1	14.0			04.3	
1957 03 09	14:23	Central Aleutian	4	E	3.5	Enewetak, Marshall Is.	0.3	08.0		09-20:51	06.5	(See also Alaska, Hawaii, West Coast, and Samoa sections.)
	51.5N	Islands				Guam, Marianas	<0.1	54.0		09-21:02	06.7	
	175.7W					Johnston Island	0.1	10.0		09-19:17	04.9	
	8.3	(DNAG)				Kwajalein, Marshall Is.	0.3	08.0		09-20:40	06.3	
	33					Truk, Caroline Is.	<0.1	14.0		09-21:34	07.2	
						Wake Island	0.4	09.0		09-19:07	04.8	
1958 11 06	22:58	S. Kuril Islands,	4	E	2.0	Kwajalein, Marshall Is.	<0.1	16.0			06.0	Range? (See also Alaska, Hawaii, West Coast, and Samoa sections.)
	44.3N	USSR				Wake Island	0.1	15.0			04.1	
	148.5E											
	8.1	(Iida)										
	80											
1960 05 22	19:11	S. Central Chile	4	E		Enewetak, Marshall Is.	0.2	30.0		23-13:03	17.9	(See also Alaska, Hawaii, West Coast, and Samoa sections.)
	39.5S				-1.0	Guam, Marianas	0.2	30.0		23-16:40	21.5	
	74.5W					Johnston Island	0.5	54.0	R	23-11:30	16.3	
	8.6	(PAL)				Kwajalein, Marshall Is.	0.4	10.0		23-13:20	18.2	
	33					Truk, Caroline Is.	OBS	34.0		23-14:26	19.4	
						Wake Island	0.5	14.0		23-13:33	18.4	
1963 10 13	05:17	Kuril Islands, USSR	4	E	2.0	Guam, Marianas	<0.1					(See also Alaska, Hawaii, West Coast, and Samoa sections.)
	43.8N					Johnston Island	<0.1	12.0			06.4	
	150.0E					Kwajalein, Marshall Is.	0.2	14.0			05.8	
	8.1	(Iida)				Truk, Caroline Is.	0.1	34.0			05.2	
						Wake Island	0.1	13.0			03.8	
1963 10 20	00:53	Kuril Islands, USSR	4	E	2.0	Kwajalein, Marshall Is.	<0.1					(See also West Coast, Hawaii, and Samoa sections.)
	44.1N					Truk, Caroline Is.	<0.1					
	150.1E											
	6.7	(Iida)										
	0											

DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOTION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1964 03 28	03:36 61.1N 147.5W 8.4 23	Gulf Of Alaska- Alaska Peninsula (DNAG)	4	E	4.5	Enewetak, Marshall Is.	OBS			28-11:45	08.2	(See also Alaska, Hawaii, West Coast, and Samoa sections.)
						Guam, Marianas	<0.1	42.0	R	28-12:48	09.2	
						Johnston Island	0.2	26.0	R	28-09:39	06.1	
						Kwajalein, Marshall Is.	0.2	41.0	R	28-12:00	08.4	
						Truk, Caroline Is.	<0.1	33.0	R	28-13:00	09.4	
						Wake Island	<0.1	15.0	R	28-10:21	06.8	
1966 10 17	21:42 10.7S 78.8W 8.0 40	Peru (PAL)	4	E	1.0	Guam, Marianas	<0.1					(See also Alaska, Hawaii, West Coast and Samoa sections.)
					1.5	Wake Island	<0.1					
1966 12 28	08:18 25.5S 70.6W 7.8 32	Chile (PAL)	4	E		Wake Island	<0.1					(See also Hawaii, and Samoa sections.)
1968 05 16	00:49 40.7N 143.6E 7.9 0	Honshu, Japan (Iida)	4	E	2.0	Guam, Marianas	<0.1					(See also Alaska, Hawaii, West Coast, and Samoa sections.)
					-0.5	Johnston Island	<0.1					
						Kwajalein, Marshall Is.	<0.1					
						Truk, Caroline Is.	<0.1					
						Wake Island	<0.1					
1968 08 01	20:19 16.5N 122.2E 7.3 36	E. Luzon Island, Philippines (ISC)	4	E		Guam, Marianas	<0.1					(See also Alaska, Hawaii, and Samoa sections.)
						Wake Island	<0.1					
1968 08 05	16:17 33.3N 132.2E 6.5 10	Seikaido-Nankaido, Japan (Iida)	1	E		Wake Island	<0.1					Doubtful tsunami, not recorded in Japan.
1969 08 11	21:27 42.7N 147.6E 7.8 30	N. Japan, Kurils, USSR (Iida)	4	E	1.0	Kwajalein, Marshall Is.	0.1					(See also Alaska, Hawaii, and Samoa sections.)
						Wake Island	0.1					
1969 11 22	23:10 57.7N 163.6E 7.1 51	Kamchatka (ISC)	4	E		Wake Island	0.2					Range? (See also Alaska, Hawaii, and Samoa sections.)
1970 01 10	12:07 6.8N 126.8E 7.3 46	Philippines (ISC)	4	E		Malakale, Palau Is.	<0.1					
1971 07 14	06:11 5.5S 153.9E 7.9 43	New Ireland (ISC) (PDE)	4	E		Kwajalein, Marshall Is.	0.1					(See also Alaska, Hawaii, and Samoa sections.)
						Truk, Caroline Is.	<0.1					
						Wake Island	<0.1					
1971 07 26	01:23 4.9S 153.2E 7.9 43	New Ireland (ISC) (PDE)	4	E		Kwajalein, Marshall Is.	0.1					(See also Hawaii and West Coast sections.)
						Truk, Caroline Is.	<0.1					
						Wake Island	<0.1					
1971 12 15	08:30 56.0N 163.2E 7.8 39	Kamchatka, USSR (ISC) (PDE)	4	E		Guam, Marianas	<0.1					(See also Alaska and Hawaii sections.)
						Wake Island	<0.1					
1972 12 02	00:20 6.4N 126.6E 7.4 33	Mindanao Island, Philippines (ISC) (PDE)	4	E		Guam, Marianas	<0.1					
						Truk, Caroline Is.	<0.1					
						Yap, Caroline Is.	<0.1					
1974 10 03	14:21 12.2S 77.6W 7.6 13	Peru (ISC) (PDE)	4	E		Wake Island	<0.1					(See also Hawaii, West Coast, and Samoa sections.)
1975 06 10	13:48 42.8N 148.2E 7.0 0	Kurils, USSR-N. Japan (Iida)	4	E	1.0	Kwajalein, Marshall Is.	<0.1					(See also Alaska and Hawaii sections.)
						Truk, Caroline Is.	<0.1					
						Wake Island	<0.1					
1975 10 31	08:28 12.5N 126.0E 7.6 50	Philippine Trench (ISC) (PDE)	4	E		Truk, Caroline Is.	<0.1					
						Wake Island	<0.1					
						Yap, Caroline Is.	<0.1					

ORIGIN DATA			V	C	TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOTION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1975 11 29	14:48 19.3N 155.0W 7.2 8	Hawaii (Cox)	4	E		Johnston Island	<0.1					(See also Alaska, Hawaii, West Coast, and Samoa sections.)
						Kwajalein, Marshall Is.	<0.1					
						Wake Island	<0.1					
1978 03 24	19:48 44.1N 148.6E 7.7 62	S. Kuril Islands, USSR (ISC)	4	E	-1.0	Wake Island	<0.1					(See also Hawaii section.)
1979 12 12	07:59 1.6N 79.3W 7.7 28	Ecuador (ISC)	4	E		Johnston Island	<0.1					(See also Hawaii section.)
1986 05 07	22:47 51.5N 174.8W 7.6 19	W. Aleutian Islands (ISC)	4	E		Johnston Island	<0.1					(See also Alaska, Hawaii, West Coast, and Samoa sections.)
						Truk Island	<0.1					
						Wake Island	<0.1					

7. EAST COAST OF THE UNITED STATES (INCLUDING COAST OF THE GULF OF MEXICO)

7.1 BACKGROUND INFORMATION

The possibility of locally generated tsunamis causing damage on the East Coast is remote. The Charleston, South Carolina, earthquake in August 1886 (magnitude = 7.5), the largest ever reported on the East Coast, did not generate a tsunami. However, according to Berninghausen (1968), a local tsunami generated off the Burin Peninsula of Newfoundland in November 1929 caused much property damage and 29 deaths along the coast of Newfoundland; it was recorded at Atlantic City, New Jersey, and Charleston, South Carolina, and possibly other places on the East Coast. Berninghausen also reported that three earthquakes on the East Coast caused small swells or fluctuations on tide gages, but that none produced observable runup or damage.

Large tsunamis that would have a major impact on the East Coast are not generated in the North Atlantic. Costello (1985) stated that many local tsunamis have occurred in the Azores in the Mid-Atlantic Ridge, but that earthquakes there and elsewhere along the Ridge have never produced a tsunami that was reported on any Atlantic coastline. The reason may be that most of the faulting, either normal or strike-slip, is accompanied by only small amounts of vertical motion.

The most destructive tsunami ever reported in the Atlantic Ocean was generated off the coast of Portugal on November 1, 1755. In addition to the local tsunami damage in Portugal, damage was reported at Funchal, Madeira Islands; Cadiz, Spain; Safi, Morocco; Praia da Vitoria, Azore Islands; Durham, England; and as far distant as La Martinique in the West Indies, and Santiago, Cuba. It is unlikely, however, that the tsunami impacted the East Coast adversely because: 1) the orientation of the fault along which the earthquake occurred directed the tsunami toward the West Indies (waves were about 4 m there), not toward the United States; 2) the wide continental shelf off most of the Atlantic coast of the United States would likely dissipate the energy of the tsunami (Costello, 1985).

In summary, the East Coast has sustained few effects from tsunamis because the mechanism for tsunami generation does not exist there nor in the North Atlantic. In addition, the wide continental shelf along much of the East Coast would moderate the effects.

7.2 DESCRIPTION OF TSUNAMI EVENTS

1755, November 18, 09:12. A magnitude 5.8 earthquake at 4:11 A.M. threw down chimneys and walls in Boston. Gabled ends of buildings collapsed, and stone walls were shaken down. Located east of Cape Ann, Massachusetts, the shock was felt over a 300,000-square-mile (777,000 km^2) area from the Chesapeake Bay to Nova Scotia. Aftershocks continued for more than a month. (Coffman et al, 1982) It was reported to have produced a noticeable sea wave. The only mention of wave action in Brigham (1871) is a 2:00 P.M. wave at St. Martin, West Indies. This wave report is confused with the report of the wave produced by the November 1, 1755, Lisbon earthquake, and no wave was produced by the November 18, 1755, Cape Ann earthquake. (Berninghausen, 1968; Brigham, 1871; Rothman, 1968)

1840, November 11. A severe shock felt at Philadelphia produced a large and unusually sudden swell in the **Delaware River**. On November 14th a noise and shock were observed. (Brigham, 1871; Berninghausen, 1968; Coffman and Stover, 1982)

1872, November 17. Fluctuations were registered on the tide gages at **North Haven** and on the **Fox Islands in Penobscot Bay, Maine**. The fluctuations continued from midnight until nearly 6:00 A.M. at somewhat irregular intervals of about 17 minutes from crest to crest, with an average vertical range of about 23 cm. The largest wave at 3:00 A.M. had a height of 50.8 cm. Corresponding earthquake phenomena are not known, although it is possible that a shock occurred in the Atlantic Ocean. (Berninghausen, 1968)

1918, October 11, 14:14. This magnitude 7.5 earthquake occurred about 15 km off the northwest coast of Puerto Rico. "The sea waves had an unobstructed sweep across the deep waters of the North Atlantic and were registered on the tide gage at **Atlantic City, New Jersey**, about 2,200 km north of the origin. The disturbance appears to have begun at 2:00 P.M., 75th meridian or Eastern Standard Time, with a depression [and then an elevation] of the sea...and the oscillations of water level lasted for several hours. The amplitude of the waves was between 3 and 6 cm, and the period between 10 and 15 minutes. The tide gage at Atlantic City is not in an enclosed basin, but is on the open coast where no ordinary seiche could occur. Nor can...the periodic movements be a seiche set up between the coast and the edge of the continental shelf, for the period is much too short. They [the periodic movements] are more probably auxiliary waves following a short group [of waves] started by a sudden disturbance, but the matter is still obscure." (Reid and Taber, 1919a)

"The tide gages in New York Harbor, at Key West, Florida, and Colon, Canal Zone, did not register the waves. The first is apparently too well protected to register small waves with periods as low as 10 or 15 minutes; the second is protected by the great Bahama bank; and the comparatively shallow water of the Mona

Passage may have reduced the wave too much for registration at Colon." (Reid and Taber, 1919a)

1918, October 25, 03:43. This aftershock of the October 11, 1918, earthquake occurred at 11:43 P.M. October 24 (local date). A small wave was recorded on the tide gage at **Galveston, Texas**. However, there are no reports of its being observed in Puerto Rico. (Heck, 1947; Berninghausen, 1968)

1922, May 2, 20:24. A small earthquake with an epicenter near Isla de Vieques, Puerto Rico, reportedly produced a 0.6-m wave at **Galveston, Texas** (Berninghausen, 1968). Parker (1922), then the director of the United States Coast and Geodetic Survey, observed a train of three waves with a period of about 45 minutes on the **Galveston** tide record (fig. 61), followed 8 hours later by a similar but smaller train of waves. He associated it with the Vieques earthquake occurring approximately 4 hours earlier. The earthquake was felt in Vieques in masonry buildings, but according to Campbell (undated), it was a slight shock lasting only 2 seconds, an unlikely candidate to produce a tsunami. Other sources for the waves are not known. (Parker, 1922; Campbell, undated)

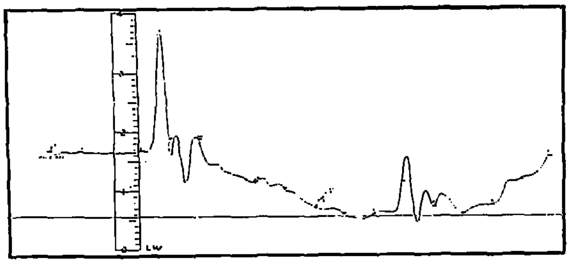


FIGURE 61.—Tidal registration at Galveston, Texas, May 2-3, 1922.

1926, January 9. A "tidal wave" was reported at **Bernard, Mt. Desert Island, Maine**. The following was taken from the Associated Press Wire Services Bulletin of January 9, 1926: "Unexplained in its origin, the phenomenon which occurred about noon caused the sudden emptying of **Bass Harbor**, followed a minute later by a 10-foot (3.0-m) rush of water, and then two smaller waves. No one was injured, but about 50 fishing boats were hurled ashore, and two men in a dory had a narrow escape from falling cakes of ice when their craft suddenly grounded.

"The first sign of something wrong was a rumbling from the direction of the harbor. Townspeople ran to the piers to see their harbor emptied with a rush. William Kelley, who has a fish-packing plant on the eastern shore of the harbor, told what happened next: 'It was about low tide when the first wave came,' he said. 'It flowed in steadily like the even flow of a river. Then came two lesser ones, and in less than 10 minutes the whole harbor was filled to near high water mark. Great whirlpools were formed. Small boats were tossed about at their moorings, and the 70-foot (21 m) fishing boat *Fish Hawk* broke from her lines at the Underwood Dock and crashed against the pilings. The entire harbor was a mass of foam.'

"'The water left the harbor so rapidly that a waterfall was created at the harbor mouth. In less than 15 minutes it was all over.'" (Associated Press Wire Service Bulletin, Jan. 9, 1926, 8:45 A.M.)

"...In **Vinalhaven**, an island in **Penobscot Bay** 25 miles (40 km) southwest of here, rumbling noises were heard 4 or 5 hours before the Bass Harbor disturbance, and an hour before it the islanders felt what they thought were slight earthquake shocks. A fisherman reported seeing a 10-inch (0.25-m) ripple on the waves, although the sea was calm, and he said the water was roily and peculiar in appearance. A steamer captain said that the occurrence at **Bernard** was probably what natives call a 'bore' wave, peculiar to coves and harbors of a certain shape.

"From the head of the cove (of Bass Harbor), which is the inner extreme of the harbor, to Parker's wharf is a distance of a quarter of a mile (0.42 km). This whole area was drained entirely." [The water had previously been 8 to 10 feet (2.4 to 3 m) deep in the drained area.] "Bar Harbor, summer resort for many wealthy persons also on the island, did not feel the tidal wave."

"Prof. Kistlay F. Mather, dean of the observatory at Harvard University, said the University seismograph showed no record of any earth disturbance. He believed it possible that the outgoing tide had carried enough ice with it to form a dam at the head of the ragged inlet which forms the harbor, and that the incoming tide had broken this dam and caused the sudden inrush of water."

(1926, January 9, continued)
However, the Associated Press wire release of 8:07 A.M. January 14, 1926, indicates a wider source. "From the remote fishing village of **Corea** on the northeastern Maine coast comes news that at about the same time Saturday that the phenomenon was observed at **Bass Harbor**, a monster wave smashed lobster cars, tore boats adrift, and washed thousands of flounder from their winter beds in the Harbor bottom mud. These fish were gathered up in barrels by the natives. The tidal wave came at 11 A.M. and was preceded by a rushing flood tide several hours earlier." An explanation for this event is not known. However, the offshore sediments contain glacial deposits, and a non-seismically generated submarine slump or landslide is a possibility.

1929, November 18, 20:32. A tsunami generated by the magnitude 7.2 Grand Banks earthquake swept up several inlets to a height of 15 m, destroying villages and causing heavy loss particularly on the Burin Peninsula on the south coast of Newfoundland. The tsunami reached the shore when an abnormally high tide was expected, and there was a gale at sea. Twenty-six lives were lost. (Johnstone, 1930) The earthquake was felt as far south as Washington, D.C., and Baltimore, Maryland. Twelve trans-Atlantic cables were broken, all more than once for a total of 28 breaks over a large area, indicating a turbidity current. The source was probably on the Cabot trench, a graben-like feature trending northwest across the continental shelf. (Keith, 1930; Smith, 1968) The wave was recorded on tide gages on the New Jersey coast. (Heck, 1947) In the New England area the records were complicated by waves produced by a severe storm. Press and other reports mention wave phenomena not necessarily attributable to the storm alone.

Bar Harbor, Belfast, and Portland, Maine, reported waves. **Exeter, New Hampshire; Barnstable, Massachusetts;** and **Block Island, Rhode Island**, reported high tides. The **Ocean City, Maryland**, tide gage recorded a change of approximately 0.3 m. (Berninghausen, 1968) Tide gage records show that it was recorded at **Atlantic City, New Jersey**, and **Charleston, South Carolina.**

1946, August 4, 17:51. This magnitude 8.1 earthquake occurred about 65 km off the northeast coast of the Dominican Republic. The waves were recorded at **Daytona Beach, Florida,** at **Atlantic City, New Jersey,** and at Bermuda. (Bodle and Murphy, 1948)

1946, August 8, 13:28. This magnitude 7.9 earthquake, an aftershock of the August 4, 1946, earthquake, produced a small tsunami that was recorded at **Daytona Beach, Florida,** at **Atlantic City, New Jersey,** and at Bermuda. (Berninghausen, 1968)

1964, May 19. A disturbance that probably originated near the northeastern end of Long Island was widely recorded in the area from **Providence, Rhode Island** to **New Jersey.** At **Plum Island, New York,** the record shows an impulsive beginning with an amplitude of 0.28 m and a period of 4 minutes at 5:25 P.M. EST. The short period waves continued over 10 cycles with decreasing amplitude. Waves of about 0.11 m maximum amplitude began impulsively also at **Montauk, Long Island, New York** (fig. 62), and the wave activity continued for eight or more hours. Smaller amplitudes were observed on nine other tide gage records. The source of these waves is not known, but there are no reports of recordings from local seismic stations, and the waves do not appear to be of meteorological origin. A submarine landslide or explosion are possible causes.

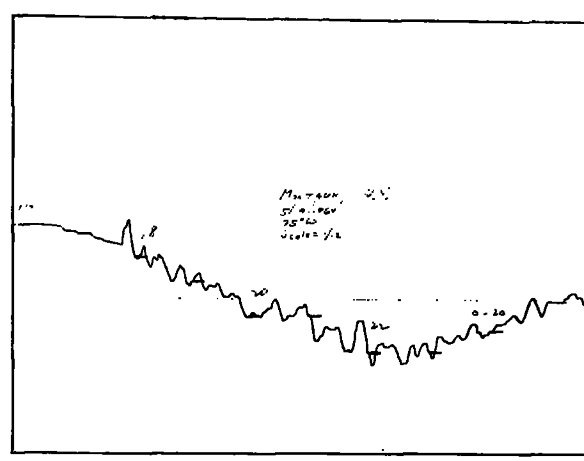


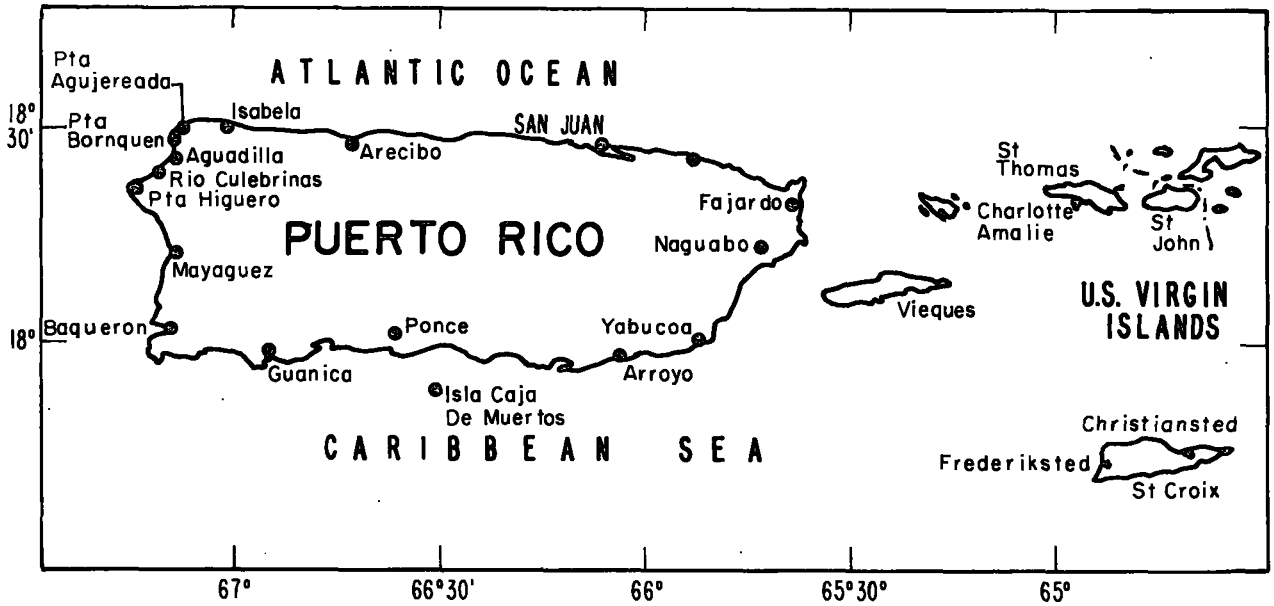
FIGURE 62.—Marigram of the May 19, 1964, tsunami at Montauk, Long Island, New York.

(East Coast tables begin on next page.)

TABLE 9. TSUNAMI DATA FOR THE EAST COAST OF THE UNITED STATES
(including Coast of the Gulf of Mexico)

ORIGIN DATA			VALID	CAUSE	TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA			MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOT-ION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1755 11 18	09:12 42.7N 70.3W 5.8	Cape Ann, Massachusetts (DNAG)		E		Northeast coast of U.S.						Confused report for wave from Nov. 1, 1755, Lisbon earthquake at St. Martin, West Indies. Not observed in U.S.
1840 11 11	39.8N 75.2W 5.2	Pennsylvania (DNAG)	3	E		Philadelphia, Pennsylvania	OBS					Great swell on Delaware River.
1872 11 17	43.2N 71.6W	New England	2	E		Fox Islands, Maine	0.3	17.0				Fluctuations on tide gages.
						North Haven, Maine	0.3	17.0				Fluctuations on tide gages.
1918 10 11	14:14 18.5N 67.5W 7.5	Puerto Rico (DNAG)	4	E	2.0	Atlantic City, N.J.	<0.1	15.0	F	10-19:00		Registered on tide gage. (See also Puerto Rico/ Virgin Islands section.)
1918 10 25	03:43 18.5N 67.5W	Puerto Rico	4	E		Galveston, Texas	OBS					Recorded on tide gage; not reported in Puerto Rico. (See also Puerto Rico/ Virgin Islands section.)
1922 05 02	20:24	Puerto Rico	1	E		Galveston, Texas	0.6	45.0				Unlikely that waves were produced by this earthquake. Not reported in Puerto Rico.
1926 01 09		Maine	2	E	1.5	Bernard, Maine	3.0	<10.0	F			Boats broke moorings.
						Corea, Maine	OBS					Lobster cars smashed, boats set adrift, flounder washed from winter beds.
						Vinalhaven, Maine	0.2					
1929 11 18	20:32 44.5N 56.3W 7.2	Grand Banks, Newfoundland (DNAG)	4	E	3.0	Atlantic City, New Jersey	OBS					Recorded on tide gage.
						Bar Harbor, Maine	OBS					Waves reported; severe storm in progress.
						Barnstable, Mass.	OBS					High tides.
						Belfast, Maine	OBS					Waves reported.
						Block Island, R.I.	OBS					High tides.
						Charleston, South Carolina	OBS					Recorded on tide gage.
						Exeter, N.H.	OBS					High tides.
						Ocean City, Maryland	0.3					
						Portland, Maine	OBS					Waves reported.
1946 08 04	17:51 18.9N 68.9W 8.1	Dominican Republic (DNAG)	4	E	4.0	Atlantic City, New Jersey	OBS				04.8	Recorded on tide gage.
					4.0	Daytona Beach, Florida	OBS				04.0	Recorded on tide gage. (See also Puerto Rico/ Virgin Islands section.)
1946 08 08	13:28 19.7N 68.5W 7.9 16	Dominican Republic (DNAG)	4	E	4.7	Atlantic City, New Jersey	OBS				04.7	Recorded on tide gage.
					4.0	Daytona Beach, Florida	OBS				04.0	Recorded on tide gage. (See also Puerto Rico/ Virgin Islands section.)
1964 05 19		Northeast Coast U.S.				Atlantic City, New Jersey	OBS?					High frequency noise, unreadable.
						Battery, New York	OBS?					Feeble recording.
						Montauk, New York	0.1	15.0	R	19-22:42		Activity continues for over 8 hours.
						New London, Connecticut	OBS			19-22:39		Feeble
						Newport, Rhode Island	<0.1	11.0	R	19-22:14		
						New Rochelle, New York	OBS					Feeble
						Plum Island, New York	0.3	4.0	R	19-22:25		Contrast on record poor but initial 10 cycles of short period waves visible.
						Port Jefferson, New York	OBS			19-23:10		Weak beginning.
						Providence, Rhode Island	OBS					Weak.
						Sandy Hook, New Jersey	OBS					Feeble.
						Willets Point New York	<0.1			20-00:00		

8. PUERTO RICO AND THE UNITED STATES VIRGIN ISLANDS



8.1 BACKGROUND INFORMATION

The Caribbean region bounded by Honduras, Nicaragua, Costa Rica, Panama, Colombia, Venezuela, the Lesser Antilles, Puerto Rico, Hispaniola, and Jamaica defines a plate of Earth's surface that moves semi-independently of the surrounding plates. The Caribbean plate, flanked by the North American and South American plates, moves eastward, or possibly slightly north of eastward. As the Caribbean plate moves, the American plates are driven under it on its eastern side, a process known as subduction. A vertical offset of the ocean floor can occur in this area. The crust of the Atlantic plates begins to melt as it descends into the hot rocks of the mantle. The molten material, or magma, thus created rises to form volcanoes that become the Lesser Antilles island arc. Along the northern and southern boundaries the Caribbean plate is sliding past the American plates along broken and irregular boundaries that contribute to the complexity of the movement. Finally, on the west, the Cocos plate is being driven northeastward, and is being subducted beneath the Caribbean plate. This movement causes the plate to strain against the surrounding plates, and thus, its boundaries are disclosed by a band of earthquakes that extends around the plate's periphery.

While the eastern boundary with its typical island arc structure of oceanic trough and volcanic islands would be expected to be the source of tsunamigenic earthquakes, the two major tsunamis affecting Puerto Rico and the Virgin Islands originated on structures transverse to the arc. The 1867 Virgin Islands earthquake and tsunami most probably originated on the Anegada Trough and the 1918 Puerto Rico event occurred along the northeast boundary in the region between Hispaniola and Puerto Rico. Stresses along this northern plate boundary have caused uplift in many of the islands and subsidence in some other areas. Upraised limestone strata (layers) on a fault block create the spectacular cliffs of Mona Island between Puerto Rico and Hispaniola. Upraised limestone strata also are found on Puerto Rico's north coast although they are deeply weathered and eroded.

Intensive study of this region by side-scan sonar has revealed an unusual formation on the northern slope of Puerto Rico. A large amphitheater and a smaller one farther to the east apparently were created by slumping that could have been triggered by earthquakes in this area of high earthquake frequency. If these large areas of rock and sediment slid as a single mass, large and destructive sea-surface waves (tsunamis) would have been generated.

This area also has experienced at least one major remote-source tsunami. The tsunami produced by the earthquake of November 1, 1755, in Lisbon, Portugal, was reported widely in the West Indies. However, specific reports of that tsunami being observed in the Virgin Islands and Puerto Rico have not been found. Puerto Rico and the Virgin Islands clearly are vulnerable to tsunamis generated both locally and along the fault zone off the shore of Portugal.

8.2 DESCRIPTION OF TSUNAMI EVENTS

1690, April 16. This is the earliest written record of a tsunami that affected any of the United States Territories, and its effects at St. Thomas have not previously been reported. In searching for a tsunami earlier than the 1867 event described below, which was reported to be unique in the memory of any living inhabitant, a brief mention was found in Taylor (1888) of an earthquake in 1690. He reported that a violent earthquake had occurred on Sunday, April 9 at 4:00 P.M., which was "the only one which could in any way be compared to the memorable one of November 18, 1867, as it is spoken of as a terrible earthquake lasting a long time and cracking the walls of the company store. The sea receded a while after..." A request for information on this event was made of Poul Olsen, Archivist for Denmark, who supplied the following in a letter dated May 9, 1988:

". . .concerning the 1690 earthquake, the "Journal over der paa St. Thomas Passerede" (Journal about daily events of St. Thomas) in the records of the Danish West Indian and Guinea Company, paragraph 498, states for April 6, 1690: 'Sunday. Sermon held for the Lutheran community. In the afternoon about 4 o'clock we had a terrible earthquake which lasted half of one quarter of an hour (sic). All people have run out of their houses not to be killed, and the big Company warehouse has got a large crack in the wall. The sea has sunk so much that one has been able to catch fishes on dry land.' (Translated from German). In "Breve og dokumenter fre Vestindien 1674-98" (West Indian letters and documents, 1674-98), a letter, dated April 8, 1690, from the governor to the Company board in Copenhagen states that: 'Last Sunday, which was April 6, this island has been hit by a terrible earthquake lasting one half of a quarter hour, so that people feared their houses would come down. Some hours after that the sea receded so much, that one could walk about 9 - 10 fathoms (16.5 - 18.5 m) into the sea and pick out fishes on dry land.'" (Translated from Danish)

The April 6 date is for the Julian calendar and is a Sunday. It corresponds to April 16 in the Gregorian calendar. The statement that the sea receded after "some hours" could not be correct if the earthquake was the cause of the tsunami. The earthquake effects indicate a much closer source than that necessary for a tsunami to cover in 2 hours. Taylor's (1888) date of April 9th probably was the result of his trying to reconcile the fact that the event occurred on Sunday, but April 6th was not a Sunday in the Gregorian calendar. April 9th was a Sunday.

Robson (1964) assigns an intensity of IX on the Modified Mercalli scale (MM) to the observations of an earthquake of April 5 between 4:00 and 5:00 P.M., which "laid some...buildings in rubbish and killed some persons" at Antigua. Aftershocks continued almost daily for a month and continued into June. Damage was given as 2,000 pounds. It was reported at St. Kitts (St. Christopher) also with intensity IX (MM). "The earth opened 9 feet (2.7 m) in many places and buried solid timber, sugar mills... It threw down the Jesuit college and all other stone buildings." A landslide occurred on Nevis Island. The sea withdrew about 200 m (a furlong) from Charlestown, Nevis Island, returning after 2 minutes. The earth in the lower part of Charlestown was fissured and water was discharged. Robson (1964) also gives an intensity IX (MM) to this locality and to Guadeloupe, which "suffered as severely." He reports an earthquake of intensity IV (MM) at Barbados, Martinique, and St. Lucia on April 10. These are almost certainly the same event.

1755, November 1, 10:24. A large earthquake at about 9:40 A.M. in Lisbon, Portugal, produced a large tsunami along the coast of Portugal, Spain, and North Africa. It was also quite noticeable in the West Indies with runups of nearly 7 m at Saba, 3.6 m at Antigua, and 4.5 m at St. Martin. It may have produced significant runups in Puerto Rico and the U.S. Virgin Islands, although it was not reported from there. (Davison, 1936; Berninghausen, 1968)

1761, March 31, 13:14. An earthquake near Lisbon, Portugal at about 12:30 P.M., produced an "extraordinary flux and reflux of the sea" at Barbados. It may have produced significant runups in Puerto Rico and the U.S. Virgin Islands, although it was not reported from there. (Davison, 1936; Berninghausen, 1968)

1867, November 18, 19:07. A 7.5 magnitude earthquake originating in the Anegada trough between St. Croix and St. Thomas occurred at about 2:45 P.M. (variously estimated as 2:25 to 3:10 P.M.). According to observers there were two severe shocks separated by an interval of about 10 minutes, and each of these shocks was followed by a great sea wave. A great sea wave was generated by the first shock, and a second larger one by the second shock some 10 minutes later; other waves followed but were relatively unimportant. It was observed from **Puerto Rico** to the west and throughout the Leeward Islands as far as Grenada, nearly 800 km from the origin. It must have reached the north shore of South America, but was not reported from there. It was not noticed nor recorded on the tide gages at Old Point Comfort, Virginia, or Sandy Hook, New Jersey. (Reid and Taber, 1920) The tsunami caused damage at **St. Croix** and **St. Thomas** in the Virgin Islands and as far south as Grenada. It was the most destructive tsunami ever to affect the **Virgin Islands**. The source may have been due to a down-dropped part of the Anegada trough, as the initial tsunami wave was observed as a recession on both sides of the source.

The earthquake could not have occurred at a worse time. The most destructive hurricane in the history of the island had struck St. Thomas on October 29, just 20 days earlier. Damage was severe, most buildings sustained some damage, and perhaps 600 people were killed. Many ships were sunk or left onshore, including the 3,000-ton *HMS British Empire*, which ended up on top of three smaller vessels. A squadron of American warships was visiting the islands, and a Danish envoy had just arrived on the Royal Mail Steamer *La Plata* to tell the inhabitants of St. Thomas and St. John that, with their concurrence, the King of Denmark planned to sell the islands to the United States. St. Croix was not part of the purchase, since Denmark had purchased it from France, and needed permission to sell it to another country. The United States was eager to obtain a base in the Caribbean to control smuggling and privateering in the area, a problem during the just-concluded Civil War.

The election was to be held on October 23, but the untimely earthquake delayed it until January 9, 1868, when it was overwhelmingly approved by the islanders. However, the United States Senate did not ratify the treaty. The disasters raised questions about the desirability of owning the islands, and the delays had moved the decision into a new Congress and Administration. Thus, the United States purchase of the Virgin Islands was delayed for 50 years. (Paiewonsky, Nov. 2, 1981, and Dec. 24, 1979)

There are two principal sources of information on this tsunami: Reid and Taber (1920) and a series of 14 newspaper articles by Isidor Paiewonsky in the *Daily News* of St. Thomas between July 30 and December 24, 1979 and another article dated November 2, 1981. The Paiewonsky articles make extensive use of the contemporary newspapers, the *Sanct Thomae Tidende* and the *St. Croix Avis*, as well as family records, official U.S. Navy archives, and other contemporary documents.

At **Charlotte Amalie, St. Thomas**, about 10 minutes after the first shock, the sea receded from the land about 60 m and returned as a straight white wall of water 4.5 - 6.1 m high with a "skirmish line" of tumultuous rollers in front sweeping and upsetting vessels before it. It broke over the lower parts of **Charlotte Amalie** to a height of about 0.6 m and an extent of about 75 m depending on the level

(1867, November 18, continued)
of the land. A second wave of the same or greater height followed in about 10 minutes. Other waves followed, but after the third wave they were 0.3 m or less in height. (Reid and Taber, 1920)

Rear Admiral J.S. Palmer of the flagship U.S.S. *Susquehanna* reported that a small steamer and sailing craft near the harbor entrance was engulfed and never seen again (Reid and Taber, 1920). However, Mr. William Maskell, a passenger on the *La Plata*, reported seeing a small steamer just outside the harbor ride over the wave. (Paiewonsky, August 6, 1979). (Except for Admiral Palmer's report, there is no mention of these ships being lost or of casualties. Probably, as the ships went over the wave they were lost to view to Admiral Palmer who supposed they were sunk.) Vessels at anchor near the entrance were lifted from their moorings and carried onto the rocks to leeward. The U.S.S. *De Soto* anchored with the U.S.S. *Susquehanna* was lifted up, breaking her anchor chains, and was thrown against the iron pilings of the wharf. She was picked up again and redeposited in the harbor, but leaked badly from three holes in her hull. (Reid and Taber, 1920) Admiral Palmer died in St. Thomas a few weeks later of yellow fever, another scourge of the islands. (Paiewonsky, December 3, 1979)

The U.S.S. *Susquehanna* rode over three waves in succession. Ships were rushing to and fro with great velocity. Small craft were lifted up and thrown into the streets where they were left stranded. Boats were capsized, and men were in the water swimming for their lives. Boats from the U.S.S. *Susquehanna* were able to rescue several and recovered one body. (Reid and Taber, 1920)

The first heavy wave was ruinous for the bay-front stores. The stores were swamped, and their goods were washed out and scattered. The jail had been opened and the prisoners allowed to leave. (Paiewonsky, November 9, 1979)

Rear Admiral Palmer reported that three female passengers from the *La Plata* were drowned (Reid and Taber, 1920), but William Maskell, a passenger on the *La Plata* who wrote a pamphlet about the event, did not mention any loss of passengers. He commented that they and the children had managed to hold on. He believed 10 to 11 of a crew of workers who were carrying coal to the *La Plata* were drowned when a ship's boat they were trying to launch fell. Three or four others were saved. (Paiewonsky, August 6, 1979) There is no other report of the loss of the workers.

Mr. Maskell reported the wave was 12.2 m high and that it piled up like a wall as it approached the *La Plata* (frontispiece), anchored near the southern point of **Water Island** about 4 km from Charlotte Amalie (fig. 63). The ship was partly protected by a point of the island, and the wave was not more than 3 m above the rail at the stern of the ship when it arrived. The ship rose over each of three waves, but suffered flooding of the cabins and saloons and breaking of the quarter deck and upper works. Of the three coaling scows fueling the *La Plata*, one was sunk and the other two were washed ashore 1.6 km away. (Paiewonsky, August 6, 1979)

The passengers were put ashore where they found every imaginable kind of debris. Mr. Maskell reported that they thought the loss of life was great, as many of the inhabitants had put to sea to escape the earthquake. (Paiewonsky, August 13, 1979) (This is not supported by any other report.) Main Street, which paralleled the shore, was flooded to a depth of 0.6 m (several feet). At the coaling station on **Hassel Island** heavily damaged by the hurricane further damage was done. The water was reported to have been 4.9 m deep there. (Paiewonsky, August 13, 1979)

Reports from the local newspaper, the *Sanct Thomae Tidende*, give the water height as 1.2 to 1.5 m in the stores and shops from King's Wharf westward through the whole harbor. Sloops, schooners, buoys, and marine structures were left stranded in the streets. Much merchandise was destroyed. At Gregerie Channel (Crown Bay), where a village (**Altona**?) had sprung up, houses were picked up and carried a long way inland. Large fish were left onshore. (Paiewonsky, November 5, 1979)

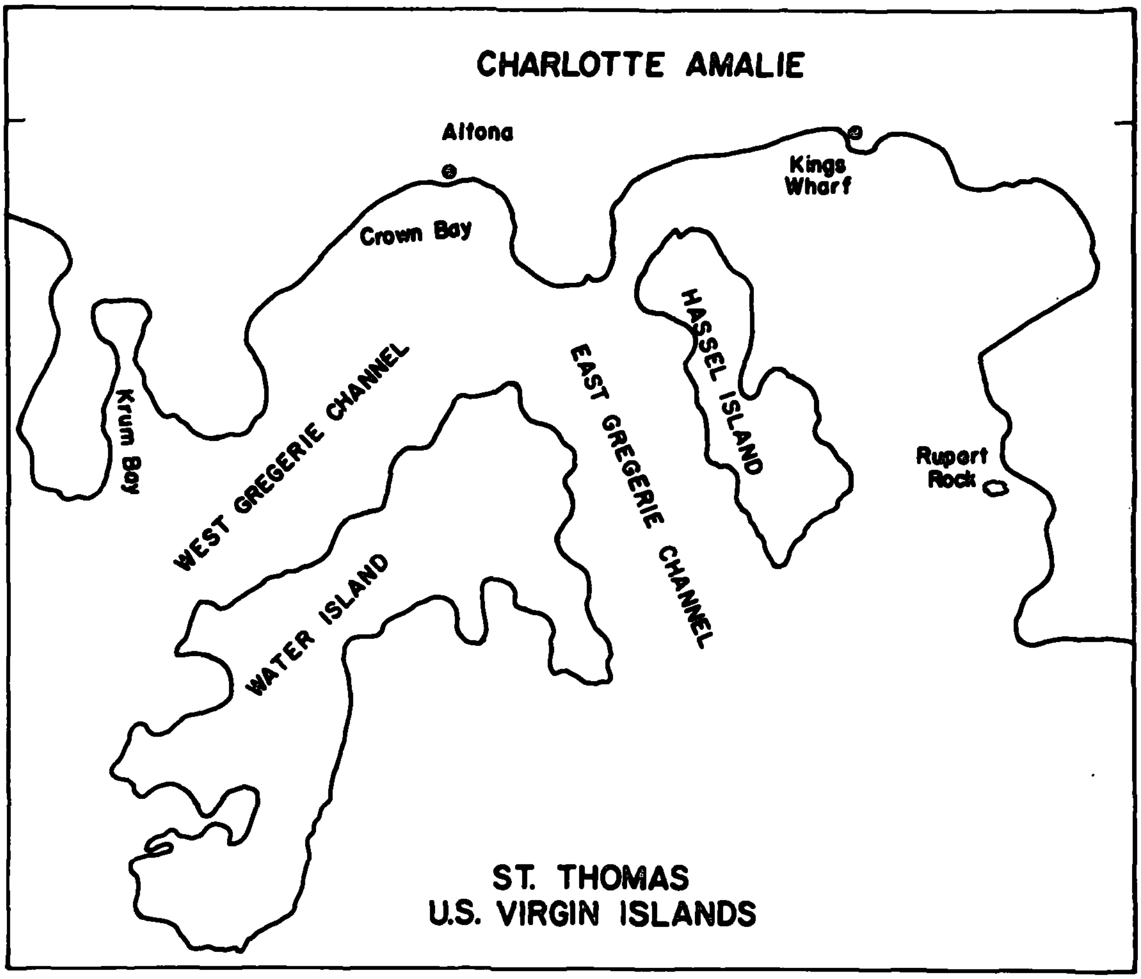


FIGURE 63.—Location map for St. Thomas Harbor.

Commodore W.H. Boggs (1867) of the U.S.S. *De Soto*, also anchored at the harbor on St. Thomas, is quoted by Reid and Taber (1919a) as follows: "In a few minutes a great wave was seen approaching from the southeast between the Islands of **St. Thomas** and **St. Croix**, reaching soundings it began to break, assuming the appearance of a great 'bore,' not less than 23 feet (7.0 m) in height; this wave was broken and retarded more and more by the shoal water, especially by Prince Rupert's Ledge, at the mouth of the harbor. 'Called all hands save ship,'--this wave as it passed into the harbor swung the ship with extraordinary rapidity with her head to the southward, causing a great rise in the water of the harbor that raised above the wharves in front of the city about 8 feet (2.4 m) and at the same time swamping our boats at the booms; then receded as violently, the ship appearing as a mere feather on the surface. This ebb parted both lower chains, leaving us with only a light sheet anchor of 1500 lb (682 kg), and 45 fathoms (82 m) of cables, we swung towards the shore where the current was most irregular and full of whirlpools. At the first swing of the ship, we had 6 fathoms (11 m) under our stern, the ebb was so rapid that in a few minutes we took the bottom, having only 1.25 fathoms (2.3 m) under us. Just before swinging to the ebb, (part) of the iron wharf suddenly gave way, and when we took bottom, we seemed to be deposited among the debris of the iron piles. A second wave soon came in with a much greater volume than the first, or any of them--I think the water rose 20 feet (6.1 m) above where it had fallen; the island appeared

(1867, November 18, continued)
to be sinking; when the next ebb came, we swung against the end of the iron wharf that still stood but soon gave way, and disappeared entirely injuring the starboard wheel and forcing a 6-inch (15.2 cm) iron pile through the ship forward the wheel, starboard side and about 2 feet (0.6) below the water line. Other injuries appeared to be sustained and the ship leaking badly--all the guns were manned. . . .

"The third wave was not so large as the first two, and the fourth did not appear to rise more than 0.3 to 0.4 m. By this time we had driven over towards the western entrance of the harbor when as she swung, her stern took the bottom, scraping on the rocks. At this moment the engineer reported steam, and turning the engine over we took her sufficiently far from the rocks and let go a small anchor. Before we were able to control the ship, it must have swung around all points of the compass not less than 20 times." (Reid and Taber, 1920)

At Frederiksted, St. Croix, people rushed into the streets following the earthquake. There was a loud outcry when they saw the sea had receded, and a wave was coming. The people fled to higher ground. The sea washed far into the town in immense sheets, and many stores and buildings were damaged. Damage along Bay Street (now Strand Street) was great. Wooden buildings had been tossed about like corks and floated inland a considerable distance. (Paiewonsky, November 12 and 26, 1979)

There was at least one fatality on land. A woman and her son were gathering wood near a salt pond. The chief boatswain of the U.S.S. *Monongahela* was riding a pony nearby when he saw the approaching wave. He told the boy to hold on to the pony's tail and carried him to safety across the pond. The boy's mother, however, was drowned. (Paiewonsky, December 3, 1979)

Commodore Bissell reported the following of the experience of the U.S.S. *Monongahela* in the harbor of Frederiksted on the west coast of St. Croix. "I have to state with deep regret that the *Monongahela* under my command is now lying on the beach in front of the town of **Frederiksted, St. Croix**, where she was thrown on the 18th instant by an influx of the sea, the effect of the most fatal earthquake ever known here (fig. 64). The quake lasted some 30 seconds, and immediately after the quake, the water was observed receding rapidly from the beach. The current changed almost immediately, and drove the ship towards the beach, carrying out all the cable and drawing the bolts from the kelson without the slightest effect in checking her terrific speed towards the beach. When within a few yards of the beach, the reflux of the tide checked her speed for a moment, but when the sea returned in the form of a wall of water 25 to 30 feet (7.6 to 9.1 m) high it carried her over the warehouse into the first street fronting the bay. (See comment below.) The reflux of this wave carried her back toward the beach, leaving her nearly perpendicular on a coral reef, where she has now keeled over to an angle of 15 degrees. All this was the work of only some 3 minutes of time. Soon after, the waters of the bay subsided into their naturally quiet condition, leaving us high and dry on the beach." (Reid and Taber, 1920) Note that the time interval between the shock and first recession was given as less than 1 minute. If so, it would be a locally generated tsunami followed closely by the main tsunami from the Anegada trough. The ocean bottom at Frederiksted is sandy, and a local slump could have caused the initial wave or the time estimate could be incorrect.

The U.S.S. *Monongahela* sustained little damage, losing only a gun (later recovered), two sheets of copper plating, and part of her keel. She remained on the reef until May 11, 1868, when U.S. Naval engineers managed to free her. Two other American vessels were in the harbor, a brigantine and a sloop (*Dauntless*), which were also carried far up on land. An eyewitness on a nearby hill described the Monongahela as floating on the top of the great incoming wave, on an apparent level with the tops of the houses in Bay Street. This seems to corroborate Commodore Bissell's account. (Paiewonsky, November 26, 1979) Figure 64 shows the Monongahela stranded on the reef. Note that the warehouses still stand and could not have survived total submersion nor could the wave have been big enough to submerge the

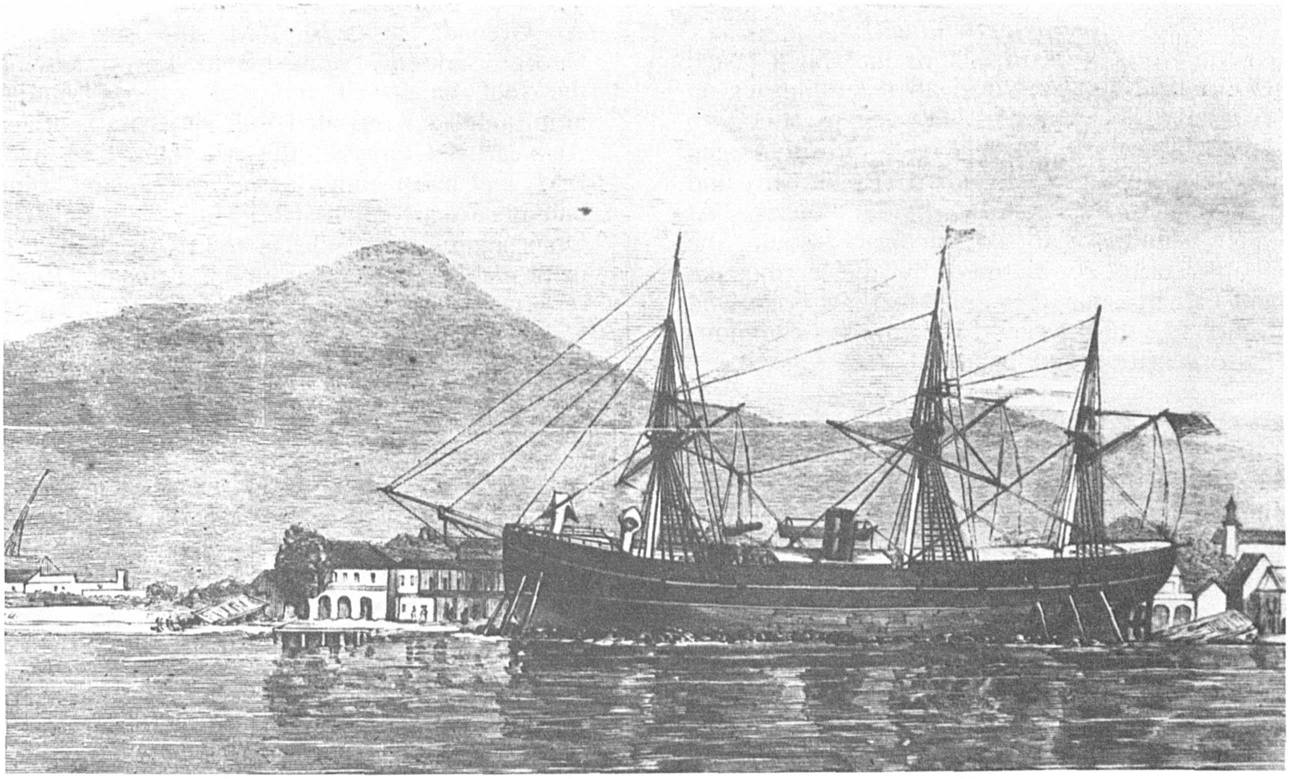


FIGURE 64.—Position of the *Monongahela* following the tsunami of November 18, 1867. Photo Credit: Harpers Weekly.

warehouse. A more likely explanation is that the Monongahela was carried over the waterfront at a place where no or only small structures stood. Her decks and superstructure would have been at roof top level.

Four crewmen were killed, although Commodore Bissell's initial report stated only three were killed. All were in ship's boats at the time. Three or four men had broken arms or legs when they jumped off the ship while it was onshore (Paiewonsky, December 3 and 10, 1979; Reid and Taber 1920). This was not mentioned in Commodore Bissell's report.

The waves broke upon the northern and western coasts of **St. Croix** with great violence, washing many other vessels and boats ashore, sweeping away some smaller houses, and doing great injury to others. (Reid and Taber, 1920)

At **Christiansted, St. Croix**, people rushed from their houses following the earthquake to behold a troubled sea. It first receded, then rushed back "furious and mountain high," sweeping inland as far as 91 m. The greatest damage was at **Gallows Bay**, a low-lying area on the east side of **Christiansted**. There, 20 houses were upturned or demolished, and small boats were cast onshore. The roar could be heard a long distance, and the people had fled to higher ground. (Paiewonsky, November 12, 1979)

The earthquake was very severe at Vieques and Culebra Islands, east of Puerto Rico. Immediately after the shock a high wave broke on the south side of **Vieques** and later washed the northern shore as well. The earthquake caused severe damage over the eastern part of **Puerto Rico**, particularly to churches. At **Yabucoa** the sea retreated about 137 m and returned about the same distance since the land is low there. It was noted as a small wave as far north as **Fajardo**, 32 km to the northeast, and two or three times as far along the shore to the west. In all cases the water first withdrew, then advanced. (Reid and Taber, 1920)

(1867, November 18, continued)
At the British Virgin Islands the shock lasted 15 minutes and damaged all the buildings on Tortola. The sea receded, then rose 1.2 to 1.5 m above its usual level. It submerged the lowest part of the town (Roadtown) and swept away most of the smaller houses. At Peter Island, 4.8 to 6.4 km farther south, the people were so alarmed by the earthquake and tsunami that they took to their boats and went to the larger and more populous Tortola. (Reid and Taber, 1920)

Elsewhere, a high wave invaded Saba causing minor damage and a moderate wave occurred at St. Christopher. At St. John's, Antigua, the water rose 2.4 to 3.0 m. (Reid and Taber, 1920) Moderate damage was reported from St. Martin and St. Barthelemy.

In the Guadeloupe Islands the sea suddenly withdrew far from the coast at Basse Terre, exposing places usually covered, and then returned. The range of the wave was estimated at not less than 2 m. It was just a weak swell at Pointe-a-Pitre. On Sainte Rose the sea withdrew 100 m from the shore and returned as "a wave of at least 60 feet (18.3 m) high." (Reid and Taber (1920) consider the reports of this wave to be exaggerated.) It broke on the beach, flooding houses and setting adrift boats, fishing nets, wood, materials, etc. Second and third waves were reported. At Deshaies one writer reported: "Big disaster! The sea devastated and destroyed all of the houses in the village. There is no bread. Everyone took refuge in the church." In the small islands of Isles des Saintes all of Fond du Cure was submerged. The water inundated the houses up to 1 m. (Deville, 1867)

The waves were reported to have arrived at Guadeloupe at 3:00 P.M. immediately following the earthquake. Reid and Taber (1920) suggest that the reported time was in error as the wave should have arrived an hour later.

The waves were noted at Martinique, and at St. Vincent the water was observed as unusually high. At Bequia Island, 16 to 24 km farther south, three great slow waves of about 1.8 m were observed over a 40-minute period. (Reid and Taber, 1920)

At Grenada at 5:20 P.M. the sea at St. George suddenly sank 1.2 to 1.5 m leaving the reef bare. It returned with a similar amplitude and repeated this pattern six times. At nearby Gouyave, the sea ebbed at 5:00 P.M. and had a range of 6.1 m, causing some damage to the town. (Reid and Taber, 1920) Once again Reid and Taber (1920) think this is probably an exaggeration. Robson (1964) reports that the wave was 1.2 to 1.5 m in St. George, damaging boats and buildings.

1868, March 17, 11:37. Aftershocks continued from the November 18, 1867, earthquake culminating in the sharpest of all on March 17 at 7:15 A.M. The sea receded about 0.6 m (several feet) as reported in the local newspaper, *Sanct Thomae Tidende* on March 18, 1868. The location was not given but was probably Charlotte Amalie. Reid and Taber (1920) report the earthquake occurred at 6:45 A.M. The sea receded and returned a short distance at **Naguabo** and **Arroyo, Puerto Rico**.

1918, October 11, 14:14. This magnitude 7.5 earthquake occurred about 15 km off the northwest coast of Puerto Rico. It generated a large tsunami that was well noted along the western shore of **Puerto Rico** with runups as high as 6 m. Officially, 116 people were killed by the earthquake and tsunami of which 40 were due to the latter. About $4 million in damage resulted. Cables of the West Indian and Panama Telegraph Company connecting San Juan with Kingston, Jamaica, and the Campagnie Francaise des Cables Telegraphiques from **St. Thomas** to Puerto Plata, Dominican Republic, were both broken in several places. All the breaks occurred in an area bound by 18° 25'N to 18° 35'N and 67° 15'W to 67° 30'W. (Reid and Taber, 1919a; Berninghausen, 1968)

The following is from Reid and Taber (1919a): "The great sea wave which followed the earthquake of October 11 was the highest at points near the northwest corner of **Puerto Rico**, where it was observed almost immediately after the earthquake. In passing along the coast toward the south and toward the east, the wave decreased in height, though not uniformly, and the time interval between the earthquake shock and the arrival of the sea wave gradually increased. Wherever the wave was seen on the coasts of **Puerto Rico** and neighboring islands, observers report that the ocean first withdrew from the land, in places exposing reefs and stretches of sea bottom never visible during the lowest tides, and then the water returned reaching heights that were equally high above normal. At some places the great wave was followed by one or more smaller ones, and especially in sheltered bays, the water continued to ebb and flow for some time.

"At the **Point Borinquen** lighthouse the keeper, who was up in the tower when the earthquake began, immediately started down the stairs, and as he went down he noticed that the water along the shore had already begun to recede. It returned quickly, and measurements to points indicated by him show that the height reached by the water, not counting the wash of the wave, was about 4.5 m above mean sea level. Just southwest of the lighthouse, where the land is lower, the water is reported to have washed inland 100 m into a grove of coconut palms. The lighthouse keeper had the impression that the wave came from the northwest.

"Near **Point Agujereada** the limestone cliffs are 100-120 m in height, and at their base there is a narrow strip of beach, which, in the wider places, was planted with coconut palms and was also used for pasturage. Several hundred palms were uprooted by the wave, and the beach was turned into a sandy waste. In this vicinity a few small houses were destroyed, and eight people are reported to have been drowned. Several persons visiting the district soon after the occurrence estimated the height of the wave as 5.5 - 6 m, and the evidence remaining at the time of our visit supported these estimates.

"At many places we were able to make fairly accurate measurements of the height of the wave, as the water had entered the ground floors of houses, staining wall paper and leaving a record that was plainly visible for a long time afterwards. At **Aguadilla** the height of the wave seems to have varied somewhat in different parts of the city, but at no place were the measurements less than 2.4 m above sea level, and near the head of the bay the crest of the wave must have been at least 3.4 m in height. In this town 32 people are said to have been drowned, and about 300 little huts built along the beach were destroyed. Estimates of the time interval between the earthquake shock and the arrival of the sea wave, made by different observers, range from 4 to 7 minutes, one of the best being 5 to 6 minutes. The calculated time for the wave to travel from the earthquake origin to **Aguadilla** is 5 minutes.

"The Columbus Monument, which stood on the beach near the mouth of the **Culebrinas River**, about 4 km southwest of **Aguadilla**, was thrown down probably by the earthquake, and rectangular blocks of limestone weighing over a ton (1,000 kg) were carried inland and slightly downhill by the wave to distances of 45 and 75 m. The water washed over dune sand which was 3.4 m above sea level, and the effects on vegetation indicated that the wave could not have been less than 4 m high.

"At the **Point Jiguero (Punta Higuero)** lighthouse the keeper, shortly after the earthquake, saw the ocean retire from the shore; and upon returning about 2 minutes later, it uprooted coconut palms a short distance north of the lighthouse and crossed the railroad track, leaving fish between the rails which are here 5.2 m above sea level. At the time of our visit the vegetation by the track still showed marks of the rush of the water.

"At **Mayaguez** the sea wave entered the lower floors of buildings near the water front and destroyed a few native huts along the beach, but did comparatively little damage. (fig. 65) A small house was carried seaward by the retiring wave and left stranded a short distance from the shore. (fig. 66) Lighters and other small boats, anchored 300 to 400 m off shore, were not affected. In the northern part of the city a narrow brick wall running S. 76 degrees E was overturned by the wave. In this vicinity the watermarks on houses indicate that the wave reached a height of 1.1 to 1.2 m above sea level; farther south in **Mayaguez** the height was 1.5 m. In the interval between the earthquake and the arrival of the sea wave, an automobile traveled from Central Corsica near Rincon to Mayaguez, a trip that is estimated to require

(1918, October 11, continued)
25-30 minutes. The calculated interval is about 23 minutes.

"At **El Boqueron**, near the southwest corner of **Puerto Rico**, the wave was about a meter in height. An observer states that the ocean withdrew about an hour after the earthquake, the water going out gradually during a period of 20 minutes. The calculated interval is about 45 minutes. A small boat anchored 50 m from shore, where the water is normally 1.5 m in depth, rested on the bottom for a few minutes. The ocean returned more rapidly than it retired, and the first wave was followed by several smaller ones.

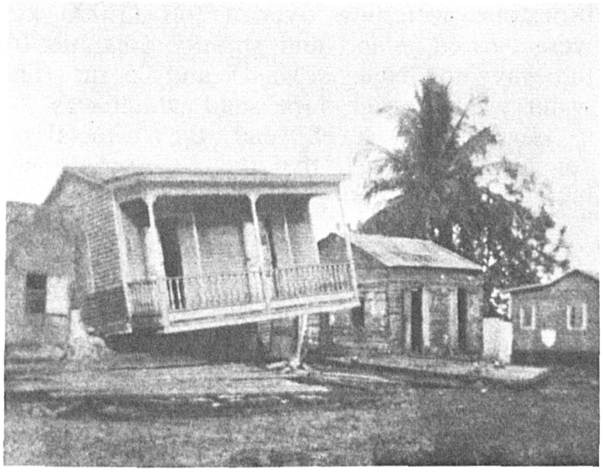


FIGURE 65.—Houses damaged by tsunami at Mayaguez, Puerto Rico, on October 11, 1918. Photo Credit: Bulletin of the Seismological Society of America.

"The wave was observed at **Ponce** and at several neighboring points, but the reports are not very consistent, as is to be expected where the wave has become small and less noticeable. Observers at **Ponce** and **Guanica** also reported a disturbance of water immediately after the earthquake; such disturbances are probably due to oscillations of the land." (Reid and Taber, 1919a). The wave was 0.5 m at **Guanica** and 1.5 m at **Isla Caja de Muertos**. (Western Geophysical Research, Inc., undated).

Continuing with the Reid and Taber (1919a) account: "The north coast of **Puerto Rico** is beaten by the heavy waves due to the northeast trade winds, and, therefore, small fluctuations in the height of sea level would be less noticeable than on the south and west coasts of the island. Moreover, the houses are not built so close to the shore as they are on the coasts where there is more protection. For these reasons the sea wave, especially at more distant places where it had become small, was noticed chiefly in the estuaries of the larger rivers. The tides on all these coasts are very small, and consequently the attention of beach dwellers is attracted by any abnormal fluctuation in sea level, particularly if it occurs on a gently sloping beach.

"At **Isabela** and **Arecibo** the wave was large enough to be easily observed, even on the unprotected coast, but it was not noticed in the bay at San Juan, Puerto Rico, probably because there it was smaller and was obstructed by the narrow entrance. [Western Geophysical Research, Inc. (undated) reports the amplitude of the wave was 2 m at **Isabela** and 0.6 m at **Arecibo**.] The water in the **Rio Grande de Loiza** near its mouth is reported to have subsided and then to have risen about 1 m above normal, the phenomenon occurring 25 or 30 minutes after the earthquake. Calculations show that the wave should have reached the mouth of the river about 20 minutes after the shock.

FIGURE 66.—Beach at Mayaguez, Puerto Rico, strewn with the debris of houses. Note house carried seaward by retreating wave and left stranded in the Bay. Foundation posts of houses have been destroyed by the tsunami of October 11, 1918. Photo Credit: Bulletin of the Seismological Society of America.

"On the west coast of **Mona Island** the water first retired, and after a short interval, returned, washing away a small pier and filling with salt water an open cistern, about 4 m above sea level.

"At Santo Domingo City, Dominican Republic, the waters of the Ozama River fell about 70 cm, remaining at that elevation for about 10 minutes, and then rose nearly as high above normal. The water continued to rise and fall, with a period of about 40 minutes, for 2-3 hours. The movement was first noticed about an hour after the earthquake. The calculated interval is 53 minutes. The periodic movement of the water was probably a seiche, started by the arrival of the sea wave.

"The wave was apparently noticeable as far east as the island of **St. Thomas**, although the time of arrival reported by observers is much later than would be expected. Mr. S. Fisher, captain of the harbor at **Charlotte Amalie**, states that at about 1:00 P.M. the water in the harbor rose and fell several times, the maximum height being about 45 cm. The normal tide gives a rise and fall of only about 30 cm. At **Krum Bay**, just west of the harbor of **Charlotte Amalie**, the water commenced to rise at 12:30 P.M. (more than an hour later than would be expected) and reached its maximum height, about 1.2 m, a half hour later, after which oscillations continued until 4:00 P.M.

"The decrease in the height of the wave as it spread out from the origin was not uniform, and in some places there was even a local increase in height. Such fluctuations as were observed, however, are readily explained by irregularities in the shoreline and variations in the topography of the sea bottom. The seiches or periodic oscillations of water level reported at Santo Domingo, Charlotte Amalie, Krum Bay, and elsewhere were started in basins or bays, partly cut off from the ocean, by the arrival of the seismic sea wave, after which the water continued to oscillate with a period determined by the depth and size of the basin. The phenomenon is similar to the back and forth movement of water in a small vessel when it is disturbed.

"The sea waves had an unobstructed sweep across the deep waters of the North Atlantic and were registered on the tide gage at Atlantic City, New Jersey, about 2,200 km north of the origin. (Reid and Taber, 1919a)

1918, October 25, 03:43. This aftershock of the October 11, 1918, earthquake occurred at 11:43 P.M. October 24 (local date). Once again a cable was cut and buried at the same place as the October 11 break. The earthquake was felt aboard the *Steamship Mariana*, which was about 11 km southwest of the Mona Island lighthouse. According to Captain Thebald, the boat plunged and then rolled heavily. It is likely that the northwest coast of Puerto Rico experienced at least a small tsunami, since a small wave was recorded on the tide gage at Galveston, Texas. However, there are no reports of its being observed on Puerto Rico. A moderate wave may have escaped notice at that hour of night. (Heck, 1947; Reid and Taber, 1919a; Berninghausen, 1968)

1922, May 2, 20:24. A small earthquake with an epicenter near Isla de Vieques, Puerto Rico, reportedly produced a 0.6-m wave at Galveston, Texas (Berninghausen, 1968). Parker (1922), then the director of the United States Coast and Geodetic Survey, observed a train of three waves with a period of about 45 minutes on the Galveston tide record, followed 8 hours later by a similar but smaller train. He associated it with the Vieques earthquake occurring approximately 4 hours earlier. The earthquake was felt in Vieques in masonry buildings, but according to Campbell (undated), it was a slight shock lasting only 2 seconds, an unlikely candidate to produce a tsunami. Other sources for the waves are not known. (Parker, 1922; Campbell, undated)

1946, August 4, 17:51. This magnitude 8.1 earthquake occurred about 65 km off the northeast coast of the Dominican Republic. The tsunami caused by this earthquake was recorded on the tide gage at **San Juan, Puerto Rico**. Reports from the north and west coast of Puerto Rico do not show evidence of a tsunami. (Berninghausen, 1968) The waves were recorded on tide gages at Daytona Beach, Florida, at Atlantic

(1946, August 4, continued)
City, New Jersey, and at Bermuda. (Bodle and Murphy, 1948)

1946, August 8, 13:28. This tremor, a magnitude 7.9 aftershock of the August 4, 1946, earthquake, produced a small tsunami that was recorded on the tide gage at **San Juan, Puerto Rico**. The small tsunami was observed at **Mayaguez, Puerto Rico**, where the sea retreated 76 m and returned, and at **Aguadilla**, where the sea retreated 24 m and returned. (Berninghausen, 1968) The waves were recorded at Daytona Beach, Florida, at Atlantic City, New Jersey, and at Bermuda.

(Tables for Puerto Rico and the Virgin Islands begin on the next page.)

TABLE 10. TSUNAMI DATA FOR PUERTO RICO AND THE UNITED STATES VIRGIN ISLANDS

ORIGIN DATA					TSUNAMI DATA							
DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AREA	VALID	CAUSE	MAG & INT	LOCATION OF EFFECTS	RUN UP/ AMP (M)	PERIOD (MIN)	1ST MOTION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1690 04 16	17.5N 61.5W 7.8 (DNAG)	Leeward Islands?	2	E		Charlotte Amalie, St. Thomas	OBS		F			Sea receded 16.5-18.5m from shore.
1755 11 01	10:24 36.0N 11.0W	Lisbon, Portugal	4	E		Saba, West Indies	7.0					Not reported from U.S. Virgin Islands or Puerto Rico.
1761 03 31	13:14	Lisbon, Portugal	4	E		Barbados, West Indies	1.2					Extraordinary flux and and reflux of the sea. Not reported from U.S. Virgin Islands or Puerto Rico.
1867 11 18	19.07 18.5N 65.5W 7.5 (DNAG) 33	Virgin Islands				Altona, St. Thomas	OBS					Houses washed far inland.
						Charlotte Amalie, St. Thomas	2.4	10.0	F		00.3	(2.4 m measured at wharf). Lower parts of city flooded, heavy damage, U.S.S. De Soto damaged. Possibly 11-12 killed.
						Christiansted, St. Croix	OBS		F			Wave swept inland 91 m.
						Fajardo, P. R.	OBS		F			Very small wave.
						Frederiksted, St. Croix	OBS		F		00.2	U.S.S. *Monongahela* washed onto wharf; stranded on shoal. Five killed, 3 or 4 injured.
						Gallows Bay, Christensted, St. Croix	OBS					20 houses damaged.
						Hassel Island, St. Thomas	4.9					Some damage.
						Vieques, P. R.	OBS		F			High wave on south shore.
						Yabucoa, P. R.	OBS		F			Sea retreated 137 m.
1868 03 17	11:37	Virgin Islands	4	E		Arroyo, P. R.	OBS		F			Small recession & flooding.
						Naguabo, P. R.	OBS		F			Small recession & flooding.
						St. Thomas, Charlotte Amalie	0.6		F			
1918 10 11	14:14 18.5N 67.5W 7.5 (DNAG)	Puerto Rico	4	E		Aguadilla, P.R.	3.4				00.1	300 huts destroyed. 32 people drowned.
						Arecibo, P.R.	0.6					
						Charlotte Amalie, St. Thomas	0.5					
						El Boqueron, P.R.	1.5	20.0	F		01.0	Several waves.
						Guanica, P.R.	0.5					
						Isabela, P.R.	2.0					
						Isla Caja de Muertos, P.R.	1.5					
						Isla Mona, P.R.	4.0		F			Pier washed away. Cistern flooded.
						Krum Bay, St. Thomas	1.2					
						Mayaguez, P.R.	1.5				00.4	First floors flooded; a few huts destroyed; brick wall overturned.
						Ponce, P.R.	OBS					
						Punta Agujereada, P.R.	6.0					Several hundred palms uprooted and several small houses destroyed. 8 drowned.
						Punta Borinquen, P.R.	4.5					Sea inundated 100 m. Submarine cables cut in several places offshore.
						Punta Higuero, P.R.	5.2	02.0	F			1,000-km blocks of limestone move 45 to 75 m.
						Rio Culebrinas, P.R.	4.0					
						Rio Grande de Loiza, P.R.	1.0		F		00.4	(See also East Coast section.)
1918 10 25	03:43 18.5N 67.5W	Puerto Rico	4	E		Mona Passage	OBS					Submarine cables again cut. Steamship plunged and rolled heavily. Not reported on Puerto Rico. (See also East Coast section.)
1922 05 02	20:24	Puerto Rico	1	E								Recorded waves in Galveston, Texas, were ascribed to this earthquake, but this is unlikely. Not reported in Puerto Rico. (See also East Coast section.)
1946 08 04	17:51 18.9N 68.9W 8.1 (DNAG)	Dominican Republic	4	E		San Juan, P. R.	OBS				00.6	On tide record.
1946 08 08	13:28 19.7N 68.5W 7.9 (DNAG) 16	Dominican Republic	4	E		Aguadilla, P. R.	OBS		F			Sea retreated 24 m and returned.
						Mayaguez, P. R.	OBS		F			Sea retreated 76 m and returned.
						San Juan, P. R.	OBS				00.6	Recorded on tide gage. (See also East Coast section.)

TABLE 11. T MI DATA FOR NON UNITED STATES AREAS AFFECTED BY TSUNAMIS ENERATED NEAR THE VIRGIN ISLANDS AND PUERTO RICO

ORIGIN D. DATE	TIME LAT./LONG. MAGNITUDE DEPTH (KM)	AR	VALID	CAUSE	MAG & INT	TSUNAMI DATA: LOCATION OF EFFECTS	RUN UP/ AMP (M)	PER-IOD (MIN)	1ST MOT-ION	ARRIVAL TIME DA-HR:MN	TRAVEL TIME (HRS)	COMMENTS
1867 11 18	19:07	Virgin				British Virgin Islands						
	18.2N					Peter Island	OBS					People left island in alarm and went to larger Tortola I.
	65.0W					Tortola,						
	7.5					Roadtown	1.5		F			Houses swept away.
	33					Saba	OBS					Some damage.
						St. Christopher	OBS					
						St. Martin	OBS					Some damage.
						St. Barthelemy	OBS					Some damage.
						Antigua,						
						St. John	3.0					
						Guadeloupe						
						Basse Terre	1.0		F			Sea retreated far from coast.
						Deshaies	OBS					Houses in village destroyed.
						Isles des Saintes						
						Fond du Cure	OBS					Houses inundated up to 1 m.
						Pointe-a-Pitre	OBS					Slight swell.
						Sainte Rose	10.0?		F			Sea withdrew 100 m. Return of sea flooded houses and caused damage.
						Martinique	OBS					
						St. Vincent	OBS					Unusually high water.
						Becquia	1.8					
						Grenada						
						Gouyave (Charlotte Town)	3.0		F			Some damage to town.
						St. George	1.5					Boats and buildings damaged.
1918 10 11	14:14	Puerto				Dominican Republic						
	18.5N					Santo Domingo	0.7	40	F			Waves continued for two or or three hours.
	67.5W											
	7.5 (DNAG)											

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HAWAII

HAWAII ISLAND

Anaehoomalu: Apr. 1, 1946.

Apua (Point?): Apr. 3, 1868.

Cape Kumukahi: July 24 or 25, 1869; Mar. 9, 1957; May 22, 1960; Nov. 29, 1975.

Coconut Island: May 10, 1877; Apr. 1, 1946; Nov. 4, 1952; Mar. 9, 1957.

Haena: Nov. 4, 1952.

Hakalau: Apr. 1, 1946 (Hakalau Gulch); Mar. 9, 1957; May 22, 1960.

Halape: May 22, 1960; Nov. 29, 1975.

Hawaii Island: Oct. 5, 1903(?).

Hilo: Apr. 12, 1819; Nov. 7, 1837; May 17, 1841; Jan. 27, 1854; Apr. 3, 1868; Aug. 13, 1868; Aug. 23, 1872; May 10, 1877; June 15, 1896; Jan. 31, 1906; Aug. 17, 1906; Sept. 21, 1908; Sept. 7, 1918; Apr. 30, 1919; Dec. 16, 1921(?); Nov. 11, 1922; Feb. 3, 1923; Apr. 13, 1923; Nov. 4, 1927; Dec. 28, 1927; June 17, 1928; Mar. 7, 1929; Oct. 3, 1931; June 3, 1932; June 18, 1932; June 22, 1932; Mar. 2, 1933; Nov. 21, 1935(?); Nov. 10, 1938; Apr. 1, 1946; Dec. 20, 1946; Sept. 8, 1948; Aug. 22, 1949; Oct. 19, 1949; Oct. 5, 1950; Oct. 23, 1950; Aug. 21, 1951; Mar. 4, 1952; Sept. 26, 1952; Nov. 4, 1952; Sept. 14, 1953; Nov. 25, 1953; Apr. 19, 1955; Mar. 30, 1956; Mar. 9, 1957; Nov. 1, 1957(?); July 10, 1958; Nov. 6, 1958; Nov. 12, 1958(?); May 4, 1959; May 21, 1960; May 22, 1960; Nov. 20, 1960; Oct. 13, 1963; Oct. 20, 1963; Mar. 28, 1964; Feb. 4, 1965; Mar. 30, 1965; July 2, 1965(?); Oct. 17, 1966; Dec. 28, 1966; May 16, 1968; Aug. 11, 1969; Nov. 22, 1969; July 14, 1971; July 26, 1971; Dec. 15, 1971; Jan. 30, 1973; June 17, 1973; Oct. 3, 1974; Nov. 29, 1975; June 22, 1977; Dec. 12, 1979; July 17, 1980; Mar. 3, 1985; Sept. 19, 1985; May 7, 1986; Oct. 20, 1986; Nov. 30, 1987.

Honaunau: Apr. 1, 1946; Mar. 9, 1957; May 22, 1960.

Honokaa: Apr. 1, 1946; Mar. 9, 1957; May 22, 1960.

Honokohau: Apr. 1, 1946; Nov. 29, 1975.

Honomu: Apr. 1, 1946; Mar. 9, 1957; May 22, 1960.

Honuapo: Apr. 3, 1868; June 15, 1896; Aug. 9, 1901; Apr. 1, 1946; Mar. 9, 1957; May 22, 1960; Nov. 29, 1975; Mar. 3, 1985; May 7, 1986.

Hookena: Dec. 21, 1812; June 15, 1896; Aug. 9, 1901; Apr. 1, 1946; Aug. 21, 1951; Nov. 4, 1952; Mar. 9, 1957; May 22, 1960; Nov. 29, 1975.

Hoopuloa: Aug. 9, 1901; Oct. 2, 1919.

Kaalualu: Apr. 3, 1868; June 15, 1896; Mar. 2, 1933; May 22, 1960; Nov. 29, 1975 (Kaalualu Bay).

Kaawaloa: June 15, 1896.

Kahaluu: May 22, 1960.

Kahaualea: Oct. 1, 1868; July 24 or 25, 1869.

Kailua (Kailua-Kona): Apr. 3, 1868; June 15, 1896; Aug. 9, 1901; Aug. 17, 1906; Oct. 2, 1919; Mar. 2, 1933; Apr. 1, 1946; Aug. 21, 1951; Nov. 4, 1952; Mar. 9, 1957; May 22, 1960; Nov. 29, 1975; July 17, 1980; Dec. 19, 1982; Mar. 3, 1985; May 7, 1986; Oct. 20, 1986 (Kona).

Kaimu: Apr. 3, 1868; Apr. 1, 1946; Mar. 9, 1957; May 22, 1960; Nov. 29, 1975.

Kaiwilahilahi: June 15, 1896.

Ka Lae Cape (South Point): Apr. 3, 1868; Apr. 1, 1946; Mar. 9, 1957; May 22, 1960; Nov. 29, 1975.

Kalapana: Apr. 3, 1868; Aug. 13, 1868; July 24 or 25, 1869; Apr. 1, 1946; Mar. 18, 1952; Nov. 4, 1952; Mar. 9, 1957; May 22, 1960; Nov. 29, 1975.

Kamaili: July 24 or 25, 1869.

Kamoamoa: Nov. 29, 1975.

Kapoho: July 24 or 25, 1869.

Kapua: Jan. 22, 1872(?).

Kawaa: Apr. 3, 1868.

Kawa Bay: Apr. 3, 1868.

Kawaihae: Apr. 3, 1868; May 10, 1877; June 15, 1896; Mar. 2, 1933; Apr. 1, 1946; Nov. 4, 1952; Mar. 9, 1957; May 22, 1960; Mar. 28, 1964; Nov. 29, 1975.

Keaau: Apr. 1, 1946; Mar. 9, 1957; May 22, 1960.

Keahialaka (Southwest of Kapoho): Apr. 3, 1868.

Kealakekua: Apr. 3, 1868; May 10, 1877 (Kealakekua Bay).

Kealakomo: Apr. 3, 1868.

Keauhou: June 15, 1896; Aug. 9, 1901; Oct. 2, 1919; Mar. 2, 1933; Apr. 1, 1946 (Keauhou Bay); Nov. 4, 1952; Mar. 9, 1957; May 22, 1960; Nov. 29, 1975 (Keauhou Bay).

Keauhou Landing: Apr. 3, 1868; Nov. 29, 1975.

Keokea Point: Apr. 1, 1946.

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Kohala: June 15, 1896.

Kolekole: Apr. 1, 1946 (Kolekole Stream).

Kona Coast: Feb. 24, 1877(?).

Laupahoehoe: Apr. 1, 1946 (Laupahoehoe Peninsula); Mar. 9, 1957; May 22, 1960; Mar. 28, 1964.

Mahukona: Aug. 9, 1901; Apr. 1, 1946; Mar. 9, 1957; May 22, 1960; Mar. 28, 1964; Mar. 3, 1985; May 7, 1986.

Milolii: 1887-1909; Apr. 1, 1946; Aug. 21, 1951; Mar. 9, 1957; May 22, 1960.

Napoopoo: June 15, 1896; Aug. 9, 1901; Mar. 2, 1933; Apr. 1, 1946; Aug. 21, 1951; Nov. 4, 1952; Mar. 9, 1957; May 22, 1960; Nov. 29, 1975.

Ninole: Apr. 3, 1868.

Off Northeast Coast: Aug. 17, 1906.

Onomea: Apr. 1, 1946; Mar. 9, 1957; May 22, 1960.

Opihikao: Apr. 3, 1868; July 24 or 25, 1869; May 22, 1960.

Papaikou: Apr. 1, 1946; Mar. 9, 1957; May 22, 1960.

Pepeekeo: Apr. 1, 1946; Mar. 9, 1957; May 22, 1960.

Pohoiki: Apr. 3, 1868; July 24 or 25, 1869; Apr. 1, 1946; Mar. 9, 1957; May 22, 1960.

Pololu Valley: Apr. 1, 1946; Mar. 9, 1957; May 22, 1960.

Puako: Mar. 28, 1964.

Puna Coast: July 24 or 25, 1869.

Punaluu: Apr. 3, 1868; July 24 or 25, 1869; June 15, 1896; Oct. 8, 1903(?); Nov. 17, 1903(?); Apr. 30, 1919 (Punaluu Bay); Apr. 1, 1946 (Punaluu Bay); Mar. 9, 1957 (Punaluu Bay); May 22, 1960 (Punaluu Bay); Nov. 29, 1975 (Punaluu Bay).

Pu'uloa: March 3, 1985.

South Point: (See Ka Lae Cape.)

S. Puna to Kau: Apr. 3, 1868.

Upolu Point: Apr. 1, 1946; Mar. 9, 1957; May 22, 1960.

Waiakea: Apr. 3, 1868; Aug. 13, 1868; May 10, 1877 (Waiakea River area); Jan. 31, 1906.

Wailoa River: Jan. 31, 1906; Feb. 3, 1923; Mar. 7, 1929; Mar. 28, 1964.

Waipio Bay: Mar. 28, 1964.

Waipio Valley: Apr. 1, 1946; Mar. 9, 1957; May 22, 1960.

West and Southern Coasts: May 22, 1960.

Western Shore: Apr. 12, 1819.

KAUAI

Anahola Bay: Mar. 28, 1964.

Aneoweonui (sp?): May 22, 1960.

Anini: May 22, 1960.

Haena: Apr. 1, 1946; Mar. 9, 1957; May 22, 1960; Mar. 28, 1964.

Hanalei: Aug. 23, 1872 (Hanalei Bay); Apr. 1, 1946 (Hanalei Bay); Mar. 28, 1964; May 7, 1986.

Hanamaulu Bay: Apr. 1, 1946.

Kalihiwai: Apr. 1, 1946 (Kalihiwai Bay); Mar. 9, 1957.

Kapaa: June 15, 1896; Mar. 28, 1964; May 7, 1986.

Kauai Island: Feb. 20, 1835.

Kaumakani: Apr. 1, 1946; May 22, 1960.

Kekaha: May 22, 1960.

Kilauea: June 15, 1896 (Kilauea Landing).

Kukuiula: Mar. 2, 1933.

Moloaa: Apr. 1, 1946; Mar. 28, 1964.

Nawiliwili: Aug. 23, 1872; May 10, 1877; June 15, 1896; May 30-31, 1924; May 2, 1933; Apr. 1, 1946; Mar. 30, 1956; Mar. 9, 1957; Nov. 1, 1957(?); July 10, 1958; Nov. 6, 1958; May 4, 1959; May 22, 1960; Oct. 13, 1963; Oct. 20, 1963; Mar. 28, 1964; Feb. 4, 1965; Oct. 17, 1966; May 16, 1968; Aug. 1, 1968; Aug. 11, 1969; Nov. 22, 1969; July 14, 1971; July 26, 1971; Dec. 15, 1971; Jan. 30, 1973; June 17, 1973; Oct. 3, 1974(?); Nov. 29, 1975; June 22, 1977 (Lihue); Dec. 12, 1979; May 7, 1986; Nov. 30, 1987.

North Coast: Nov. 4, 1952; Feb. 4, 1965.

Pakala: Mar. 2, 1933; Apr. 1, 1946 (Pakala Point); May 22, 1960.

KAUAI (continued)

Port Allen: Apr. 1, 1946; Sept. 8, 1948; Aug. 22, 1949; Oct. 19, 1949; Oct. 5, 1950; Oct. 23, 1950; Dec. 14, 1950; Aug. 21, 1951; Mar. 4, 1952; Nov. 4, 1952; Sept. 14, 1953; Oct. 13, 1963.

Wahiawa Bay: Nov. 4, 1952; May 22, 1960.

Wailua: May 22, 1960; Mar. 28, 1964.

Waimea Bay: Aug. 13, 1868; Apr. 1, 1946.

Wainiha: Apr. 1, 1946; Mar. 9, 1957.

LANAI

Kaumalapau: May 30-31, 1924.

Lanai Island: May 22, 1960.

MAUI

Halehaku: Jan. 20, 1878 (Halehaku Valley).

Hamoa: Apr. 1, 1946.

Hana: Apr. 1, 1946 (Hana Bay); Nov. 29, 1975.

Honokohau: Nov. 29, 1903(?); Apr. 1, 1946.

Honomanu: Jan. 20, 1878.

Kaanapali: June 15, 1896; Apr. 1, 1946; Oct. 13, 1963.

Kahakuloa: Apr. 1, 1946.

Kahului: Apr. 12, 1819; Nov. 7, 1837; Dec. 1, 1860; Aug. 13, 1868; May 10, 1877; Jan 31, 1906; Aug. 17, 1906; Feb. 3, 1923; Apr. 1, 1946; Mar. 4, 1952; Nov. 4, 1952; Sept. 14, 1953; Apr. 19, 1955; Mar. 30, 1956(?); Mar. 9, 1957; Nov. 1, 1957(?); July 10, 1958; Nov. 6, 1958; Nov. 12, 1958(?); May 4, 1959; May 22, 1960; Oct. 13, 1963; Oct. 20, 1963; Mar. 28, 1964; Oct. 17, 1966; Dec. 28, 1966; May 16, 1968; Aug. 11, 1969; Nov. 22, 1969; July 14, 1971; July 26, 1971; Dec. 15, 1971; Jan. 30, 1973; June 17, 1973; Oct. 3, 1974; June 10, 1975; Nov. 29, 1975; Jan. 14, 1976; June 22, 1977; Dec. 12, 1979; July 17, 1980; Mar. 3, 1985; Sept. 19, 1985; May 7, 1986; Oct. 20, 1986.

Kanaio: Aug. 13, 1868.

Kaupo: July 24 or 25, 1869.

Keanae: Apr. 1, 1946 (Keanae Peninsula).

Kihei: May 22, 1960.

Lahaina: Nov. 7, 1837; May 17, 1841; Apr. 3, 1868; May 10, 1877; Mar. 2, 1933; Apr. 1, 1946; May 22, 1960; Nov. 29, 1975.

Lower Paia: Apr. 1, 1946; Mar. 28, 1964.

Maalaea: Aug. 17, 1906; Apr. 1, 1946; Mar. 9, 1957.

Mala: Apr. 1, 1946.

Maliko: Dec. 1, 1860; Jan 20, 1878; January 28, 1895(?); Apr. 1, 1946 (Maliko Bay); Mar. 28, 1964 (Maliko Bay).

McGregor's Landing: Aug. 17, 1906.

North Coast: July 12, 1848(?).

Paia: Apr. 1, 1946; May 22, 1960.

Paukukalo: Apr. 1, 1946; May 22, 1960.

Spreckelsville: Apr. 1, 1946; May 22, 1960.

MIDWAY ISLANDS

Midway Islands: Mar. 2, 1933; Nov. 4, 1952; Nov. 25, 1953; Mar. 30, 1956; Mar. 9,1957; Nov. 1, 1957(?); Nov. 4, 1958(?); Nov. 6, 1958; May 4, 1959; May 22, 1960; Oct. 13, 1963; Oct. 20, 1963; Mar. 28, 1964; Feb. 4, 1965; Oct. 17, 1966; May 16, 1968; Aug. 11, 1969; Nov. 22, 1969; July 14, 1971; July 26, 1971; Oct. 3, 1974(?); Mar. 24, 1978; May 7, 1986.

MOLOKAI

Hakaaano: Apr. 12, 1819(?); Nov. 7, 1837(?); May 17, 1841(?).

Halawa: Mar. 9, 1957.

Kalaeloa: 1500-1600.

Kalaupapa: Nov. 29, 1903(?); Apr. 1, 1946.

Kaunakakai: Apr. 1, 1946; Mar. 9, 1957.

Molokai Island: Dec. 1, 1860; Aug. 13, 1868; May 22, 1960.

Waialua: Jan. 28, 1862(?).

Waikolu Valley: Apr. 1, 1946.

NIIHAU ISLAND

Kii Landing: Apr. 1, 1946.

Naina: Apr. 1, 1946.

Niihau Island: Apr. 1, 1946; Mar. 9, 1957.

Nonopapa Landing: Apr. 1, 1946.

OAHU

Ala Wai Harbor: Oct. 13, 1963.

Coconut I. (Mokuoloe): July 10, 1958; Nov. 6, 1958; May 4, 1959; May 22, 1960; Oct. 13, 1963; Oct. 20, 1963; Mar. 28, 1964; May 16, 1968; Aug. 11, 1969; Nov. 29, 1975.

Haleaha: Apr. 1, 1946.

Haleiwa: Jan. 13, 1872(?); Feb. 3, 1923; Apr. 1, 1946; Mar. 9, 1957; Nov. 6, 1958; Oct. 13, 1963; Oct. 20, 1963; Mar. 28, 1964.

Hauula: Mar. 28, 1964.

Honolulu: Apr. 12, 1819; Nov. 7, 1837; May 17, 1841; Apr. 3, 1868; Aug. 13, 1868; Aug. 23, 1872; May 10, 1877; Jan. 20, 1878; Aug. 27, 1883(?); June 15, 1896; Aug. 9, 1901; Nov. 29, 1903(?); Jan. 31, 1906; Aug. 17, 1906; Oct. 11, 1913; May 26, 1914; May 1, 1917; June 26, 1917; Aug. 15, 1918; Sept. 7, 1918; Apr. 30, 1919; Nov. 11, 1922; Feb. 3, 1923; Apr. 13, 1923; Sept. 1, 1923; Oct. 4, 1925(?); Oct. 24, 1927(?); Nov. 4, 1927; Dec. 28, 1927; June 17, 1928; Mar. 7, 1929; Oct. 3, 1931; June 3, 1932; Mar. 2, 1933; Mar. 6, 1938(?); Nov. 10, 1938; Apr. 6, 1943; Dec. 7, 1944; Apr. 1, 1946; Dec. 20, 1946; Sept. 8, 1948; Aug. 22, 1949; Oct. 19, 1949; Oct. 5, 1950; Oct. 23, 1950; Aug. 21, 1951; Mar. 4, 1952; Nov. 4, 1952; Sept. 14, 1953; Apr. 19, 1955; Mar. 30, 1956; Mar. 9, 1957; Nov. 1, 1957(?); July 10, 1958; Nov. 6, 1958; Nov. 12, 1958(?); May 4, 1959; May 22, 1960; Dec. 21, 1962(?); Oct. 13, 1963; Oct. 20, 1963; Mar. 28, 1964; Feb. 4, 1965; Oct. 17, 1966; May 16, 1968; Aug. 1, 1968; Aug. 11, 1969; Nov. 22, 1969; July 14, 1971; July 26, 1971; Dec. 15, 1971; June 17, 1973; Oct. 3, 1974; Nov. 29, 1975; Jan. 14, 1976; June 22, 1977; July 17, 1980; Dec. 19, 1982; Mar. 3, 1985; May 7, 1986; Oct. 20, 1986; Nov. 30, 1987.

Kaena Point: Apr. 1, 1946.

Kahana: Apr. 1, 1946 (Kahana Bay).

Kahuku: Apr. 1, 1946 (Kahuku Pt.); Nov. 4, 1952 (Kahuku Pt.); Mar. 9, 1957.

Kaiaka Bay: Mar. 28, 1964.

Kaloko: Apr. 1, 1946.

Kawela Bay: Apr. 1, 1946.

Kuliouou: May 22, 1960.

Lanikai: Apr. 1, 1946.

Makalii Point: Apr. 1, 1946.

Makapuu Point: Apr. 1, 1946; Nov. 4, 1952.

Mokapu Peninsula: Apr. 1, 1946.

Northeast Coast: Nov. 4, 1952.

Oahu Island: May 30-31, 1924.

Pearl Harbor: Mar. 4, 1952; Nov. 4, 1952.

Puaena Point: Mar. 28, 1964.

Punaluu: Apr. 1, 1946.

Sandy Beach: Nov. 1, 1946.

Waialee: Mar. 28, 1964.

Waialua: Jan. 20, 1878; Nov. 4, 1952; Mar. 9, 1957.

Waianae: Apr. 1, 1946; Sept. 8, 1948.

Waikiki: June 15, 1896; Apr. 1, 1946; Mar. 9, 1957.

Wailupe: Mar. 20, 1926(?).

Waimea Bay: Mar. 28, 1964.

ALASKA

ALEUTIAN ISLANDS

Adak Island: Dec. 7, 1944 (Sweeper Cove); Mar. 4, 1952 (Sweeper Cove); Nov. 4, 1952 (Sweeper Cove); Mar. 30, 1956 (Sweeper Cove); Mar. 9, 1957 (Sand Bay and Sweeper Cove); Nov. 6, 1958 (Sweeper Cove); Nov. 12, 1958(?) (Sweeper Cove); May 22, 1960 (Sweeper Cove); Mar. 28, 1964 (Sweeper Cove); Feb. 4, 1965 (Sweeper Cove); Oct. 17, 1966 (Sweeper Cove); May 16, 1968; Nov. 22, 1969; May 2, 1971; July 26, 1971; Dec. 15, 1971; June 10, 1975(?); Mar. 3, 1985; May 7, 1986.

Akutan (Ikatan) (Unimak Island): Apr. 1, 1946.

Aleutian Islands: Mar. 7, 1929; Nov. 1, 1946(?).

Amchitka Island: Feb. 4, 1965; Nov. 6, 1971 (Constantine Harbor); Nov. 6, 1971 (Square Bay).

ALEUTIAN ISLANDS (continued)

Attu Island: Dec. 7, 1944 (Massacre Bay); Mar. 4, 1952 (Massacre Bay); Nov. 4, 1952 (Massacre Bay); Nov. 25, 1953 (Massacre Bay); Mar. 30, 1956 (Massacre Bay); Mar. 9, 1957 (Massacre Bay); Nov. 6, 1958 (Massacre Bay); Nov. 12, 1958(?) (Massacre Bay); May 4, 1959 (Massacre Bay); May 22, 1960 (Massacre Bay); Oct. 13, 1963 (Massacre Bay); Mar. 28, 1964 (Massacre Bay); Feb. 4, 1965 (Massacre Bay); Mar. 30, 1965; Oct. 17, 1966 (Massacre Bay); Apr. 1, 1968; May 16, 1968; Aug. 1, 1968; Aug. 11, 1969; Nov. 22, 1969; July 14, 1971; July 26, 1971; Dec. 15, 1971; Feb. 28, 1973; June 17, 1973.

Constantine Harbor (Amchitka Island): Nov. 6, 1971.

Dutch Harbor (Unalaska): Nov. 10, 1938; Apr. 1, 1946; Mar. 4, 1952; Nov. 4, 1952; Mar. 30, 1956; Mar. 9, 1957; May 22, 1960; Mar. 28, 1964; Feb. 4, 1965; July 2, 1965; May 16, 1968.

Fox Islands: Aug. 23, 1872.

Makushin (Unalaska): Aug. 29, 1878.

Massacre Bay (Attu Island): Dec. 7, 1944; Mar. 4, 1952; Nov. 4, 1952; Nov. 25, 1953; Mar. 30, 1956; Mar. 9, 1957; Nov. 6, 1958; Nov. 12, 1958(?); May 4, 1959; May 22, 1960; Oct. 13, 1963; Mar. 28, 1964; Feb. 4, 1965; Oct. 17, 1966.

Sanak Island: July 21, 1788; Apr. 1, 1946.

Sand Bay (Adak Island): Mar. 9, 1957.

Scotch Cap (Unimak Island): Apr. 1, 1946; Mar. 9, 1957.

Shemya Island: Mar. 28, 1964; Feb. 4, 1965; Nov. 22, 1969; Dec. 15, 1971; Feb. 28, 1973.

Square Bay (Amchitka Island): Nov. 6, 1971.

Sweeper Cove (Adak Island): Dec. 7, 1944; Mar. 4, 1952; Nov. 4, 1952; Mar. 30, 1956; Mar. 9, 1957; Nov. 6, 1958; Nov. 12, 1958(?); May 22, 1960; Mar. 28, 1964; Feb. 4, 1965; Oct. 17, 1966.

Umnak Island: May 8, 1796; Mar. 1, 1820(?); Mar. 9, 1957.

Unalaska Island: Aug. 29, 1878 (Makushin); Nov. 10, 1938 (Dutch Harbor); Apr. 1, 1946 (Dutch Harbor); Mar. 4, 1952 (Dutch Harbor); Nov. 4, 1952 (Dutch Harbor); Mar. 30, 1956 (Dutch Harbor); Mar. 9, 1957 (Dutch Harbor); May 22, 1960 (Dutch Harbor); Mar. 28, 1964 (Dutch Harbor); Feb. 4, 1965 (Dutch Harbor); July 2, 1965 (Dutch Harbor); May 16, 1968 (Dutch Harbor); Nov. 22, 1969; Dec. 15, 1971; May 7, 1986.

Unimak Island: May 19, 1796; 1824-Fall 1825; July 26, 1856; Apr. 1, 1946 (Akutan and Scotch Cap); Mar. 9, 1957 (Scotch Cap).

ALASKA PENINSULA

Alaska Peninsula: July 21, 1788.

Chernabura Island (Shumagin Islands): August 8-9, 1827(?).

Chignik: Apr. 1, 1946.

Chirikof Island (Ukamak Island): Sept. 29, 1880.

Kaguyak (Kodiak Island): Mar. 28, 1964.

Kalsin Bay (near Kodiak, Kodiak Island): Mar. 28, 1964.

Kodiak (Kodiak Island): Oct. 17, 1966; Mar. 6, 1988.

Kodiak Island area: July 21, 1788 (Pavlof Village and Three Saints Bay); 1792 (Three Saints Bay); Jan. 27, 1854 (Pavlovskaya Harbor); Aug. 14, 1868; Oct. 6, 1883; Nov. 4, 1952 (Womens Bay); Mar. 9, 1957 (Womens Bay); May 22, 1960 (Womens Bay); Mar. 28, 1964 (and Kaguyak, Kalsin Bay, Kodiak Naval Station, Old Harbor, Ouzinkie, Sitkalidak Island, Spruce Cape, and Womens Bay); Feb. 4, 1965; Oct. 17, 1966 (Kodiak); Mar. 3, 1985(?); Mar. 6, 1988 (Kodiak).

Kodiak Naval Station (Kodiak Island): Mar. 28, 1964.

Old Harbor (Three Saints Bay) (Kodiak Island): July 21, 1788; 1792; Mar. 28, 1964.

Ouzinkie (Kodiak Island): Mar. 28, 1964.

St. Pauls Harbor (Pavlof Village, Pavlofskaya Harbor) (Kodiak Island): July 21, 1788; Jan. 27, 1854.

Sand Point (Shumagin Islands): Mar. 3, 1985; May 7, 1986.

Shumagin Islands: July 21, 1788 (Unga Island); Aug. 6, 1788 (Unga Island); Aug. 8-9, 1827(?) (Chernabura); May 15, 1868 (Unga Island); Nov. 10, 1938 (Unga Village); Mar. 3, 1985 (Sand Point); May 7, 1986 (Sand Point).

Sitkalidak Island (near Kodiak Island): Mar. 28, 1964.

Spruce Cape (near Kodiak, Kodiak Island): Mar. 28, 1964.

Unga Island (Shumagin Islands): July 21, 1788; Aug. 6, 1788; May 15, 1868; Nov. 10, 1938 (Unga Village).

Womens Bay (Kodiak Island): Nov. 4, 1952; Mar. 9, 1957; May 22, 1960; Mar. 28, 1964.

GULF OF ALASKA

Afognak Island: Mar. 28, 1964.

Augustine Island: Oct. 6, 1883.

Cape St. Elias: Mar. 28, 1964.

Cape Yakataga: Sept. 4, 1899; Mar. 28, 1964.

Chenega: Mar. 28, 1964.

Controller Bay: Sept. 10, 1899 (Katalla).

Cook Inlet: Mar. 28, 1964.

Cordova: Mar. 28, 1964.

Halibut Cove: Mar. 28, 1964.

Homer: Mar. 28, 1964.

Kachemak Bay: Mar. 28, 1964.

Katalla (Controller Bay): Sept. 10, 1899.

Kenai (Kenai Peninsula): Dec. 31, 1901.

Kenai Peninsula: Oct. 6, 1883 (Port Graham); Dec. 31, 1901 (Kenai); Sept. 22, 1911(?) (Port Wells [Bay]); Mar. 28, 1964; Oct. 17, 1966 (Snug Harbor).

Passage Canal: Mar. 28, 1964.

Perl Island: Mar. 28, 1964.

Peterson Bay: Mar. 28, 1964.

Port Ashton: Mar. 28, 1964.

Port Graham (Kenai Peninsula): Oct. 6, 1883.

Port Nellie Juan: Mar. 28, 1964.

Port Nowell: Mar. 28, 1964.

Port Wells (Bay)(Kenai Peninsula): Sept. 22, 1911(?).

Port Whitshed (near Cordova): Mar. 28, 1964.

Seldovia: Mar. 28, 1964.

Seward: Nov. 10, 1938; Sept. 27, 1949(?); Nov. 4, 1952; Mar. 9, 1957; May 22, 1960; Mar. 28, 1964; Mar. 3, 1985; Nov. 30, 1987.

Shelikof Strait: Mar. 28, 1964.

Snug Harbor (Kenai Peninsula): Oct. 17, 1966.

Valdez: Sept. 10, 1899; Feb. 14, 1908; Feb. 23, 1925; Mar. 28, 1964 (and Valdez Inlet).

Whittier: Mar. 28, 1964.

SOUTHEAST ALASKA

Baranof Island: Oct. 26, 1880 (Redoubt Lake and Whale Bay); Nov. 10, 1938 (Sitka); Apr. 1, 1946 (Sitka); Aug. 22, 1949 (Sitka); Mar. 4, 1952 (Sitka); Nov. 4, 1952 (Sitka); Mar. 9, 1957 (Sitka); July 10, 1958 (Sitka); May 22, 1960 (Sitka); Mar. 28, 1964 (Sitka); Feb. 4, 1965 (Sitka); Oct. 17, 1966 (Sitka); May 16, 1968 (Sitka); July 30, 1972 (Sitka); June 10, 1975(?)(Sitka); Nov. 29, 1975 (Sitka); May 7, 1986 (Sitka); Nov. 30, 1987 (Sitka); Mar. 6, 1988 (Sitka).

Cape Pole: May 22, 1960.

Craig: May 22, 1960; Mar. 28, 1964.

Disenchantment Bay (Yakutat Bay): Sept. 10, 1899; July 4, 1905; July 10, 1958.

Dixon Harbor: July 10, 1958.

Dry Bay: 1850-1860; July 10, 1958.

Glacier Bay: July 10, 1958.

Haines: Sept. 24, 1907.

Juneau: Oct. 24, 1927; Nov. 4, 1952; Mar. 9, 1957; May 22, 1960; Mar. 28, 1964; July 30, 1972.

Kake: May 22, 1960.

Ketchikan: Oct. 24, 1927; Aug. 22, 1949; May 22, 1960; Mar. 28, 1964.

Khantaak Island (Yakutat Bay): Sept. 10, 1899; July 10, 1958.

Klawak (Klawock): Mar. 28, 1964.

Lituya Bay: 1853-1854; 1874; Sept. 10, 1899; Oct. 27, 1936; July 10, 1958.

Logan Coast (between Knight Island and Cape Latouche): Sept. 10, 1899.

Meares Passage: Mar. 28, 1964.

Petersburg: Oct. 24, 1927.

Redoubt Lake (Baranof Island): Oct. 26, 1880.

Russell Fjord (Yakutat Bay): Sept. 10, 1899; July 4, 1905.

SOUTHEAST ALASKA (continued)

Sitka (Baranof Island): Nov. 10, 1938; Apr. 1, 1946; Aug. 22, 1949; Mar. 4, 1952; Nov. 4, 1952; Mar. 9, 1957; July 10, 1958; May 22, 1960; Mar. 28, 1964; Feb. 4, 1965; Oct. 17, 1966; May 16, 1968; July 30, 1972; June 10, 1975(?); Nov. 29, 1975; May 7, 1986; Nov. 30, 1987; Mar. 6, 1988.

Skagway: Oct. 24, 1927; Nov. 4, 1952; May 22, 1960.

Whale Bay (Baranof Island): Oct. 26, 1880.

Wrangell: Oct. 24, 1927.

Yakutat (Yakutat Bay): Sept. 4, 1899; Sept. 10, 1899; Apr. 1, 1946; July 10, 1958; May 22, 1960; Nov. 29, 1975; Feb. 28, 1979; Mar. 3, 1985; Nov. 17, 1987; Nov. 30, 1987; Mar. 6, 1988.

Yakutat Bay: Summer 1845 (?); Sept. 4, 1899 (Yakutat); Sept. 10, 1899 (Disenchantment Bay, Khantaak Island, Russell Fjord, Yakutat, and W. Shore of Yakutat Bay); July 4, 1905 (Disenchantment Bay and Russell Fjord); Apr. 1, 1946 (Yakutat); Nov. 4, 1952; Mar. 9, 1957; July 10, 1958 (and Disenchantment Bay, Khantaak Island, and Yakutat); May 22, 1960 (Yakutat); Mar. 28, 1964; Nov. 29, 1975 (Yakutat); Feb. 28, 1979 (Yakutat); Mar. 3, 1985 (Yakutat); Nov. 17, 1987 (Yakutat); Nov. 30, 1987 (Yakutat); Mar. 6, 1988 (Yakutat).

WEST COAST OF THE UNITED STATES

GENERAL

California Coast: Aug. 23, 1856(?).

Pacific Coast: June 13, 1868(?).

Southern California: Dec. 25, 1899(?).

Washington/Oregon Coast: Nov. 6, 1906(?).

West Coast of United States: June 26, 1917.

CALIFORNIA

Alameda: Apr. 1, 1946; Nov. 4, 1952; Mar. 9, 1957; May 22, 1960; Mar. 28, 1964 (NAS); May 16, 1968.

Alamitos Bay: May 22, 1960; Mar. 28, 1964.

Albion River: Mar. 28, 1964.

Anaheim Bay: Mar. 9, 1957.

Anaheim Landing: Apr. 16, 1877(?).

Avila Beach: Nov. 22, 1878(?); Nov. 4, 1927 (Port San Luis); Apr. 1, 1946; Nov. 4, 1952; Mar. 30, 1956(?); Mar. 9, 1957; Mar. 28, 1964; Oct. 17, 1966; May 16, 1968; Nov. 29, 1975 (Port San Luis); June 22, 1977 (Port San Luis).

Balboa: Aug. 21, 1934(?).

Benicia: Oct. 26, 1854(?).

Bodega Bay: Mar. 9, 1957 (Bodega Harbor); May 22, 1960; Mar. 28, 1964; Nov. 29, 1975.

Bolinas: Apr. 1, 1946; Mar. 28, 1964.

Cape Mendocino: Jan. 22, 1923.

Capitola: Mar. 28, 1964.

Carpinteria: Jan. 15, 1878.

Caspar Beach: Apr. 1, 1946.

Cayucos: Apr. 16, 1877(?); Nov. 22, 1878(?).

Crescent City: Nov. 24, 1885(?); Apr. 1, 1946; Dec. 20, 1946; Mar. 4, 1952; Nov. 4, 1952; Mar. 9, 1957; May 22, 1960; Oct. 13, 1963; Mar. 28, 1964; Feb. 4, 1965; Oct. 17, 1966; May 16, 1968; July 26, 1971; Oct. 3, 1974; May 7, 1986.

Drakes Beach: Mar. 28, 1964.

El Refugio (near Gaviota): Dec. 21, 1812.

Eureka: Nov. 24, 1885(?).

Fort Bragg: Mar. 28, 1964.

Fort Hornet: Feb. 13, 1869.

Gaviota: Dec. 21, 1812(?); May 10, 1877.

Government Island: Oct. 21, 1868.

Granada: Apr. 1, 1946.

Half Moon Bay: Sept. 24, 1859; Apr. 1, 1946; May 22, 1960; Mar. 28, 1964.

Humboldt Bay: Mar. 19, 1855(?); Mar. 28, 1964.

Imperial Beach: Nov. 29, 1975.

Jenner Beach: Mar. 28, 1964.

Klamath River: Mar. 28, 1964.

CALIFORNIA (continued)

Laguna Beach: Aug. 21, 1934(?).

La Jolla: May 1, 1917; Nov. 4, 1927; June 17, 1928; Mar. 2, 1933; Mar. 11, 1933(?); Apr. 1, 1946; Mar. 4, 1952; Nov. 4, 1952; Mar. 9, 1957; May 22, 1960; Mar. 28, 1964; May 16, 1968; Nov. 29, 1975.

Long Beach: Oct. 4, 1925(?); Mar. 11, 1933(?); Aug. 21, 1934(?); Mar. 9, 1957; May 22, 1960; Mar. 28, 1964 (Long Beach Harbor); Oct. 17, 1966; May 16, 1968; Nov. 29, 1975; June 22, 1977.

Los Angeles: Apr. 13, 1923 (Los Angeles Harbor); Mar. 2, 1933; Apr. 1, 1946; Mar. 4, 1952; Nov. 4, 1952; Mar. 9, 1957; May 22, 1960; Mar. 28, 1964 (and Los Angeles County Harbor); Oct. 17, 1966; May 16, 1968; July 26, 1971; Nov. 29, 1975; June 22, 1977.

Malibu Beach: Aug. 21, 1934(?).

Marin County: Mar. 28, 1964.

Martins Beach: Mar. 28, 1964.

Mendocino County: Mar. 28, 1964.

Monterey: May 22, 1960; Mar. 28, 1964.

More's Landing: Jan. 15, 1878.

Morro Bay: Nov. 22, 1878(?); Apr. 1, 1946.

Moss Landing: May 22, 1960; Mar. 28, 1964.

Muir Beach: Mar. 28, 1964.

Navarro River: Apr. 18, 1906; Apr. 1, 1946.

Newport Bay: Mar. 9, 1957; Mar. 28, 1964; Oct. 17, 1966; May 16, 1968.

Newport Beach: Aug. 21, 1934(?).

Noyo: Apr. 1, 1946; Mar. 28, 1964.

Oakland: Mar. 28, 1964.

Oceanside: Mar. 4, 1952.

Pacifica: May 22, 1960; Mar. 28, 1964.

Pacific Grove: Apr. 1, 1946; May 22, 1960; Mar. 28, 1964.

Pebble Beach: Mar. 28, 1964.

Pismo Beach: Nov. 22, 1878(?); Nov. 4, 1927.

Point Arena: Apr. 1, 1946 (Arena Cove); Mar. 28, 1964.

Point San Juan: July 10 or 11, 1855.

Port Harford?: Nov. 22, 1878(?).

Port Hueneme: Apr. 1, 1946; Nov. 4, 1952; Mar. 9, 1957; Nov. 6, 1958; May 22, 1960.

Port San Luis (Avila Beach): Nov. 4, 1927; Nov. 29, 1975; June 22, 1977.

Princeton: Apr. 1, 1946.

Rincon Island: Mar. 28, 1964; Oct. 17, 1966; May 16, 1968.

Russian Gulch: Mar. 28, 1964.

Sal Cape: Nov. 22, 1878(?).

Salinas: May 15, 1851.

Salmon Creek Beach: Mar. 28, 1964.

San Clemente Island: May 22, 1960 (Wilson Cove).

San Diego: Nov. 1853(?); May 31, 1854(?); July 24, 1854; Dec. 23, 1854; Dec. 24, 1854; Aug. 23, 1856; May 27, 1862 (San Diego Bay); Apr. 3, 1868; Aug. 13, 1868; Aug. 23, 1872; Sept. 16, 17, 1872; Feb. 26, 1902; Jan. 31, 1906; Aug. 17, 1906; Apr. 30, 1919; Nov. 11, 1922; Feb. 3, 1923; Apr. 13, 1923; Nov. 4, 1927; Oct. 3, 1931(?); Apr. 6, 1943; Dec. 7, 1944; Apr. 1, 1946; Nov. 4, 1952; Mar. 9, 1957 (San Diego Bay); May 22, 1960; Mar. 28, 1964; Oct. 17, 1966; May 16, 1968; Nov. 29, 1975; June 22, 1977.

San Francisco: 1812(?); May 15, 1851; Nov. 13, 1851(?) (San Francisco Bay); Oct. 26, 1854(?); Nov. 1, 1854 (Angel Island); Dec. 23, 1854; Dec. 24, 1854; Oct. 21, 1855(?); Feb. 15, 1856 (San Francisco Bay); May 4, 1861; Apr. 3, 1868; Aug. 13, 1868; Oct. 21, 1868 (San Francisco Bay); June 2, 1869 (Fort Point); August 23, 1872; Sept. 16, 17, 1872; May 10, 1877; Nov. 19, 1885; June 15, 1896; Jan. 31, 1906; Apr. 18, 1906 (San Francisco Bay); Aug. 17, 1906; Nov. 21, 1910(?); May 1, 1917; Sept. 7, 1918; Apr. 30, 1919; Nov. 11, 1922; Feb. 3, 1923; Apr. 13, 1923; Nov. 4, 1927 (and Fort Point); June 17, 1928; Mar. 2, 1933; Apr. 1, 1946; Dec. 20, 1946; Mar. 4, 1952; Nov. 4, 1952; Mar. 9, 1957; Nov. 6, 1958; May 22, 1960; Mar. 28, 1964; Oct. 17, 1966; May 16, 1968; Nov. 29, 1975; Nov. 30, 1987 (Presidio); Mar. 6, 1988.

San Juan Capistrano: July 10 or 11, 1855.

San Luis Obispo: Nov. 22, 1878(?) (San Luis Obispo Bay); Apr. 1, 1946.

San Mateo: Apr. 1, 1946.

San Miguel Island: Mar. 30, 1895(?).

San Pedro: Aug. 13, 1868; May 10, 1877; Jan. 1, 1927(?); Apr. 1, 1946; Nov. 4, 1952; Mar. 9, 1957; May 22, 1960.

CALIFORNIA (continued)

San Rafael: Mar. 28, 1964.

San Simeon: Apr. 1, 1946.

Santa Barbara: Dec. 21, 1812; Nov. 13, 1851(?); May 31, 1854(?); Jan. 15, 1878; Dec. 17, 1896(?); Oct. 3, 1931; May 22, 1960.

Santa Catalina Island: Nov. 29, 1975.

Santa Cruz: Jan. 16-18, 1840(?); Oct. 8, 1865; Oct. 21, 1868; June 15, 1896; Apr. 1, 1946; May 22, 1960; Mar. 28, 1964.

Santa Monica: Aug. 10, 1879; Aug. 30, 1930; Mar. 2, 1933; Nov. 10, 1938; Nov. 4, 1952; Mar. 9, 1957; May 22, 1960; Mar. 28, 1964; Feb. 4, 1965; May 16, 1968.

Sausalito (San Francisco Bay): Nov. 12, 1884; July 8, 1887(?); Oct. 14, 1895; June 15, 1896; Mar. 28, 1964.

Shelter Cove: May 22, 1960.

Smith River: Mar. 28, 1964.

Stenson Beach: May 22, 1960.

Surf: Nov. 22, 1878(?); Nov. 4, 1927.

Terminal Island: Apr. 6, 1943; Dec. 7, 1944; May 22, 1960.

Tomales Bay: Mar. 28, 1964.

Trinidad: Mar. 28, 1964.

Van Damme State Park: Mar. 28, 1964.

Ventura: Dec. 21, 1812; Jan. 15, 1878.

Wilmington: Aug. 13, 1868 (Wilmington Beach); May 10, 1877; Nov. 22, 1878(?).

Wilson Cove (San Clemente Island): May 22, 1960.

OREGON

Astoria: Dec. 23, 1854; Dec. 24, 1854; Aug. 13, 1868; Aug. 23, 1872; Sept. 16, 17, 1872; Nov. 4, 1952; Mar. 9, 1957; May 22, 1960; Mar. 28, 1964.

Cannon Beach: Mar. 28, 1964.

Clatsop Spit: Apr. 1, 1946.

Coos Bay: Apr. 1, 1946 (Charleston); Mar. 28, 1964.

Depoe Bay: Mar. 28, 1964.

Florence: Mar. 28, 1964.

Nehalem River: Mar. 28, 1964.

Newport: Apr. 1, 1946; Mar. 28, 1964; May 16, 1968.

Rogue River: Mar. 28, 1964.

Seaside: Mar. 28, 1964.

Siuslaw River: Apr. 1, 1946; Mar. 28, 1964.

Umpqua River: Mar. 28, 1964.

Waldport-Alsea: Mar. 28, 1964.

Yaquina Bay: Mar. 28, 1964.

WASHINGTON

Boone Creek (Iron Springs): Mar,. 28, 1964.

Cape Disappointment: Mar. 28, 1964.

Copalis: Mar. 28, 1964.

Echo Bay: May 22, 1960.

Franklin D. Roosevelt Lake: Apr. 8, 1944-Aug. 19, 1953; July 27, 1949; Feb. 23, 1951.

Friday Harbor: Nov. 4, 1952; May 22, 1960; Mar. 28, 1964.

Grays Harbor: Mar. 30, 1904 (Grays Bay); May 22, 1960; Mar. 28, 1964 (Grays Harbor County).

Hoh River: Mar. 30, 1904; Mar. 28, 1964 (Hoh River mouth).

Ilwaco: Mar. 28, 1964.

Joe Creek: Mar. 28, 1964.

Lapush: Mar. 28, 1964.

Moclips: Mar. 28, 1964.

Neah Bay: Apr. 1, 1946; Mar. 4, 1952; Nov. 4, 1952; Mar. 9, 1957; May 22, 1960; Mar. 28, 1964; Oct. 17, 1966; May 16, 1968; May 7, 1986.

Ocean Shores: Mar. 28, 1964.

Pacific Beach: Mar. 28, 1964.

Queets River: Mar. 30, 1904.

WASHINGTON (continued)

Quinault River: Mar. 30, 1904.

Seattle: Nov. 4, 1952; Mar. 28, 1964.

Sea View: Mar. 28, 1964.

Taholah: Mar. 28, 1964.

Toke Point: May 7, 1986.

Vancouver: Mar. 28, 1964.

Westport: Mar. 28, 1964.

Willapa Bay: May 22, 1960.

Wishkah River: Mar. 30, 1904.

Wreck Creek: Mar. 28, 1964.

AMERICAN SAMOA

AMERICAN SAMOA: Sept. 12, 1866; Aug. 13, 1868(?); May 10, 1877(?); Mar. 24, 1883(?); June 15, 1896(?); Oct. 6, 1907(?); May 1, 1917(?); Sept. 7, 1918(?); Sept. 20, 1920(?); Feb. 3, 1923(?); June 17, 1928(?); June 3, 1932(?); Mar. 2, 1933(?); Dec. 7, 1944(?).

MANU'A ISLANDS: Feb. 11, 1915(?).

TUTUILA ISLAND

Faga'alu: May 22, 1960.

Fagasa: Mar. 9, 1957.

Leone: June 26, 1917.

Pago Pago: Nov. 7, 1837; June 26, 1917; Apr. 30, 1919; Aug. 1920; Nov. 11, 1922(?); Apr. 1, 1946; Sept. 8, 1948; Mar. 4, 1952; Mar. 9, 1952(?); Mar. 17, 1952; Mar. 19, 1952; May 13, 1952(?); July 13, 1952; Nov. 4, 1952; Sept. 14, 1953; Mar. 9, 1957; Nov. 6, 1958; May 22, 1960; Feb. 13, 1963; Mar. 30, 1963; Oct. 13, 1963; Oct. 20, 1963; Mar. 28, 1964; June 16, 1964(?); Jan. 24, 1965(?); Feb. 4, 1965; Mar. 30, 1965; July 2, 1965(?); Aug. 11, 1965; Oct. 17, 1966; Dec. 28, 1966; Dec. 31, 1966; Apr. 1, 1968; May 16, 1968; Aug. 1, 1968; Aug. 11, 1969; Nov. 22, 1969; July 14, 1971; Jan. 30, 1973; June 17, 1973; Oct. 3, 1974; Nov. 29, 1975; Dec. 26, 1975; Apr. 2, 1977; June 22, 1977; Oct. 10, 1977; Mar. 14, 1979; Sept. 1, 1981; Dec. 19, 1982; Sept. 19, 1985; May 7, 1986; Oct. 20, 1986; Oct. 6, 1987.

OTHER UNITED STATES POSSESSIONS AND CURRENT AND FORMER TRUST TERRITORIES IN THE PACIFIC OCEAN

CAROLINE ISLANDS

Palau Islands (Belau): Mar. 4, 1952 (Angaur Island); Mar. 19, 1952 (Angaur Island); Jan. 10, 1970 (Malakale).

Satawan: Jan. 24, 1849.

Truk: Nov. 4, 1952; Mar. 30, 1956(?); Mar. 9, 1957; May 22, 1960; Oct. 13, 1963; Oct. 20, 1963; Mar. 28, 1964; May 16, 1968; July 14, 1971; July 26, 1971; Dec. 2, 1972; June 10, 1975; Oct. 31, 1975; May 7, 1986.

Yap: Oct. 31, 1912(?); Dec. 6, 1912(?); Dec. 22, 1925(?); Mar. 4, 1952; Mar. 19, 1952; Nov. 4, 1952; Dec. 2, 1972; Oct. 31, 1975.

JOHNSTON ISLAND

Nov. 4, 1952; Mar. 30, 1956(?); Mar. 9, 1957; May 22, 1960; Oct. 13, 1963; Mar. 28, 1964; May 16, 1968; Nov. 29, 1975; Dec. 12, 1979; May 7, 1986.

MARIANAS

Guam: 1819(?); Jan. 24, 1849; May 16, 1892 (Agana); Feb. and continuing, 1903; Mar. 19, 1952 (Apra Harbor and Tarague); Mar. 4, 1952; Mar. 19, 1952; Nov. 4, 1952; Mar. 9, 1957; May 22, 1960; Oct. 13, 1963; Mar. 28, 1964; Oct. 17, 1966; May 16, 1968; Aug. 1, 1968; Dec. 15, 1971; Dec. 2, 1972.

MARSHALL ISLANDS

Enewetak Island: Nov. 4, 1952; Mar. 9, 1957; May 22, 1960; Mar. 28, 1964.

Kwajalein: Mar. 4, 1952; Nov. 4, 1952; Mar. 9, 1957; Nov. 6, 1958; May 22, 1960; Oct. 13, 1963; Oct. 20, 1963; Mar. 28, 1964; May 16, 1968; Aug. 11, 1969; July 14, 1971; July 26, 1971; June 10, 1975; Nov. 29, 1975.

Marshall Islands: July 1, 1906(?).

WAKE ISLAND

Mar. 4, 1952; Nov. 4, 1952; Mar. 30, 1956(?); Mar. 9, 1957; Nov. 6, 1958; May 22, 1960; Oct. 13, 1963; Mar. 28, 1964; Oct. 17, 1966; Dec. 28, 1966; May 16, 1968; Aug. 1, 1968; Aug. 5, 1968(?); Aug. 11, 1969; Nov. 22, 1969; July 14, 1971; July 26, 1971; Dec. 15, 1971; Oct. 3, 1974; June 10, 1975; Oct. 31, 1975; Nov. 29, 1975; Mar. 24, 1978; May 7, 1986.

EAST COAST OF THE UNITED STATES
(including Coast of Gulf of Mexico)

CONNECTICUT

New London: May 19, 1964.

FLORIDA

Daytona Beach: Aug. 4, 1946; Aug. 8, 1946.

MAINE

Bar Harbor: Nov. 18, 1929.

Belfast: Nov. 18, 1929.

Bernard (Mt. Desert Island): Jan. 9, 1926.

Corea: Jan. 9, 1926.

Fox Islands (Penobscot Bay): Nov. 17, 1872.

North Haven: Nov. 17, 1872.

Portland: Nov. 18, 1929.

Vinalhaven (Penobscot Bay): Jan. 9, 1926.

MARYLAND

Ocean City: Nov. 18, 1929.

MASSACHUSETTS

Barnstable: Nov. 18, 1929.

NEW HAMPSHIRE

Exeter: Nov. 18, 1929.

NEW JERSEY

Atlantic City: Oct. 11, 1918(?): Nov. 18, 1929; Aug. 4, 1946; Aug. 8, 1946; May 19, 1964.

Sandy Hook: May 19, 1964.

NEW YORK

Battery: May 19, 1964.

Montauk: May 19, 1964.

New Rochelle: May 19, 1964.

Plum Island: May 19, 1964.

Port Jefferson: May 19, 1964.

Willets Point: May 19, 1964.

PENNSYLVANIA

Philadelphia: Nov. 11, 1840 (Delaware River).

RHODE ISLAND

Block Island: Nov. 18, 1929.

Newport: May 19, 1964.

Providence: May 19, 1964.

SOUTH CAROLINA

Charleston: Nov. 18, 1929.

TEXAS

Galveston: Oct. 25, 1918; May 2, 1922(?).

PUERTO RICO AND THE UNITED STATES VIRGIN ISLANDS

MONA PASSAGE: Oct. 25, 1918.

PUERTO RICO

Aguadilla: Oct. 11, 1918; Aug. 8, 1946.

Arecibo: Oct. 11, 1918.

Arroyo: Mar. 17, 1868.

El Boqueron: Oct. 11, 1918.

Fajardo: Nov. 18, 1867.

Guanica: Oct. 11, 1918.

Isabela: Oct. 11, 1918.

Isla Caja de Muertos (Muertos Island): Oct. 11, 1918.

Isla Mona (Mona Island): Oct. 11, 1918.

Mayaguez: Oct. 11, 1918; Aug. 8, 1946.

Naguabo: Mar. 17, 1868.

Ponce: Oct. 11, 1918.

Punta Agujereada: Oct. 11, 1918.

Punta Borinquen: Oct. 11, 1918.

Punta Higuero (Point Jiguero): Oct. 11, 1918.

Rio Culebrinas: Oct. 11, 1918.

Rio Grande de Loiza: Oct. 11, 1918.

San Juan: Aug. 4, 1946; Aug. 8, 1946.

Vieques: Nov. 18, 1867.

Yabucoa: Nov. 18, 1867.

ST. CROIX, VIRGIN ISLANDS

Christiansted: Nov. 18, 1867 (Gallows Bay).

Frederiksted: Nov. 18, 1867.

ST. THOMAS, VIRGIN ISLANDS

Altona: Nov. 18, 1867.

Charlotte Amalie: Apr. 16, 1690; Nov. 18, 1867 (and Water Island); Mar. 17, 1868; Oct. 11, 1918.

Hassel Island: Nov. 18, 1867.

Krum Bay: Oct. 11, 1918.

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DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA