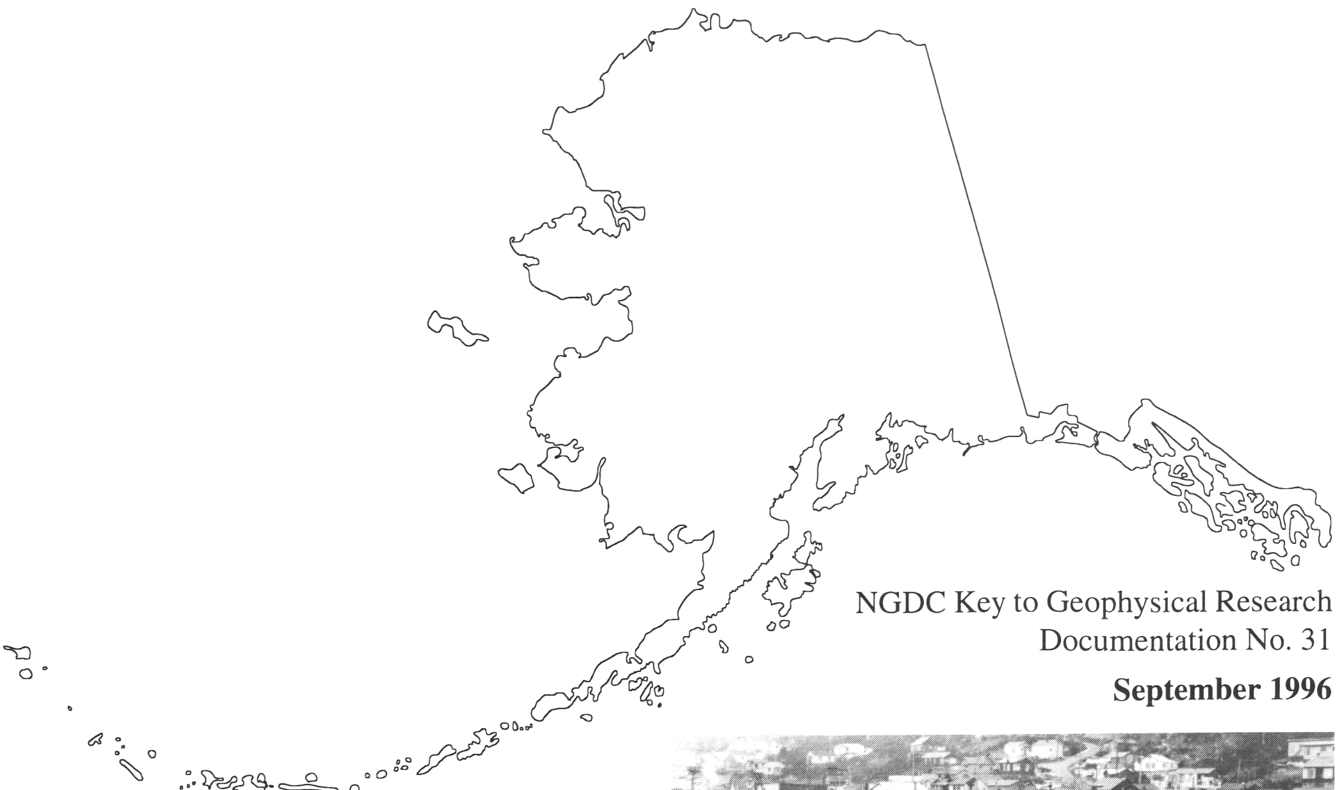
Tsunamis Affecting Alaska
1737–1996



NGDC Key to Geophysical Research
Documentation No. 31

September 1996

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL ENVIRONMENTAL SATELLITE, DATA AND INFORMATION SERVICE
National Geophysical Data Center
Boulder, Colorado

Cover photo: Damage at Kodiak, Alaska, from the March 28, 1964, tsunami. (Photograph credit: National Oceanic and Atmospheric Administration)

NGDC Key to Geophysical Research Documentation No. 31

TSUNAMIS AFFECTING ALASKA
1737–1996

by

James F. Lander
University of Colorado
Cooperative Institute for Research in Environmental Sciences (CIRES)

September 1996

CIRES is sponsored jointly by the University of Colorado at Boulder
and the National Oceanic and Atmospheric Administration

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL ENVIRONMENTAL SATELLITE, DATA
AND INFORMATION SERVICE
National Geophysical Data Center
Boulder, Colorado 80303-3328, U.S.A.

Disclaimer

Contents

List of Figures

List of Tables

Acknowledgements

First to be acknowledged is the financial support of the National Science Foundation which made the research possible with their grant number BCS 9208173.

The support of the NOAA National Geophysical Center, principally Herbert Meyers and Allen Hittelman, the chiefs of the Solid Earth Geophysical Division during the time of preparation, in providing much logistical support in the form of access to their data files, office space, and many other ways, including publishing the work in this series is also gratefully acknowledged. Editing was done by Joy Ikelman and assistance was also given by Lowell Whiteside, CIRES, in graphics, seismic data and other areas.

This volume depended heavily on earlier work, including J.F. Lander and P.A. Lockridge, *United States Tsunamis (including United States Possessions) 1690–1988* (1989) in which we acknowledged the value of the earlier catalogs of Kumizi Iida, Doak C. Cox and George Pararas-Carayannis, *Preliminary Catalog of Tsunamis Occurring in the Pacific Ocean* (1967); S.L. Soloviev, and Ch. N. Go, *A Catalogue of Tsunamis on the Eastern Shore of the Pacific* (1975) and *A Catalogue of Tsunamis on the Western Shore of the Pacific Ocean* (1974); S.L. Soloviev, Ch.N. Go, and Kh.S. Kim, *Catalog of Tsunamis in the Pacific, 1969–1982* (1992 English Edition); Doak C. Cox and George Pararas-Caryannis, *Catalog of Tsunamis in Alaska* (1976; revisions by Jeffrey P. Calebaugh).

In addition to the earlier catalogs, it is appropriate to acknowledge the many papers in the eight volumes of the National Academy of Sciences Committee on the Alaskan Earthquake, *The Great Alaskan Earthquake of 1964* (1970–1972), the Coast and Geodetic Survey's three volume *The Prince William Sound, Alaska, Earthquake of 1964 and Aftershocks* edited by Fergus J. Wood (1966-1969), and the report of Basil W. Wilson and Alf Tørum, *The Tsunami of the Alaskan Earthquake, 1964: Engineering Evaluations* (1968), for the vast amount of data on the most destructive tsunami to have affected Alaska. I also acknowledge the loan of the unpublished manuscript of John N. Davies and Jerome B. Kisslinger for Alaskan earthquakes prior to 1880. Also Joy Griffin and David Swarthout lent me manuscripts related to tsunamis from their book *Alaska Earthquake 1964: Where Were You?* There are too many scientific papers to mention individually but these are acknowledged at the appropriate places in the text and in the References.

Katherine Arndt of the University of Alaska in Fairbanks researched and translated many of the earlier documents from the Records of the Orthodox Church in America and the Records of the Russian American Company 1802–1867. She also prepared most of the history of Alaskan settlements for the Russian period.

The original marigrams are archived by the NOAA National Ocean Survey and these were made available through Stephen Gill, chief of the NOS Product and Services Branch and by James Hubbard, Chief of the Datums Section and their staff, notably William Cherry and Raymond Smith. Prof. Harold Loomis, formerly with the University of Hawaii, was responsible for overseeing the digitization of the marigrams.

Marianne Johnson, Director of the Baranov Museum at Kodiak, and Joe Leahy of the Valdez Museum generously made their collections available for me to examine.

There are many individuals who have given of their time and expertise to answer questions. Especially helpful were the librarians at the State Library at Juneau, Alaska, the librarians at NOAA and the University of Colorado, and the librarians at the Z.T. Loussan Library in Anchorage.

James F. Lander
September 1996

1.0 Introduction

1.1 Purpose

This catalog describes all known tsunamis that have affected Alaska in historic time. A thorough understanding of past tsunamis is essential to designing an effective mitigation plan. Although *United States Tsunamis (Including United States Possessions), 1690-1988* (Lander and Lockridge, 1989) included a section on Alaskan tsunamis, the overall task was too large to allow extensive research beyond previously published catalogs. The preparation of *Tsunamis Affecting the West Coast of the United States, 1806-1992* (Lander, Lockridge, and Kozuch, 1993) expanded the earlier catalog for the west coast section and demonstrated that extensive new information could be found if a detailed search was made. This catalog continues the research into Alaskan tsunamis. It has resulted in significant improvements in the numbers of tsunamis cataloged and the details of their effects.

Alaska has a complex tsunami history due to the varied tectonic regimes, its history of colonization by the Russians and Americans, and its geography of many isolated bays and islands. It is the one area of the United States which produces tsunamis capable of causing damage at far removed locations in the Pacific, including those most destructive to Hawaii and the United States west coast. Alaska has a history of frequent and huge waves generated by submarine and subaerial landslides related to glaciation. It has more local tsunamis than any other location in the United States and has had at least one damaging tsunami generated by an active volcano. Due to Alaska's low population density in many geographic areas, the history is probably less complete than other areas in the United States, making a thorough search of the literature all the more important.

1.2 Definition of Tsunami

Tsunamis are traveling gravity waves in water generated by a sudden vertical displacement of the water surface. As gravity waves, these waves travel with velocities dependent on the water depth. The term is a Japanese word pronounced by starting to voice a "t" and switching to "su-na-mi." In English the initial "t" is usually ignored with little affect on the pronunciation. This term is now preferred in the scientific realm, replacing "seismic sea waves"—a cumbersome phrase that has etymological problems. Not all tsunamis are caused by seismic disturbances (earthquakes). Also, some reseachers believe that this term may be confused with seismic signals transmitted through the ocean water column as seaquakes. A seaquake is the shaking felt on ships in the epicentral area of submarine earthquakes much as earthquakes are felt on land, or with a T-phase, the seismic energy transmitted great distances in the ocean's low-velocity acoustic channel, SOFAR (the sound fixing and ranging channel).

Tsunamis are most often incorrectly referred to as "tidal waves" by the general public. This term implies a relation with astronomically-generated tides. Tsunamis often do appear as rapidly changing "tides" and their effects are modified by the state of the tides. However, as phenomena they are not related to tides. The tides are essentially governed by the gravitational attraction of the sun and moon.

Even the Japanese term *tsunami* is not without etymological problems. It literally means "harbor wave" and is used in Japan to include both the impulsively-generated gravitational wave *and* storm surges, the elevated sea level associated with hurricanes and typhoons.

Although tsunamis are sometimes confused with storm waves and storm surges, storm surges are the up-welling of the water surfaces under the extreme low pressures in the eye of a hurricane or typhoon, causing flooding when they come ashore. Storm waves are generated by strong winds operating over a long stretch of water (fetch) over time. They are surfacial and depend on the wind for their height and velocity. They may reach shore after the winds have stopped blowing and become confused with true tsunamis but are of much shorter periods. Storm waves may excite natural periods of water bodies such as harbors and coasts with longer periods and be mistaken for tsunamis.

"Tsunami" was used in Western literature in the first half of the 20th Century to refer to meteorologically-induced waves as well as impulsively-generated gravity waves. *The term is now limited* to describing a single natural phenomenon—a traveling gravity wave (in water) that was impulsively generated. Typically these are generated by sudden uplift or depression of the water surface by: (1) an uplift or drop of a large area of the ocean floor or the thrusting of a subducting plate into the oceanic trench caused by a large earthquake; (2) a land fall into a body of water or movement of material on the bottom by submarine landslides; or, (3) by several volcanic processes such as crater collapse under water, mass flows into the water, explosions, etc. The water, once displaced up or down, will move to regain its equilibrium. Once set in motion it may continue to move perhaps as far as to the opposite side of the ocean.

There is nothing in the definition of a tsunami about size. Large breaking waves popularized by the famous Hokusai picture (Figure 1) are rare and almost unheard of outside of the generating area. The Hokusai painting is almost a logo for tsunamis but is just an artist's interpretation and probably based on meteorological waves. Most tsunamis, like most earthquakes, are small and detected only by instruments.

Figure 1. Detail from the wood block print by Hokusai Kasushika (1760–1849).

Usually the waves are observed on shore as a relatively rapid rise and fall of the "tide," or as surges with periods from between six to sixty or more minutes. In river channels they appear as bores, a wall of water from several inches to several feet high moving against the current. In harbors and harbor entrances they may appear as swift currents and eddies. The outgoing wave is likely to be stronger than the incoming wave, setting up currents that may scour around bridge and pier supports.

The misconception that tsunamis are large, breaking waves leads to a communication problem between scientists, officials, and the public. As recently as April 28, 1992, the *Crescent City Triplicate*, which, because of its history with severe tsunamis would be expected to be more than usually well-informed, reported that "tides in Crescent City Harbor fluctuated two to four feet—but no tsunami was generated." The same misconception has appeared with most observed tsunamis since 1946, even by government sources such as the United States Coast Guard.

1.3 Other Definitions

1.3.1 Seiche. Pronounced "say-sh," this phenomenon is closely related to tsunamis but is a standing wave rather than a traveling wave. It is the "sloshing" as with water in a basin; these have periods depending on the length and depth of the body of water (Figure 2). They oscillate about fixed points called nodes.

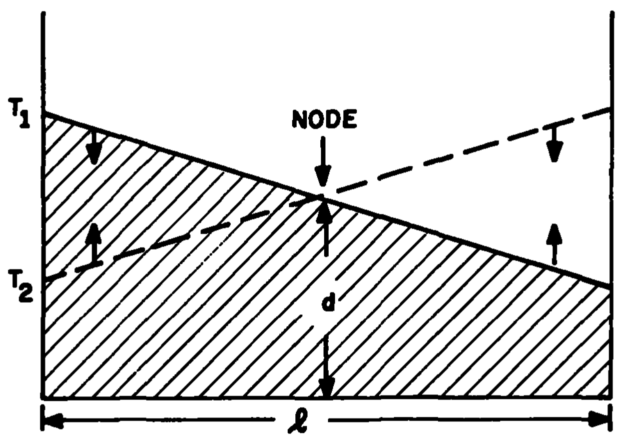


Figure 2. Model of seiche.

In nature, seiche can be generated by wind, water waves, and by seismic waves that impart energy to standing bodies of enclosed or partially enclosed water. If the periods of the forcing source approximate one of the natural periods of the body of water, it will begin to resonate.

The body of water can be a bay or harbor or a basin such as that formed by Channel Islands and the southern coast of California. Seiche are also formed in the shelf water with a node at the break of the continental slope. Tsunamis, as water waves, also generate seiche. Much of what is recorded on the marigram after the initial waves are really seiche.

The term was widely misused in descriptions of the 1964 Alaska event. Local landslide-generated tsunamis were mistakenly referred to as seiche. It may be impossible to generate seiche from seismic waves in the source region due to the short period of time available for developing resonance and the undispersed, mixed frequencies of the seismic waves that exist in the epicentral region.

1.3.2 Tsunami Magnitude. This is an attempt to characterize the strength of the tsunami based on the maximum wave amplitude at the source (Iida, 1963) or an average of amplitudes in the source region (Soloviev and Go, 1974). The tsunami magnitude (m_t) is given by:

$$m_t = \text{Log}_2 \bullet H$$

where "H" is the maximum height reached in meters (Iida, 1963).

1.3.3 Tsunami Intensity. Since the maximum height is really a measure of intensity, Soloviev and Go's (1974) tsunami intensity for the source area, I_o, is similar to the tsunami magnitude and is given by:

$$I_o = \text{Log}_2 (\sqrt{2 \bullet H})$$

where "H" is the average height in the source area. These systems have several problems. They allow for negative magnitudes, a confusing concept for non-professionals and a minor problem for catalogers. These values are low with respect to the well-known earthquake magnitude scale. A tsunami magnitude of "5" does not convey a sense of great size in the public mind as a magnitude "8" does for earthquakes.

The variability of wave heights along the coast and the directionality of the waves to remote coasts are problems for determining a measure of their total energy implicit in a magnitude. Local tsunamis in semi-enclosed bays may have great heights such as in Lituya Bay (Alaska) in 1958 (1,725 ft. surge) but are confined to a small area.

Table 1. Tsunami Magnitude and Height Relationship

Magnitude (Mt)	Height (H)	
	meters	feet
-2 to -1	<0.30 to 0.75	<1.0 to 2.5
-1 to 0	0.75 to 1.50	2.5 to 4.9
0 to 1	1.50 to 3.00	4.9 to 9.9
1 to 2	3.00 to 6.00	9.9 to 19.7
2 to 3	6.00 to 12.00	19.7 to 34.2
3 to 4	12.00 to 24.00	34.2 to 79.0
4 to 5	24.00 to >32.00	79.0 to >105.0

1.3.4 Teletsunami. This is the preferred term for tsunamis observed at places 1,000 kilometers from their source.

1.3.5 Amplitude. There are several measures of the wave size in use. This volume uses amplitude in the physical sense to be the rise above or drop below the water level. Often it is determined as one-half the total observed rise or fall (wave height). A close reading of reports of directly-observed waves will usually resolve whether they are reporting an amplitude or height. Estimates of the size of an approaching wave are more closely related to the height while descriptions of an initial rise or fall of the water level are more closely related to the amplitude.

The wave height is the more commonly-reported value in the literature although it is sometimes misidentified as "amplitude." The wave height relates more directly to the potential for generating currents, and the amplitude more directly to runup and flooding.

In this publication the amplitude is given in feet for local observations as this is the most common unit in the original reports and the unit still in predominant use in the region. Meters are used for reports of amplitudes for foreign source regions as it is the internationally used unit. Table 14 and Table 15 (pages 117–141) use only meters.

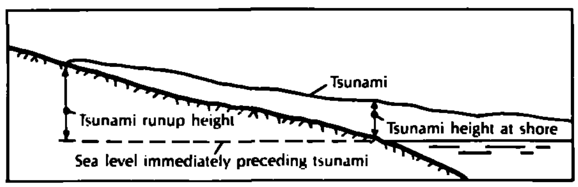


Figure 3. Illustration of runup height (modified from Steinbrugge, 1982, p. 233).

1.3.6 Runup. This is the measure of the height of the tsunami at the point of maximum penetration above the state of the tide at the time. This is differentiated from the maximum water level, which is the greatest height reached by the tsunami above the state of the tide at the time. In the literature there is considerable confusion with respect to the datum used such as the mean lower low water (MLLW), sea level, or sea level at the time of the wave. It usually is greater than the instrumental amplitude due to the damping inherent in the instrumental responses and may include some surging (Figure 3). Also, the tide gage is probably not positioned to be at the place of maximum runup. In the source region there may be tectonic uplift of subsidence occurring immediately with the earthquake. This complicates the measurement of the runup.

The MLLW datum is frequently used as it is the reference for coastal maps. Surveys done after the tsunami may report debris or water lines referenced to MLLW and it may be impossible to determine the tide at the time the deposit was made. Frequently, the maximum runup will be a wave that arrived near high tide.

1.3.7 Period. This is the time between two successive crests or troughs. When available, the period is of the first cycle or largest wave and is given in minutes. The initial period is most representative of the source, with longer periods up to sixty or more minutes associated with great tsunamis and short periods with small local tsunamis. The period of the largest wave allows for the calculation of the maximum currents expected. The period is one of the identifying characteristics of tsunamis. A tsunami period is intermediate between the periods of high frequency storm waves and the twelve-hour tidal period.

1.3.8 Date and Time. Local time units are used except for the initial date and time of teleseismic events. The GMT date may be one day ahead of the local date since usually 10 hours must be added to the local time to get GMT time. The local time is important as a factor in evaluating effects and responses and is the time reported by local observers. For early reports, before the 1884 convention adopting standard zones of about fifteen degrees per hour, the times were given in sun time.

Greenwich time can be calculated by dividing the degrees and decimal degree equivalents of the minutes and seconds of the longitude for a location by 15 for the whole hour and multiplying the decimal remainder by 60 for minutes and fractions of a minute and adding to the local time for west longitude. Thus, Kodiak at

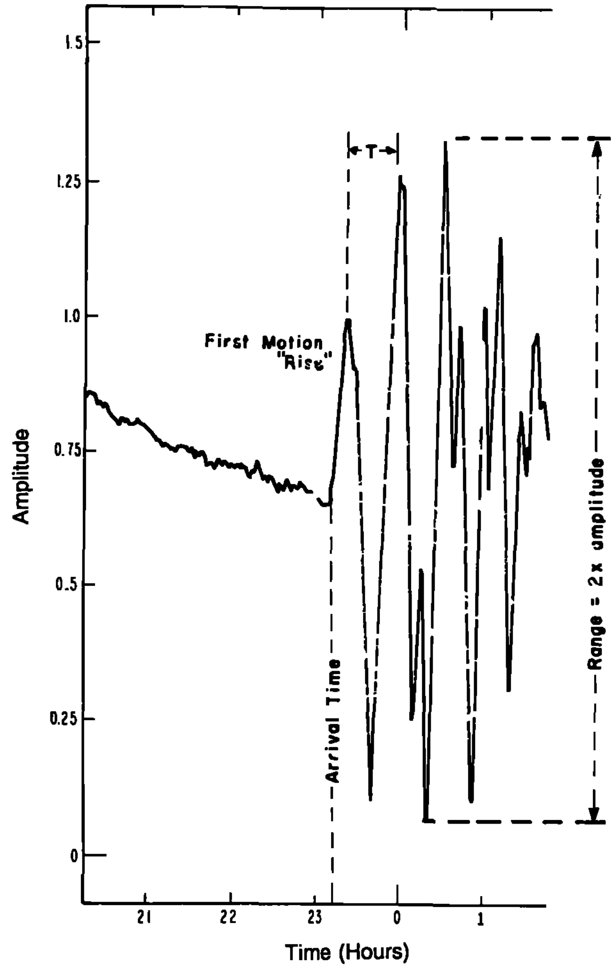


Figure 4. Marigram illustrating arrival time, first motion, period, range, and amplitude.

152°31.2" W (152.537°W), 12 noon sun time, would be 22 hours and 10 minutes Greenwich time. The time at Yakutat (139.75°W) would be 21 hours and 19 minutes or 51 minutes ahead of Kodiak time. This becomes important only when comparing times between the two localities or in calculating travel times between the source and point of observation when sun time is given. Time on the original marigrams is local time and for the early records this is sun time. In the 20th Century, the records may have local time one hour ahead of standard time due to periods of "war time" and summer daylight savings time.

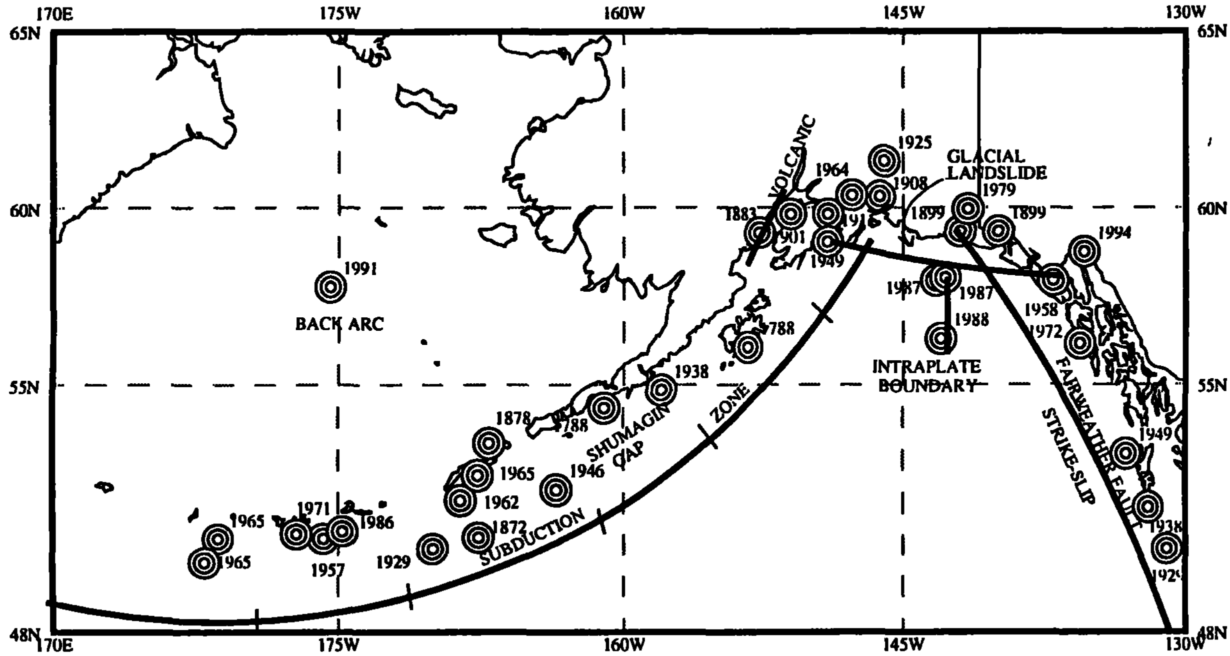


Figure 5. Areas of occurrence for different types of tsunamis.

1.3.9 Arrival Time. This is the time of the arrival of the first wave of the tsunami at the location of the effects given in day, hour, and minutes. This is local time in the descriptive text and Greenwich time in the tables in order to facilitate calculation of travel times and comparison with other localities.

1.3.10 Travel Time. This is the time in hours and tenths of hours that it took the tsunami to travel from the source to the location of effects. Usually this is based on the origin time of the earthquake which may be a few minutes earlier than the origin time of the tsunami if the tsunami was generated in the trench.

1.4 Tsunami Characteristics

Tsunami characteristics will vary with the type of source. In Alaska there are an unusual number of source regimes. Figure 5 shows the location of these regimes and the location of the source of local tsunamis. All of the great tsunamis affecting the Pacific Basin are associated with subduction zones and are probably generated by thrusting into the trench by the over-riding continental plate (Figure 6). Such tsunamis may have source regions of 500 miles in length. Once a displacement has occurred, the water acts under gravity to regain its equipotential. The outflow has a velocity (v) which is proportional to depth of the water (d) and the gravitational constant (g) such that:

$$v=\sqrt{gd}$$

In 21,660 foot deep water and gravity at a constant of 32 feet/sec^2 the wave will be traveling at a speed of 568 miles/hr. Once generated, tsunamis can travel for great distances. Although the speed may exceed 500 miles per hour in the deep ocean, tsunamis may travel for hours or more than a day before striking the distant shore. The May 28, 1960, Chile tsunami reached Attu, 9,167 miles away, after traveling 20 hours and 19 minutes.

As the wave reaches the coast the velocity decreases since it is a function of the water depth. This causes the wave to increase greatly in height.

This fact is the justification for evacuation of boats to deeper water where waves are lower—a good strategy if there is enough time to clear the harbor. For locally-generated waves from a subduction source this may be as little as 15 to 30 minutes warning, depending on the distance to the trench.

Tsunamis are strongly directional in their propagation away from the source. For tsunamis generated by great earthquakes, the source region may be several hundred miles long parallel to the coast and some tens of miles wide. The tsunami's energy is directed both toward the adjacent coast and in the opposite direction.

A consequence of the directionality is that the adjacent coast suffers the greatest effect. The effect may decrease quickly away from the epicentral area to either side but areas diametrically opposite the epicentral area may also suffer damage even at great distances.

Those far-ranging waves, called teletsunamis, may be steered by variations in depth (including submarine ridges) and focussed by convergence due to the spherical great circle paths the waves follow. Thus, waves generated by major earthquakes along the Alaska Peninsula (such as the 1964 event) are aimed directly at the west coast of the United States. Tsunamis generated along the southern Mexico coast are aimed toward the sparsely inhabited South Pacific and away from populated areas.

Saint Augustine Volcano in Cook Inlet has caused one destructive tsunami but because of the shallow water in Cook Inlet, the waves may take an hour to reach the opposite coast, and signs of volcanic activity may provide an alert days in advance.

The region including Prince William Sound and extending to Skagway and the Lynn Canal are subject to huge subaerial and submarine landslide tsunamis due to the glacial topography of steep-sided and deep fjords, and moraine deltas. These can occur in multiple events triggered by a single large earthquake (e.g., the 1964 event was associated with about twenty separate landslide tsunamis) or occur without any earthquake (e.g., the 1994 Skagway event). These waves can arrive within several minutes of the triggering and many are 100 feet high or higher.

Submarine events are more likely to occur during times of low tide as there is more of the water-soaked delta above the supporting water. Loading of the delta in terms of structures, equipment, storage tanks, etc., also may increase the likelihood of a failure. The short lead time and high amplitudes make it impossible to effectively communicate warnings. People must know that if they are near the shore and an earthquake occurs they should immediately leave

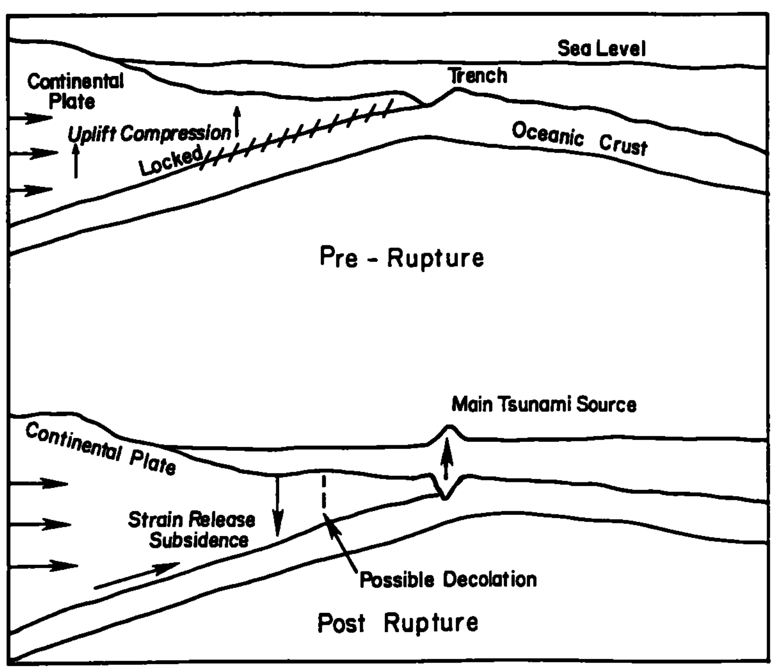


Figure 6. Schematic illustrating possible source of subduction zone tsunamis.

for higher ground. Although the waves can be disastrous within the source bay and in fact account for most of the tsunami fatalities in Alaska, they do not effect areas beyond the bay of origin.

Another form of landslide tsunamis occurs in deep lakes in glaciated valleys. These are caused by delta collapses from swift flowing streams and are similar to the landslide tsunamis in glaciated bays.

Southeastern Alaska has a history of only minor tsunamis associated with riverine delta collapses and slumps in lake sediments. There have been many cable breaks due to submarine slumping, but even though waves from them were expected they were rarely observed or reported.

Normal faulting produced uplift of forty feet at Disenchantment Bay, but because the bay is relatively narrow compared with Yakutat Bay, the wave it produced was not high at Yakutat. There are areas of submarine earthquakes behind the Aleutian arc and at the east end of the subduction zone at the Yakataga Gap. These have been minor and only observed instrumentally or as minor waves at Yakutat.

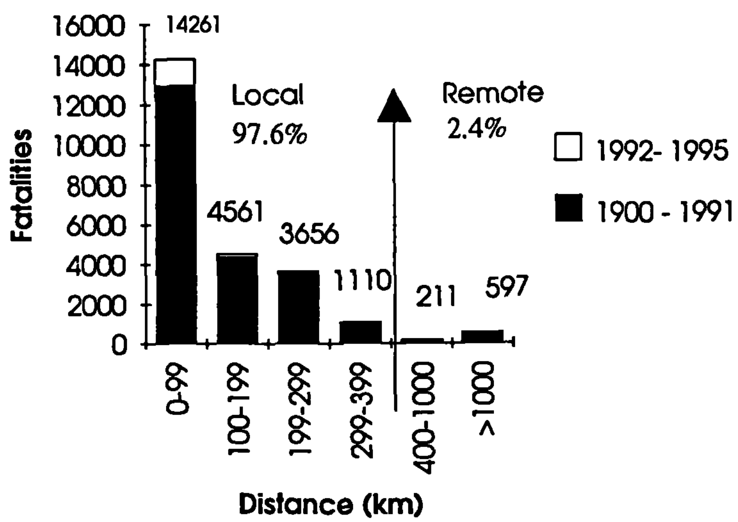


Figure 7. Fatalities caused by tsunamis in the Pacific Ocean (1900–1995) as a function of distance from the source.

The severity of the effects close to the source can be seen in Figure 7. Most fatalities occur within 250 miles (400 km) of the source of the tsunami. This includes all of the fatalities in Alaska from tsunamis.

The wavelength, (λ), the distance successive between peaks or troughs, is given by

$$\lambda = v \cdot t$$

where v is the wave velocity and t is the period. The initial period is believed to be related to the size of the original displacement and usually is between 15 minutes and one hour for subduction source tsunamis and shorter for landslide events. Thus, the wavelength would be 100 miles for a wave with a velocity of 200 miles/hour and a period of 0.5 hours (30 minutes). In the open ocean the wave's long wavelength and low amplitude make it invisible to the human observer but it is now detectable by sensitive ocean bottom pressure gages. Thus, knowing the depth of the ocean, it is possible to calculate the travel time of the wave between any two points.

Figures 81 to 88 (pages 160–167) give the travel time charts for: Adak (Sweeper Cove); Attu (Massacre Bay); Cold Bay; Kodiak (Womens Bay); Seward; Sitka; Unalaska (Dutch Harbor); and Yakutat. These maps can be used to compute the expected arrival times of tsunamis from distant origins if the earthquake epicenter and origin time are known. Approximate arrival times at other localities can be determined by interpolation between expected arrival times at mapped locations.

The first wave is not usually the largest for tectonic tsunamis. At Kodiak during the 1964 tsunami the first wave was about 11 feet at the Naval Air Station and the fifth wave was about 25 feet at high tide.

The effect of the tide is also an important factor. A smaller wave coming at high tide may have a larger runup than a larger wave at low tide. Waves arriving at high tide can cause more flooding damage, but initial waves arriving at low tide can also be dangerous, particularly where people engage in clamming and bottom fishing. Landslide tsunamis usually have only two or three large waves followed possibly by smaller seiche.

Many marinas and harbors are not designed for the currents which can be set up by the 15 to 30 minute period waves. Tides with 12-hour periods produce much lower currents. Storm waves with periods of less than a minute do not have time for the mass movements of water to set up strong currents.

Later arriving tsunami waves are more complicated. The earlier waves may set up resonances of several natural periods of the harbor or resonances between the coast and the continental slope. The sudden increase in tsunami velocity beyond the continental slope acts as a boundary and reflects the waves back. Waves with different periods may periodically coincide and reinforce each other.

There is nothing in the definition of a tsunami to restrict them to oceanic areas. Landslides into bays, lakes and reservoirs set up an identical phenomenon. Their effects are usually limited to the immediate area. Tsunamis were generated in Kenai Lake during the 1964 earthquake, Manzanita Lake, Revillagigedo Island in 1949, Redoubt Lake, Baranof Island in 1880, and Avoss Lake, Baranof Island, in 1972. Clues for a submarine landslide source for a tsunami include loss of material from deltas or fjord sides, waves arriving within several minutes of earthquake-shaking onset, seeing the water flow out and forming a mound, broken submarine cables, and the disappearance of sandy spits.

The hazard from a tsunami may last many hours. All of the 25 fatalities caused by the main tectonic tsunami in 1964 occurred after the initial wave and the people knew that a tsunami was in progress. They were trying to get from one safe place to another, save boats, or clean up debris.

1.5 Occurrence

Most tsunamis are generated in the near-shore areas of lands bordering the Pacific. Earthquakes and volcanoes are common in the great "Ring of Fire" stretching along the coast of the Americas from Chile to Asia, southward from Siberia through Japan, and the Philippines to New Zealand. This "ring" marks the subduction of Pacific Ocean plate boundaries under the continental land masses.

Tsunamis also occur in the Indian Ocean, particularly in Indonesia; in the Mediterranean and Caribbean Seas; and rarely, in the Atlantic Ocean.

In Alaska there are two distinct tectonic regimes: (1) the subduction zone of the Aleutians (including the Prince William Sound) that produces Pacific basin-wide tsunamis, and (2) the strike slip faulting of the Fairweather fault, a similar system to the San Andres further to the south, which produces great local landslide tsunamis.

Figure 8 (next page) shows the distribution of tsunamis and damaging tsunamis per decade. Tsunamis are relatively rare phenomena even in the Pacific Ocean basin where one per year is observed (on the average) and only one per decade causes substantial damage in locations around the Pacific Ocean. Tsunamis are even more rare on any segment of the basin margin; only about 2 per decade have occurred in Alaska.

However, with the growing settlement and development of the coastal areas it is important to have a long tsunami history in order to evaluate the tsunami hazard.

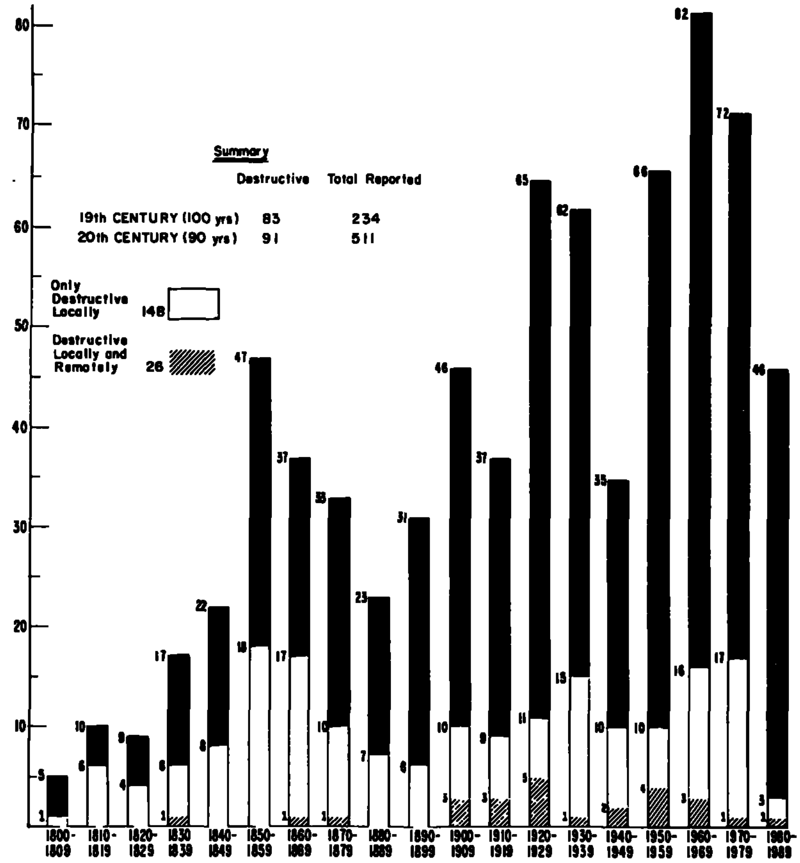


Figure 8. Total number of tsunamis per decade, 1800–1989. The increase following 1850 probably reflects beginning use of tide gages. Drops during the 1910 and 1940 decades probably reflect decreased reporting during war years.

Figure 9 (next page) shows the frequency of tsunamis affecting Alaska by decade. Note that the history essentially begins with the 1850s and that the damage is associated only with local events.

1.6 Warning Considerations

Teletsunamis—those with source regions more than 1000 kilometers from Alaska—historically have not been a hazard in Alaska. The reported wave heights of 40 to 50 feet generated by the 1737 Kuril tsunami in Amchitka, and the heights of the great Chilean tsunami of 1960 (which produced waves of 5.5 feet at Attu and caused some minor damage in southeastern Alaska) are sufficient to remain alert to the possibility of a future damaging teletsunami. Teletsunamis, since they originate at some distance, allow the time to locate the source earthquake, and issue warnings. As a rule they are generated only by energetic sources such as major earthquakes that can be detected soon after occurrence.

If the tsunami-generating earthquake can be located quickly, remote sites can be warned of the possibility of a wave being generated. Report of wave effects near the source can confirm the generation of a tsunami and there is time for warning and evasive action. Ships can leave for deep water where the tsunamis are harmless. Warning can be given to coastal inhabitants, workers, and visitors for evacuation to higher ground.

These mitigation possibilities led to the establishment of the Seismic Seawave Warning Center, now the Pacific Tsunami Warning Center, in 1948. The Alaskan Tsunami Warning Center in Palmer, Alaska, was established following the 1964 disaster. Unfortunately, even today (1996) it is not possible to predict with high precision or certainty the height of an expected wave. It should be possible to estimate the range of amplitudes to be expected, reducing the "false alarm" rate for warnings for true tsunamis that are not threatening.

Since most tsunamis are small, there is a high percentage of "false alarms." This is costly in terms of man hours of emergency personnel, business down time, and evacuation expenses (especially for large ships). This also results in inappropriate action such as refusal to evacuate, returning to closed businesses to move stock or records, or just gathering at the shore with hope of seeing this rare phenomenon.

Using historical accounts of earlier tsunamis (such as this publication) and mathematical models, it should be possible to predict at least rough classifications of tsunami wave heights from a given source region, for given localities. This would be a most useful addition to the warning.

Local tsunamis—those adjacent to the generating area or generated by less energetic sources such as volcanoes or landslides—need to be treated separately as the effects may be quite severe locally but affect only a limited area. They may reach the coast in a few minutes, leaving little time for reaction. The prudent action is to leave a coastal area for higher ground immediately after feeling an earthquake. It is nature's warning. Similarly, if the water is seen to withdraw or to rise rapidly one should immediately seek higher ground. The returning wave or following waves could be much larger.

In 1958, a collapse of a fjord wall in Lituya Bay sent a surge of water up the other side, clearing trees to a height of 1,725 feet and sending a 100+ foot tsunami down the bay. It was barely recorded at Hawaii. Since each locale has unique wave characteristics, effects, and reaction times, each must be studied separately.

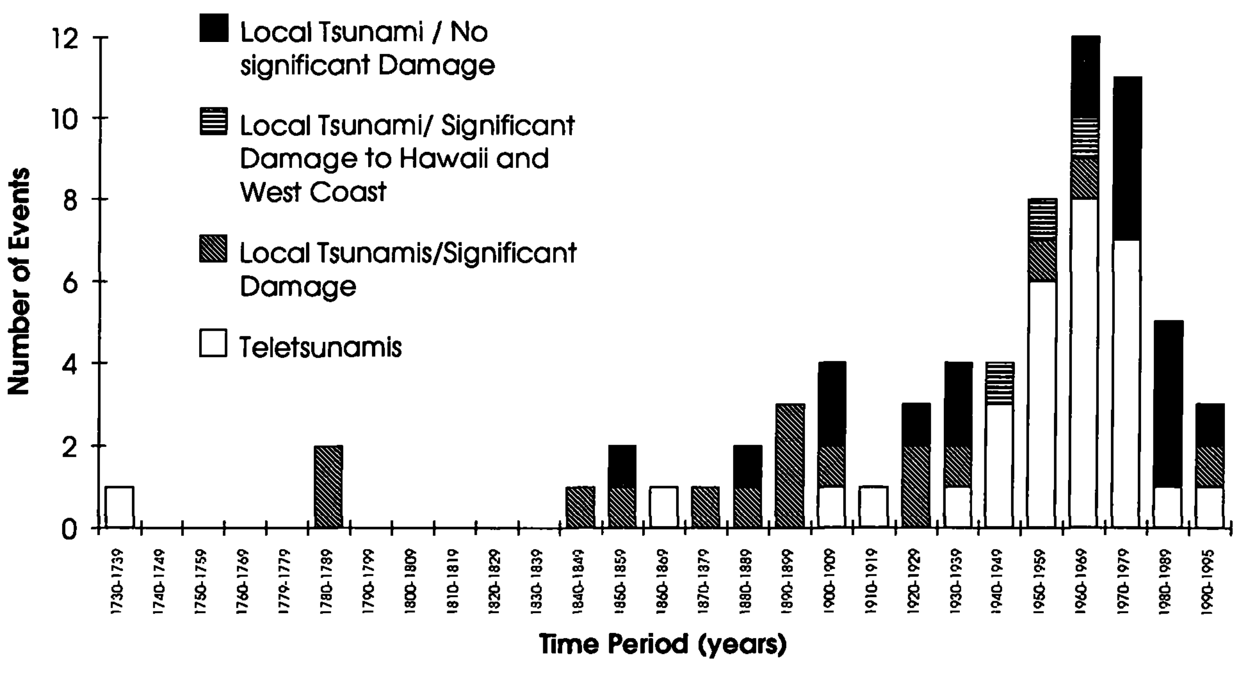


Figure 9. Number of Alaska tsunami events per decade.

1.7 The Tsunami Validity Scale

Reports of tsunamis and their effects may be more or less accurate. Errors may be introduced in later histories by simple transcription errors. Rewording of original reports also changes the interpretation. For example the March 21, 1825, event reported by Veniaminov (1984 translation) described volcanic eruptions including:

> On this occasion the ice and snow lying on the range melted and for several days flowed as a dreadful river, 5 to 10 versts wide [3.3 to 6.6 miles]. These waters poured over the eastern side of the island in such quantity that the nearby sea remained muddy until late autumn.

Perry (1865), an early cataloger, transcribed the passage as:

> The volcano disgorged flames, ashes and streams of water, mixed with rubble, which inundated the southern coast of the island for a distance of 4 km. The outpouring did not last long but the sea was still agitated even into the following fall.

Soloviev (1984) picked this up and listed it as a tsunami; this was continued in Lander and Lockridge (1989). The original description clearly describes a lahar—a debris flow—and not a tsunami. This report can now be given a validity of 0.

There are several phenomena that may be confused with tsunamis, including local storm waves, earthquake-induced seiche, remote storm-generated waves, high astronomic tides, and meteorologic microbursts.

To quantify this uncertainty, a validity scale has been devised (Soloviev and Go, 1974; Cox and Morgan, 1977). The continuum from almost certainly not a valid tsunami report (validity 0) to almost certainly a valid tsunami report (validity 4) is divided into five steps:

0 Not a valid tsunami report
1 Probably not a valid report
2 Possibly a valid report
3 Probably a valid report
4 Certainly a valid report

The criteria for assigning a validity are not fixed. Some factors include:

Validity 0: Date is proven to be in error; source of water disturbance is known to be from a meteorological or an astronomic tide source; reported tsunami effects shown to be in error in later documents which are based on primary references.

Validity 1: Duration of disturbance over several days without reports from distance locations; lack of clear report of wave activity (i.e., water "disturbed" or "shipping affected"); probable source not tsunamigenic; reports of winds, and/or waves at sea.

Validity 2: Insufficient information, single non-expert observation, descriptions not clear (i.e. shipping rolled, water agitated); source uncertain.

Validity 3: Reports associated with probable seismic or other cause; descriptions from several independent sources; descriptions of waves in the 10-30 minute period range.

Validity 4: Well-known source; well-recorded at more than one tide gage with a clear arrival at expected travel time, and/or observed at widely separated places. 100% valid.

In general, reports with validity 0 and 1 can be ignored for tsunami evaluations. They are included here so that it will be known that they were examined. Validity 2 can also be ignored unless the event is critical to the particular study where additional research may be needed. Validity 3 and 4 reports can be used with a fair degree of confidence although even those with a validity 3 may need a critical reevaluation if they are key to a study. These validities are based on the author's judgment of the available reports but other reports may be discovered or other evaluators may come to a different conclusion.

In this report the validity is for the material reviewed and referenced. The validity is usually for the tsunami event but occasionally the validity may be an evaluation of the authenticity of tsunami occurrence at a given location. A known tsunami in Japan with validity 4, for example, may have a spurious report (validity 0) of effects in Alaska but this will be clear in the text.

1.8 Methodology

This compilation is based principally on the events identified in Lander and Lockridge (1989) which were based on earlier catalogs and regional studies, notably Soloviev and Go (1974) and Cox and Pararas-Carayannis (1976). From this list each event was researched for its earliest reference. This process occasionally led to new events—1737, 1788, 1826, 1865, 1866, 1897, 1900, 1906, 1903, 1918, 1927, 1933, and 1949—but a general search for new events was not undertaken.

Also, while a number of analytic studies are referenced, there are many others relevant to the study of tsunamis such as inundation modeling, coastal and harbor resonance, geology, tectonics, wave effects, submarine land sliding modeling, etc., which were not consulted. The objective of this study was to collect reports of tsunami observations and effects and to evaluate them for validity.

Additional reports were sought from contemporary sources, principally newspapers and marigrams. Original marigrams were examined at the National Ocean Survey's archive. This led to the location of several significant new records, including those for the 1872 Fox Island event, the 1883 Saint Augustine event, and for several new teletsunamis.

For the Russian period, Katherine Arndt of the University of Alaska at Fairbanks read microfilmed copies of documents from the Russian Orthodox Church and the Russian-American Company.

Russian dates were recorded using the Julian calendar. These dates were 11 days behind the Gregorian calendar, in use in the West during the 18th Century. In 19th Century records, the Julian dates were 12 days behind.

Additionally, the Russians in Alaska were using the same dates as were being used in Russia. The International Date Line Convention had not yet been established. This makes the calendars 10 and 11 days behind the dates in use in the rest of the Americas and western Europe.

The dates given in this publication are Gregorian, with a ten day correction from the Julian for the 18th Century and 11 days for the 19th Century. This will match any reports that may be found from the west coast or South America and may be used to calculate the tides retrospectively. Many of the earlier catalogs do not take this fact into account and the dates given may be a day later than those used here.

Many Alaskan communities have local historical museums—Kodiak, Homer, Seward, Whittier, Sitka, and Valdez were visited. Records from the city files were used for the 1964 event and long time residents were interviewed for this event and earlier tsunamis. Newspaper articles were also examined. (Note: Newspaper references are given at the appropriate places in the text and are deemed complete enough not to be repeated in the References. Other citations are carried in full in the References, page 169.)

The substantive part of this report starts with Section 3.0 (page 19) which addresses local tsunamis of tectonic, volcanic and landslide sources, and teletsunamis. This section also reports cable breaks with a list of events, a brief description of effects for significant events, and general conclusions. A complete description of each event can be found in the Description of Tsunami Events (Section 4.0, page 33) which lists all events in chronological order.

Section 5.0 (page 117) summarizes all of the events in tabular form listing the date, validity, source, and effects at each locality. Marigrams are displayed in Section 6.0, and Section 7.0 provides travel time charts that have been published for Alaska.

City, towns, and other place names are indexed following the References. This allows a user to find mention of specific localities in the text.

Damage values are for the dates of the event and not corrected to a common date.

2.0 History and Tectonics

2.1 History of Settlements

The European exploration of Alaska is generally considered to have commenced in 1741, when a Russian naval expedition commanded by Vitus Bering and Alexei Chirikov sighted the shores of southeastern Alaska, the Gulf of Alaska, and the Aleutian Islands and added them to the rudimentary charts of the North Pacific. Within four years, Russian fur hunters and traders had begun to visit the westernmost Aleutians, and by the 1760s they had reached as far east as the Alaska Peninsula and Kodiak Island.

The intensity of Russian contact with any particular island or island group varied with the intensity of hunting and trading in its vicinity. As the focus of the hunt shifted ever eastward, the more westerly islands were visited less frequently, and by smaller parties, than in the initial years.

The earliest of the hunter-traders spent only a season in the Aleutians before returning to their home ports, but by the mid-1750s multi-year voyages were common. The voyagers would anchor their vessels in safe harbors, split up into small work groups, and disperse to temporary coastal base camps for a season or longer. Favored sites were repeatedly reoccupied, and by the mid-1770s the one at Iliuliuk, on Unalaska Island, was for all appearances a permanent Russian settlement.

In addition to the explorations conducted by the hunter-traders as they sought new sources of furs, there were a number of government sponsored exploratory expeditions to the Alaskan coasts in the late 18th Century. The Russians sent two such expeditions. Petr Krenitsyn and Mikhail Levashov explored the Fox and Krenitsyn Islands and spent the winter of 1768–1769 on Unimak and Unalaska Islands. Joseph Billings and Gavriil Sarychev visited Unalaska, Kodiak, and Prince William Sound in 1790 and the Aleutians and islands of the Bering Sea in 1791. The author examined the Sarychev expedition account, hoping that the 1790 expedition date would yield descriptions of effects from the 1788 tsunami. No references to that event were found (Sartyschew [*sic*], 1806).

The British also sent two expeditions. James Cook explored portions of the coast from southeastern Alaska to the eastern Aleutians and north through Bering Strait to Cape Lisburne in 1778. George Vancouver made a detailed survey of the Alexander Archipelago, Cook Inlet, and part of Prince William Sound in 1793–1794. In six expeditions between 1775 and 1792, the Spanish explored portions of the coast from Dixon Entrance to Prince William Sound and Cook Inlet. French activity was limited to explorations in the vicinity of Lituya Bay in 1786 and Sitka Sound in 1791. Tsunamis are not mentioned in these early explorations. However, the texts were not examined in depth for this study.

Narratives of Cook's voyage published in the mid-1780s attracted many foreign traders to the Alaskan sea otter grounds. Primarily British and American in nationality, the traders were particularly active in the waters of southeastern Alaska, but also visited Prince William Sound, the eastern Aleutians, and Kodiak. They rarely wintered in Alaskan waters and established no permanent settlements on shore.

None of these early visits resulted in reports of tsunami observations except that of the Bering expedition's observations of the 1737 tsunami effects on Bering Island. This is not surprising considering the rarity of large tsunamis, the few possible western observers at any one place and time, and their predominate purpose of fur trapping.

The first permanent Russian settlement was established by Grigorii Shelikov at Three Saints Bay, Kodiak Island, in 1784. The settlement experienced a destructive tsunami on July 21, 1785, which resulted in a permanent subsidence of the bay. By 1786, the settlers had a fort on Afognak Island and a foothold in the lower Cook Inlet. The main post was gradually transferred to Pavlovskaya, which today is the city of Kodiak.

From 1787 to 1798 the Lebedev-Lastochkin Company was in competition with Shelikov's company establishing settlements east of Kodiak at Kasilof in 1787, Kenai on the Cook Inlet in 1791, and a fort at Nuchek, Hinchinbrook Island, on the east side of Prince William Sound. Shelikov's company established a shipyard at Resurrection Bay in 1793 and a post at Yakutat during 1795–1796. The Lebedev-Lastochkin Company withdrew from Alaska in 1797–1798. Shelikov's company, which was granted a monopoly for trade and development in Alaska in 1799 as the Russian-American Company, took over the posts at Kenai and Nuchek. The settlement at Kasilof had been abandoned and the one at Resurrection Bay was reduced to a trading post.

In 1799, a settlement was made in Starrigavan Bay on Baranof Island; it was destroyed by a native attack in 1802. It was rebuilt at the present site of Sitka in 1804. The settlement at Yakutat was also destroyed by native attack in 1805 and not re-established by the Russians. In subsequent years, southeastern Alaska was not further settled except at the Ozersk redoubt built at Redoubt Bay on Baranof Island, and a fort built at Saint Dionysius/Stikine (present-day Wrangell) which was occupied from 1834 to 1840 by the Russians and from 1840 to 1849 by the Hudson Bay Company. The Hudson Bay Company built Fort Durham on Taku Inlet (on the Alaska mainland) in 1840 and abandoned it in 1843. The Russian-American Company maintained administrative centers on Unalaska and Atka, and major work stations at Attu, Unga, and in the Pribilof Islands at Saint Paul and Saint George Islands.

Although the Russians were the main European presence in Alaska for a hundred and thirty years, their population stayed around 700. In 1818 there were only 321 Russian settlers in nine settlements and only about 500 by 1867 when the Russian claim was sold to the United States. The Russian settlers were largely repatriated or left for other localities, leaving behind their presence in the Orthodox Church, and Russianized and mixed-race natives. Priests who had followed the early settlements remained and left behind a body of records and writings.

With the American purchase of Alaska and its formal transfer at Sitka on October 18, 1867, the United States military began a 17-year nominal rule. The Russian-American Company holdings were sold to Hutchinson, Kohl and Company which later became the Alaskan Commercial Company, operating in the Pribilof Islands and other areas of Alaska outside of the southeastern area. The United States Coast and Geodetic Survey was among the early Federal Government agencies with a presence in Alaska. The agency prepared navigation maps and installed tide gages at many locations. However, most of these were only operated during a few months in the summer to determine tidal constants.

The first tide station was located at Iliuliuk, Unalaska. It operated during 1871 and in 1872 for four months. A second station was installed at Saint Paul Island in the Pribilof Islands in 1872 and operated until December when ice flows destroyed it. It recorded the August 23, 1872, Fox Island tsunami which had been recorded in Hawaii and on the United States west coast. The event had not been firmly identified and located before the Alaskan marigram record was found.

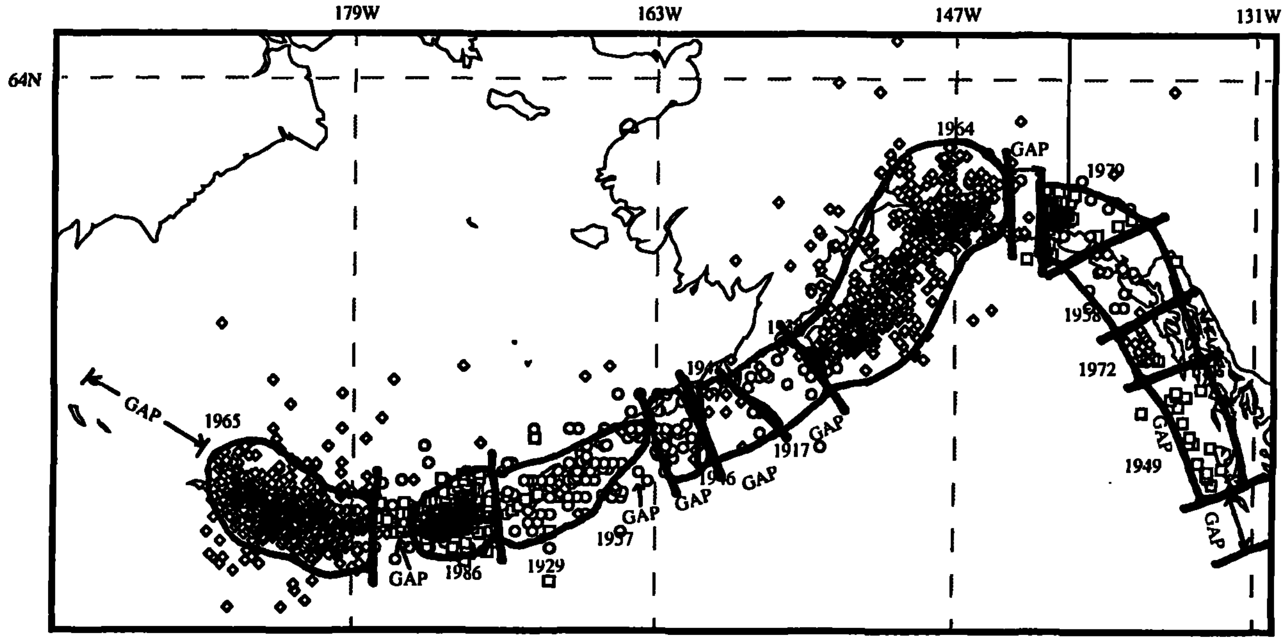


Figure 10. Tectonic blocks of Alaskan earthquake zone in the 20th Century. Dates and enclosed areas are for a main earthquake and aftershocks. Gaps are areas that have not had a major earthquake to release the energy; these are possible sources for future earthquakes and tsunamis. Circles are depths of focus computed to be less than 33 km, squares are earthquakes with focal depths of 33 to 70 km, and diamonds are depths greater than 70 km. Accuracy is not high for most of the period.

Marigraphic stations were operated at Kodiak from 1880 to 1891. These recorded the tsunami associated with the 1883 eruption of Saint Augustine volcano. The Coast and Geodetic Survey operations were also responsible for the descriptions of the effects of the Arica, Peru, tsunami of 1868 at Kodiak, and the description of the effects of the 1874 Lituya Bay tsunami, without realizing the cause of the observed effects.

Fishing, fur trapping, and gold mining were the main attractions for settlement. Prospecting for gold resulted in the building of communities at Juneau and at Skagway. In 1880 there were only 430 Caucasians in Alaska, but this number grew to 8,000 by 1896. By 1930 the population was nearly 60,000—about half native and half non-native.

World War II brought a large influx of residents, and added the military to the major contributors to the economy. There was an increase in the number of seismic stations and marigraphic stations after the war, making the detection of earthquakes and tsunamis more certain. The great earthquake and tsunamis of 1964 resulted in the establishment of the Alaskan Tsunami Warning Center in Palmer, Alaska, in 1967.

Today, the population is concentrated in several larger cities—Anchorage, Fairbanks, and Juneau—which do not have a tsunami hazard. In the highly seismic Aleutian Island chain the population is quite small and the communities are usually located on the north shore as protection from Pacific storms and tsunamis.

2.2 Tectonic Setting

The source for Alaskan tsunamis that can effect the Pacific Basin is the Aleutian Islands arc from Attu Island on the west to the Prince William Sound on the east (Figure 10). It is marked by an oceanic trench, volcanic islands (including approximately 40 with active volcanoes extending into Cook Inlet) and an active zone of earthquakes extending from the trench to behind the island arc, ranging from shallow depth of focus to depths of 170 km. To the east the arc becomes the Alaska Peninsula and finally includes Cook Inlet and Prince William Sound. The arc is divided into about 12 separate tectonic blocks such that a major earthquake is largely confined to a defined block. These blocks are about 300 to 750 kilometers long and have a recurrence rate for large earthquakes about every 100 to more than 200 years.

As the tsunamis from these blocks radiate perpendicular to the arc, tsunamis generated in the western Aleutian Islands may effect Japan and the western Pacific. Tsunamis from the central part will effect Hawaii most strongly and those in the east end will effect the west coast of North America. For example, a tsunami generated from the Shumagin Islands, a gap area, would be expected to strongly effect the California coast centered north of San Francisco. At least one tsunami was generated behind the arc but it was minor. However, the history is short and the risk is not fully known. The recent destructive Sea of Japan earthquakes and tsunamis also arose in the back arc area without much of a history of prior occurrence.

Tsunamis can also be generated by several volcanic processes. There have been a number of possible tsunamis reported with volcanic eruptions. However, only the 1883 Saint Augustine eruption definitely produced a tsunami, probably by a mass slide of material from the crest. Other events were reported as agitated water or submarine eruptions; these reports did not mention any waves being generated. Volcanoes are capable of generating a tsunami provided that the height to distance to the water ratio is not less than 1 to 10 (Kienle and Swanson, 1983).

The second major tectonic feature is the Fairweather Fault which runs from north of Russell Fjord to Palma Bay where it continues offshore. It is a left-lateral strike slip fault as is the San Andreas further south. Since it does not have a large vertical displacement and is mainly on land, it would not be expected to generate tsunamis by displacement. It had a 47-foot vertical displacement in its 1899 earthquake. The small body of water it crossed resulted in a small wave beyond Russell Fjord, but it did not have notable effects beyond Yakutat Bay. The vibrations from earthquakes on this and other faults (including the 1964 Prince William Sound tectonic earthquake) are able to cause very large local tsunamis due to the failure of glacial outwash deltas, and the failure of the steep-sided fjords. This zone extends from the Prince William Sound to the Lynn Canal and Skagway.

Waves of 100 or more feet are not uncommon, but they are rarely seen outside of the bay of their generation. Great earthquakes are capable of generating dozens of separate landslide tsunamis and some landslide tsunamis have been generated without any earthquake for a trigger. Low tide increases the risk as the exposed sediments are not supported by water. Sub-aerial landslides usually create larger waves. Most of the fatalities in Alaska due to tsunamis have resulted from landslide-generated tsunamis.

The islands south of Icy Straits, the southernmost Alaskan panhandle, do not have a history of damaging tsunamis. The principal source of risk seems to be from collapses on the several large river deltas. These have been responsible for dozens of reported submarine cable breaks, but only one or two resulted in a report of a wave being observed and these were small. There have been several small tsunamis in lakes, caused by the collapse of sediments from streams feeding the lake.

3.0 Summary and Evaluation

3.1 Introduction

Alaska has one of the most complex tsunami regimes in the world. This history presents the known observations for 71 tsunamis of validity 3 and 4, and 23 reported events of lesser certainty. It is an incomplete history, partly due to the low population density in the highly active earthquake zone along the Aleutian Arc and in many of the landslide-prone glacial bays in Prince William Sound and southeastern Alaska. Fortunately, marigraphs have been installed in the last fifty years, insuring more complete record keeping.

The Aleutian Arc has produced destructive tsunamis in Hawaii resulting in 175 fatalities there and 19 more on the United States west coast—more than have occurred in Alaska from all tsunamis. The 1946 tsunami was such a disaster to Hawaii that it gave rise to the creation of the Pacific Tsunami Warning System. Alaskan tsunamis have been damaging to Canada, Japan, and as far away as Chile. Alaska does not have a major problem with tsunamis generated outside of the State.

The landslide-generated tsunamis in Prince William Sound and southeastern Alaska north of Cross Sound and Icy Straits are unique in the world and notable for their frequency and size. These are usually triggered by earthquakes and can be submarine and subaerial. Waves of 100 feet and more are not rare. They are directly related to the glacial terrain including the steep sided fjords and moraine out-wash deltas. Norway, the other locality with a tsunami problem related to fjords, has only a minor problem by comparison.

There have been 122 fatalities caused by tsunamis in Alaska since 1900, when the first counts of fatalities appear in the record. In the 18th and 19th Centuries, fatalities were reported for four tsunamis, all to natives and all unspecific as to the number. The records indicated "many," "people in 8 canoes," "100," and "village destroyed." Most of the fatalities of the 20th Century were associated with the 1964 tsunamis, with about 80% due to some of the 20 individual landslide tsunamis associated with the great earthquake. The lower number of fatalities in Alaska are due to its low population and the fact that Aleutian natives build their settlements on the sheltered northern coasts of the islands.

3.2 Teletsunamis

All tsunamis originating outside of Alaska are treated here as teletsunamis. Figure 11 (next page) shows the locations of teletsunamis known to have been recorded or observed in Alaska; these events are listed in Table 2. Only three were directly observed and another, the 1737 Kuril Islands event, was listed on the basis of reported driftwood heights not definitely tied to the tsunami. Only the great 1960 Chilean tsunami caused any damage. A log boom broke free in southeastern Alaska and there was minor damage to pilings at MacLeod Harbor, Montague Island where a 14–15 foot wave was reported. A wave of 4.5 feet amplitude caused minor, non-damaging flooding at Attu in 1952. Most of the other teletsunamis were only recorded. Massacre Bay, Attu, had the largest amplitude in 20 of the 34 events. They all had amplitudes of less than 1 foot except the November 22, 1969, tsunami which had an amplitude of less than 2 feet, and the February 17, 1996 (Indonesia) tsunami with an amplitude of 14 inches.

Almost all of the teletsunamis were recorded after the beginning of World War II, coinciding with increased instrumentation in the Aleutians. Most of the events originated in Japan, and in the Kuril Islands and Kamchatka, Russia. Although many of the earthquakes were of high magnitude, the waves recorded in the Aleutians were very small. The tsunamis from Chile were larger, probably due to a convergence of waves at great distances due to the curvature of Earth.

No other geographic sites have been identified which would be expected to cause damage in Alaska via teletsunamis. The hazard from teletsunamis is minor, with some risk to the westernmost Aleutians and areas in southeastern Alaska where currents could be unexpectedly high.

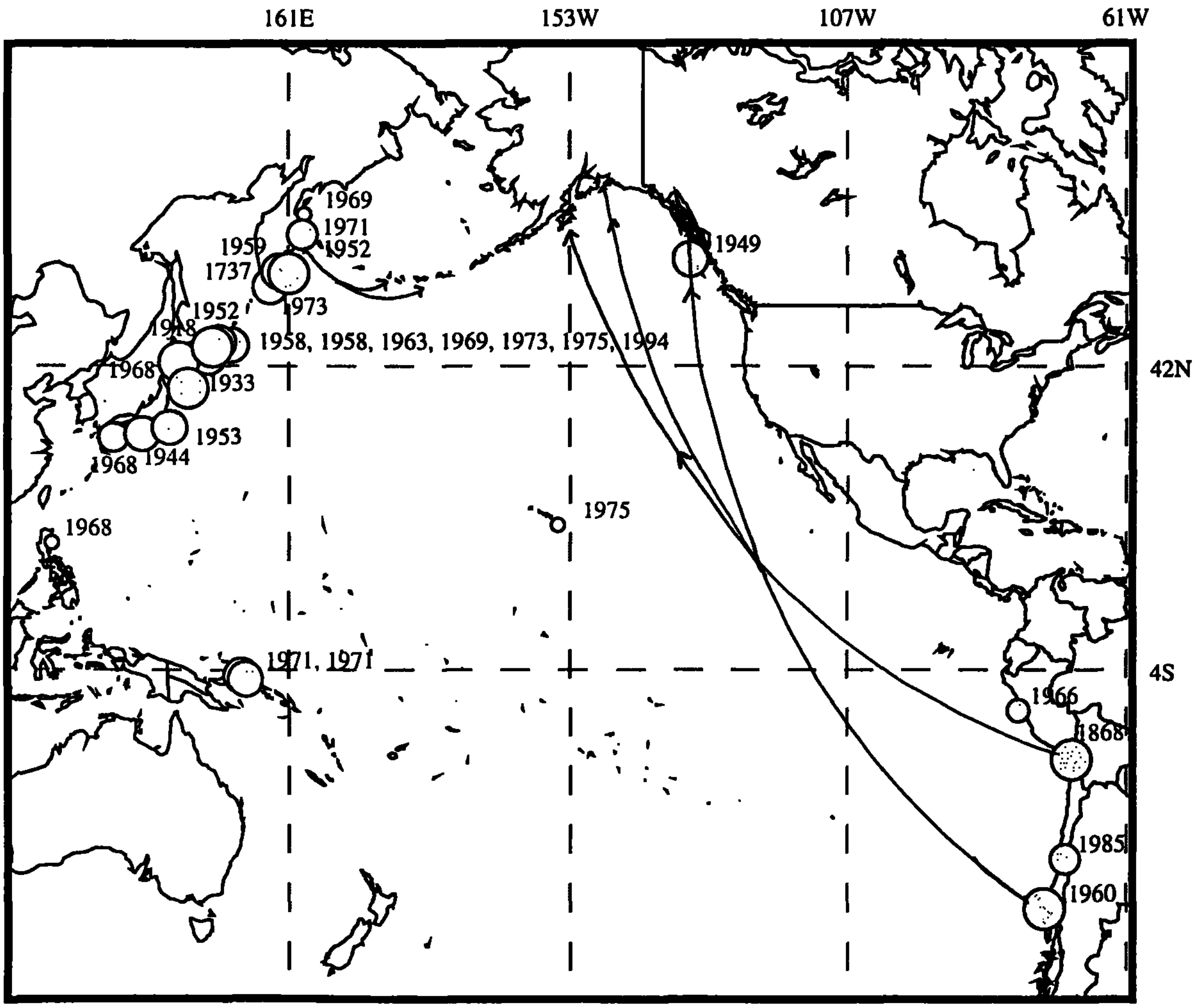


Figure 11. Teletsunamis affecting Alaska.

Table 2. Teletsunamis Affecting Alaska

Date	Source area	Eq. Mag	Max. amp. Alaska (m)	Location of max. amplitude	Effects
1737, Oct. 17	Kuril Is., Russia		12-16??	Amchitka	Based on height of driftwood
1868, Aug. 14	Chile	8.5	2.2	Kodiak	Observed
1906, Aug. 17	Chile	8.6	0.2	Port Chatham	First recorded teletsunami
1918, Sept. 7	Kuril Is., Russia	8.2	>0.1	Craig	Recorded
1933, Mar. 2	Sanriku, Japan	8.3	Trace	Seward	Arrival late—seiche?
1944, Dec. 7	Honshu, Japan	8.0	0.2	Massacre Bay	
1949, Jan. 27	Kamchatka, Russia	5.9	0.1	Adak	
1949, Aug. 22	British Columbia	8.1	0.3	Ketchikan	
1952, Mar. 4	Hokkaido, Japan	8.1	0.2	Massacre Bay	
1952, Nov. 4	Kamchatka, Russia	8.2	1.5	Massacre Bay	Minor flooding at Adak and Attu
1953, Nov. 25	Honshu, Japan	7.4	0.3	Massacre Bay	
1958, Nov. 6	Kuril Is., Russia	8.1	0.2	Massacre Bay	
1958, Nov. 12	Kuril Is., Russia	7.0	0.2	Massacre Bay	Doubtful
1959, May 4	Kuril Is., Russia	8.0	0.15	Massacre Bay	
1960, May 22	Chile	8.6	2.3	Montague I.	Minor damage to pier
1963, Oct. 13	Kuril Is., Russia	8.1	0.2	Massacre Bay	
1966, Oct. 17	Peru	8.0	<0.1	Massacre Bay	
1968, Apr. 1	Shikoku, Japan	7.5	<0.1	Massacre Bay	
1968, May 16	Honshu, Japan	7.9	0.2	Massacre Bay	
1968, Aug. 1	Luzon, Philippines	7.3	0.05	Massacre Bay	
1969, Aug. 11	Hokkaido, Japan	7.8	0.10	Massacre Bay	
1969, Nov. 22	Kamchatka, Russia	7.3	0.4	Massacre Bay	
1971, Jul. 14	New Ireland	7.9	<0.1	Massacre Bay	
1971, Jul. 26	New Ireland	7.9	<0.1	Massacre Bay	
1971, Dec. 15	Kamchatka, Russia	7.8	<0.1	Massacre Bay	
1973, Feb. 28	Kamchatka, Russia	7.2	0.1	Massacre Bay	
1973, Jun. 17	Hokkaido, Japan	7.4	<0.1	Massacre Bay	

Date	Source area	Eq. Mag	Max. amp. Alaska (m)	Location of max. amplitude	Effects
1975, Jun. 10	Kuril Is. Russia	7.0	<0.1	Massacre Bay	
1975, Nov. 29	Hawaii	7.2	0.1	Sitka	
1985, Mar. 3	Chile	7.8	<0.1	Adak	
1994, Oct. 4	Kuril Is., Russia	8.2	0.1	Adak, Shemya	
1995, Jul. 30	N. Chile	7.8	0.15	Adak	
1995, Dec. 3	Kuril Is., Russia	8.0	0.1	Adak, Shemya	
1996, Feb. 17	W. Irian, Indonesia	8.1	0.35	Shemya	

Table 3. Possible Volcanic Tsunamis in Alaska

Date	Val.	Location	Volcano	Effects
1796, May 29	1	Bogoslof	Bogoslof	No Details
1820, Mar. 01	1	Unimak	Pogromni	Sea highly disturbed
1825, Mar. 21	0	Unimak	Shishaldin	Sea agitated for months
1826, Oct. 22	0	Unimak	Shishaldin	Wild hogs perished
1827, Aug. 8-9	0	Chernabura Is.	Pogromni	Erroneous report of swine drowning
1856, Jul. 26	1	Unimak	Shishaldin	Geysers, whirlpools, disorderly waves
1878, Aug. 29	1	Unalaska	Makushin	Village reported destroyed
1883, Aug. 27	0	Kodiak	Krakatau, Indonesia	Air waves and seiche recorded
1883, Oct. 6	4	Port Graham	St. Augustine	25-30 foot waves, flooded homes, scattered boats
1901, Dec. 31	1	Cook Inlet	Redoubt	Unsubstantiated report of damaging waves
1903, Aug. 2	2	Iniskin Bay	St. Augustine?	Waves observed
1956, Mar. 30	1	Unalaska, Attu, Adak	Bezymianny, Kamchatka	Air waves recorded at 3 stations; max. amp. 0.3m

3.3 Volcanic Tsunamis

Table 3 lists the 12 events that were associated with volcanic activity. All of these except the 1883 Saint Augustine event and a possible event in 1903 were of validity of 0–1, definitely not valid reports or probably not valid tsunami reports. All are associated with descriptions of sea agitation, recordings associated with the air waves from volcanic explosions, and lahars, but not with any organized wave activity.

The 1883 Saint Augustine event was a true tsunami generated by debris flow from the summit of the volcano. It created waves that reached a height of 30 feet at Port Graham and English Bay on the other side of Cook Inlet. It flooded houses and carried boats ashore but the damage was limited due to the low tide. This was the only known tsunami produced by the six eruptions of the Saint Augustine volcano in the last 250 years.

A report of a wave on a calm day at Iniskin Bay in 1903 could be a volcanically-generated tsunami. Other volcanoes in Cook Inlet such as Redoubt have the potential for generating local tsunamis. The possibility of a tsunami should be considered anytime there are signs of volcanic activity.

A recently found marigram from Kodiak for the 1883 tsunami is shown in Figure 16. The initial arrival is taken to be the air wave from the explosion, and the change in character of the waves at about 11:00 A.M. to be the arrival of the tsunami. The small amplitude of 8 cm indicated the local nature of tsunamis from such a source, and future waves may be expected to be locally high, but of limited areal extent. The record indicates an origin time for the explosion of about 8:21 A.M. and for the tsunami of about 9:00 A.M. As the timing was carefully maintained for the tide gage, these times are probably more accurate than the reported times from Port Graham.

3.4 Seismically-Generated Local Tsunamis

Seismically-generated waves are characterized by a large source region, up to 750 kilometers in length. The waves reach the islands some 20 to 45 minutes later depending on the distance from the trench, the probable source of the waves. These tsunamis may affect areas outside of Alaska.

Table 4 lists 31 local tsunamis that were generated by tectonic displacements associated with earthquakes. Most were along the Aleutian Arc with one connected to normal faulting in Yakutat Bay, one occurring in the back arc area in the Bering Sea, and four offshore along the eastern boundary of the Aleutian Arc plate. Several of these earthquakes, notably 1899 Yakutat and 1964 Prince William Sound, also generated a number of landslide tsunamis. The table includes all of the local tsunamis that were destructive outside of Alaska (i.e., the 1946, 1957, and 1964 tsunamis). It also includes all of the tsunamis generated by movement along the subduction zone of the Alaskan Arc.

The 1788 events had been treated as a single tsunami by Lander and Lockridge (1989). However, the Shumagin Islands and Kodiak are in separate tectonic blocks and both experienced subsidence. This is evidence that these were separate earthquakes and tsunamis, as postulated by Soloviev (1990). The 1946 event caused five fatalities locally and 159 fatalities in Hawaii.

The 1964 event caused $84 million in damages and 106 fatalities. Eighty-two fatalities were due to secondary landslide-generated tsunamis. All of the fatalities due to the tectonically-generated tsunami were to people who knew that a tsunami was in progress and tried to save their boats or personal effects. Others left a place of relative safety for another location. This tsunami resulted in the creation of the Alaskan Tsunami Warning Center in Palmer, Alaska. It was by far the most significant tsunami to have occurred in Alaska.

A marigram was found for Saint Paul Island (in the Pribilof Islands) for the tsunami of 1872, allowing a location to be calculated for the Fox Islands even though there are no local reports of its having been observed there. This event was recorded on the United States west coast and Hawaii but the source of the waves was not known for certainty until the marigram clearly put the location in the Fox Islands. Earlier speculation had suggested sources in Hawaii, the Kuril Islands, and the Marianna Islands. It is the first source located entirely by instrumental data and also represents an early earthquake location.

Earlier reports include an event in which the village of Makushin was reportedly destroyed by earthquakes and a tidal wave. A search of contemporary church records indicates that Makushin was beset by earthquakes and volcanic activity, ruining the fishing. The village was relocated but there was no mention of its having been destroyed or of a tidal wave. The source of the original report is not known for certain but probably came from a passing ship that found the village deserted and assumed it must have been destroyed.

Table 4. Seismically-Generated Local Tsunamis

Date	Val.	Eq. Mag.	Location	Max. Amp. (m)	Local Effects
1788, Jul. 21	4	8.0	Kodiak	7	Many Aleuts drowned, huts destroyed
1788, Aug. 8	4		Sanak	30	Second event not observed at Kodiak
1792	1		Three Saints Bay		Unusual & irregular choppiness; ship damaged
1854, Jan. 27	3		Kodiak		Water oscillated in harbor
1865, Jul. 16	1		Unimak I.		Community flooded, subsidence
1866, Sept. 5	2		Kodiak		Houses damaged
1868, May 15	2		Unga I.	6	Water agitated, rose
1872, Aug. 23	4		Fox Islands		Recorded U.S. west coast, Alaska & Hawaii, and observed in Hawaii. Instrumentally located
1878, Aug. 29	1		Unalaska		Makushin reported destroyed
1880, Sept. 29	3		Chirikof Is.		Sea inundated 55 meters
1880, Oct. 26	3	6.3	Baranof I.	1.8	Huge wave ran in Whale Bay
1899, Sept. 4	4	7.9	Yakutat & Yakataga	3.1	Indian village flooded. Sea ran out and returned
1899, Sept. 10	4	8.9	Yakutat	18.0	Damage to saw mill, Indian village
1929, Mar. 7	4	7.5	Fox Is.		Cherni I. overrun, killing cattle
1938, Nov. 10	4	8.3	Unga I.	<0.1	Recorded
1946, Apr. 1	4	7.3	Unimak & Sanak	35	5 killed, lighthouse destroyed, houses gutted, shop destroyed

Date	Val.	Eq. Mag.	Location	Max. Amp. (m)	Local Effects
1957, Mar. 9	4	8.3	Andreanof Is., Aleutian Is.	15	Structures destroyed on Adak. Two docks destroyed on Unmak
1964, Mar. 28	4	8.5	Prince William Sound	9.2	Complex event, 106 fatalities, $84 million damage. Tectonic tsunami affected whole Pacific Basin, about 20 local landslide-generated tsunamis
1965, Feb. 4	4	8.2	Rat Is., Aleutian Is.	10.7	Warehouse flooded on Shemya, minor flooding on Amchitka
1965, Mar. 30	4	7.4	W. Aleutian Is.	0.1	Recorded at Attu and Adak doubtful
1965, Jul. 2	4	7.0	Unalaska	<0.1	Recorded
1971, May 2	4	7.1	Andreanof Is.	<0.1	Recorded at Adak
1972, Jul. 30	4	7.6	Sitka	0.1	Recorded at Juneau & Sitka
1979, Feb. 28	4	7.1	Yakutat	0.1	Recorded at Yakatat & Sitka
1986, May 7	4	7.7	W. Aleutian Is.	0.9	Recorded
1987, Nov. 17	4	6.9	Gulf of Alaska	<0.1	Recorded at Yakutat
1987, Nov. 30	4	7.6	Gulf of Alaska	0.4	Boats bump together at Yakutat
1988, Mar. 6	4	7.6	Gulf of Alaska	0.2	Recorded
1991, Feb. 21	4	6.5	Bering Sea	0.3	Recorded at Adak and Dutch Harbor
1996, June 10	4	7.7	Andreanof Is.	0.51	Recorded at Adak, Shemya, Kodiak, Unalaska, and Sand Point
1996, June 10	4	7.2	Andreanof Is.	0.1	Recorded at Adak

3.5 Landslide-Generated Tsunamis

3.5.1 Overview. Landslides, both submarine and subaerial, are capable of generating very large tsunamis. The 1958 Lituya Bay subaerial landslide sent a surge of water up the opposite shore, clearing trees to a height of 1,722 feet. The tsunami that went down Lituya Bay cleared trees to a height of 160 feet on Cenotaph Island.

The subaerial tsunamis are the largest due to the kinetic energy (from falling through air) which they carry. They are usually associated with earthquakes that trigger them and they are confined to the bay or lake of origin. Some, however, occur without an earthquake trigger, such as the 1994 tsunami at Skagway. Low tide is a factor for submarine landslides as it leaves a larger portion of water-saturated sediments exposed without the support of the water. Loading on the delta such as trains, warehouses, or added stone facing or fill can be factors adding to the instability.

Landslide tsunamis are found principally in the heavily glaciated areas of Prince William Sound and the part of southeastern Alaska north of Norton Sound. They can be generated in lakes such as those that occurred with the 1964 earthquake at Kenai Lake, and at Ward Lake and

Manzanita Lake on Revillagigedo Island in 1949. Slumps along the Stikine and Katzehin River deltas have been responsible for many cable breaks but it is uncertain if these have generated tsunamis. (See Table 7, Wrangell and Haines entries.) There have been 18 separate events that have produced more than 50 separate tsunamis (Table 5). The 1964 event was the largest and produced over 20 separate landslide tsunamis. One at Anderson Bay reached a height of 220 feet.

Landslide tsunamis have caused most of the deaths from tsunamis in Alaska—about 95 of the 122 fatalities for which there is a count. They are particularly dangerous as they arrive within a few minutes after generation, leaving no time for a communicated warning. The only warning is nature's. When a strong earthquake occurs or unusual water behavior is observed, people near the shore should leave immediately for higher ground.

Table 5. Landslide-Generated Tsunamis

Date	Val.	Eq. Mag.	Location	Max. Amp. (m)	Effects
1845–1847	3		Yakutat		"100" natives perished near Haenke I., date uncertain
1853–1854	3		Lituya Bay	120	Dated by tree rings, 8 canoes of natives perish
1874, May	3		Lituya Bay	24	Scouring observed
1880, Oct. 26	3	6.3	Redoubt Lake, Baranof I.	1.8	Debris line
1897, Apr. 17	3		Nuchek	OBS	2 buildings damaged
1899, Sep. 10	4	8.9			At least 5 separate tsunamis
			Glacier Bay		Boats overturned
			Katalla	1.2	4-ft. wave on Bering River
			Lituya Bay	60	Native saltery destroyed
			Logan coast	12	Trees uprooted
			Russell Fjord	18	Prospectors narrowly escape
			Valdez	2.1	Whirlpools formed
1900, Aug. 11	3	8.4	Lituya Bay		5 natives killed; date questionable
1905, Jul. 4	4		Disenchantment Bay	35	Hanging glacier collapses
			Russell Fjord	6	
1907, Sep. 24	3		Haines	OBS	Water fluctuated
1925, Feb. 23	4	6.0	Valdez	OBS	Boardwalk destroyed, cable cut
1927, Oct. 12	2		Ketchikan	<0.1	
1927, Oct. 24	3	7.1	Cape St. Elias		Heavy seas broke towline
	2		Wrangell		Cables broken
1936, Oct. 27	4		Lituya Bay	150	2 small buildings destroyed, salted salmon washed away, trees uprooted

Date	Val.	Eq. Mag.	Location	Max. Amp. (m)	Effects
1949, Aug 22	4		Blue Lake		Gun & pack washed off beach
			Ketchikan	0.3	
			Knutson Cove	0.3	At Revillagigedo I.
			Ward Lake	0.6	
			Manzanita Lake		
			Wrangell		Cables broken & buried; wave reported
1958, Jul. 10	3	7.9			At least 7 separate tsunamis
			Disenchantment	6.0	Ice fall
	3		Bay		
	3		Dixon Harbor	0.5	
	3		Dry Harbor	2.0	Collapse at river mouth
			Glacier Bay	0.5	Landslide-induced wave
			Haines/Skagway	OBS	6 underwater cables cut
	4		Inian I.	0.9	Mooring lines broken
			Khantaak I.,	6.1	3 killed, tip of island slid
			Yakutat Bay		
	4		Lituya Bay	50	2 killed, surge to 525 m
			Sitka	0.1	Recorded
	4		Skagway	7.6	Cable breaks
			Yakutat	0.9	Mooring lines broken
			Wrangell	OBS	Cables cut
1964, Mar. 28	4	8.5			At least 20 separate tsunamis in Alaska
			Aialik Bay	30	
			Anderson Bay	67	1 fatality
			Blackstone Bay	24.2	
			Chenega	27.4	23 fatalities
			Crab Bay	6.1	1 fatality
			Homer	6.0	Buildings flooded
			Kenai Lake	10	9 separate tsunamis
			Point Nowell	12	1 fatality
			Portage Canal	31.7	
			Port Ashton	12	3 fatalities
			Port Nellie Juan	15	1 fatality
			Seward	8.3	12 fatalities; $14.6 million damage
			Shoup Bay	52	
			Thumb Cove	9	
			Unakwik Inlet	9	
			Valdez	6.1	$15 million damage, 31 fatalities
			Whittier	32	13 fatalities
1979, Feb. 28	4		Yakutat	<0.1	
			Sitka	0.1	
1994, Nov. 04	4		Skagway	7.6	1 killed, $25 million damage, no earthquake

Table 6. Landslide Tsunamis in Lakes

Date	Location of Effects	Effects
1880, Oct. 26	Redoubt Lake, Baranof I.	6 foot wave determined by debris line
1949, Aug. 22	Blue Lake, Baranof I. Manzanita Lake, Revillagigedo I. Ward Lake, Revillagigedo I.	Gun and pack washed off shore Wave submerged sandbar, observed by approaching aircraft Water rushed to west as though the lake was tipped
1964, Mar. 28	Kenai Lake, Kenai Peninsula Aleknagik Lake, Wood-Tikchik St. Park	5 separate tsunamis; boat house, shed, log cabin, and trees destroyed; max. height 72 ft. Waves 1 foot high and 150 feet apart observed

Table 7. Submarine Communication Cable Breaks and Burials

Note: These may have generated small tsunamis but none is known to have been observed.

Date	Val.	Eq. Mag.	Location
1911, Jun.	2		Valdez
1911, Sep. 22	2	6.9	Valdez
1912, Jan. 31	2	7.3	Golden
1913, Jul. 6	2		Wrangell
1915, Oct. 4	2		Wrangell
1918, Sep. 2	2		Wrangell
1920, Aug.	2		Wrangell
1920, Oct. 6	2		Haines
1920, Nov. 29	2	OBS	Valdez
1921, Aug. 20	2		Valdez
1923, Jun. 29	2		Valdez
1923, Sep. 27	2		Wrangell
1924, Jun. 1	2		Wrangell
1924, Aug. 13	2		Haines
1924, Dec. 10	2		Wrangell
1949, Aug. 22	2	8.1	Wrangell
1964, Mar. 28	2	8.5	Haines

3.5.2. Landslides in Lakes. Tsunamis originating from slides in lakes deserve special mention since Alaska has more of this type than any other geographic location. These events are listed in Table 6. Other incidences of landslide tsunamis in lakes have occurred in the State of Washington, and in Italy, Peru, and Norway. Landslide-generated tsunamis in Franklin D. Roosevelt Lake (Washington) were due to the rising of the water table behind the Grand Coulee dam. At the Vaiont Dam, Italy, slide-induced waves caused the collapse of the dam, causing 3,000 fatalities. At Chungar, Peru, a talus slide generated a wave in Lake Yanahuin killing 400–600. At Loen Lake, Noway, rock falls generated tsunamis in 1905 (61 deaths) and 1936 (73 deaths) (Plafker and Eyzaguierre, 1979).

In Alaska, these types of tsunamis are associated with the collapse of deltas in glacial lakes having great depths. They may also be associated with delta deposits from rapidly-flowing streams and rivers carrying glacial debris. There is no doubt that these events are under-reported, due to lack of witnesses and inhabitants living along the shore line. McCulloch (1968, p. 80) states that building on lake deltas carries the risk of having the structure destroyed by the slump, washed away by the waves it generates, or damaged by the fractures in the unconsolidated ground. Although building sites are scarce along lakes in glacier valleys it would be prudent to investigate a site for evidence of prior wave effects such as tree trim lines, or debris lines. Fortunately, the damage from such events has been minor, at least to date. Residents should know that strong earthquakes may precipitate a wave on lakes and they should evacuate immediately.

3.5.3. Underwater Cable Breaks. There is a record of at least 18 incidences of the cutting and burial of underwater communication cables. These are usually associated with collapse of river deltas or moraines in fjords such as at Valdez. The military began installing a network of cables early in the 20th Century and largely abandoned it in the late 1920s. Some of the cables were buried for distances of several miles, but reports of waves being associated with these events is largely lacking as such waves would be small, local, and not damaging. Table 7 lists the dates of these cable breaks. The listing is important because it may point toward unreported landslide-generated tsunami events.

3.6 Fatalities

The tsunamis reported to have caused fatalities are listed in Table 8.

Table 8. Tsunamis Causing Fatalities in Alaska

Date	Location	Type of Source	Number of Fatalities
1788	Shumagin Is.	tectonic	Many natives drown
1845-1847	Yakutat Bay	landslide	"100" natives perished
1853-1854	Lituya Bay Dry Bay	landslide landslide	Natives in 8 canoes lost Many natives drowned
1899	Lituya Bay	landslide	Native village destroyed
1900	Lituya Bay	landslide	5 natives drowned
1946	Scotch Cap, Unimak	tectonic	5 Coast Guardsmen lost

Date	Location	Type of Source	Number of Fatalities
1958	Lituya Bay	landslide	2 drowned
	Yakutat Bay	landslide	3 drowned
1964	Anderson Bay	landslide	1 drowned
	Cape St. Elias	tectonic	1 Coast Guardsman drowned
	Chenega	landslide	23 drowned
	Crab Bay, Evans I.	landslide	1 drowned
	Kaguyak	tectonic	3 drowned
	Kalsin Bay, Kodiak	tectonic	6 drowned
	Kodiak	tectonic	8 drowned
	Old Harbor	tectonic	1 drowned
	Point Nowell	landslide	1 drowned
	Port Nellie Juan	landslide	3 drowned
	Port Whitshed	landslide	1 drowned
	Seward	landslide	8 (1 heart attack)
		tectonic	4 drowned
	Spruce Cape	tectonic	1 drowned
	Valdez	landslide	31 (1 heart attack, 2 crushed)
	Whittier	landslide	13 (1 exposure)
1994	Skagway	landslide	1 drowned

3.7 Summary and Conclusions

A number of new findings are presented in this publication.

- Event corrections and additions:

1737 New. Reported debris line on Amchitka at an elevation of 30 to 40 feet.

1788 Recognition that there were two tsunamis 16 days apart as Soloviev (1968) had reported. There was subsidence in two independent tectonic blocks.

1825 Effects due to a lahar and not a tsunami. Validity dropped from 2 to 0.

1872 Marigram located from Saint Paul Island, Pribilof Islands. This proves the Fox Island source for this tsunami and provides the first instrumental location for an earthquake.

1874 Reports by Dall (1883) of pools of standing water and discolored water indicating a date for the Lituya Bay tsunami shortly before it was visited by Dall in May.

1878 Contemporary records do not support the report that village of Makushin was destroyed by a "tidal wave." The village was relocated and no unusual fatalities were reported. Validity changed from 3 to 1.

1883 Marigram found for Kodiak, fixing the time and size of the Saint Augustine volcanic tsunami.

1897 New report of a tsunami at Nuchek Bay destroying one house and damaging another.

1900 New event listing 5 fatalities in Lituya Bay.

1903 Report in Tarr and Martin (1912) of waves on a calm bay at Iniskin Bay north of Saint Augustine suggests a possible local tsunami due to volcanic activity.

1938 The report that the tsunami was observed at Unga was shown to be a misplaced report for the 1946 tsunami.

1957 The report that a 40 foot wave reached Scotch Cap too early to be from the main tsunami and was probably due to a landslide was shown to be incorrectly based on the belief that the tsunami originated at the epicenter, and not the nearby trench.

1994 New non-seismic landslide-generated tsunami at Skagway. This event, which caused one fatality and $25 million in damage, was not known to the tsunami community until reported by the author as part of this study.

■ Fourteen new tsunamis of validity 3 or 4 are listed in this catalog for the first time including eight that occurred since the last catalog was published. Additional information raised the validation of eight events to validity 3 or 4, and dropped the validity of five events from 3 or 4 to below 3. Substantial additional information is included with many of the reports, including the 1946 and 1957 tsunamis from interviews with survivors.

■ The delay times for the tsunami to reach communities within the deformation zone for the main earthquake in 1964 suggests that the source is not related to the regional uplift and subsidence observed there, but probably to the thrusting of the continental plate into the trench. There is much confusion in the literature for the 1964 event ascribing many of the early landslide tsunamis to seiche, tilting and movement of land masses. The term "water waves" is inappropriately used for these landslide tsunamis. There is also misuse of the term epicenter in that event. Previously the distances from a community to the epicenter was used to indicate its distance from the main part of the earthquake. It is now known that every community from Kodiak Island to Cape Saint Elias was in the epicentral region and equally experienced the earthquake with variations due to local geology. [More remote communities should quote distance to the epicentral zone as defined by the aftershock pattern to determine their distance from the earthquake source.]

■ Alaska may be divided into distinct tsunami regimes that have tsunamis of different characteristics. For example, tectonic tsunamis are associated with the subduction zone along the Aleutian Arc. These typically have source regions of several hundreds of miles and lead times of 20 to 45 minutes after the earthquake and before the tsunami arrives.

■ Almost all of the fatalities due to tectonic tsunamis occurred when people who knew that a tsunami was in progress tried to move from a place of safety to another location or to save boats or other possessions. This illustrates the importance of education in tsunami hazard mitigation. These tsunamis also may be damaging to locations on the United States west coast, Hawaii, and Japan.

■ A unique zone of landslide tsunamis associated with glacial features extends from Prince William Sound to the Lynn Canal. These tsunamis may be very large and have lead times of only a minute or two but only effect a single bay. These are responsible for most of the tsunami fatalities in Alaska. They are usually triggered by large earthquakes; several independent events may occur with one earthquake. They are not always triggered by earthquakes; low tide and loading on the deltas are factors.

■ Alaska has an unusual problem with tsunamis generated in lakes that occupy glacial valleys. The rapidly flowing glacier-fed streams deposit material as deltas that are subject to collapse under strong earthquake shaking. To date these have not been notably damaging but with waves up to 72 feet, they are a hazard. They are also probably severely under-reported. Only Norway has a similar problem and about 210 people have been killed there at Langfjord, Loen Lake, and Tafjord.

■ Teletsunamis have not been a significant problem historically nor have small tsunamis associated with the Stikine and Katzehin River deltas in southeastern Alaska. But the possibility of larger events of these types cannot be ruled out in the future.

■ Except for the 1899 earthquake studied by Tarr and Martin (1912), and the 1964 tsunami, few events were subjected to field studies, including, notably, the 1946 and 1957 events.

4.0 Description of Tsunami Events

4.1 Tsunamis of the Russian Period: 1737–1867

1737, October 16 GMT (October 6, Julian date, in Kamchatka). A great earthquake and tsunami occurred in the Kuril Islands and Kamchatka at 3 A.M. The tsunami had heights of 20 m in the Northern Kuril Islands and 30 m at Avacha on Kamchatka. Natives were killed, buildings destroyed, and the topography changed.

G.V. Steller, a scientist traveling with the Bering Expedition in 1740, stopped at the island now known as Bering Island, Komandorskiye Islands, Russia. He noted in his journal that "Great changes on the island [Bering] may have resulted from earthquakes and high sea tides." He found driftwood, and sea mammal bones high up on the shore. He also found trees washed up on a bluff to a height of 30 *sazhens* [230 feet], and trees buried upright in new sand dunes which he attributed to the 1737 Kuril earthquake (Soloviev and Ferchev, 1961).

Tikhmenev (1978, p. 403 and 498) quotes Teben'kov (1825) as follows: "Half-rotten drift-wood is piled up on the shore of Amchitka Island in some places forty and fifty feet above the water mark." Footnote 11 continues: "The circumstances and the large quantity of driftwood on the shores of Alaska and Norton Sound, is attributed by natives to the terrible earthquake of 1737, which shook Kamchatka and the Kuril Islands."

Soloviev and Ferchev (1961) see this tsunami as similar to that of the November 4, 1952, event but the reported tsunami effects on Alaska are much greater for this earlier event. It is expected that such a great tsunami in the Kuril-Kamchatka region would have an effect on Alaska. However, these observed effects are not definitely connected to the Kuril tsunami. Validity 3 as a teletsunami.

1788, July 21. This event is also dated July 11, which is the Julian date, and as July 22, the Gregorian date uncorrected for the now-existing International Date Line. The date of July 21 is the date that would be compatible with any Western Hemisphere reports, should any be found.

This report followed the first permanent Russian settlement on August 13, 1784 (August 3, Julian date) at Three Saints Bay by a little less than four years. Although it is referred to as Old Harbor in contemporary Russian literature, it is not the present site of Old Harbor, a site located about seven miles northeast of Three Saints Bay.

Soloviev (1968) estimated the wave heights to be 3 to 10 meters at Kodiak and published a newly found description of this event. Vasili Merkulev, the manager of the settlement, wrote a letter to G.I. Shelikov, founder of the Russian American Company. This letter, dated May 2, 1789, states:

> . . . in 1788 on July 11th, here on Kodiak Island we had a great earthquake and some thought that the earth would collapse. The earthquake was so strong that one could not stand on his feet. We did not have time to recover from this earthquake when a flood came in from the sea. We had a deluge in our harbor [Three Saints Bay], and at that time every man was looking for a safe place to save his life. The flood caused great damage. First, my *barabora* [a half sunken hut] was flooded and the merchandise was carried away as were other small structures and the fence. In your garden all of the soil and vegetation were washed entirely away and at this

> place water brought in gravel and dug holes in the ground. The rise of the level of water was almost up to the windows in your room. The water was very swift and lasted only for a very short time. There were two large waves and the rest of them were minor. After this the earth was shaking two or three times a day and even more often. Since the time of the earthquake, our place near the harbor is closer to the sea.

(*Archives of Russian Internal Affairs*, F 339, OP 888, D 774, L 4, as quoted by Soloviev, 1968). This indicates local subsidence on Kodiak Island as was the case with the 1964 tsunami.

Davydov (1812, p. 154–155; p. 206 in the 1977 translation) reports:

> Even now it is all [the Kuril Islands, the Aleutian Islands and northwestern America] prone to earth tremors that happen every year on Kad'iak. In 1788 this island and its surroundings suffered a severe earth tremor that lasted for 17 days. At this time the fire breathing mountains [volcanoes] on Alaska beyond Kamyshatsk Bay [Kamishak Bay] opened a new crater that is still smoking to this day.
>
> On Kad'iak the earthquake was terrifying. After the first tremors the sea suddenly withdrew from the shore; then the Koniags and Russians took to the hills. Several moments later the water came back in a huge mountainous rush and cracked onto the shore. This incoming tidal wave broke the ships' hawsers [ropes used for mooring the ships] and carried them up onto one of the villager's huts. Some *yurtas* [dwellings] were washed away altogether.
>
> On the same day there were two such tidal waves. For 17 days there was a series of violent tremors that caused landslides from the mountains and shores. Many capes fell away and left many pillars of rock standing.

Clearly there was an earthquake and tsunami at Three Saints Harbor on July 11 (Julian date). It is uncertain whether the events described below for Sanak, and other places in the Shumagin seismic gap area, relate to this date, or to a second event on July 27 (August 6, Gregorian date). The Shumagin seismic gap area is one of the sections of the Alaskan Arc which has not had a (known) great earthquake in more recent historical times. Soloviev (1968) thought these were two separate events, citing the frequency of pairs of large earthquakes and tsunamis in the Kuril Islands and elsewhere. He accepted the Veniaminov (1984, p. 14) account of a wave on Unga Island on July 27, 16 days after the earlier earthquake. Lander and Lockridge (1989) considered this to be one event given the lack of clear evidence of two events having been experienced at either locality, the closeness in time of occurrence, and the lack of a history of earthquake and tsunamis occurring in pairs in Alaska.

This account treats these as two distinct events based on the 16 day gap reported by Veniaminov and the report of subsidence at Three Saints Bay. Three Saints Bay on Kodiak is part of the tectonic block or blocks including Prince William Sound that was activated again in 1964. For subsidence to have occurred there, that block must have been activated. The descriptions of waves at Sanak, Unga, and on the Alaska Peninsula are clearly related to the Shumagin block. The 1964 tsunami was observed as waves of less than one meter west of Chirikof Island, and would not have been exceptionally noteworthy in 1788. Effects of the earthquake and tsunami in the Prince William Sound area, if they did occur, would not have been observed by the Russians.

The ship *Three Saints* had been sailing along the coast of southeastern Alaska near Lituya Bay and had started for Three Saints Bay on July 9 (Julian date). The ship would have been in the open ocean when the July 11 tsunami occurred and would not have observed it. *Three Saints* arrived in port on July 15. If the effects of the tsunami at Three Saints Bay had occurred on July 27th, the ship would have been in the harbor and the effects noted in its log. Due to the directionality of the tsunami waves, the July 27 event in the Shumagin Islands would not have been expected to have produced a large wave in Three Saints Harbor. Both waves would have produced significant effects on the United States west coast and Hawaii, but there is no written history from these areas for this early date. The early arrival of the wave in Three Saints Bay following the July 11 earthquake indicated a nearby source. Validity 4.

1788, August 6. The Russian missionary Ioann Veniaminov kept a journal of his service in Unalaska and Sitka during the period 1824 to 1838, called *Notes on the Islands of the Unalaska District*. In one entry, he wrote: ". . . In one record I saw, it says that, 'on the 11th of July 1788 also on Unga there was so strong an earthquake that one could not keep on one's feet. Many mountains crumbled. Sometime after this event there was a terrible flood'" (Veniaminov, 1984 translation, p. 16). The July 11th date is 16 days earlier than the inundation on Unga. Veniaminov (1984, p. 14) gives the following:

> That the sea had [once] been in a state of extraordinary turbulence is confirmed by the Aleut tradition which says that, during the inundation which occurred on Sannakh around 1790, the water advanced in heavy rolling swells at considerable intervals. I have seen a note in one church book written in an ancient hand, in which it said that, 'In the year 1788 on the 27th of July there was a terrible inundation on Unga Island in which many Aleuts perished but God spared the Russians.' And the old men say that the water rose to a height of 50 *sazhen*. Such a rise in the water is almost incredible even if one measures not by ordinary but by hand *sazhen*.

Fifty *sazhen* is equal to 117 m or 383 feet. One *sazhen* equals 233.6 cm. A hand *sazhen* is measured by outstretched arms or about 5.8 feet. This would reduce the height to about 88 meters or 287 feet, still a great height.

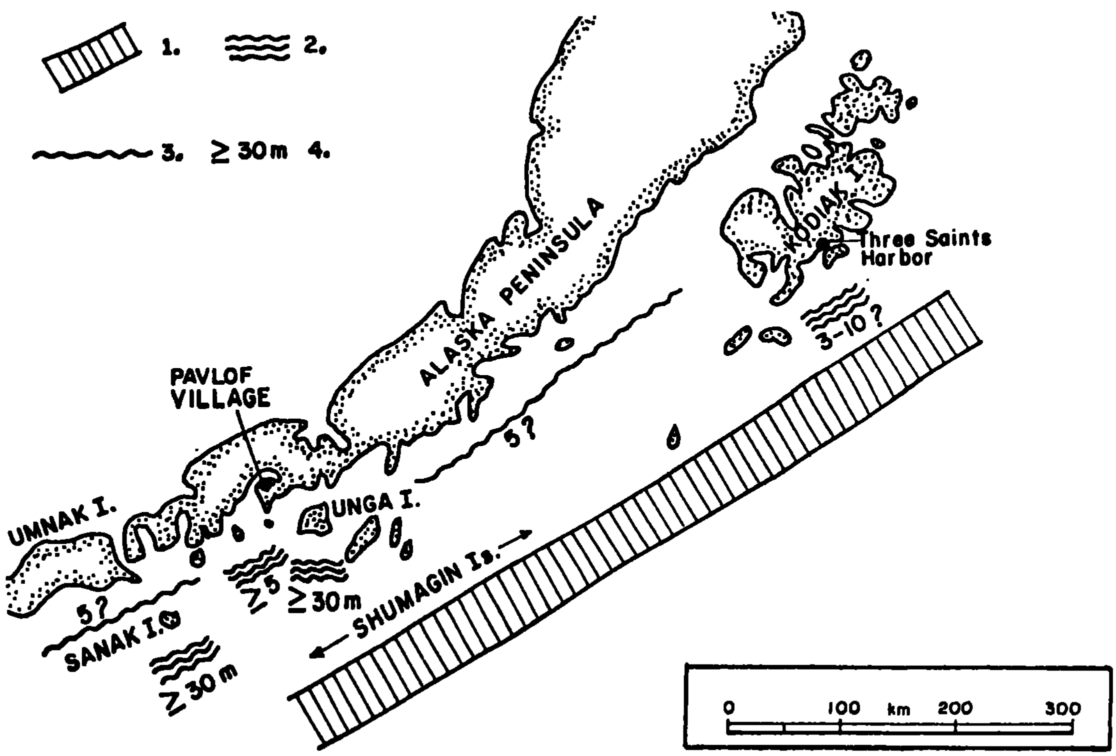


Figure 12. Estimated tsunami heights for the 1788 tsunamis (Soloviev, 1990). Legend: (1) presumed location of earthquake rupture zone; (2) places of observed tsunami; (3) location of possible occurrences of tsunami; (4) approximate heights of tsunami in meters.

Soloviev (1968) gives the heights as 30 meters or more at Unga and Sanak, and 5 meters at Pavlov and elsewhere on the Alaska Peninsula.

"The flood which occurred in Sannakh about 1788 occurred here too [in the village of Pavlov, on the Alaska Peninsula] although it was much less extensive. . . .The flood or inundation, occurring on Unga and on the south side of the Aliaksa [Alaska] Peninsula in 1788 did not have any effect on the north side of Unimak Island" (Veniaminov, 1984, p. 122).

In a chapter describing floods on the Aleutian Islands, Veniaminov (1984, p. 14) reports a number of indications of recent sharp rising of the land on the south side of the Alaska Peninsula and on the islands adjoining it. He may be describing indications of recent catastrophic floods in these places due to the 1788 tsunami:

> In many places quite high up and long since inaccessible to the sea, lie immense tree trunks with their roots which have been thrown up by the sea. Some of them are already rotted; others are still fairly solid and fresh. It seems that everywhere they are found at the same height above sea level, which can be approximated at from 2½ to 3 *sazhen* [5.8 to 7 m]. On a mountain on Unga Island, at a height more than 30 *sazhen* [70 m above the sea], there has been found a large tree with roots, already petrified.

He notes that on many of the bars and spits (composed of pebbles and sand) and on the necks of land, undulating hillocks (dunes) are seen, lying parallel to the shore and already covered with a layer of soil of different thickness. "The height of such spits and isthmuses is almost everywhere one and the same, from 2 to 3 *sazhen* [4.7 to 7 m, above the sea level]" (Veniaminov, 1984, p. 14).

Dall (1897, p. 310) writes, "1788. An earthquake caused a tidal wave, which passed from Aliaksa to Sanak Island, and created a great inundation in the island of Unga, during which many natives lost their lives."

Dall (1897, p. 467) also writes, "1788. An earthquake attended with a tidal wave visited the Shumagins. On the 27th of July the water overflowed Sanak Island destroying the hogs which had been placed there. From this point the inundation extended to Aliaksa."

The wave at the mentioned part of the island reached as high as 50 meters. Dall's report on the drowning of the hogs written a century later is probably a misdated reference to the hog drowning associated with the 1826 event. The four-year period since the first permanent settlement probably would have been too short for the introduction of hogs into the wild and their successful propagation. This reference to the drowning of swine, written more than a century later, is not found in contemporary records.

Veniaminov also mentions an earthquake and terrible flood on Unga Island on July 27, 1788 (Veniaminov, 1984, p. 27). This would be August 6 on the Gregorian calendar. The date is repeated in Dall, using Veniaminov as a reference. Whether Dall had any other source for the July 27 date is not known.

There were probably deaths among the Aleuts, but none were counted. There were no deaths reported for the Russians. Unfortunately, this event just preceded the written historical period of the Hawaiian Islands and no account of effects there or from the California missions have been found. No remote source observations have been found from any other locality around the Pacific. Validity 4.

1790, September 11. "In the year [1790], on 1 [11] September, an earthquake to the south of Unalaska in the Aleutian Archipelago at latitude 52°59'46" N in a wind raging from the ENE. 'We hugged,' says Sarychev, 'the SE side. During the night and all morning the sea was very agitated, we therefore suffered a heavy roll. Suddenly our ship was violently shaken and experienced blows as if its keel had struck against a rough body; this continued for several seconds and we became convinced that this was due to an earthquake" (Mushketov and Orlov, 1893, p. 180–181). The reported sea conditions are related to the raging storm and there was apparently a seaquake experienced later. Validity 0.

1792. Davydov (1812, p. 156; p. 206 in 1977 translation) reports, "On Kad'iak in 1792 there was another severe earthquake which lasted for 18 hours. All the native huts were destroyed and several cliff faces collapsed. A ship which was entering Three Saints Bay at the time encountered a violent storm and suffered a great deal of damage from the abnormal buffeting."

Tikhmenev (1863, p. 56) quotes a letter from Baranov to Shelikov from Chugach Bay, on the south tip of the Kenai Peninsula, July 24, 1793: "Our old harbor has become hopeless as a place for men to live in. After the earthquakes, the ground settled and became so low that there are regular straits between the buildings and during the extreme high tides there is very little dry ground left."

This report does not seem to be for another event separate from the 1788 event. The Davydov report does not mention any wave activity and could describe another earthquake and seaquake or storm effects. The Tikhmenev report seems to recount the condition of Three Saints Bay that resulted from the 1788 event. The Russians continued to use the Three Saints Bay location into the early 19th Century, but by 1792 had moved most of their activities to Pavlovskaya, now the community of Kodiak. Validity 1.

1796, May 29. Ponyavin (1965) reported a tsunami accompanying the appearance of Bogoslof Island, north of Umnak Island, but Soloviev and Go (1975) consider this to be an erroneous report since it is not mentioned in Mushketov and Orlov (1893). Veniaminov (1984, p. 17) describes the eruption and an earthquake on Umnak Island. There were thunderous sounds, flames, dense smoke, and a lot of pumice accompanying the birth of the island, but no mention of waves. Wave activity with an emerging volcano is a possibility but there is no known report of one being observed. Validity 1.

1820, March 1–2. Due to a strong eruption of Pogromni Volcano on the northern tip of Umnak Island, ashes injected into the air were observed as far away as Unalaska and Unimak Islands. There was a strong earthquake on the night of March 1. The sea was observed to have became highly disturbed by dawn (Soloviev and Go, 1975). Mushketov and Orlov (1893, p. 207–208) describe the eruption as having taken place on February 19–20 (March 1–2 in Gregorian date) and another account dated March 1 referring to ash fall clouding the sea. Although the highly disturbed sea is suggestive of a tsunami, there is no specific mention of waves. See also the following three reports. Validity 1.

1825, March 21 (Gregorian date). A powerful eruption of Shishaldin Volcano on Unimak Island began at the end of 1824 with the sound of explosions being heard from the Alaska Peninsula to Unalaska. The ashes and water mixed with rubble inundated the southern coast of the island for a distance of 2 miles. The outpouring did not last long, but the sea was still agitated even in the following fall (Soloviev and Go, 1975). The term "inundated" may imply that the material was washed upon the shore for the considerable distance of 2 miles. The report that the sea was agitated six months later, and the lack of reports of waves at the time of the main eruption, casts doubt on this as a report of a tsunami. This account in Soloviev and Go (1975) that was taken from Perry (1865) forty years later is in error regarding the date. Veniaminov (1984, p. 18) reports:

> On March 10, 1825 [Julian date] after a loud subterranean thunder very similar to a cannonade, which lasted almost the whole day and was audible on Unalaska, Akum, and the tip of Aliaksa [the Alaska Peninsula] in the middle of the day, the northeast range of Unimak exploded in five or more places and over a large area with an eruption of flames and a great quantity of

> black ash which covered the whole end of Aliaksa for several inches. At nearby Aliaksa and especially Morzhevskoi settlement, it was dark for 3 or 4 hours. On this occasion the ice and snow lying on the range melted and for several days flowed in a dreadful river, 5 to 10 *verst* wide [3.3 to 6.6 miles; a *verst* is 0.6624 miles]. These waters poured over the eastern side of the island in such a quantity that the nearby sea remained muddy until late autumn.

This second account by Veniaminov (who began serving this area shortly after this event) seems to account for the six month agitation of the sea, and fixes a date. The 3.3 mile width may account for the distance of inundation reported by Soloviev but this was a lahar, or mud flow from melting ice and snow on the volcano. It does not mention anything that could be considered a tsunami report. See following entries for 1826 and 1827. Validity 0.

1826, October 22 (Gregorian date). Veniaminov (1984, p. 19) reports, "On October 11, 1826 [Julian date] with a dull noise, it [Shishaldin Volcano on Unimak Island] burst, emitting strong flames and a large quantity of ash of whitish color, which covered part of Aliaksa, Sannakh [Sanak], and the islands closest to the latter, and was carried even to Unga."

"Chernoburoi Island . . . is a long, low island, abounding in different kinds of edible roots. On this account in 1823 a single pair of hogs were let loose on it and after three years about a hundred of them were seen. In the winter of 1827, however, all, without exception, perished, partly because of Unimak's soot and partly also—and more—from the cold " (Veniaminov, 1984, p. 125).

A letter from the chief manager Christiakov to the Main Office of the Russian-American Company (January 18, 1828) reports:

> Manager Petrovskii [of the Unalaska office] reports to me that on 12 October 1826 the ridge of mountains lying on the southwest side of Unimak Island split after the strong rumbling of an earthquake and terrible shaking, having thrown out much ash, so that islands lying nearby, especially Sannakh and Chernoburoi were covered shin-deep in it. And according to *baidarshchik* [work leader] Kharion Merkul'ev, who was on Unimak, he and his *artel* [work party] did not see the light of day for eight days and it was impossible to go out into the open air because of dust from the ash, and after that all the inhabitants suffered with eye disease and a cough. . . .The pigs released on Chernoburoi Island in 1823, which since that time have multiplied greatly, all died either from the great frosts and deep snows or from the soot with which the whole island was covered after the earthquake. They were found by the streams in dead heaps.

(Russian-American Company Records, 1828). There is no mention of wave action in this account and it is included as it may relate to the previous and following accounts. Validity 0.

1827, August 8 and 9. This is apparently a confused entry of an earthquake on Copper Island and the eruption of Pogromni Volcano. (See the 1820, 1825, and 1826 entries above). The eruption resulted in the deaths of some swine on Chernabura Island. Dall (1897, p. 335) reports, "1827. All the hogs on Chernobour perished from the tidal wave which accompanied an earthquake and eruption of the volcano on Unimak."

He did not give a date more precise than 1827. He mentions that the volcanoes of Shishaldin and Pogromni (on Unimak Island) and Tanaga and Koniuji (in the Andreanof Islands) were erupting in 1827 until 1829. He lists an earthquake as having occurred on Copper Island in 1827 but does not relate it to the volcanic eruptions. However, Copper Island is in the Kommandorski Islands, Russia, and not related to these eruptions (Dall, 1897, p. 469).

Soloviev and Ferchev (1961) state that while an earthquake did take place there, there were no reports of a tsunami. The swine drowning report is almost certainly related to the swine deaths due to ash fall mentioned in the previous event.

There probably was no tsunami event being described in these four accounts. The volcanic activity continued for several years. Validity 0.

1845–1847? The 1905 collapse of a perched glacier, now named Fallen Glacier, into Disenchantment Bay was studied by Tarr (1909, p. 68). He reports:

> The Indians stated that this was the third time the glacier had fallen; but on questioning them it was evident that the tradition merely referred to a glacier falling from the west side of the bay, and not specifically to this one. The last fall, which was said to have occurred about sixty years ago, is listed in several catalogs as having occurred in 1845, perhaps summer. However, this date is very approximate. It is reported to have destroyed a hundred Indians who at the time of the ice fall were at the summer sealing camp a few miles south of Haenke Island. It is said that only one of the Indians in the camp was saved.

Frederica de Laguna (1972) reports the following as a legend "long before the massacre . . . All of a sudden a glacier, now only a tiny canyon glacier straight opposite Wuganiye, [collapsed] and it came as such a sudden slide, i.e., it killed many of the young people camped at Wuganiye across the bay." Wuganiye was a sealing camp located about one mile east of Point Latouche at the second stream feeding into the bay. These events are not very precisely dated. If the sixty year period was literally taken, it would imply a date of summer, 1845. However, the Sitka earthquake might have been the triggering event.

Tikhmenev (1978, p. 420–421) states, "Earthquakes are frequent at New Archangel [Sitka]. Those which occurred in December 16, 1843 at 4 P.M. and in March 18, 1848 [Julian dates] were of considerable magnitude. The latter lasted for 25 seconds, chimneys knocked down and stoves cracked." They were described as coming from the northwest and strong enough to cause terror in the populace. Scidmore (1897, p. 116) reports, "Governor Kupreanoff built a large mansion which was nearly completed at the time of Sir Edward Belcher's visit, 1837. It was destroyed by the great earthquake of 1847." There is no mention of an earthquake in Sitka in 1847 in the Russian-American Company records. The report for that year was written by the company manager, who also lived at the mansion. Any repair to this structure would have been a major expense and noted in the report. Thus, extensive damage to Sitka at this date is unlikely.

". . . in 1847, at the time of the great Sitkan earthquake, flame and ashes came from Mt. St. Elias' summit" (Scidmore, 1897, p. 132). Mount Saint Elias is not a volcano.

"In 1847 a general earthquake was felt on the Alaskan Coast being very severe at Sitka. This is doubtless the shock referred to by the newspapers of 1899, which allude to the Yakutat Bay earthquake as 'the most severe since the time of the Russians'" (Tarr and Martin, 1912, p. 88).

The collapse of glaciers into Disenchantment Bay has happened several times (1958, 1905, 1899) in conjunction with large earthquakes. As the date of occurrence of this event is only approximate (based on the "60 years" of the Indian legend), it probably was associated with a large earthquake. However, neither of the Indian legends mention the occurrence of an earthquake with the glacier collapse and the 1905 event that Tarr observed did not have an earthquake associated with it. In a letter to the Metropolitan of Moscow dated May 1, 1848, Khlebnikov states, "On 18 March of this year we had a strong earthquake. With the first shock, which lasted for more that 10 seconds, all the wall clocks in town stopped and the stove chimneys on the large houses were damaged" (Liapunova and Fedorova, 1979, p. 200). Validity 3, but the date is uncertain.

Late 1853/Early 1854. Studies conducted by Miller (1960) in Lituya Bay during the period of 1948 to 1953 uncovered evidence of a large wave that had occurred there a century earlier. The evidence was a well-marked zone in the forest that grew on the north and south shores of

Lituya Bay. Above the demarcation line grew the old forest while below it only younger trees grew. By counting growth rings on older trees (which had been injured in the event) it was determined that a wave had cleared the forest at the lower elevations between the growing season of August 1853 and May 1854. The maximum height of this boundary was 120 meters and the maximum distance of the inundation was 750 feet. The area swept was at least 1.3 square miles, similar to the event of 1958. The source region is uncertain. However, the pattern of the trim line suggests that it was probably from a rock slide on the south side of the bay near Mudslide Creek. (See Figure 13.)

There are Indian legends possibly relating to this event. Williams (1938, p. 19) relates a story of a large Indian settlement near the entrance of Lituya Bay. One day when the men returned from hunting at sea they found the village destroyed and only a single woman survivor, who had been berry picking high on the hill. The village site was abandoned. In another version, two hunters in the mountains looked down on the lake (Lituya Bay?) on which their town was situated. They saw a great flood pour down between the mountains and destroy the town. This would indicate a source at the head of the bay in the Gilbert or Crillon Inlet.

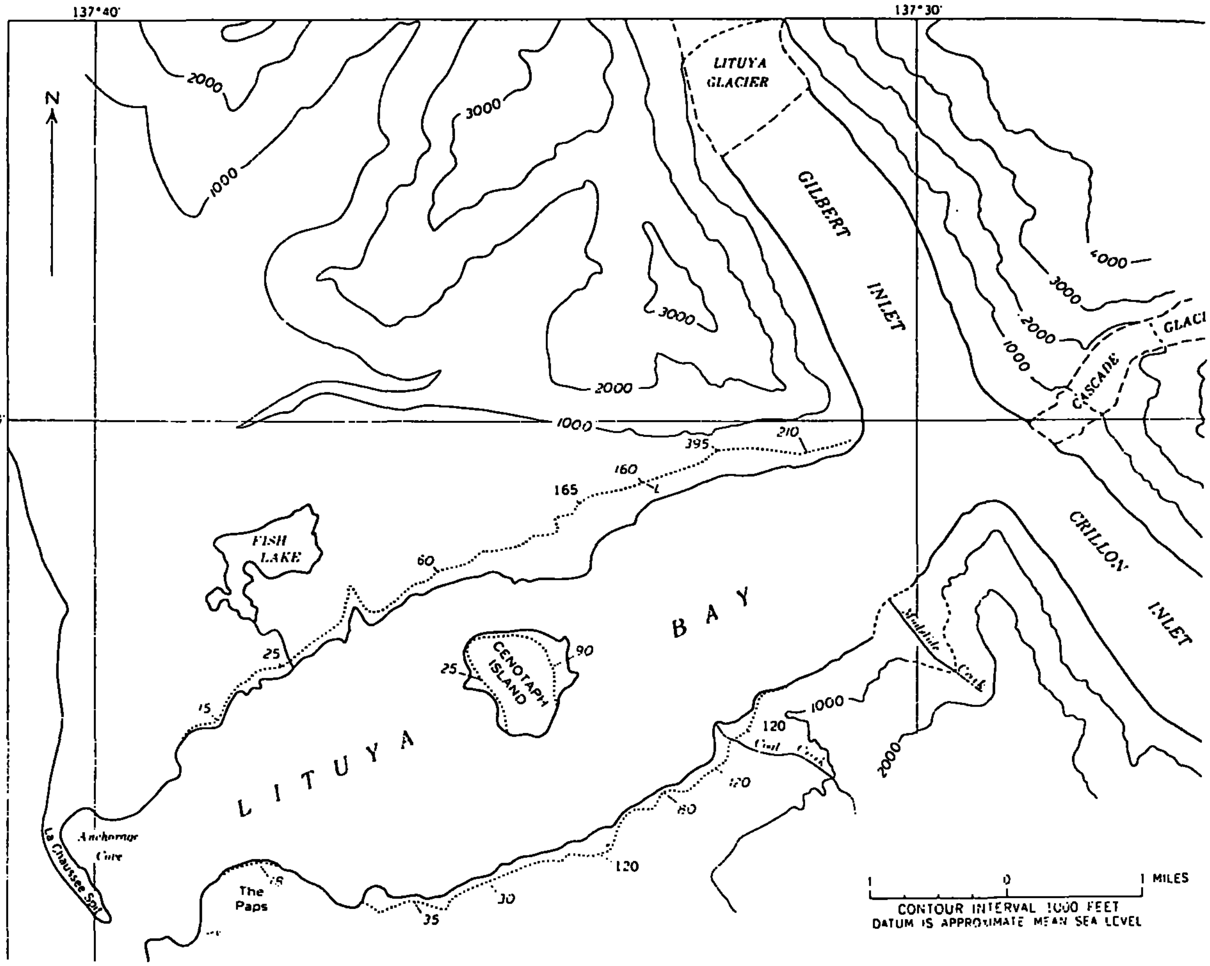


Figure 13. Map of Lituya Bay showing trim lines for the landslide tsunami which occurred in 1853 or 1854 (Miller, 1960).

"This flood was caused by an avalanche which poured into the lake and filled it up, forcing the water out" (de Laguna, 1964, p. 276). Also, de Laguna (1972, p. 270) mentions that the town of Gusex in Dry Bay was abandoned when several canoes from the town were lost at Lituya Bay, but cannot date the event. The final abandoning of the town was after 1852. Another account by de Laguna (1972, p. 273) records that 10 war canoes with eight men each were supposedly lost when they arrived at the entrance during the wrong stage of the tide and were killed on Sea Lion Rock. Yet another account mentions seven and eight canoes being capsized at Lituya Bay. Whether these accounts are of one or more disasters and whether they refer to destruction by waves or by the treacherous tides at the bay entrance is unclear. It seems unlikely that eight or ten canoes would all have been lost to the currents at the bay entrance.

There is another Indian legend that a glacier broke on the Alsek River and the natives tied their boats to an island in Dry Bay. The young people untied their boats too soon and a great wave came along and upset the boats carrying the people to the ocean. Only the old people survived (de Laguna, 1972, p. 276). This sounds similar to the damming of the river caused by the 1958 earthquake, but would not be a tsunami.

It is tempting to combine these events with the poorly dated account of the 1845 glacier collapse in Disenchantment Bay and the 1847 Sitka earthquake. However, the tree-ring date for the Lituya Bay seems to fix that event to near the 1853–1854 period but an under-counting is possible. Therefore, these are considered as separate events; the Lituya Bay event does not seem to have been associated with an earthquake. This is the earliest of five landslide tsunamis reported for Lituya Bay by Miller (1960). The others occurred on 1874, 1899, 1936, and 1958. A possible new event in 1900 is reported in this volume (page 56) for the first time. The 1958 event removed all but about one mile of the old trim-line on the north shore.

La Perouse (1798) discovered the bay in 1786 and lost 21 men in two boats to the treacherous tides while surveying the harbor entrance. His writings and those of the Russian trappers and fur traders did not mention any Indian stories of large waves so there probably had not been any in the recent history preceding their visits. Validity 4 with some uncertainty on the date.

1854, January 27. An earthquake shortly after 8 A.M. lasted more than a minute in Pavlovskaya Harbor (Saint Paul's Harbor, now Kodiak on Kodiak Island). "At the first onset of the underground thunder on January 16 [January 27, 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). Both the statement that the waves began at the first onset of the shaking and the short period of the waves suggest a local landslide source.

This event was not recorded by the tide gages at San Diego, San Pedro, or North Beach, but apparently was observed in Hilo. Cox and Morgan (1977, p. 14) cite a letter dated January 30 written by Titus Coan, a missionary at Hilo. Coan mentioned unusual water level oscillations occurring not long before. Cox and Morgan estimate that the wave was 4 to 8 feet—large enough to have been noteworthy and yet not to have caused damage. Given the lack of a recording, the event would have to have been quite small. Validity 3.

1856, July 26. There was a volcanic eruption in Unimak Pass. It is described by Captain Neville, of the whaler *Alice Fraser*. Crossing Unimak Pass on his ship with six other whalers, he observed an enormous mass of dense black smoke from a volcanic eruption on the adjacent islands. The ships were becalmed, leaving them exposed to the danger of the eruption. After twelve hours, a light breeze enabled the ships to begin moving away in the pitch blackness. Sailing west and north of the eastern shore they were near the northern base of the volcano when a prolonged dull rumble was heard and an underwater eruption began almost under the flotilla. The water churned and began to rise stormily in the form of disorganized waves. Then it rushed up, as if ejected from an enormous spring, forming a dazzling column of water of colossal height. A shaft of fire and smoke rose from the depths, with peals of thunder. Volcanic ejecta, the size of walnuts to cannon balls, landed on the ships. This phase ended quickly and water rushed into the abyss forming a colossal whirlpool. The ships escaped (Perry, 1859, 1865). The volcano was Mount Shishaldin. As this is a report taken from American sources the date is Gregorian. None of the effects describe organized wave actions, and this probably is not a tsunami report. Validity 1.

1865, July 15, 4:00 P.M. Chief Manager Maksutov wrote to the Main Office of the Russian-American Company:

> On Unalaska Island on 4 July 1865 [Julian date], at the beginning of the fifth hour in the afternoon [just after 4 P.M.], in calm, clear weather, the inhabitants were suddenly startled by a strong rumble and noise from the southwest and a strong earthquake that continued for five minutes. The cliffs collapsed and the locality where the settlement of Unalaska is located sank considerably. The earth in some places was cleft and from the fissures water appeared. The fissures remained to this day. Some Aleut *yurts* were completely demolished, and of the company buildings, some were considerably damaged and others were completely demolished.
>
> Immediately after the earthquake, the water, contrary to the ordinary, began to rise more and more, so that the manager of the island, fearing inundation of the company stores standing in a low place, was forced . . . to commence transferring the goods and supplies to an elevated and safe place . . .

(Russian-American Company Records, 1865). This description is clearly of a major earthquake, but the effects describe subsidence with nothing to suggest wave action. Validity 1.

1866, September 5, 3:00 A.M. There was a strong earthquake at Kodiak that half destroyed the landing at Woody Island. Many buildings and most stoves and chimneys were damaged (Davies and Kisslinger, 1987). In Huggins (1981) there is a description of the effects of the Arica, Peru, tsunami of August 1868 with a mention of the still-remaining effects from an earlier event. Huggins states, "A very severe earthquake, accompanied by a tidal wave, occurred there [Kodiak] some years ago. The effects of which are still visible in the warping and twisting of such houses as have not been built or rebuilt." From the Russian-American Company Records, 1866:

> At Pavlovsk Harbor [Kodiak], at the beginning of the fourth hour in the morning [just after 3 A.M.] of 25 August there was a strong earthquake in complete darkness and a strong wind with rain. In nearly all the houses chimneys tumbled down and stoves split . . . On Lesnoi [Woody] Island the dock was demolished and the shed fell on its side . . . In one place [at Kalsin] the earth settled by an *arshin* [28 inches] . . . In the middle of the broad bay opposite the *kekurs* [sea stacks] the water seethed for three days.

The report doesn't specifically mention a tsunami as the Huggins report asserts without details. Since the event occurred at night waves may not have been noticed, or reported. No tsunami was seen on the San Diego marigram for this date and the San Francisco record was not found. Validity 2.

4.2 Tsunamis of the American Period: 1868–1964

1868, May 15. Tarr and Martin (1912, p. 89) report, "Becker states that 'during a slight earthquake the elevation is said to amount locally at Unga to over 20 feet.'" Perry (1875, p. 51) states, "During the earthquake, the water in the port on the northern side of Unga Island was agitated. At some places the level rose 6 meters [20 feet]." It is not clear from the report whether the elevation refers to the height of the wave, the height of the runup, or uplift of the land. The latter seems impossible given the small size of the earthquake. Similarly, it seems excessive as a wave height. A landslide source could account for the small earthquake and large wave but it is not known if there are potential sources for landslides at Unga.

A third possibility is that this report is a misdated report for the August 14, 1868, Arica tsunami described below. The size of the reported wave would be similar to that reported from Kodiak and the earthquake report could have been an unrelated minor event on May 15 combined with a wave from the Arica event. It was not recorded on the Fort Point or San Diego marigrams for this date. Validity 2.

1868, August 14, 01:30 GMT. The great Arica, Peru (now Chile) earthquake was observed at Kodiak. Huggins (1981, p. 18) reports:

> A singular phenomenon was observed on the 7th [*sic*] of August [1868]. A ship approaching the harbor struck a rock about twelve miles distant and sprung a leak. After reaching the harbor and unloading her cargo, her stem was run as far as possible upon the beach at low tide and a hole dug under her keel to enable the ship's carpenter to make repairs. Just before noon [the first waves from the first tsunami would have been expected at about 5:20 A.M., and from the second at about 9:20 A.M.] although no tide was due for some hours, the sea rose several feet, drove the workmen away, and in a few moments again subsided. This was the tidal wave accompanying the destructive earthquake which laid ruins to Arequipa and other cities in South America . . . It created a good deal of excitement in Kodiak, especially upon the vessels, of which there happened to be three in the harbor.

The following letter report is from Tidball (1870):

> Saint Paul, Kodiak, Alaska Territory
> October 18, 1868
>
> Dear Sir:
>
> Supposing that it would be of interest to you I have the honor of reporting the occurrence, at this place, of an extraordinary ocean-wave which took place between 10 o'clock A.M. and 2 P.M. on the 14 of August.
>
> I was not here myself to witness it and there was no special or accurate observation made of it but from those who did witness it I learned that at the time of the first wave the tide was about one-third ebb—the tide here runs about ten feet—and in about half an hour it rose to about four feet above ordinary high water. It then receded and afterwards, at intervals of about an hour each it would come and go each time going less and less.
>
> I observe by the papers that this was on the day of the great earthquake in Peru and no doubt this wave was caused by it, and being so marked at this distant point, it will no doubt prove an interesting fact to you.
>
> I will make further inquiries, when I have an opportunity of so doing whether any wave was observed at Ounalaska (Unalaska), Saint Paul, or any other islands westward of this.

No other report from Tidball was found. Tidball's estimates of the tide would be a wave amplitude of between 7 and 8 feet. Given a tide range of 10 feet, the tide stage of 1/3 ebb or 3.3 feet below high tide and a wave height of 4 feet above high tide, would make the wave 7.3 feet. These include several estimated values so that an amplitude of 7 to 8 feet is indicated.

This is the first reported and one of only three directly observed teletsunamis reported for Alaska. Validity 4.

1872, August 23, 18:00 GMT. On August 23, 1872, a tsunami was recorded on the marigrams at Astoria, San Francisco, San Diego, and Honolulu. The Honolulu marigram showed an arrival time of 12:25 local time (reported in the *Pacific Commercial Advertiser*, October 6, 1872). It was observed at Hanalei, Nawiliwili, Honolulu, and Hilo. Cox (1984) calculated the source of this event as being in the Fox Islands. This calculation was not fully convincing since the west coast readings were somewhat emergent and afforded little azimuthal control. The Hawaiian marigram could not be located and its critical control depended on newspaper accounts.

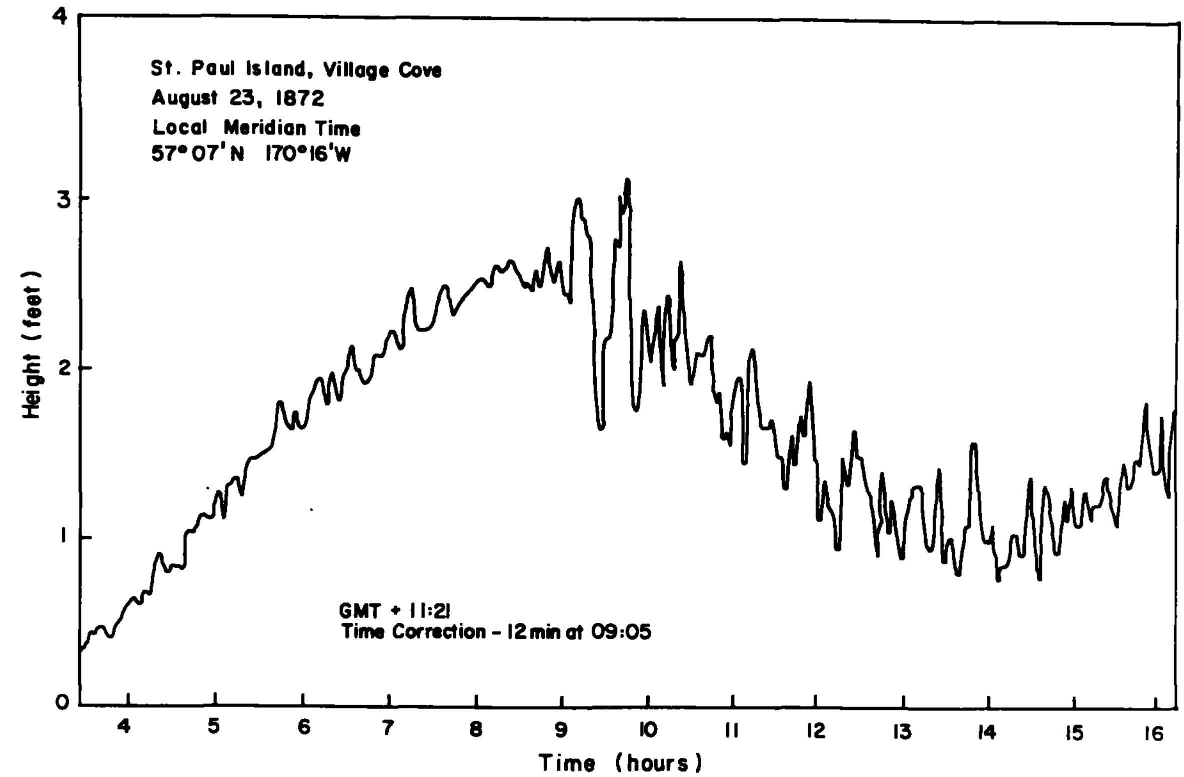


Figure 14. Marigram from Village Cove, St. Paul Island (Pribilof Islands) for August 23, 1872.

The first attempt to locate this event by Professor Davidson of the Coast Survey and the University of California, was published by Yale (1872), based on the west coast marigrams and a reported time from Honolulu supposedly two and three-fourths hours earlier than at San Francisco. This faulty time difference led him to compute a Kuril Islands source for the event. The time difference should have been about one and one-half hours.

A report from Hilo by the missionary Coan of a 4 foot 2 inch wave was incidental to a report of a recent eruption of Mauna Loa and later writers associated the wave with the eruption and an implied Hawaiian location.

Soloviev and Go (1974, p. 191) noted the report of a tsunami in the Bonin Islands at about this date and suggest that might be the source.

Recently, Lander found a marigram from Saint Paul Island, in the Pribolof Islands, Bering Sea, which recorded this event (Figure 14). It shows an initial rise of 0.5 feet at 20:14 GMT and a period of 33 or 34 minutes. The new data essentially confirms Cox' solution and puts to rest a 120-year search (Cox and Lander, 1995). The marigram is the earliest of an Alaskan tsunami, and the location is the first instrumentally-located tsunami source in the world. It is also the first instrumentally-located earthquake source as well and a new entry for the earthquake catalogs. It fills a seismic gap as identified in Davies et al., 1981. The earthquake and tsunami were not reported as directly observed in Alaska. Validity 4.

1874 May. Miller (1960, p. 74–76), during his field investigations in 1953, reported seeing evidence of another great wave in the form of an earlier tree trim line near the Fish Lake outlet and above the trim line of the 1936 tsunami tree line. He was able to determine the age to be about half way between the 1853–1854 tsunami trim line and the 1894 photograph. He did not take a cross section of one of the trees; a tree ring count could not be made. The date halfway between 1854 and 1894 would imply an origin of 1874. Dall (1883, p. 203) reported:

> There is some reason to believe that in winter the bay freezes over, and when this ice breaks up ice gorges occasionally form in the contracted portion near the entrance, backing up the waters of the bay behind them, as drift and evidences of flooding and washing were observed along the shores by the U.S. Coast Survey party in 1874 to a height of at least ten feet above high-water mark. The ravines show evidence of freshets when the snow melts, but in May were mostly dry, and little running water was observed, though there are a good many little ponds or lagoons of fresh water a short distance from the beach in low places . . . The water of the bay is discolored by melting ice mixed with mud derived from the glaciers.

The date of 1874 is based on half the interval between the 1854 and 1894 estimated from the trim lines report, and the date of May now given is based on the above report of still-muddy water and standing water. Dall's explanation of an ice dam is rejected. The bay has never been known to freeze over but the water is murky due to the sediment carried by the glacial streams that feed it.

Miller (1954, p. 74–76) reports that vegetation was destroyed over a distance of 4 or more miles along the north shore, reaching a maximum altitude of 80 feet, and maximum width of 2,100 feet back from the shore. Most of the evidence of this trim line was destroyed during the 1936 wave and all the remaining traces by the 1958 event. The 1894 photographs show fresh-looking scarps on the northeastern wall of Gilbert Inlet, and in the valley of Mudslide Creek. The Gilbert Inlet site is unlikely as the photographs do not show a corresponding trim line on the opposite shore, the expected site of the maximum runup. Therefore, the likely source of this slide was from Mudslide Creek Valley. There is no report of an earthquake with this event but there were few observers in the area. Validity 3.

1878, August 29. Rockwood (1879, p. 161) reports "Letters from Alaska dated September 1, state that frequent shocks had occurred during the summer, in connection with renewed activity of the volcanoes of the Aleutian Islands. On August 29 the village of Makushin on Unalaska Island was destroyed by earthquake shocks and tidal wave." Fuchs (1879, p. 115) reports, "29 August [1878]. About this day a destructive earthquake and following tsunami destroyed Makushin on Unalaska Island." This same short report was picked up and repeated in all subsequent catalogs. Mushketov and Orlov (1893, p.468) state, ". . . the village of Makushin on Unalaska Island was destroyed by an earthquake" and cite *Vsemirnaia Illustratsia*, 1878, No. 515, p. 406, November 11 1878, a Leningrad journal. As this reference predates the Rockwood and Perry references it may be the source of the reported letters.

Martinson (1973, p. 102) reports, "The Village of Makushin was moved from its former position at Volcano Bay some five miles to the southwest to its present location on Makushin Bay sometime between 1832 and 1880. No other village sites seem to have been occupied in the area since about 1875." The move may have been made due to the poor landing beach at Volcano Bay (Martinson, 1973, p. 151). Petroff (1884, p. 21) reported:

> In the year 1878 the island (Unalaska) was disturbed by a volcanic eruption and a small mud volcano arose between the prominent peak near the southern end of the island and the village. In 1880, both the old and new peaks were still smoking, and the latter spattering. During the shaking and trembling connected with these phenomena the fish seem to have left the shore and the inhabitants were for a season obliged to go to adjacent islands to lay in their winter supply. . . . Makushin is a very poor village of about fifty inhabitants, with a chapel, but no store. . . . Their fishing grounds were so disturbed in 1878, by the

volcanic eruption on Oomnak Island, that they were compelled to move their old village to the present site.

Nick Galaktionoff, an longtime resident of Unalaska, gives an account of a plague that struck the islands at this time. He believed that about thirty people died at Makushin. The people were still living at Volcano Bay but were in the process of building new homes at the Makushin Bay site. Lumber from the new homes was carried back to the old site and used for coffins. When the illness passed, the survivors knocked down the homes at Volcano Bay and moved to the new site to prevent the disease from returning (Galaktionoff, 1978, p. 25–26). However, this plague struck in 1881 with 6 people dying of Kolot'e, a disease of stabbing pains in the abdomen and lungs. In Unalaska, 92 people died that year from this disease and asthma, and 35 more the following year as given by the vital statistics records for the *Alaskan Russian Church Archives*, Unalaska Parish, Reel 400.

No mention of a tsunami disaster or plague has been found in contemporary records and the villagers apparently continued to trade with Kodiak during this period. The *Church Archives* (Reel 400) vital statistics lists only one death in 1878 in Makushin due to "blood-spitting." The villagers had petitioned the church officials in Kodiak to move their church to the new site. (A new chapel was built and consecrated in 1885.) A letter from the priest Shaiashnikov to Bishop Nestor on November 13, 1881 (Gregorian date) noted that the inhabitants wanted to transfer their chapel to their new settlement at Staraia Gavin "where they are living for the second year already." It describes the poor condition of the existing chapel and the difficulty of continuing to use it because of its 6 or 7 *verst* distance from the new settlement. It does not give any reason for moving the settlement but does fix the date of the move to 1878 or 1879 (*Church Archives*, Reel 67, Frame 405).

A search of Rockwood's papers at Princeton's library failed to locate the source of the 'letters from Alaska.' It seems unlikely that the letters were sent directly to him as he used mostly newspaper clippings for his histories. The village was abandoned during World War II, and not reoccupied. Apparently, volcanic activity, associated earthquakes, and the loss of fishing grounds caused the move of the village. Validity 1.

1880, September 29, 04:00 GMT. From *U.S. Signal Corps Annual Report for 1882* (U.S. War Department, 1883, p. 120):

September 28, 1880, 6 P.M., three very heavy and successive shocks, direction of the first shock N to S, the remaining two from W to E; 9 P.M., severe shock from W to E. 29th 3 A.M., very heavy shock from W to E; 1 P.M. Extremely heavy shock from W to E. From the commencement of this phenomenon, September 28, 1880, until its subsidence October 16, 1880, there was an uninterrupted trembling motion of the earth interspersed with heavy subterranean rumbling sounds.

During a short trip over a portion of the island [Ukamok or Ookanok, now known as Chirikof] on September 29, deep fissures with a width of from 15 to 20 inches were found to be numerous. The residence of Mr. Newlander, one story high and substantially built of logs, was situated about 500 yards from shore [the Southwest Anchorage], on rising ground and about 20 feet above sea level. During the heavy shocks shelves were wrenched from the walls, a brick stove upset, the flooring twisted out of shape and heavy beef and flour barrels (full) were pitched from one side of the room to the other. Outside of the building no one was able to stand on their feet owing to a violent jerky, and rotary motion of the earth, which continued for at least 20 minutes.

The action upon bodies of water is given as follows: Several times at low water the sea rose in a body, traveling inshore about 60 yards, when it would subside, immediately followed by a succession of similar waves. The water in the creeks overflowed their banks to the eastward, as indicated by the condition of the ground on that side, which was dotted by numerous small pools of water, some of which were fully 40 yards distant from the east bank. On the south side of the island a small, shallow creek, across which

> one could easily stepped previous to the earthquake, was now widened about six feet; the fresh water was changed to salt water, and the depth was so increased that the bottom was not discernible. After the shocks, heavy breakers were observed on the southwestern shore of the island, where, for the past four years, no such phenomenon has been observed. On the west side of the island, the tide does not rise as high as before the shocks.

Moore (1962, p. 9) reports that the northeast trending boundary fault was tilted abruptly to the southeast and the southeast boundary fault showed vertical displacement of 6 feet still preserved in dammed streams and uplifted wave cut terraces. Petroff (1884, p. 90–91) mentions that the earthquake was felt in the Semidi Islands and Chirikof Island. It was not felt at Kodiak and the adjoining islands. The marigrams from Kodiak, Honolulu, and Sausalito were examined for this study and no unusual activity was noted. The shock must have been very local to have produced such a sharp earthquake with a vertical uplift of 6 feet and a tsunami. It was not felt at Kodiak nor recorded on the Kodiak tide gage. The shore would have had a very gentle slope if the house was 150 feet from the shore and still only 20 feet above sea level.

Soloviev and Go (1974) following Petroff suggest a connection between this event and the October 26, 1880 (Julian date) event at Sitka that follows. These are two separate events. This event clearly was local to Chirikof with observed faulting and the October 26 tsunami appears local to Sitka. Validity 3.

1880, October 26, 22:20 GMT. "A severe shock was felt at Sitka, Alaska, followed half an hour later by a second shock and by seven or eight more in the succeeding 48 hours. The first and most violent continued twenty or thirty seconds, none of the others more than two or three seconds. This earthquake appears to have been felt along the coast of British America and to have been accompanied by a tidal wave, of which, however, no details have been received" (Rockwood, 1881, p. 198–202).

The *Monthly Weather Review* (Chief Signal Officer, 1881, p. 999) states:

> The following graphic description of a remarkable series of shocks occurring in Sitka, Alaska in October and November, 1880 and which lasted for several days, is taken from the report of a special correspondent of an Oregon paper. . . . 1:20 P.M. severe shock of an earthquake—oscillations from true east to west. Rumbling; earth wave passed; second severe upheaval, with cracking and splitting noise in and under the ground; third slight shock with apparent return wave. The houses of the town were regularly upheaved in the order in which they stood, showing a true wave. Time from the first to the third, about 18 seconds.

The Weekly Intelligencer (Seattle, Washington, December 4, 1880, p. 3):

> Earthquake at Sitka—M.P. Berry writes from Sitka as follows concerning the great earthquake at that place in October last: On board the ship *Jamestown* the earthquake of the 26th was so violent that it was compared to striking a rock. On Tiniagreff Island (north of this island [Chichagof Island]) southeast end it was very violent. At Hoonah village, north end [Chichagof Island], it threw the Indians around like chips in an eddy. On the southeast end of Admiralty Island it shook things up lively. On the mainland, due east from the last named island, a friend who was on a quartz prospect informs me that the 'quake' as he calls it threw him on his head, and I believe him. The Indians here and hereabout were very much excited. Redoubt Lake, on this island, rose six feet instantly, and fell as quick—measurement by the lodgement of drift. At Warm Springs, twenty miles southeast, the invalids who were there tell me that the spring spouted like geysers. Two Russians, who were prospecting at Whale Bay, 36 miles southeast, say that the shocks were very severe and that a tidal wave of huge proportions ran into the bay, which I think is very likely as it opens broad to the sea.

This appears to be a report of two local tsunamis on Baranof Island, one in Redoubt Lake, and a second in Whale Bay. These probably were very local submarine landslide-generated tsunamis. Validity 3.

1883, August 27, 02:59 GMT. Small waves were recorded on the Kodiak marigram of August 27 at about 1:30 A.M. local time. These had been generated by the air waves from the explosion of Krakatoa Volcano in Indonesia. These are not considered to be tsunamis since they traveled by air and not water to the gage.

Later-arriving waves probably were generated by air waves acting on the coastal water of the Western Pacific over time and also do not fit the definition of a tsunami (Ewing and Press, 1955). Validity 0.

1883, October 6, 19:04 GMT. Davidson (1884, p. 186–188) reports that at about 8 A.M., residents of English Harbor near the south end of Kenai Peninsula heard an explosion and saw a dense cloud of smoke rising from the top of Saint Augustine Volcano, 85 kilometers to the west, across Cook Inlet. The cloud moved toward the northwest. It soon expanded to obscure the sky and fine ash began to fall. Davidson writes:

> At about twenty-five minutes after 8 A.M. or twenty-five minutes after the great explosion, a great 'earthquake wave' estimated as from twenty-five to thirty feet high, came upon Port Graham [English Harbor] like a wall of water. It carried off all of the fishing-boats from the point and deluged the houses. This was followed at intervals of about five minutes by two other large waves, estimated at eighteen and fifteen feet; and during the day several large and irregular waves came into the harbor. The first wave took all the boats into the harbor, and the receding wave swept them back again to the inlet and they were finally stranded. Fortunately, it was low water, or all the people at the settlement must inevitably have been lost. The tides rise and fall about fourteen feet. . . .
>
> [According to statements of a hunting-party of natives in Kamichak], a column of white vapor arose from the sea near the island, slowly ascending and gradually blending with the clouds. The sea was also greatly agitated and boiling making it impossible for boats to land on or leave the island.

Port Graham is the name of the inlet and the community at the entrance to the inlet is English Bay. English Bay has been called English Harbor and Alexandrovsky, and there is now a community in Port Graham Inlet also called Port Graham.

The final thickness of ash was 4 to 5 inches at Kodiak (Davidson, 1884, p. 188) but Siebert et al. (1989) think this may be high. Ash was collected as far away as Iliuliuk settlement on the northeast coast of Unalaska.

Before the eruption on Augustine Island, seven or eight Aleuts had landed to hunt otter during the winter. Two women who had come with them refused to stay on the island, being frightened by the loud rumble coming from the volcano. They were taken to Saint Paul, Kodiak. After the eruption, no trace could be found of the hunters who had remained on the volcano, although a rescue party had gone along the coast to learn of their whereabouts.

The following is from the daily log of the Alaskan Commercial Company at Alexandrovsky (English Bay):

> At this morning at 8:15 o'clock 4 tidal waves flowed with a westerly current, one following the other at the rate of 30 miles p. hour into the shore, the sea rising 20 feet above the usual level. At the same time the air became black and foggy, and it began to thunder. With this at the same time it began to rain finely powdered brimstone ashes which lasted for about 10 minutes and which covered all the parts of land and everything to a depth of over one-fourth inch, clearing up at 9 o'clock A.M. Cause of the occurrence: Eruption of the active volcano at the Island of Chonoborough.

An annual report of the Russian Missionary at Kenai dated 28 May 1884 makes a similar reference to the waves generated. "This region suffered from inundation caused by the eruption of Chernobura Volcano." Both are references to the Saint Augustine Volcano.

A recently discovered notebook from 1898 by J.A. Spurr, U.S. Geological Survey, says:

> Trader says here at Katmai that eighteen years ago three families from Kodiak went with families and *baidarkas* [boats] to Saint Augustine Island to spend the winter. . . . The mountain began to shake so violently that they put all their effects in their *baidarkas* and started on a stormy day. Scarcely were they at the mouth of the bay when an explosion occurred. Ashes, boulders and pumice began pouring down and the *baraboras* [shelters] were buried and the bay filled up with debris. At the same time there were many tidal waves so that the natives nearly perished with fright, yet finally escaped.

Davidson had speculated that the tsunami must have been registered by the tide gage that had been established at Kodiak in 1880. Lander found the record in the NOAA archives. It has an arrival time of 8:31 A.M. and an initial drop in water level. Sokolowski (personal communication, June, 1994) questioned the record's appearance as a tsunami. Interpreting the records first arrival as the tsunami would imply an origin time of about 6:30 A.M., substantially earlier than the reported time of the explosion.

Lander interprets the first arrival as the air wave's effect on the water in Kodiak Harbor; the first motion of the water would be expected to be a drop. This would imply a time of about 8:21 A.M. for the explosion and ten minutes travel time for the shock wave to reach Kodiak. The tsunami would reach Kodiak in about 1 hour and 54 minutes or 10:15 A.M. according to travel time chart supplied by Paul Whitmore at the Alaska Tsunami Warning Center (Figure 15, next page).

There is a distinct change in character to a shorter period at about 11:00 A.M. which is probably the tsunami. The difference of 45 minutes between the expected time based on the air wave origin and the tsunami origin may be that the tsunami was generated that much later than the explosion. The explosion would have been heard in English Bay about 4 minutes after it occurred, or 8:25 A.M., and the tsunami would have arrived at 9:20 A.M. This is not in close agreement with the Alaskan Commercial Company's report of waves arriving at Alexandrovsky (English Bay) at 8:15 A.M. unless they were seeing initial air shock wave generated water waves. The tsunami travel time to English Bay is given as 63 minutes (Kienle et al., 1987). The maximum amplitude is only about 3 inches on the marigram. (See Figure 16, page 51).

Augustine Island is a nearly circular volcanic island about 7 miles in diameter and 6 miles off the western shore of Cook Inlet. It was named by its discoverer, Captain Cook, on Saint Augustine's day, May 26, in 1778. It is also mentioned as Chernoburyi Island, its Russian name, and variations of this spelling. It has had six significant eruptions: 1812, 1883–1884, 1935, 1963–1964, 1976, and 1986. Only the 1883 eruption produced a tsunami. However, there may have been an eruption or slide in 1903, as waves were observed in Enochkin Bay which opens directly north of Augustine Island (Tarr and Martin, 1912, p. 93).

The tsunami was apparently generated by a debris avalanche from the collapse of the north face of the peak. Except for Fuchs' confused report, no others report an earthquake. The slide consisted of about 325 million cubic yards of material moving down from a peak height of 4,100 feet and over a distance of about 5½ miles including 1 mile of newly created land at Burr Point and 1.5 miles further underwater (Siebert et al., 1989).

The island is essentially surrounded by similar underwater deposits indicating that tsunamis were probably generated repeatedly in prehistorical times. Beget and Kienle (1992) believe these have reoccurred about every 150 to 200 years on the average, based on the geologic record of deposits over the last 2,000 years.

The steam reported by the Aleut families fleeing the island could be the result of rocks heated by friction as they fell and on entering the water or

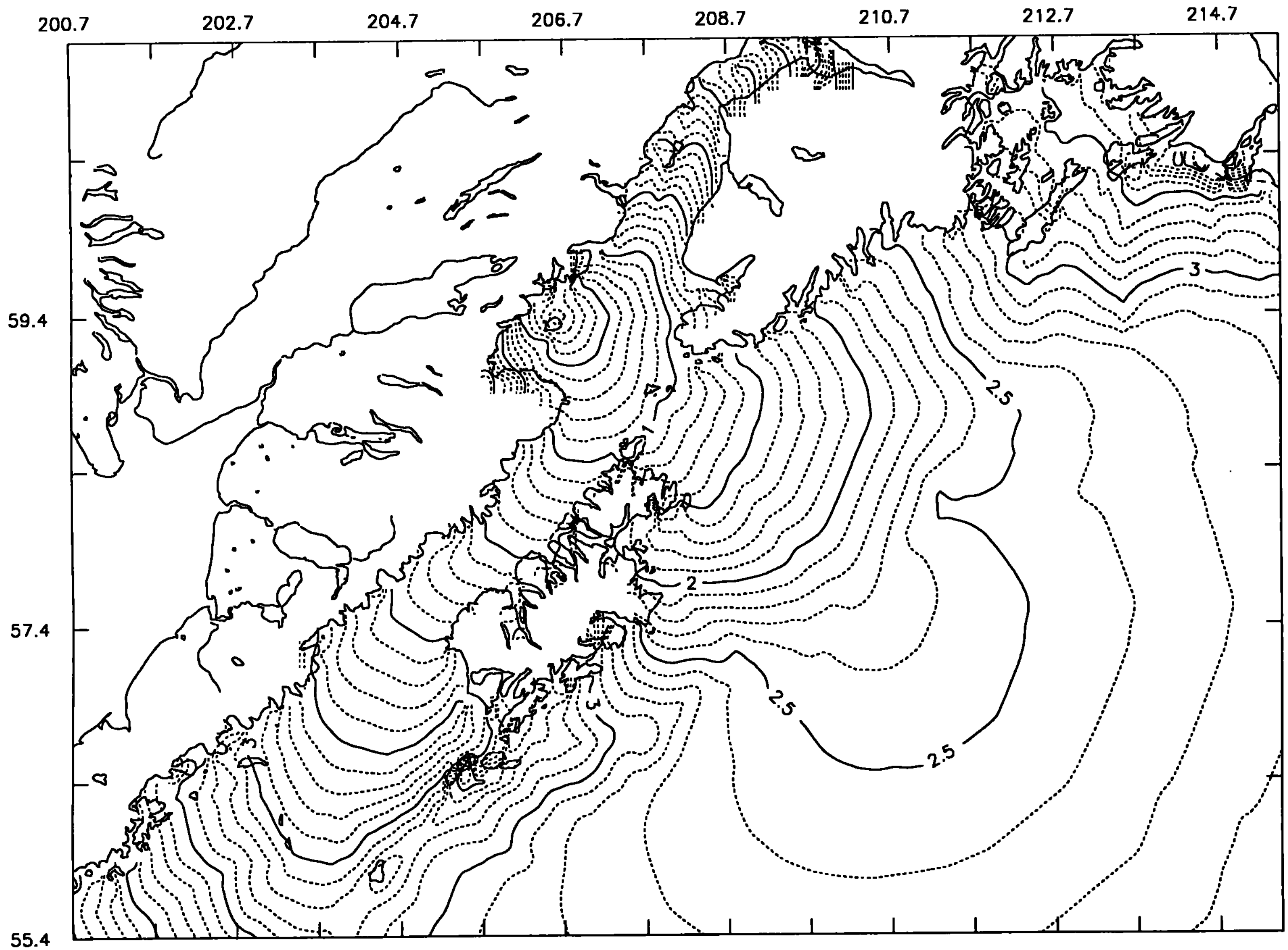


Figure 15. Tsunami travel time from Augustine Island. Contour lines are equal to 6 minutes. (Paul Whitmore, Alaska Tsunami Warning Center, 1995).

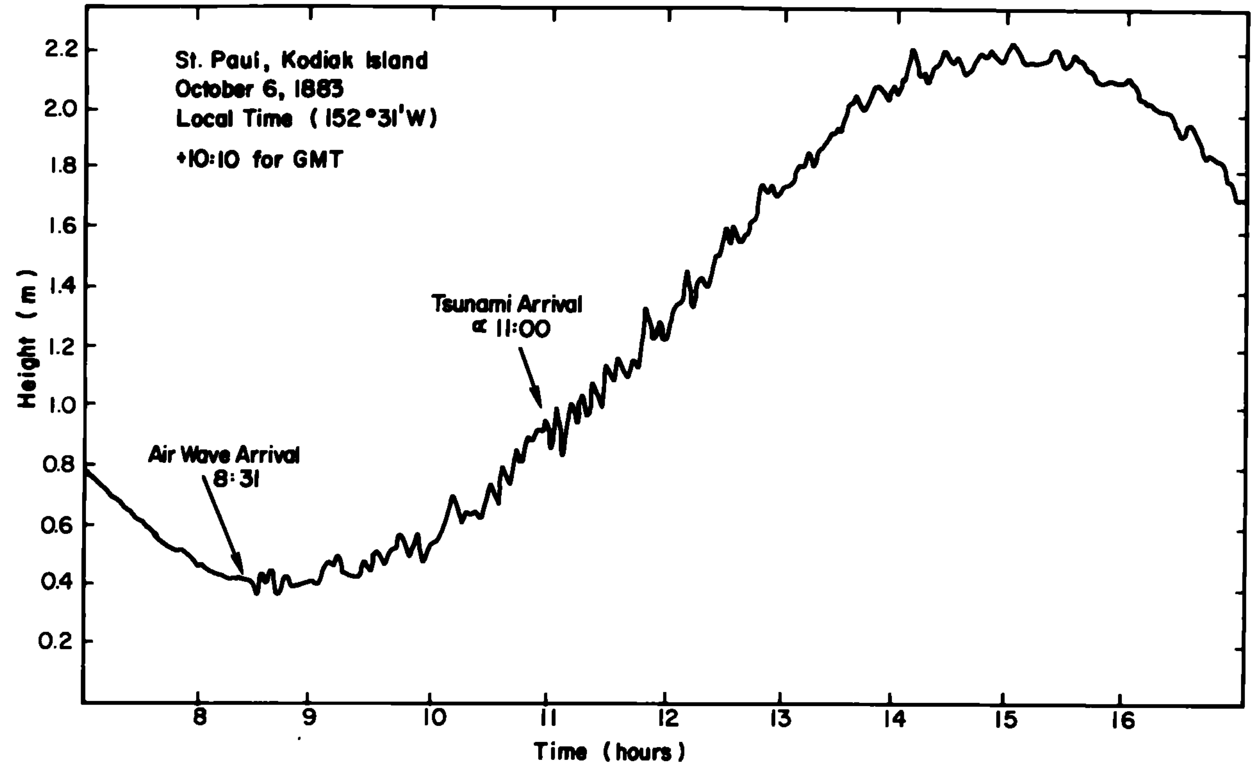


Figure 16. Marigram from Kodiak showing arrival of air wave and tsunami from the Saint Augustine volcanic explosion and debris tsunami.

material heated by the volcano. The mountain was normally snow covered.

Siebert et al. (1989) suggest that the explosion heard at 8 A.M. may have followed the landslide by 30 to 45 minutes. This would explain the apparent early arrival at English Bay twenty five minutes after the explosion was heard. Reports of a new island having been formed between Augustine Island and the Alaska Peninsula in Davidson were not substantiated by the bathymetric surveys and may have been a pumice raft. There may have been some casualties to the Aleuts, but the descriptions are not clear. Fuchs (1885, p. 218–219) gives an incorrect time of 15:30 for the October 6th event and wave heights of 10 and 6 meters. He also gives a second event as occurring on October 8th at 8:30 A.M. and wave heights of 5 to 6 meters. This latter event is repeated in later catalogs and is clearly a garbled account of the October 6th event. No activity was seen on the Sausalito marigram. Validity 4; validity 0 for the October 8th date.

1897, April 17. In a letter from Charles Swanson to M.L. Washburn, May 6, 1897:

> On the night of the 17th of April we had a tidal wave at this place [Nuchek, a small island in Port Etches, Hinchinbrook Island] which caused considerable damage. The old house of Captain Humphrey that you bought last fall washed away from its foundation and came very near going into the bay. The shed broke off of it altogether. The house is yet standing but has to be repaired some or it will blow down next winter. The new house that I built last summer also got some damages to it but it did not move it. Two window sashes broken and some of the siding torn off of the front part of it. It is about 100 feet of siding gone, I think.

There is no known earthquake between February and June for this area. The north shore of Port

Etches, which is about one mile north of Nuchek Island, rises steeply from the bay to a height of 2,421 feet in about one mile. A storm source from the Gulf of Alaska, or a landslide source, would have been possible. The marigraph at Sitka was not operating and only hourly staff readings are available. Validity 3.

1899, September 4, 00:22 GMT. At about 3:05 P.M. on September 3 (local sun time) a strong earthquake of magnitude estimated as 7.9 struck the Cape Yakataga area. "When the earthquake wave reached the reef in the harbor [Yakutat] there was a report as if it had been rent asunder by dynamite. It was partly out of the water and we could plainly see it shake. The water was agitated and was thrown up to a height of ten feet. . . Johnson's [a missionary] schooner was held upright on the flats in the lagoon. She was thrown over on her side, starting every seam" (*The Alaskan, Sitka*, September 16, 1899, p. 3). "At Kyak [Kayak] Island great fissures were opened in the earth and a tidal wave followed that swept inland hundreds of feet beyond the highest water mark on record" (*The Alaskan Miner*, September 16, 1899, p. 1).

Tarr and Martin (1912, p. 70–71) repeat eyewitness accounts:

> 'We all rushed out of doors to find the whole village gathered in the streets. Everybody was scared, and it was enough to frighten almost anyone, for looking toward the timber we could see the trees rocking back and forth, and the water [at Yakutat] crossing the reef in the bay was whipped into a mass of seething foam.' . . . At Cape Yakataga, 100 miles west of Yakutat, Capt. Ben Durkee, commanding the schooner *Bellingham*, also experienced this earthquake. On September 3 he was on board the schooner a mile off the coast. . . The first shock was plainly felt on the boat, which vibrated and shook as it were on a rock. Dust and smoke 'from the breaking of the tops of the mountains' were plainly seen, beginning at Icy Bay, 40 miles to the east, and extending to Cape Suckling [six miles southeast of Controller Bay] 70 miles to the west, consuming five to six minutes in running that distance. The tide set out from the shore at the rate of 3 or 4 miles an hour, and the schooner sailed out at the end of her anchor chain. The tide was slow about returning and reached about half the proper height, according to the tide tables. It returned quietly. . . . Capt. Durkee reached Kayak about 4 P.M. September 4 after a run in a heavy sea which taxed the schooner to the utmost. . . . S.E. Doverspike, a prospector and miner who was ashore at Yakataga, writes . . . 'The tide was at half ebb and receded to low water in 20 minutes, not to return high for 36 hours. The ocean beach was raised 3 feet, as noticed at the landing place on Yakataga Beach, the tide not rising high enough to get over the reef.'

A search of the marigrams for Ayogon and Saint Michael did not yield any records for this date and it was not recorded by west coast stations or Honolulu. This is at least two separate tsunamis, one in Yakutat Bay and one at Yakataga. At Yakataga there is a mention of the beach being uplifted and is probably of tectonic origin. The cause of the Yakutat Bay tsunami is less certain but is probably also tectonic. Validity 4.

1899, September 10, 21:40 GMT. There was a catastrophic earthquake of magnitude 8.9 in Yakutat Bay. It cause a maximum uplift of 47 feet on the western side of Disenchantment Bay (Tarr and Martin, 1912, p. 16). It was felt over an area estimated at least 216,300 square miles on land (Martin, 1910, p. 342). It triggered a number of separate tsunamis by both tectonic uplift in Yakutat Bay and submarine and subaerial landslides from Valdez to Lituya Bay.

Among the widely reported effect was the accounts of two groups of miners on Russell Fjord. The first group consisted of three men, Capt. Tom Smith, S. Cox and Dr. D.A. Cox, who were camped on a glacier outwash fan about 1,000 feet from the water on the north shore near its entrance to Disenchantment Bay and about fifteen feet above the water level. They were about one and three quarters miles southeast of Hubbard Glacier. About a mile further to the southeast was the second party of five men—A. Flanner, Dwight Stevens, Jack

Fultz, Jr., Tom Boland, and A. Anderson. The two camps were separated by a swift and unfordable glacier stream known as Johnson Creek.

The men had been there since before the earthquake of September 3, which they felt, and they reported aftershocks continued until September 10 with varying intensity. At 9 A.M. on the 10th there was a violent shock so severe that they could hardly keep from falling. At about 1:30 P.M. the hardest of all struck. They reported that it must have lasted two and a half to three minutes. They heard a terrible roar in the direction of the bay and saw a tidal wave of about twenty feet high approaching. It was preceded by great geysers shooting into the air, some of which were several feet across and thirty or forty feet high. This reported observation is not explained but could have been water geysers squeezed from compaction of sediments. The men immediately ran for higher ground. Realizing that the first wave would not reach their camp and needing to save their supplies to survive in the inhospitable environment, they returned to their tent. As soon as Capt. Smith reached the tent they heard the second and larger wave approaching that was twenty to thirty feet high. He escaped just as the water entered the camp. They reached higher ground, which required them to jump a number of crevasses.

The other group of miners also had a difficult time, threatened from the front by the tsunami and from the rear by the flood from a breached lake. Johnson Creek briefly divided into a number of channels and the men were able to wade through it and reach the Cox party. They had not been able to save anything, even coats and hats in some cases, and their boats were smashed. Their situation was desperate as they were on the wrong side of the fjord to be able to walk toward Yakutat, forty-five miles away, and were blocked from walking inland by two impassible glaciers. The Cox party, on returning to their camp a second time, found one serviceable boat and a little food. They decided that three should leave in the morning to find help for the others.

They spent a sleepless night in wet blankets, hearing the continuing crack of ice and the roar of landslides. Shortly after leaving they found a damaged Indian canoe and returned for the other five men. They repaired the craft and all were able to depart at one time after another wet night. It seems unlikely that a damaged but serviceable canoe would have been abandoned. This type of canoe could carry as many as eight people. (There is no word of the fate of the former owners of the boat.) There was little progress the next day, as the bay was full of ice. The men were forced to camp after making only about five miles progress. The site proved unfortunate and the nearby streams changed course, flooding their camp. They took to their boats at 3 A.M. The following day they were able to make good progress and observed places where the tsunami had left it mark fully forty feet above the water level in Disenchantment Bay. They reached Yakutat after another night of camping, surviving by eating the fish killed by the shock (*The Alaskan, Sitka*, October 14, 1899).

At Yakutat the most severe shock occurred at 12:30 P.M. The schooner *Crystal* lying in on the mud rocked from side to side. People were unable to stand. From the ocean three great tidal waves rolled in at about five minute intervals. The water rose fifteen feet from low tide to a foot above high tide. The bay was full of whirlpools, spinning trees, lumber, and driftwood moving around so fast that the eye could hardly follow. The water was churned into a seething mass. The chute of the sawmill nearby was caught by the whirlpool and instantly torn away. About 25 acres of a sandy point of Khantaak Island in the bay near Yakutat slid into the bay. This acreage held an Indian graveyard; a thirty-foot high pole with a cross on the top stood about six feet above the highest tide. The pole remained upright with only the top four or five feet rising above the water at low water and at some distance from the new shore (*The Alaska*

Miner, September 16, 1899, p. 1). Residents rowed out to the site and saw the tops of trees (brush spruce).

A similar collapse of the naturally-restored point at Khantaak Island occurred in 1958 causing three fatalities and a small tsunami. If a slump-generated tsunami occurred in 1899 as in 1964, reports of its effect were lost in those of the larger tsunami.

Tarr and Martin (1912, p. 70) carry an account by a Mrs. Early in their discussion of the September 4 event. It probably describes the effects of the September 11 event:

> Then we had no earthquake before the following Sunday at 8 or 9 A.M., which lasted for about three minutes and was more severe and stronger than the earthquake we had the previous Sunday. Then again in the afternoon at about 3 or 4 o'clock we had a still stronger earthquake than the first or second; the water in the bay began to run out towards the ocean heavily and went far below any low-water mark that I had ever seen, but after a short while returned in a strong current and made a big swell on the beach, and the houses in the Indian village came pretty close to being washed away as the water washed all around them.

In a letter quoted in *The Alaskan, Sitka* (September 16, 1899, p. 3) Mr. Beasley of Yakutat reports that the water began to rise eight to ten feet in as many minutes moving Johnson's schooner high and dry near the saw mill. He had difficulty keeping the boat from being carried out into the bay. The wave occurred near low tide, saving the community.

In 1906, Tarr and Martin explored the delta of the Kwik River in Yakutat Bay on the opposite shore from Yakutat. There they found driftwood wrapped around the trees at an elevation of 15 feet. The driftwood had settled after the wave had cross the barrier beach and lagoon. There were also driftwood deposits along the entrance

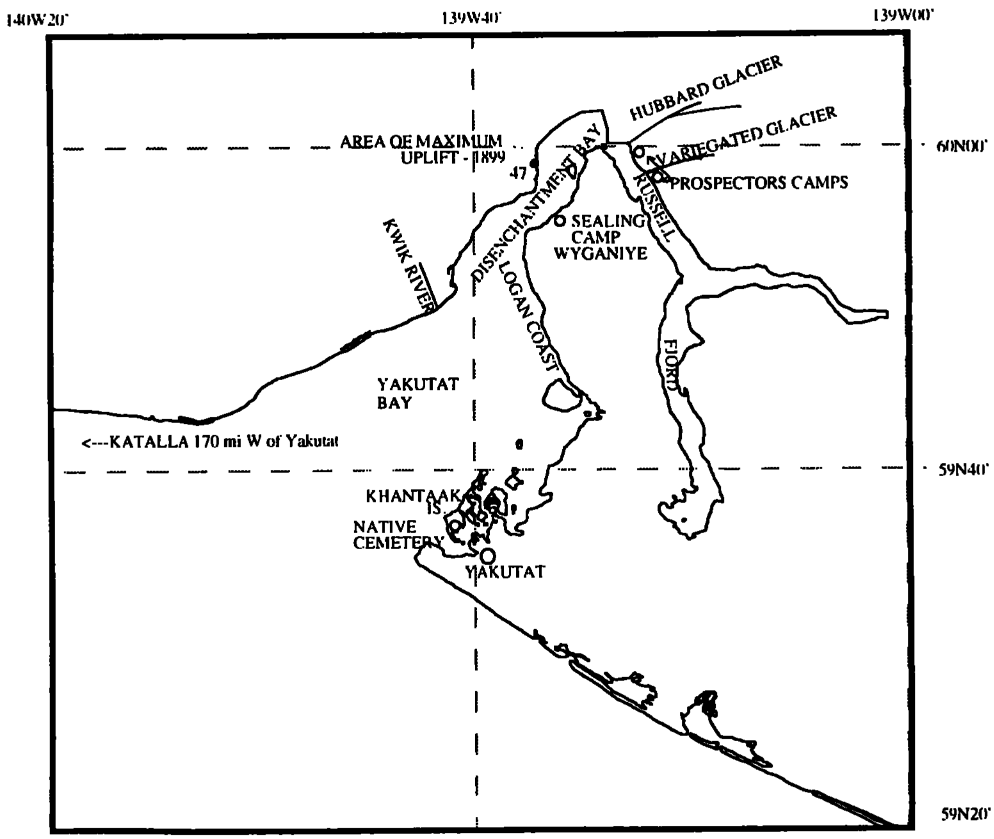


Figure 17. Map of Yakutat Bay and vicinity.

of Disenchantment Bay. On the eastern shore the effects were dramatically higher—three times higher at the Logan Beach area. Here all vegetation was killed to a height of forty feet above the present water level. The wave had the power to break mature trees of 75 years of age. Other areas were spared, such as Knight Island where the forest still exists undisturbed to the water's edge.

On the west side of Yakutat Bay near Disenchantment Bay (which was uplifted 42 feet), the waves inundated a quarter of a mile inland and reached a height of 30 feet, uprooting trees. The wave crossed a sandy peninsula connecting Cape Stoss with a rocky island (Osier Island?) at the northeastern end of Disenchantment Bay and left a tangle of driftwood higher than the elevated beach.

The variability in wave heights over short distances suggests several sources. The thick ice jams encountered by the prospectors came from the glaciers at the juncture of Russell Fjord, and Disenchantment Bay, the Hubbard, and Variegated Glaciers. These may have caused the first waves seen by the men. The high tectonic uplift on the west side of Disenchantment Bay undoubtedly caused a high wave there. The high waves on the Logan coast and Kwik River could have risen from the local uplift on the Logan Coast and/or a slumping on the Kwik River Delta.

The source of the wave at Yakutat may have been from the large uplift in Disenchantment Bay and a wave traveling down the bay missing Knight Island, which is somewhat sheltered by an eastward bend of the coast. It may have had its origin in slumping from Khantaak Island or some other source. Clearly the source was complex and probably involved slumping, glacial ice falls, and tectonic sources. The relatively small waves (15 foot range) seen at Yakutat (considering the large vertical uplift of 47 feet) is due to the smaller volume of water uplifted in Disenchant-ment Bay with respect to the larger Yakutat Bay. The uplifted block was tilted such that it was 47 feet at the mouth of Disenchantment Bay but only about 9 feet in Russell Fjord.

Elsewhere, at Katalla, 170 miles west of Disenchantment Bay, a four-foot wave rose upstream along the Bering River (Tarr and Martin, 1912, p. 36). This would have been caused by a separate landslide source.

At Glacier Bay, where Muir Glacier and a number of smaller glaciers are found, the earthquake loosened the Taku Arm Glacier and it tumbled into the sea with a terrific roar, creating a regular tidal wave as it toppled over. The force of the waves caused boats to capsize over a mile distant from the glacier face (*Seattle Daily Times*, September 20, 1899, p. 1).

At Valdez, 250 miles west-northwest of the source, a seven-foot wave rolled on shore. This came at low tide, which mitigated its effects. The low tide probably contributed to the slide as more of the water-saturated sediments were exposed. This, too, would have been a separately generated slump tsunami. A small tidal wave of 1 or 2 feet high was reported on the Lynn Canal (Tarr and Martin, 1912, p. 74).

At Lituya Bay, 110 miles to the southeast, a trim line shows on photographs taken in 1916–1917. On the basis of unsubstantiated eyewitness reports, one of which mentioned the destruction of a native village and saltery, the state of the new tree growth, and a report in Tarr and Martin (1912, p. 79) of a great amount of drift timber and muddy water in the ocean two days after the largest of the shocks, Miller (1960, p. 75) dated this trim line at 200 feet on the northeast side of Crillon Inlet and the implied tsunami with this event. See the following event for a possible additional report from Lituya Bay.

Most of the information on this event can be found in the Tarr and Martin (1912) report which was the result of their field work, newspaper searches, interviews, and a questionnaire survey that generated 600 replies. Almost certainly there were additional waves and effects not observed or reported. The event may have been weakly recorded at Honolulu at 08:04 P.M. local time. This is about three hours later than would have been expected which makes the recording doubtful. There were no marigraphic recordings in Alaska, or elsewhere in the Pacific. The temporary stations at Ayogon and Saint Michael were not operating in early September. This great earthquake generated at least six landslide tsunamis outside of Yakutat Bay and Disenchantment Bay and several inside the bays as well as probable tectonic tsunamis in the bay. A search for the original questionnaire cards collected by Tarr and Martin was not successful. Validity 4.

1900, August 11, 04:40 GMT. "An earthquake is reported at Lituya Bay on August 11. The shock was so heavy as to dislodge great quantities of ice from the five glaciers that discharge in Lituya Bay. Five Indians, who were on a small island near the foot of one of the glaciers, were drowned in the tidal wave caused by the falling ice" (*The Alaskan, Sitka,* September 29, 1900, p. 4). The description sounds like a report by survivors. Miller (1960, p. 74) mentions a flood in Lituya Bay reported by fishermen to him in 1952. The flood destroyed a native fish saltery near the mouth of the bay and occurred about 1899. There are three, not five, glaciers feeding Lituya Bay: Lituya, Cascade and North Crillon. There is only one permanent island in the bay, Cenotaph, but there is the possibility of small islands forming in the moraine material at the base of the glaciers. Validity 4.

1901, December. Reid (undated) reported that 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 and an eruption in late 1901 or early 1902 accompanied by a severe earthquake with "several tidal waves doing much damage." A magnitude 7.1 earthquake (Abe and Noguchi, 1983) occurred on December 31 at 09:03 GMT near Umnak Island and probably was the event Reid reports as recorded at Baltimore, Maryland, on December 30 or 31. However, Umnak Island is about 850 miles from the Kenai Peninsula and the earthquake is probably unrelated to the volcanic activity reported there. There was another earthquake of magnitude 7.8 on January 1, 1902, at 05:20 GMT near Unimak Island (Richter, 1958, p. 710).

Simkin et al. (1981, p. 84) lists eruptions for Redoubt Volcano on January 18, 1902, but this volcano is 12 miles inland. They list an eruption in 1902 for Saint Augustine Volcano but it was a minor event. It may have had a mud flow associated with it. From the available information it cannot be determined if a tsunami did occur and, if so, with which event. A search of the marigraphic archives did not find an Alaskan gage in operation during this time. Many of the temporary stations only operated during the summer months. The Kenai Peninsula does not have active volcanoes. No local reports of damage were found. Validity 1 for 1901, but see following event.

1903, August. Tarr and Martin (1912, p. 93) mention a report of waves on the still water in Enochkin Bay by G.C. Martin in response to their questionnaire. Martin also reported an earthquake in July that caused cliffs to collapse at Dry Bay, about 15 miles to the west. Enochkin Bay, now know as Iniskin Bay, is on the west side of Cook Inlet due west of Homer. It is directly north of Augustine Island. Any slide from the north side of the volcano (as occurred in 1883) that produced any wave would be noticeable there.

Johnston and Detterman (1978) conclude, based on comparison of photographs taken in 1895 and 1904, and the absence of ash layers on Augustine Island and Kenai, that an eruption did not occur in 1902. They quote unpublished notes of T.W. Stanton of the U.S. Geological Survey, who visited the island in 1904. Stanton wrote that, according to an eyewitness from the mainland, there was a large mud flow when one side of the crater broke off and slipped down. There is no information as to the cause of the waves and no earthquake is listed for this date.

It is possible that the mud flow was triggered by an earthquake, or generated by snow melt. The length of time between the earthquake in July and the waves in August suggests that a continuing process such as a volcanic activity may have been involved or that there was an error in date. Validity 2, new event. See previous event.

1905, July 4. Dr. R.S. Tarr (1909, p. 67), a famous geologist of the late 19th and early 20th Centuries, was working in Russell Fjord when he saw a series of large waves. The water rose and fell 15 to 20 feet for half an hour. There had not been an earthquake but there had been a moderate rain on July 3 and 4. Later his Indian guides reported that a hanging glacier—now called Fallen Glacier—had slid into Disenchantment Bay 15 miles away. When he examined the site, he found that the entire glacier had slid out of its valley and tumbled a thousand feet down a steep slope and into the bay. Alder bushes had been cleared from a half mile wide swath by the slide. The resulting tsunami broke branches to a height of 110 feet at a distance of half of a mile from its origin.

Three miles north, near Turner Glacier, vegetation was killed to a height of 65 feet. At Haenke Island waves reached 50 to 60 feet on the north end of the island and 115 feet elsewhere. The Indians stated that this was the third time that a glacier had fallen in this vicinity. "It is fortunate that in 1905 the Indians had left the bay before the glacier fell, for it is hardly conceivable that their canoes could have lived in the floating ice during the passage of such waves as this glacier avalanche generated in their sealing grounds" (Tarr and Martin, 1912, p. 68). The last time was about 60 years earlier. (See 1845–1847 event.) No marigrams were found for this event. This is a subaerial landslide tsunami. Validity 4.

1906, August 17, 00:40 GMT. A magnitude 8.6 earthquake occurred near Valparaiso, Chile and generated a tsunami that was recorded at Hawaii, the United States west coast, and Japan. It was recorded on the marigram of Port Chatham at 10:11 A.M. local time and continued for about a day. It had a maximum amplitude of 0.7 feet and an initial period of 26 minutes. It is the earliest recorded teletsunami known for Alaska. Port Chatham is near the southern tip of Kenai Peninsula. Validity 4.

1907, September 24, 12:58 GMT. A shock lasting 40 seconds at 4 A.M. rattled dishes and spilled water at Skagway. A report from Haines said that the Davidson Glacier was moved a half mile by the shock (*Alaska Daily Dispatch*, September 24, 1907, p. 1). Captain Nyland of the *Petrel*, which was four miles north of Haines, observed a slight temporary change in water level (Tarr and Martin, 1912, p. 96). The earthquake was recorded on the seismograph at Sitka, and Soloviev and Go (1975, p. 216–217) estimate the magnitude to have been 5.5 based on the small record there. They believe the water change was seiche as the magnitude was small. However, landslides and ice falls could be associated with small-to-moderate earthquakes. Seiche, if they are possible at all in the earthquake source region, are not usually found with small earthquakes.

The report of cable disruptions by the cable ship *Burnside* states that it was advised of a cable interruption to the Sitka-Valdez cable on the morning of October 2 and repaired a break on October 6 caused by "submarine upheaval." "It is believed that this interruption was caused by a submarine upheaval as advices afterwards received from the Weather Bureau at Sitka show that a seismic disturbance occurred west of that station at the time the cable became interrupted." As there is not another earthquake reported for the following week this cable break is probably for the event of September 25. The *Burnside*'s report that the break occurred on October 2 is probably when they heard of the break while in Valdez.

The location of the break was not given other than 348 nautical miles from Valdez and 172 nautical miles from Sitka. It was a complete separation. This seems to put the break in the open ocean south of Yakutat Bay.

This appears to be the first of 39 reports of cable breaks ascribed to submarine slides and earthquakes in southeastern Alaska and the Prince William Sound area. Fourteen of the breaks occurred near Wrangell and were caused by submarine movement from the sediments in the Stikine River. Four of these were associated with earthquakes. Except for the 1949 and 1957 events, none produced reports of any wave activity. Similarly, fourteen cable breaks occurred near Haines and Skagway. Many were associated with the deltas from the Katzehin River and Skagway River. Four of these were associated with earthquakes, and only those of 1958 and 1964 had observed waves with them. Ten more cable breaks were associated with Valdez and the delta of the Lowe and Robe Rivers. Six of these were associated with earthquakes, including those of 1908 (see following event), 1925, and 1949, which were observed (Heezen and Johnson, 1969; National Archives, Alaska Region, Record Group 342). Validity 3. Probably due to a local submarine landslide.

1908, February 14, 11:25 GMT. An earthquake was felt in Valdez for about three seconds at 1:27 A.M. local time and some residents ran into the street. Others estimate the shock lasted one or two minutes. A roaring coming from south to north preceded the shock by about 30 seconds. "It caused tidal waves large enough to make the Steamer *Northwestern* rock perceptibly" near Valdez, and an engineer on board thought it felt as though the ship hit bottom (Tarr and Martin, 1912, p. 96–97). The cable to Sitka was broken in seven places 5/8 to 7/8 miles apart and the Valdez to Seward cable was broken in four places 3/8 to 1 1/8 miles apart, all in the Port of Valdez area. Several sections of the broken cable were buried. An examination of the area by a geologist did not find evidence of fresh faulting. Nevertheless, Tarr and Martin (1912, p. 98) reject hypotheses of submarine slumping or amplified motion due to the soft sediments, in favor of rupture due to direct faulting. They believed that the slope is not great enough to have extensive slumping but the water drops to a depth of 800 feet in less than one mile transverse to the channel axis. "There was no marked sea wave" and there were people on the wharf, possibly waiting for the steamer. There is little direct evidence for a wave.

It is reasonable to conclude that the cable breaks were due to submarine landslides (within the Port of Valdez) which also buried sections of them. There were eight breaks near the toe of the glacial out-wash delta on which Valdez sat, and four breaks near Shoup Bay, both sites of submarine landslide tsunamis in 1964. This suggests that two slides occurred. It is also reasonable to expect that a minor tsunami was also generated. The report that it felt like the boat hit bottom is possibly a description of a seaquake, or the ship could actually have hit the bottom. The report that the boat rocked perceptibly would indicate wave action. The hour of the event, 1:27 A.M., probably would account for the lack of reports of a direct observation. The *Burnside* report states that this was the same cable broken in 1907, and ascribed the break to "submarine upheaval." Validity 2.

1911, September 22, 05:01 GMT. A magnitude 6.9 earthquake occurred in the vicinity of Valdez. Another cable break occurred in the Port of Valdez. An account in Tarr and Martin (1912, p. 100) quotes a report by A.H. Brooks, a geologist with the U.S. Geological Survey located at the time eight miles to the west of Valdez. He carefully observed the time as 7:01 P.M. local time and the duration as 20 seconds. Brooks states:

> So far as I know, there was no perceptible earthquake wave at Valdez, but of this I have no definite information. It would seem that there should have

> been a wave there when the cable was broken. Curiously enough, the operator at Valdez told me that the cable was not broken immediately, but that communication was kept up with Sitka some seconds after the earthquake shock.

The submarine cable was buried for a length of 1,650 feet just north of Fort Liscum, presently the site of the Alaskan Pipeline terminus, and 3/16 miles from the dock at Valdez. About 0.3 of a mile of the cable was so deeply buried that it was abandoned. It was completely buried for two miles and the sections recovered were so badly twisted as to be of no further use (National Archives, Alaska Region, Record Group 111). Tarr and Martin (1912, p. 100) consider this event as supporting their hypothesis of a direct displacement as the cause of the cable breaks. They report that there is only 50 feet of elevation change to a mile, but that is longitudinally down the channel. Transverse, and at the Valdez shore, the bottom drops 750 feet in about a mile. They consider the cable burial and the delay in cutting the cable after the shock for several seconds to be the result of flow off of the hypothesized vertical uplift.

At Golden, Alaska, on the shores of Wells Bay, the shock precipitated tremendous land and rock slides but there was no mention that any reached into the bay. Thousands of fish of several kinds were killed, and floated on the surface. Whether this is due to a disturbance of the bottom or just to concussion is not known. The *Burnside* ascribes the break to "earthquake." Validity 1.

1918, September 7, 17:16 GMT. A magnitude 8.25 earthquake in the Kuril Islands produced a minor wave recorded at Craig, Alaska, which continued for more than twelve hours. The wave was emergent at about 5 P.M. and had a maximum amplitude of about one inch and period of 20 minutes. Validity 4, a teletsunami.

1925, February 23, 23:54 GMT. The *Valdez Miner*, February 28, 1925, states:

> About 2:10 Monday afternoon Valdez was visited by one of the heaviest earthquakes in its history, rivaling the memorable one of September, 1899. . . . The shock lasted about two minutes and brought practically almost everyone in town out to the streets, while the buildings weaved and twisted and groaned. . . . [It] was followed by a considerable tidal movement for some minutes. . . .The greatest damage done by the shock was to the Valdez-Cordova and Valdez-Seward cables both of which were put out of commission somewhere out in Prince William Sound.

The *Burnside* reported that a break to the Valdez-Cordova cable occurred in Valdez Harbor. The Valdez-Montague Island-Seward cable also broke. Both are near the Valdez dock. The *Burnside* also reported a break on the Petersburg-Wrangell cable due to a submarine slide in 1925, but did not give a specific date nor mention seeing wave action.

The earthquake was also strongly felt in Cordova, Seward, and Fairbanks. There was structural damage to buildings and to the dock. Power lines were severed, and a seismically-induced sea waves in Port Valdez caused extensive damage to the boardwalk along Water Street (Dowl Engineers, 1983).

"Passengers of the steamer *Alameda* which was in Prince William Sound at the time of the earthquake thought the vessel had scraped bottom or had struck a large log" (*Cordova Daily Times*, February 24, 1925). There was no mention of wave action in the *Seward Gateway* newspaper account of the earthquake there. The *Petersburg Herald* (February 23, 1925) puts the *Alameda*'s location as off Hutchin's Crook. Hutchin's Crook was not located but there is a Hutchin's Bay west of Bearslee Island in Glacier Bay. Coulter and Migliaccio (1966) report that the dock at Valdez collapsed in part and tipped toward shore. The knowledge of this earlier event was a factor in the decision to relocate Valdez following the 1964 disaster. No unusual signal was seen on the Sitka or Ketchikan marigrams and the Seward record was not found. No other stations were known to have been operating during the time. This would have been two separate events. Validity 4 for the event at

Valdez, and validity 2 for the Petersburg-Wrangell locality.

1927, October 11, 11:31 P.M. An emergent marigraphic record of wave activity was recorded at Ketchikan at 23:31 local time. It had a maximum amplitude of about 1 inch and a period of 11 minutes. There was no known source for these waves and no reports of cable breaks. See Figure 18. Validity 2+.

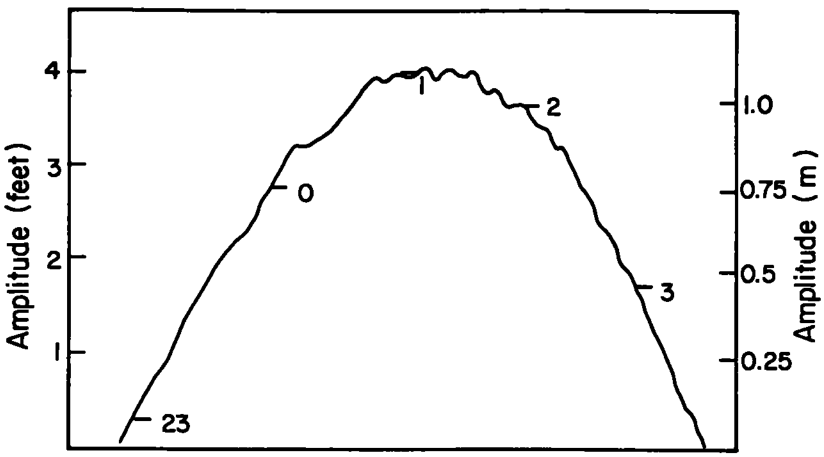


Figure 18. Marigram from Ketchikan showing the tsunami of October 11, 1927. Source unknown.

1927, October 24, 16:00 GMT. The most severe earthquake (magnitude 7.1) in the memory of local inhabitants occurred in Petersburg between 6:51 and 7:05 A.M. It was feared that a tidal wave or other disasters would result from the shock but none were reported (*Petersburg Press*, October 24, 1927). The Petersburg-Wrangell cable was cut about five miles west of Wrangell; the Juneau-Skagway-Haines cable broke in two places. Both cable breaks were ascribed to a submarine slide. Also, the Ketchikan- Wrangell cable was broken due to a "submarine landslide causing earthquake."

Neuman (1931, p. 6–7) reports that the water was churned and muddy at Icy Straits, deep sea fish were killed, and there was a prolonged rumble and roar at Inian Island off the north coast of Chichagof Island. He reports also that the water was discolored, deep sea fish came to the surface, and the sea bottom changed from rock to mud between Yakobi Island (off northwest coast of Chichagof Island), Point Adolphus (north end of Chichagof Island, north of Sitka), and Cape Spencer (point of land at Dicks Arms on the north shore of Cross Sound). Windows were broken in the Cape Saint Elias Lighthouse and heavy seas broke the tow line from the redondo to the halibuter *Seymour* which drifted helplessly for three hours (*Alaska Daily Empire*, October 27, 1927).

In addition to the "heavy seas" at Cape Saint Elias there is the indirect evidence of discolored water, and cable breaks indicated submarine landslides which would be expected to have generated a local wave. No wave action was seen on the Ketchikan marigram and the Sitka record was not found. Bois (1928, p. 384) reported the wave reached Hawaii, but this may relate to the fact that the Hawaiian Volcano Observatory had issued a warning at Hilo based on the seismic signal. They reported that no wave was observed. It was not recorded on the new tide gage at Hilo, and Cox and Morgan (1977, p. 49) concludes that there was no tsunami in Hawaii from this event. This is a multiple event with possible tsunamis in the Wrangell area, Icy Straits, Yakobi Island, Lynn Canal, and Cape Saint Elias. Validity 3 for Cape Saint Elias and validity 2 for other locations.

1929, March 7, 01:35 GMT. A magnitude 8.6 earthquake near the Fox Islands produced a small tsunami that was recorded at Honolulu and Hilo, Hawaii, and at San Francisco, California, but not recorded or reported observed in Alaska. McCartney (1994) reports hearing that a wave totally covered little Cherni Island in the 1920s or 1930s. This island was used for a cattle ranch, and had no permanent human inhabitants. All of the cattle were swept away. The respective amplitudes were 8 inches at Hilo, 2 inches at Honolulu, and 1 inch at San Francisco. The earthquake was strongly felt at Dutch Harbor, Unalaska, and as a seaquake by several ships in the epicentral area. It was directly observed in Hilo where the hawsers of a ship tied up to the dock snapped, and waves were seen on the Wailua River. The islands in the epicentral area are uninhabited and the directionality of the waves would be such that the marigraph stations at Ketchikan and Seward would be in a poor position to record them. The waves were not recorded by them, and the station at Cordova operated only from May to December. Validity 4.

1933, March 2, 17:31 GMT. A magnitude 8.3 earthquake off of the Japanese coast at Sanriku caused a tsunami that was observed throughout the Pacific Basin. Emergent waves with short periods of about 4 minutes were recorded on the marigram from Seward beginning about 7 P.M. local time, about three hours later than the expected first arrival from the Japan tsunami. They continued for more than twelve hours and probably were seiche transverse to Resurrection Bay near Seward. Validity 3.

1936, October 27, 6:50 A.M. There were four people in Lituya Bay about two hours before dawn—James Huscroft and B.V. Allen in a cabin Huscroft had built on the western side of Cenotaph Island, and Nick Larsen and F.H. Fredrickson on a 38-foot trolling boat, the *Mine*, anchored near the north shore, south of Fish Lake. The tide at the time was rising and at about mean level. At 6:20 A.M. local time a loud roar was heard coming from the mountains beyond the head of the bay. The weather was clear but it was too dark to see anything. The men felt no shaking. The roaring continued until 6:50 A.M. when a large wave was first seen in the narrow part of the bay, just west of the two arms of the head of the bay. It appeared as a steep wall of water extending from shore to shore and possibly 100 feet high. The men on the *Mine* raised anchor and started toward Cenotaph Island. An estimated ten minutes later they were about 1,300 feet northwest of the cabin site and in water at least 70 feet deep when the wave struck. There was no preliminary lowering or other disturbance of the water.

The first wave raised the *Mine* about fifty feet above normal water as it was partially sheltered by the island. On the lee side of the island the wave was about 100 feet. After the wave passed, the water fell below the normal. Huscroft's seining boat, anchored in 48-feet of water, touched bottom. The first wave was followed at intervals of about two minutes by two more waves, each higher than the former. Each time the water fell below normal. After the third wave smaller waves continued for about half of an hour. There was no sloshing of the water in the bay. About 30 minutes after the third wave, floating logs and ice appeared around the boat.

The men in Huscroft's cabin were awakened about 7:00 A.M. by a roar like "the drone of 100 airplanes at low altitude" to find the water already up to their cabin. Mr. Allen observed the scene from a higher and safer part of the island. He noted that the three waves were of increasing altitude and estimated their speed to be 20 knots (23 miles per hour). In the several published accounts the maximum height is given as 250 feet (*Alaskan Daily Press*, November 5, 1936, p. 5) and 150 to 200 feet written in the log book of the *Osa Nolde* as relayed to Miller (1960, p. 68) in a written communication to him from Caroline Jensen. The latter values agree better with the Fredrickson account.

There had been a period of unusually heavy rainfall. At the two nearest coastal weather stations, Sitka and Cape Saint Elias, the precipitation averaged about 45 percent above average for the preceding month, and 150 percent for the preceding 6-day period. Williams (1938, p. 18) gives a slightly different version of the event:

> One morning, that autumn, during a period of unusually heavy rainfall, Jim was up and about his cabin, preparing breakfast at his usual early

hour. He was suddenly startled by a terrifying roar, much louder and more continuous than the usual artillery-like booming and cracking of the nearby glaciers, to which he was accustomed. Rushing outside he was appalled. . . . It appeared as though all the water in the bay was rushing out towards the entrance in one mountainous tidal wave. Spellbound and uncertain for the moment, he hesitated long enough to see an immense 'back wave,' the reaction of the initial rush of water dammed by the ocean swells, and the narrow bay entrance, seeking to restore the normal water level. Jim says his dominant thought at this moment was to reach the highest ground on the island and that he started for it at no uncertain pace. He could see through the trees, as he made his way inland, what was going on. The waves surged and resurged over the length of the bay a number of times. One of Jim's outbuildings was smashed and another was lifted up and literally jammed into the edge of the forest, some distance up the beach. A small trolling boat, tied to a buoy, which was secured to a heavy anchor in the bay in front of the cabin, was first dropped momentarily on the muddy bottom, then quickly picked up by the backward rush of water, but miraculously escaped being swamped, and eventually came to rest as normal conditions were restored. Huscroft's dwelling, being on comparatively high ground, escaped serious damage, although flooded to a depth of several feet.

Aerial photographs were taken of the bay in 1948, and a field survey was done in 1952–1953 by Miller. The trim lines were easily detected and their age was verified from tree ring counts except in a few places on steep slopes where there was little old growth. The maximum height was 490 feet or more on the northeast wall of Crillon Inlet (Figure 19). The maximum inundation was 2,000 feet on the north shore of Lituya Bay just east of Cenotaph Island. In the middle sections of the bay, southwest of Cenotaph Island, the height of the trim line was

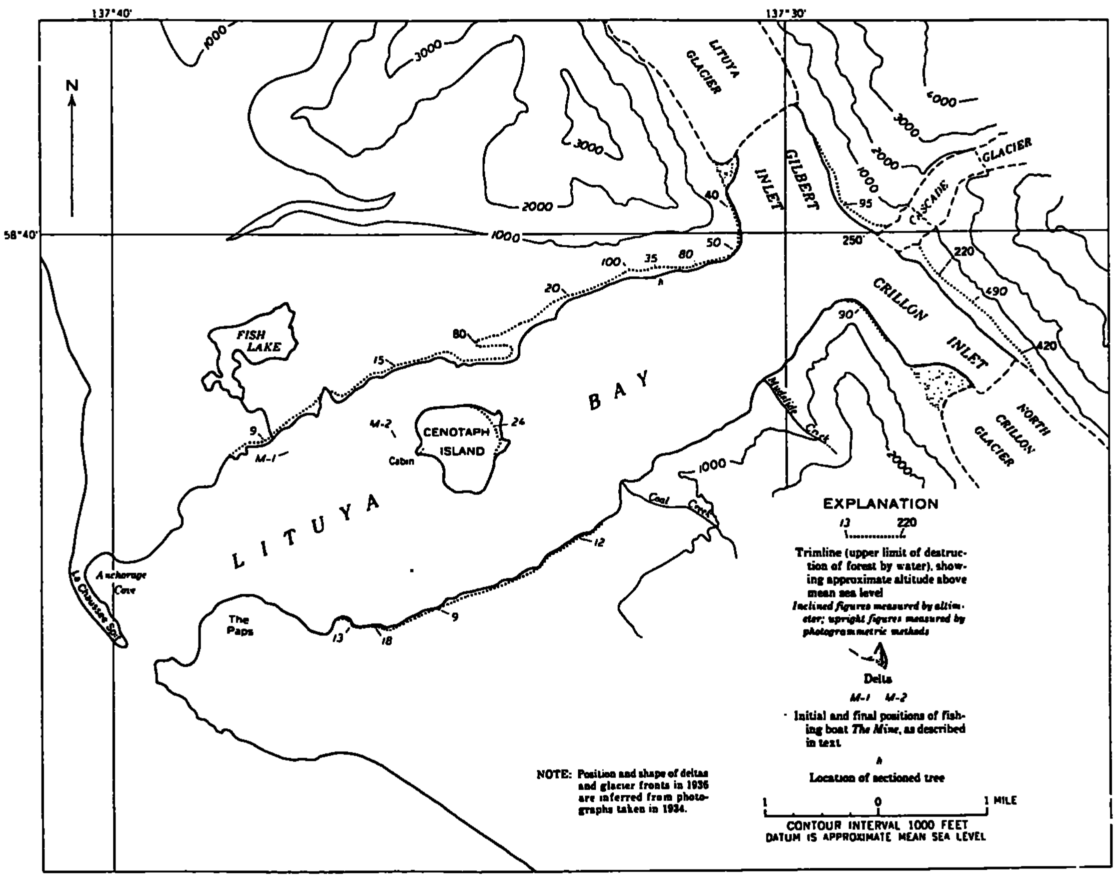


Figure 19. Map of Lituya Bay showing trim lines for the 1936 tsunami event (Miller, 1960).

9 to 15 feet. Most of the evidence for the wave trim lines was obliterated by the 1958 event.

The *Alaska Weekly* (Seattle, November 27, 1936, p. 3) reports:

> Bernard Allen, one of the four men to witness the flood told the *Alaska Daily Press* an onrushing wall of water 250 feet high washed out everything in its path, completely crushing a warehouse in which were 50 barrels of salted fish, and swept 4 miles along the shore, carving new banks from the soil and stone and hurtling rocks and trees through the waves. . . . Allen and his companion Jim Huscroft, heard the terrific roar and when they fled up the hillside, the raging flood already was at their door. Fritz Erikson [*sic*] and Nick Larsen, fur trapping, were on their trolling boat, the *Mine*, which was lifted from its anchorage and wash some distance. Trees and mountain shrubs were cleared away to an altitude of 400 feet, Allen said, and estimates that the water moved at the rate of 20 knots an hour. Captain Tom Smith, with Captain Paul Jensen and Ed Leach reached Lituya Bay four days after the flood, and reported seeing floating wreckage 50 miles south of the place.

Within a few days trees had drifted along the ocean beaches as far as fifty miles to the south. The water flowed for some distance higher than the trim line and crabs and clams were found as much one-half mile from the beach north of the mouth of the bay. The trees had their roots, bark and branches intact, indicating they were felled by erosion rather than by the force of the waves. There were some places where waves left scarps four feet high, but more usually just the thin upper soil layer was removed.

According to accounts by Fredrickson and Allen only the third wave reached the Huscroft cabin. Roberts (1961) reports that the cabin was 50 feet above the bay level. Apparently two U.S. Coast and Geodetic Survey triangulation stations were also lost. One was set in a boulder on the north shore of Cenopath Island, and the other on concrete blocks on the south shore near Coal Creek.

There is some uncertainty in determining the cause of this tsunami. There was no report of an earthquake being felt by the observers or recorded at Sitka or any other seismographic station. That eliminates direct fault displacement as a cause.

A possible breaking of a glacial lake as the source was put forth at the time. This phenomenon is a well known hazard in Alaska. Miller felt that this would explain the long lead time of thirty minutes between the time the "roaring" was first reported and the wave first appeared. However, for some form of water to have been the source, it would have to have been introduced into the bay in a mass. This would create the displacement of the bay water necessary to create a tsunami wave and not just flooding. If the wave was introduced water it would have been more plateau-like (a flood) and not the observed short period waves. If the roaring was due to the movement of the water for thirty minutes prior reaching the bay, it does not seem likely that it would be introduced into the bay in mass. An obvious source would be a subaerial landslide, as was the case in the 1958 event. Miller inspected photos from 1929 and 1948 and found close agreement even in small features as to preclude a landslide source. Also it would be hard to account for the long thirty minute interval between the roaring and the first wave if the roaring was due to the landslide into the bay.

Another suggestion was that the waves were the result of submarine landslides. These are now a recognized source of locally high waves in southeastern Alaska and elsewhere. There is a slope of up to 28 degrees and a possible elevation change of 500 feet. There is a source of sediments in the delta at the head of the North Crillon Glacier. This is a possibility, one for which direct evidence is not available since the displacements were underwater. However, it does not address two points—the roaring that would not be observed with a submarine landslide, and the extraordinary heavy rainfall over the preceding weeks (if that was a factor).

The final possible source is from the glacier. Miller suggests three modes: (1) direct calving of the glacier front into the bay, (2) the calving of the submerged portion of the glacier, and (3) a sudden surge of the glacier into the bay. None of these account for the prolonged period of roaring.

While the cause of the wave cannot be absolutely determined, a submarine landslide seems to be the likely source. The rainfall may not have been a factor. The ice reported in the bay following the wave could have fallen from the glacier triggering the landslide, or washed from the glacier as a result of the 490 foot runup near the glacier face. The duration of the roaring may be questionable as Huscroft's account would indicate that the roaring was not heard until the wave was passing the island.

The wave appears to have been reflected three times in Crillon Inlet before reaching the head of Lituya Bay. This could account for some of the 30 minutes between the beginning of the roaring and the arrival of the wave, and may have been the source of the roaring sound. The cabin on the lee side of the island may have been sheltered somewhat from the sound. The 30 minute estimate was from the men in the boat. If the source of the sound was the water attacking the land in the Crillon Inlet, it would have taken some time to reach the top of Lituya Bay. Their estimate of 30 minutes may have been high. The involvement of the glaciers in the explanation is necessary to explain the ice that was seen soon after the waves passed the *Mine*. According to Miller, there is a photograph of the North Crillon Glacier taken in 1937; it shows little change in the glacier front. Miller found no evidence of glacier surge or calving. No trace of the tsunami was found on the Juneau, Ketchikan, or Seward marigrams. Validity 4.

1938, November 10, 20:19 GMT. A magnitude 8.3 earthquake occurred near the Alaska Peninsula, producing a surprisingly small tsunami. It was recorded at Dutch Harbor with an amplitude of 2 inches, and at Seward and Sitka with amplitudes of 3 inches. It was not recorded at Juneau, and the station at King Cove was not in operation on this date. The record from Seward is missing the beginning hours due to an instrumental failure. Elsewhere it was recorded at Honolulu, and at Crescent City with an amplitude of 6 inches, Santa Monica with an amplitude of 2 inches, and weakly at San Diego. Johnson and Sataki (1994), using marigram waveforms, calculated a moment magnitude of 8.2 and a rupture length of 300 kilometers (not extending into the Shumagin gap).

Lander and Lockridge (1989, p. 94) reported on an account by geophysicist George Carte, who spoke with a woman who lived in Unga during the time of 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." As the report was very similar to one for the 1946 event, it was checked. The original report put the event at night with the discovery of the missing boats not made until the next morning. The 1946 event occurred at night while this event occurred during the day. The reported observation belongs with the 1946 event, and the 1938 event was not reported as observed directly. The very small size of this tsunami for a great earthquake is unexplained. It may have been due to submarine landslides or more likely to simply a very minor surface deformation associated with this earthquake. Validity 4.

1944, December 7, 04:35 GMT. A magnitude 8.0 magnitude earthquake off the Kii Peninsula, Honshu, Japan, produced a tsunami with an amplitude of 11 inches at Massacre Bay, Attu (see Figure 20, next page) and 4 inches at Sweeper Cove, Adak. It was not recorded elsewhere in Alaska. Validity 4.

1946, April 1, 12:29. At about 1:30 A.M., April 1, local time, the log of the U.S. Coast Guard Direction Finding (DF) Station on Unimak Island noted, "Severe earthquake felt. Building rocked severely. Objects shaken from locker shelves. Duration approximately 30–40 seconds. Building

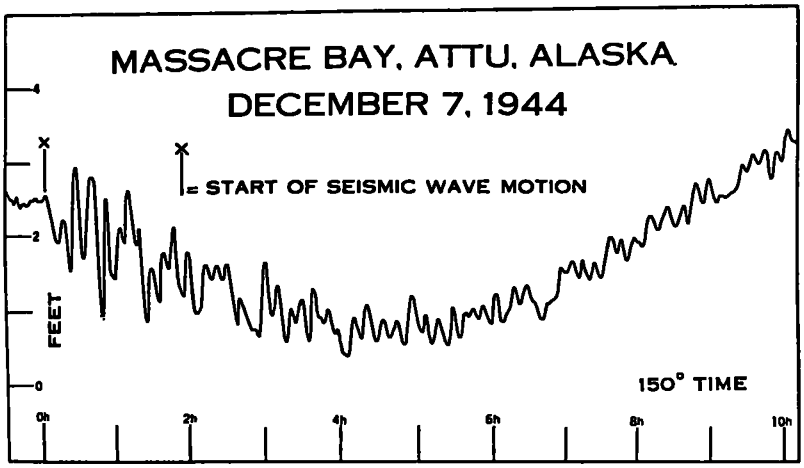


Figure 20. Marigram for the December 7, 1944, tsunami.

creaked and groaned, but no apparent damage. Weather clear and calm." At 01:57 A.M. he noted, "Second severe quake felt. Shorter in duration but harder than 1:30. Duration 15–20 seconds. Again no apparent damage although buildings were shook severely." At 02:18 A.M.: "Terrific roaring from ocean heard, followed almost immediately by terrific sea, top of which rose above cliff and struck station, causing considerable damages. Water in building, crew ordered to higher ground." The station was more than 90 feet above sea level.

The Scotch Cap Lighthouse was just below the Direction Finding Station, and there had been telephone contact after both shocks (Rutherford, 1986). Neither sustained damage from the shocks. The lighthouse had five men on duty and the facility was nearly new, having replaced a wooden tower originally built in 1903. It opened in 1940, a reinforced concrete structure sixty feet high and 92 feet above the sea at its top. It was protected by a seawall at its base and was on a bluff 32 feet above sea level. After the wave the crew at the DF Station could not raise the lighthouse on the telephone and noted that the light was out. At 03:45 A.M. the DF Station log notes, "Scotch Cap L.S. completely washed away. All hands, total loss."

Early newspaper reports put the loss at ten men, the normal complement at the station. The switchboard at the DF Station caught fire, probably due to water. An antenna 105 feet above sea level was wash away. Debris was washed to a height of 115 feet. The generator failed and the water main broke. Unusually low water levels were noted even during high tides, indicating uplift. At the lighthouse site there was nothing left but a few pieces of broken and twisted reinforced concrete. The five missing crew members were Anthony L. Pettit, Leonard Pickering, Dewey Dykstra, Paul J. Ness, and Jack Colvin. The body of Ness was found on April 20, and a torso of a second man and a leg of a third were found on the 22nd of April. The long delay in the recovery of the bodies indicated that they were probably in a portion of the lighthouse structure that remained relatively intact.

The Alaskan Empire, April 3, 1946, reports that abnormal tide fluctuations were experienced at Adak. Tidal fluctuations of 12 to 18 inches were observed at 10 to 12 minute intervals throughout the day. King Cove, on the west end of the Alaska Peninsula, reported relatively light damage at the False Pass cannery. Pilings were scattered. The tsunami was about 10 feet high (range) when it reach King Cove and had a period of about one hour. It was observed at Chignik, east of King Cove on the Alaska Peninsula, as five foot tides every hour.

The Alaska Pen (Foster, 1946), an Unga school paper, reports that at about 04:00 A.M. several people were awakened by the earthquake that was followed by a tidal wave. It swept away two dories and the dock from the old fishing station across the bay. Debris from the dock was found on Agate Beach, about a mile away. No trace was found of the dories. Sand and gravel shifted

Figure 21. 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)

and a boulder was washed away. Thousands of butter and cockle clams were washed up on the beach below Lauritzon's dock. A reef would be bared every ten minutes as four and five foot combers rolled into the bay until after noon.

Simeon Pletnikof, a long time resident of Nikolski, Umnak, reported that he was aboard a ship at Sand Point (Popov Island, Shumagin Islands) in route home from military duty when the ship rose and fell repeatedly through a large range (telephone conversation, August 3, 1994).

Sixty tremors were felt at Ikatan, on the eastern shore of Akutan Island. One man's home was washed off its foundation and towed several miles away to False Pass (where he continued to live). The dishes were not jarred from their places in the cupboard. No lives were lost. (Foster, 1946). The Coast Guard ship *Cedar* reported that the tidal wave had destroyed two houses and two sheds at Ikatan and destroyed the Pankof light at the southeast end of Unimak Island. The *Kodiak Mirror*, April 6, reported that several homes at Ikatan were swept into the sea.

At Sanak, a 20 foot wave arrived about 10 minutes after the earthquake. It demolished a carpentry shop and all of the equipment was lost. All of the houses were gutted, and dories washed

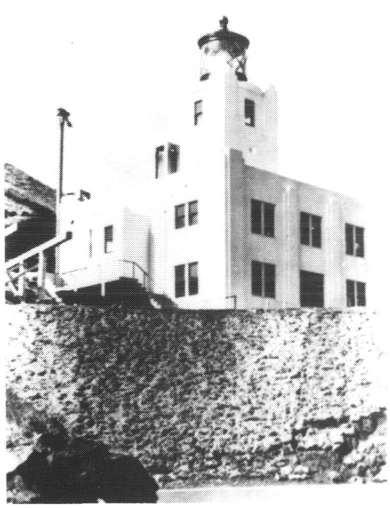


Figure 22. (Above) The devastation at Scotch Cap after the tsunami of April 1, 1946. All that remains of the lighthouse is the foundation, part of the concrete sea wall, and debris strewn over the bluff. These are seen in the bottom half of the photo.

The small photo (left) shows the lighthouse as it appeared before the event, from shore level, looking up. The concrete sea wall is at the bottom of this picture. In the photo of devastation, above, the concrete wall appears as a series of white chunks, west to east in the lower part of the picture. Debris from a warehouse is scattered to the right of this, along the newly exposed shoreline.

Note the erosion of the cliffs on the left of the picture (above). This erosion was caused by the tsunami event. The white buildings near the center of the photo were the sleeping quarters for the crew. The extent of inundation is seen to the east of these; it is marked by the abrupt end of darker soil in the middle part of the upper right quadrant of the picture.

up to the school house where the population had taken refuge (Press Release, Commandant Alaskan Sea Frontier, Kodiak). Several homes were destroyed in Sanak (Foster, 1946). The wave arrived at 2 P.M. [*sic*] Anchorage time (*Kodiak Mirror*, April 6, 1946, p. 1).

On Monday a "minor" tidal wave was reported at Dutch Harbor, which damaged several small boat landings and pilings (*Kodiak Mirror*, April 6, 1946). "The commander of the *Alaskan Sea Frontier* said a minor wave entered Dutch Harbor at 5:30 A.M. approximately an hour after striking Unimak. It carried away ferry barges that connected the base with the town of Unalaska and damaged small boat landings and pilings (*Anchorage Daily Times*, April 2, 1946).

A tide 20 feet above normal was also reported at Cold Bay on the western end of the Alaska Peninsula (*Kodiak Mirror*, April 6, 1946). An extremely low tide was reported at Chirikof Island between 3 and 4 A.M.

At Kodiak the effects were visible in tidal fluctuations. One man at Erskine's dock said his boat rose swiftly about four feet (range) and swiftly sank back down again. In the afternoon others noticed the water rushing onto the beach and suddenly rushing out again when the tide was supposed to be going out (*Kodiak Mirror*, April 6, 1946, p. 10).

At Attu, long, low swells from the southeast slowly increased in height, becoming moderately

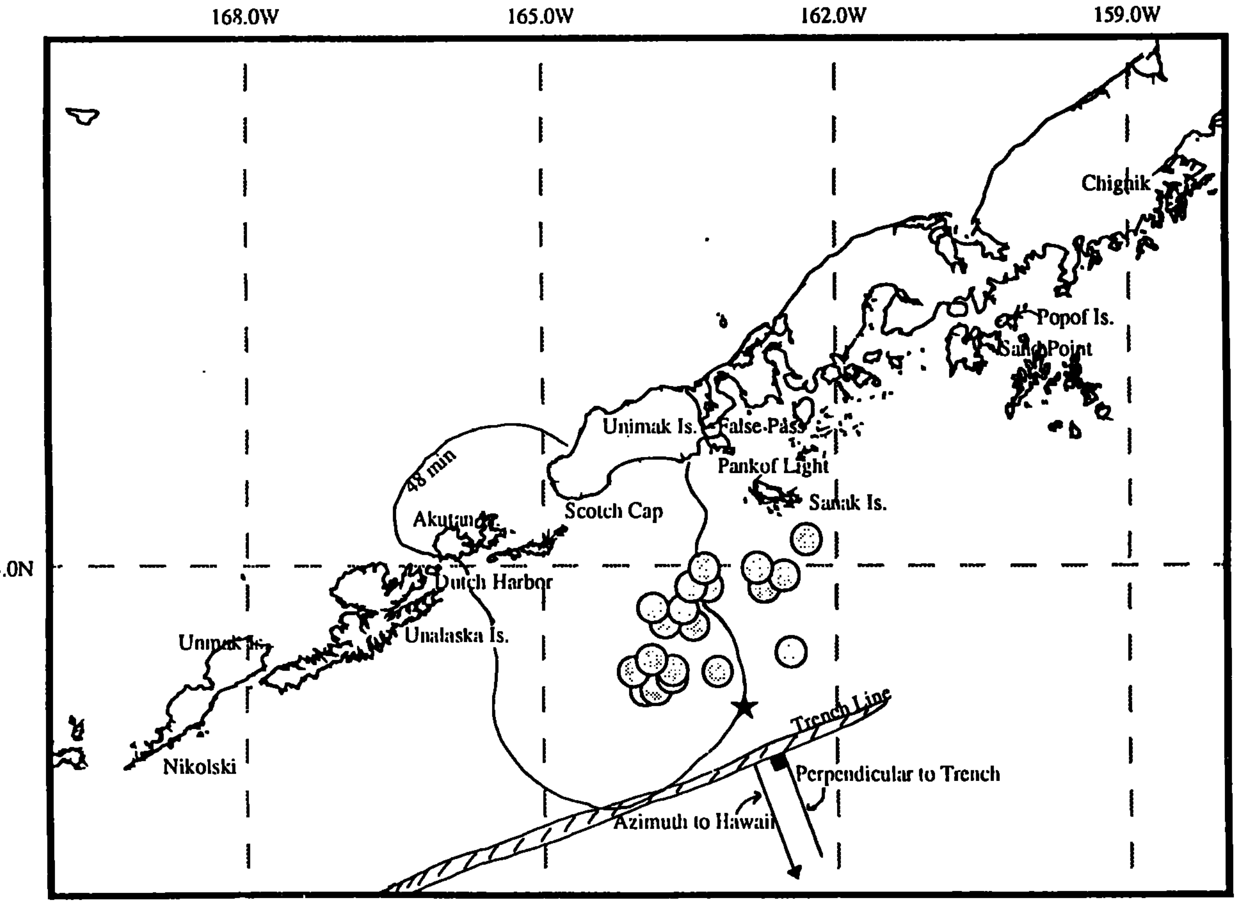


Figure 23. April 1, 1946 tsunami—location of aftershocks (circles), the 48-minute tsunami travel time contour, trench line, and direction to Hawaii.

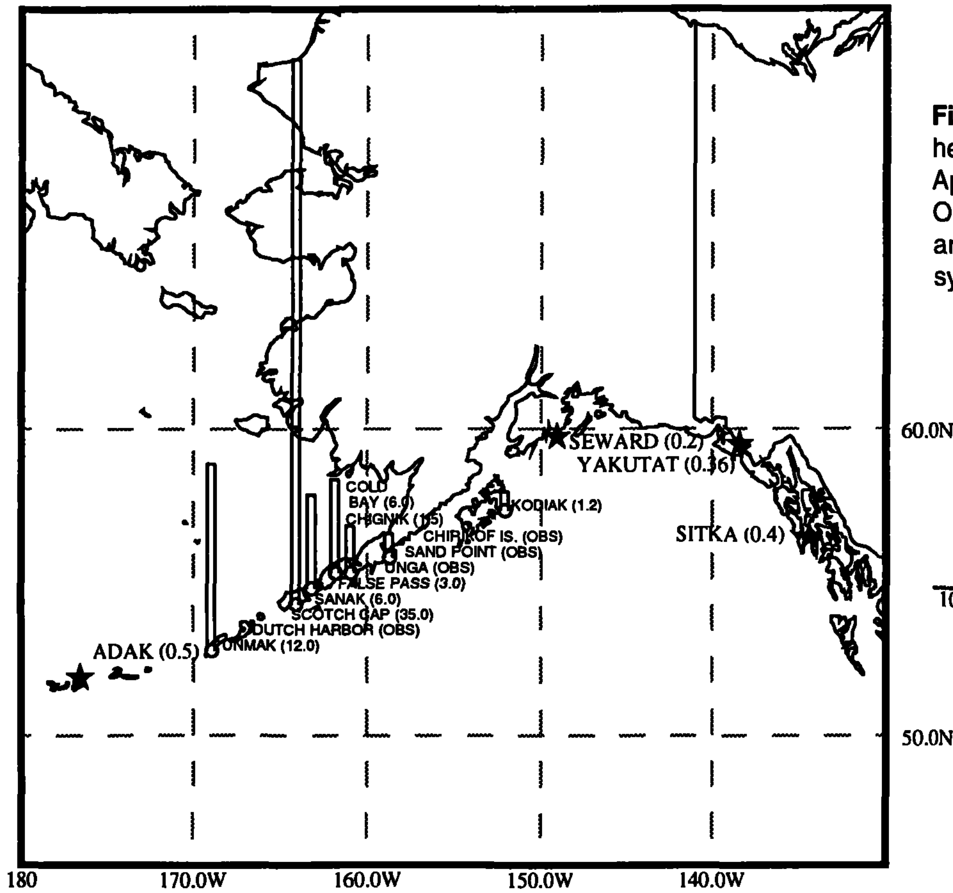


Figure 24. Wave heights reported for the April 1, 1946, tsunami. Operating tidal stations are indicated by a star symbol.

1000 km 610 mi

long swells in the afternoon. Lots of kelp was washed onto the beaches. Otherwise, no significant changes were noted.

It is reported that in the 1940s (probably 1946) Nikolski Bay ran dry (McCartney, 1994). As Nikolski Bay is on the north side of Umnak Island, it is possible that the passage of the wave from the south would create a suction, drawing water from the north side. Mr. William Ermeloff (of Nikolski) reported that the wave was over the bank and near the road. Driftwood was washed up on the ice of a lake a quarter of a mile from the Bering Sea coast. Nine *baraboras*—half sunken, sod-roofed shelters used by fox trappers—were washed away on the Pacific coast side. These were mostly 10 to 15 feet above the coast, but some were as high as 40 feet. The beach also showed signs of erosion.

The tsunami was weakly recorded at Sweeper Cove, Adak with a maximum amplitude of 4 inches, at Yakutat with an amplitude of 1.2 feet, at Sitka with an amplitude of 1.3 feet, and at Seward with an amplitude of 4 inches. It was not readable at Skagway.

The wave heights reported are anomalous, with a 115 foot run-up reported at Scotch Cap, 20 feet at Sanak and Cold Bay, and much less elsewhere. Most inhabited native communities are on the northern coasts and protected from tsunamis; there was no effort to collect wave heights from uninhabited parts of the coast. Other localities may have had 100 foot waves but they were not reported, or the location of Scotch Cap was such as to focus the waves. The 1957 tsunami also produced anomalous heights of 40 feet at Scotch Cap.

This was one of the most important tsunamis to have occurred in recent history. It caused about $250,000 in damage in Alaska, mostly to the nearly new Scotch Cap Lighthouse (which cost $150,000 to build in 1940). It caused 5 fatalities at that facility. The wave's directionality was toward the remote coast on the Fox Islands and into the Pacific where it caused $10,000 and one fatality in California, and $26 million in damage and 159 fatalities in Hawaii. This led to the development of tsunami travel time charts for the Pacific and the Pacific Tsunami Warning Service. It also led to renewed international, scientific research interest in the subject.

As seen by the aftershock pattern, the earthquake rupture occupied a block about 100 miles long by about 50 miles wide between southeast of Scotch Cap and southeast of Sanak Islands (Figure 23). There is still a question how this relatively small earthquake produced such a large Pacific-wide wave. There were only five marigraphs operating at this date and the records from Sitka and Yakutat were marginal, recording amplitudes of about 1 foot each late in the record due to resonance and with weak beginnings. There was only a trace recorded at Seward and nothing was recorded at Skagway. Validity 4.

1946, November 1, 11:14 GMT. There was a magnitude 6.9 earthquake in the Near Islands, Aleutian Islands. In Hawaii, police were dispatched to the northeast coast of Oahu to watch for a wave reported in the pre-dawn—the sea had risen almost over the highway at 5 A.M. However, Cox and Morgan (1977) report that this was about 19 minutes before the expected first arrival. The tide gage at Honolulu did not record any activity, nor were there any reports from Alaska or elsewhere. This is a doubtful tsunami report. Validity 1.

1949, January 27, 11:00 GMT. A magnitude 5.9 earthquake near Kamchatka produced a small tsunami recorded at Adak with an amplitude of 3 inches arriving at 15:50 GMT. Validity 4.

1949, August 22, 04:01 GMT. A magnitude 8.1 earthquake occurred in the Queen Charlotte Islands, British Columbia, Canada. There were widely-scattered reports of independent waves having been generated. At Manzanita Lake (on Revillagigedo Island) a miniature tidal wave was reported. As the wave crossed the lake it completely submerged a nearby sandbar. A plane descending to land saw the wave and took to the air again to avoid being tipped over. At Ward Lake a fisherman in an aluminum skiff said the water seemed to rush to the west as if it was lifted and tipped. Then it rush back in a giant wave. After the water rushed back, it seemed as if the bottom of the lake began to boil, like gas or air escaping from beneath the lake bed. The water "boiled" in an almost direct line from the inlet to the outlet of the lake. It lasted for about an hour. The water around Ketchikan also behaved erratically. One woman reported that the water look like it was receding when it should have been rising. "There was no tidal wave" (*Ketchikan Daily News*, August 22, 1949, p. 9).

"Kit Carson reported that a tidal wave of perhaps two feet [range?] was seen coasting along the surface at Knutson Cove [on west coast of Revillagigedo Island about 35 miles northwest of Ketchikan] and some fish trap operators thought their anchors had come loose" (*Ketchikan Alaska Chronicle*, August 22, 1949, p. 1). Two underwater cables of the Alaskan Communication System were broken in six places and deeply buried 0.27 to 4.8 nautical miles west of Wrangell and south of the Stikine River delta, and a third was buried off the Stikine River delta. Also, at Wrangell a considerable wave hit the beach (*Juneau Alaska Press*, August 28, 1949, p. 2). The broken cables indicate a slide from the Stikine River delta and is a possible source for these waves (Heezen and Johnson, 1969, p. 417).

The *Sitka Sentinel* (August 22, 1949, p.1) reported that four hunters said that at Blue Lake, 14 miles southeast of Sitka, a wave washed a pack sack and a gun from the beach, and the waters of the lake bubbled like champagne.

"During the August 22, 1949 earthquake, probable seiche in the tidal waterway at Ketchikan caused waves as much as 2 feet high [range?] and waves probably several feet high formed in a lake about 6 miles northwest of the city [Ward Lake]" (Olson, 1949, p. 86).

A small wave was recorded on the Sitka marigram with an amplitude of 3 inches but the record is very poor and unreliable. It was not recorded at Ketchikan. A wave was also recorded at Hilo 5.3 hours later.

The reports of waves at Manzanita and Ward Lakes were possibly small slump tsunamis. The reported observation at Ketchikan, and those recorded at Sitka and Hilo, would be one or more other tsunamis probably due to submarine slumping. Validity 4. Multiple event.

1949, September 27, 15:31 GMT. A magnitude 6.7 earthquake in the Gulf of Alaska produced a record at Seward caused by gage shaking from the earthquake, and not by a tsunami (Zerbe, 1953). Validity 0.

1952, March 4, 01:23 GMT. A magnitude 8.1 earthquake near Hokkaido, Japan, produced a tsunami with an amplitude of 7 inches at Massacre Bay, Attu, and about 2 inches at Sweeper Cove, Adak, Dutch Harbor, Unalaska, and Sitka. Validity 4.

1952, November 4, 16:58 GMT. A magnitude 8.2 earthquake off the Kamchatka Peninsula, Russia, produced a tsunami that was observed in Alaska. At Massacre Bay, Attu, the wave had an amplitude of 4.5 feet and a period of 17 minutes. This was observed on the tide staff as the gage was not initially operating and the record was clipped. Low-lying areas were flooded. At Sweeper Cove, Adak, the tsunami had an amplitude of about 3.6 feet and slightly overflowed the banks of the harbor. At Dutch Harbor, Unalaska, the schools were closed, and the people evacuated to higher ground. However, the wave was only 3 feet high (Zerbe, 1953). It was widely recorded elsewhere throughout Alaska with amplitudes of one foot or less: Womens Bay (Kodiak), Seward, Yakutat, Juneau, Sitka, and Skagway (Zerbe, 1953). Validity 4.

Table 9. Amplitudes for the November 4, 1952, Tsunami Recorded in Alaska

Location	Amplitude
Massacre Bay, Attu	1.2 m
Sweeper Cove, Adak	1.1 m
Dutch Harbor, Unalaska	0.6 m
Womens Bay, Kodiak	0.3 m
Yakutat	0.2 m
Sitka	0.2 m
Seward	0.1 m
Juneau	0.1 m
Skagway	<0.1 m

1953, November 25, 17:48 GMT. A magnitude 7.4 earthquake near Kashima, Honshu Island, Japan, produced a tsunami recorded at Massacre Bay, Attu, with an amplitude of 8 inches. Validity 4.

1956, March 30, 06:11 GMT. An explosive eruption of Bezymianny Volcano in Kamchatka, Russia, produced an air wave or tsunami observed at Massacre Bay, Attu, with an amplitude of one foot, and Sweeper Cove, Adak, and Dutch Harbor, Unalaska, with amplitudes of 4 inches. Although the volcano is about 75 kilometers from the coast, the tsunami was observed at a number of places around the Pacific. It is not clear whether the wave was generated near the Kamchatka coast and traveled through the water as a tsunami, or was generated near the tide gage by air pressure waves. Validity 1.

1957, March 9, 14:23 GMT. A magnitude 8.3 earthquake occurred south of the Andreanof Islands, generating a tsunami that was recorded throughout the Pacific Ocean basin. The aftershocks outlined a zone from Amchitka Pass to Unimak Pass, an arc more than 250 miles long. On Adak Island the earthquake and tsunami caused severe damage. Roads were cracked and two bridges were destroyed. According to reports a 26 foot wave (range?) was observed in Sand Bay. All structures at the fuel and oil dock were washed away up to the 13 foot contour. The oil pipelines were damaged (Kirsch, 1957). The rise in water was 12.5 feet (range) in Sweeper Cove.

Bill Dirk (personal communication, June 29, 1994), a long time resident of Atka, Atka Island, 100 miles to the east, reported that a large swell entered the harbor and washed the skiffs up the creek and washed away all of the boat houses. On the west end of the island, big pilings were washed to a height of about 30 feet. All of the *baraboras* (half buried shelters) used for tending the fox traps were washed away. He had been working on Adak and was home for a month's vacation when the wave struck. He remembers the damage on Adak on his return. The *Ketchikan Daily News* (March 11, 1952, p. 1) reported that the tsunami had washed away the oil supply of the village of Atka, demolished two boat houses, and knocked two others from their moorings. One boat was lost and another was damaged.

Two docks and a concrete mixer were destroyed on Umnak Island. The location of these was not given, but they probably were at Camp Glenn, a former military base on the southeast end of the island.

Simeon Pletnikof, a long time resident of Nikolski, reported seeing drowned sheep near the sheep ranch at Chernofski, on the northwest coast of Unalaska (telephone conversation, August 3, 1994). The waves reached to within 25 feet of the ranch house. The waves were 75 feet high on the Pacific side of Umnak. Mr. William Ermeloff (personal communication), also a long time resident of Nikolski, reported that four sheep camps were washed away at Trappers Cove, Vsevidof, and other Pacific coast locations. Driftwood was washed a quarter of a mile inland on the Pacific side and to heights of 40 to 45 feet.

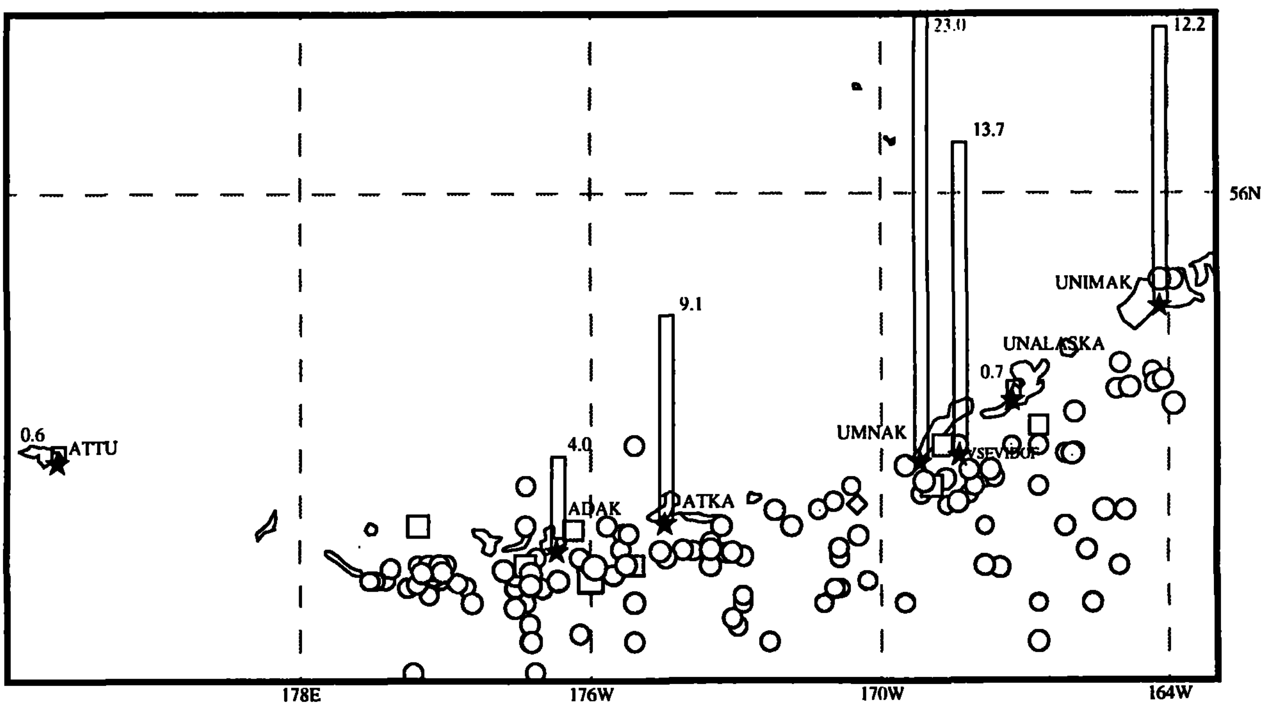


Figure 25. Location of aftershocks and effects of the March 9, 1957, earthquake and tsunami.

On Unimak Island near Scotch Cap, where the lighthouse was washed out in 1946, a 40-foot wave was reported (Iida et al., 1967). According to Cox and Pararas-Carayannis (1976), its height was 50 feet (15 meters) which they ascribed to lighthouse personnel. They thought 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. It is now known that tsunamis do not necessarily originate with the epicenter, but in a broad area, probably in the trench or at the end of the thrust plate. The report could not be verified with the Coast Guard, and the arrival time is not given. The *Honolulu Sunday Advisor*, March 10, 1957, gives a report of a 40-foot wave at Scotch Cape [*sic*] in a UP article with a Seattle dateline—the only contemporary report known to the author. It seems that a 40-foot wave was reported, but the evidence for a source other than the main tsunami was not found.

At Dutch Harbor, Unalaska, the amplitude was 2.25 feet; at Massacre Bay, Attu the amplitude was 1.9 feet; at Sitka the amplitude was 1.3 feet; at Yakutat the wave was recorded with an amplitude of 1.1 feet; and at Womens Bay, Kodiak, the amplitude was 4 inches (Salsman, 1959). Validity 4.

Table 10. Amplitudes for the March 9, 1957, Tsunami Recorded in Alaska

Location	Amplitude
Dutch Harbor, Unalaska	0.7 m
Massacre Bay, Attu	0.6 m
Sitka	0.4 m
Yakutat Bay	0.3 m
Juneau	0.2 m
Seward	0.2 m
Womens Bay, Kodiak	0.1 m

1958, July 10, 06:16 GMT. There was a magnitude 7.9 earthquake in southeastern Alaska, with its epicenter on the northern coast of Cross Sound near Palma Bay. It induced subaerial and submarine landslides, and ice falls that generated at least eight separate local tsunamis. The most destructive, and an event of historic importance, occurred at Lituya Bay. Tsunamis were generated in Yakutat Bay (from a landslide) and Disenchantment Bay (from an ice fall). Three fatalities occurred at Yakutat Bay; two occurred at Lituya Bay.

The Fairweather Fault apparently ruptured for a distance of 125 miles, but the direct evidence is limited to some fresh scarps 10 miles south of Crillon Inlet where slickensides indicate movement of about 21 feet horizontally, with right lateral movement (as is the case with the San Andreas in California). It also had 3 feet of vertical motion.

Aftershocks delineated a zone of activity from about 60.0°N, 140.5°W to 58.4°N, 136.4°W, reaching from Palma Bay to near Icy Bay. (See Figure 26, next page.) It was felt over an area of 400,000 square miles. Scientific expeditions were made in 1958 and 1959 by Miller (1960) and Tocher (1960) but much of the area is inaccessible. Damage exceeded $100,000, mainly from the three boats that were sunk. Damage and fatalities were light due to low population.

Lituya Bay is a "T" shaped bay with the upper part of the "T" being the glacially-scoured fault trace of the Fairweather fault. The northwest limb is the Gilbert Inlet with the Lituya Glacier at its end. The southeastern limb is the Crillon Inlet with the North Crillon Glacier at its end. (Refer to page 62 for a map of this area.) The combined length of the two inlets is about 3 miles. Lituya Bay is about 7 miles long and 0.8 mile wide, partially closed to the ocean by La Chaussee Spit. In the middle of the bay is Cenotaph Island. The water is about 500 feet deep. This has been the site of repeated huge local tsunamis in 1936, 1899, 1874, and 1853–1854 (Miller, 1960) and probably 1900. At

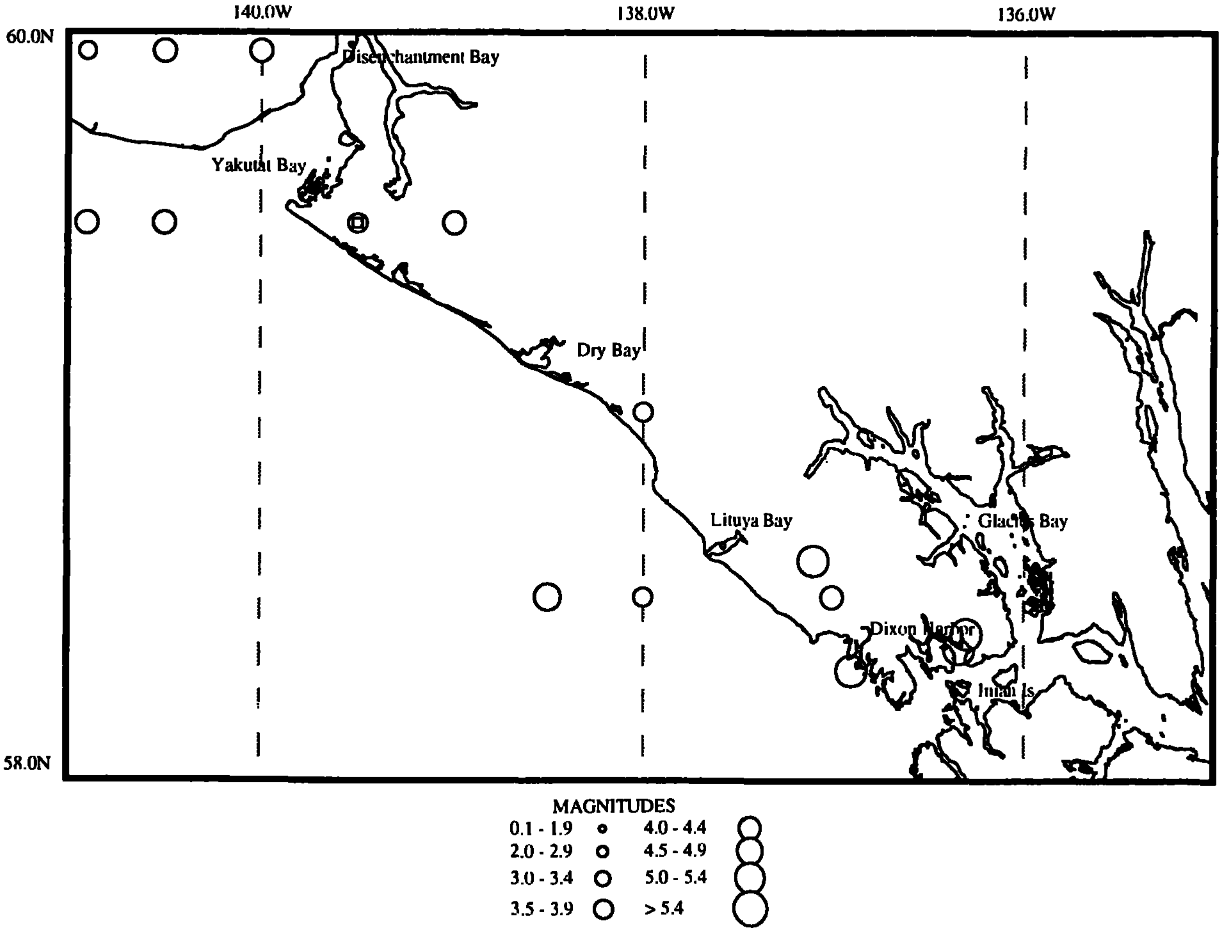


Figure 26. Aftershocks of the July 9, 1958, earthquake.

the time of the earthquake the tide was falling but still less than 1 foot above mean level. The earthquake caused 40 million cubic yards of rock weighing 90 million tons to slide from the northeastern side of Gilbert Inlet from an average height of 2,000 feet with dimensions of 2,400 to 3,000 feet and an average thickness of 300 feet.

The slide forced the water out as a surge up to a colossal height of 1,720 feet—400 feet higher than the Empire State Building—onto the opposite shore, stripping the trees from the forests to that level. This was not a true tsunami wave but a surge with its velocity depended on the kinetic energy from the slide. The water forced down Gilbert Inlet formed a true tsunami.

There were three fishing boats in the bay at the time of the earthquake. The 55-foot *Sunmore* from Idaho Inlet on the north shore of Chichagof Island, was anchored in Anchorage Cove behind Chaussee Spit near the bay outlet. Orville Wagner and his wife, Mickey, were on the boat. Brazee and Jordan (1958) cite reports from the *Badger* and *Edrie* that the *Sunmore* was swept against the cliffs near the mouth of the bay. It was sunk and the Wagners were lost. An oil slick was all that was found.

Howard G. Ulrich and his 7 year old son, Howard, Jr., had entered the bay in the *Edrie* at about 8 P.M. that evening and had anchored near the south shore well behind the Paps, twin hills about 200 to 300 feet high. Ulrich was awaken by a vigorous rocking of the boat at about 10:16 P.M. local time which was about sunset.

The weather was clear and the head of the bay was clearly visible. Avalanching could be heard in the mountains. About 2½ minutes after the earthquake there was a deafening crash. According to Ulrich:

> The wave definitely started in Gilbert Inlet, just before the end of the earthquake. It was like an explosion, or a glacier sluff. The wave came out of the lower part, and looked like the smallest part of the whole thing. The wave did not go up to 1,800 feet, the water splashed there.

Ulrich watched the wave approach until it reached his boat in 2½ to 3 minutes. He was unable to free the anchor and had let out all forty fathoms of chain and started the engine. Midway between the head of the bay and Cenotaph Island the wave appeared to be a straight wall of water, possibly 100 feet high, extending from shore to shore. The wave was breaking as it came around the north side of the island but the south side was still a smooth crest. As it approached the *Edrie* the wave appeared to be very steep and 50 to 75 feet high. There was no lowering or other disturbance preceding the wave. He called on his radio "Mayday, Mayday—*Edrie* in Lituya Bay—All Hell broke loose—Goodbye" (Roberts, 1961).

The anchor chain snapped as the boat began to rise. It was carried forward, probably over the south shore, and then in the backlash it was carried toward the middle of the bay. The wave crest seemed only 25 to 50 feet wide and the backside was less steep. After the wave passed, the water surface returned to almost normal but

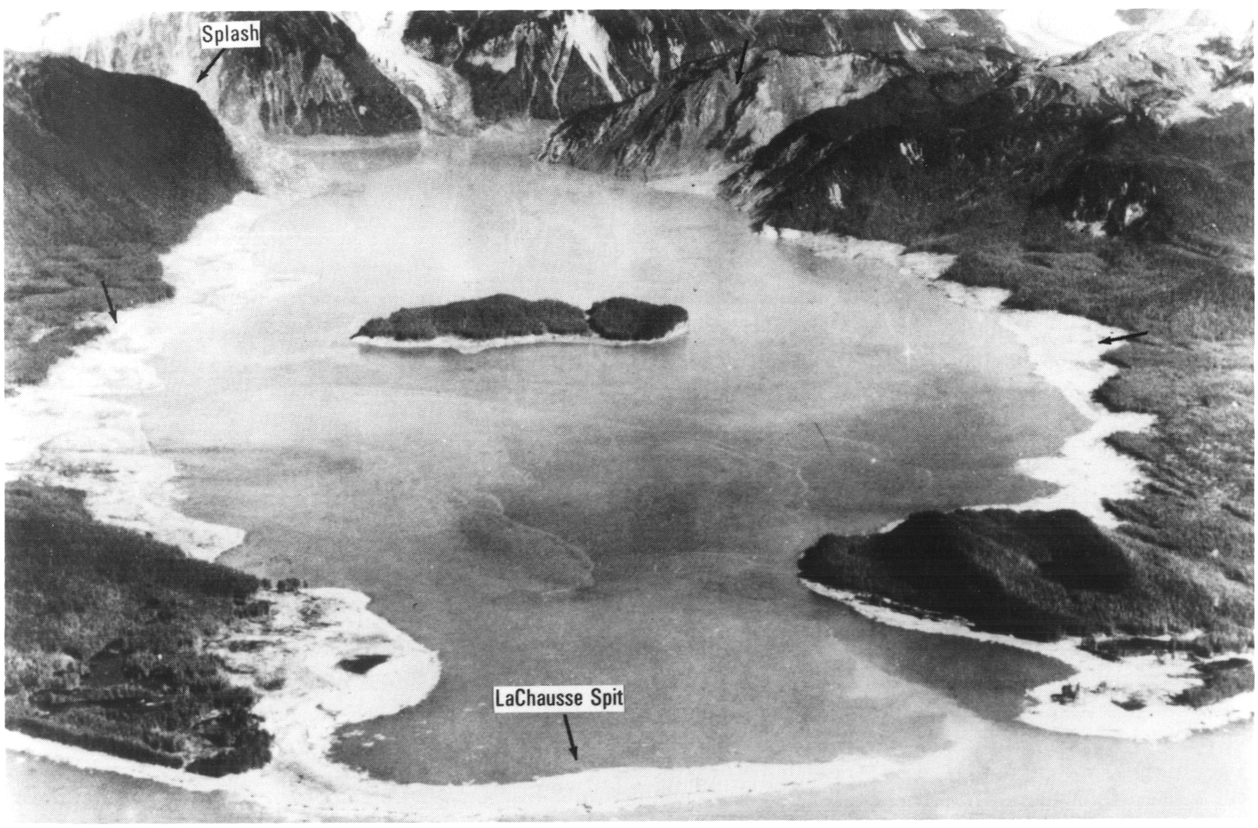


Figure 27. Lituya Bay following the tsunami of July 9, 1958. A rockslide at top left at the head of the bay generated a splash indicated by the arrow. The tsunami cleared trees and left a white rim around the bay. A swatch of trees was also destroyed on Cenotaph Island, in the center of the bay.

was very turbulent with much sloshing back and forth from shore to shore with steep, sharp waves up to 20 feet high. These waves were disorganized and did not show a pattern of moving toward the head or mouth of the bay. After about 20 or 30 minutes the bay became calm although floating logs covered the water near the shores and were moving out the entrance. Ulrich left the bay at 11 P.M. with what seemed a normal ebb tide.

William Swanson, of Pelican on Chichagof Island, and his wife, Vivian, on the third boat, the *Badger*, had entered the bay at about 9 P.M. They went in as far as Cenotaph Island and returned to anchor in Anchorage Cove near the north shore and near the *Sunmore*. Swanson was awakened by the shock. A little more than a minute after the shaking started he looked toward the head of the bay past the north end of Cenotaph Island and saw what he thought to be Lituya Glacier, which had risen in the air and moved forward so it was in sight. It seemed to be solid but was jumping and shaking. Big cakes of ice were falling off the face and down into the water. After a little while, the glacier dropped back out of sight and there was a big wave of water going over the point. He next noticed the wave going over the south shore at Mudslide Creek. As the wave passed Cenotaph Island it seemed to be about 50 feet high near the center of the bay and sloped upward toward the shore. It passed Cenotaph Island about 2½ minutes after it was sighted and reached the *Badger* about 1½ minutes later. Again no lowering or other disturbance was noticed before the wave arrived.

The *Badger*, still at anchor, was lifted up by the wave and carrier across the La Chaussee Spit stern first just below the crest of the wave like a surf board. Swanson looked down on the tops of trees growing on the spit and believed he was two boat lengths above them (80 feet). The wave broke after crossing the 200 foot wide spit and the boat hit bottom and foundered some distance from shore. The *Daily Alaska Empire* (July 10, 1958, p. 1) carried Swanson's account:

> We cleared off into the ocean and were dumped as the wave curled, then went down stern first and stuck with the pilot house just above water. Then the boat was hit by trees, brush and timber sweeping along the wake of the wave. It was like being in a tin can with someone shaking it.

Looking back, 3 to 4 minutes after hitting bottom, Swanson saw water pouring over the spit, carrying logs and other debris. He did not know if this was the second wave or a continuation of the first. The Swansons abandoned their boat using an 8-foot skiff and were picked up by another fishing boat, the *Luman*, in about 2 hours. They were flown to Juneau for a short rest in the hospital and treated for exposure.

The account by Swanson that he saw the Lituya Glacier is not credible as the glacier is only about 500 feet above the bay level and the intervening point of Gilbert Inlet is 1,700 feet above the bay. The glacier could not have surged into sight, about one thousand vertical feet. In the setting sunlight he must have been seeing dust and the slide, or confusing it with the smaller Cascade Glacier at the head of Lituya Bay.

Miller, the source for most of the above information visited the area on July 10, and observed (from an airplane) large amounts of ice in the upper parts of the bay but no ice in the runup areas. Many of the larger blocks were flat-topped and carrying boulders which he thought had come from the submerged part of the glacier. Up to 1,300 feet of ice had been sheared off the glacier but the southwestern margin had not changed significantly. The North Crillon Glacier did not show significant change. The speed of the waves was calculated as between 97 and 130 miles per hour. The wave had been 110 feet high at Fish Lake and had reached into the lake. All shellfish colonies had been killed. No trace could be found of Huscroft's well-constructed cabin on the lee side of Cenotaph Island (see the 1936 event) except for pieces of wood and some metal utensils found several hundred feet away from the former cabin site.

The lighthouse mounted on concrete piers at Harbor Point was carried away as were several geodetic markers. Equipment left by a mining company at an intended campsite on the south shore was also washed away. Davis and Sanders (1960) report that when they flew over the area on July 12, the ocean beaches for 10 miles on both sides of the mouth of Lituya Bay were covered with ice and trees stripped of their bark. Ice and trees were also being carried seaward at right angles to the coast. The bay was so full of debris that it was impossible to land the seaplane.

The inundation was about five square miles. This was a subaerial, landslide-generated tsunami.

At Yakutat Bay, Jeanne Walton, president of the Bellingham Canning Company, Robert Tibbs, a Federal Aviation Administration employee, his wife, and John Williams, postmaster of Yakutat, and his wife, Dora, had gone to Turner Point on Khantaak Island about 2 miles northwest of Yakutat in two boats to pick berries. After 9 P.M. the Williams decided to leave. A few minutes after waving good-by to the remaining three they noticed the trees were swaying. Looking back to where the others had been standing they saw a wave approaching. The wave was so high they could not see the trees on the part of Khantaak that they had just left, which was now one-half to one mile behind them. Mr. Williams increased the speed of the boat to its maximum of 25 mph 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.

The wave was observed by a resident on the shore at Yakutat with an estimated height of 15 to 20 feet initially. It was estimated to have been 3 feet at the Bellingham Cannery dock, breaking mooring lines there. Two later swells of nearly equal height also tore loose mooring lines. The three who had remained on the island were never found, although search parties reached the area about 20 minutes later. Their badly damaged boat surfaced. A section of the island tip 150 feet by 1,000 feet had slumped into the water, leaving a 3½ foot scarp. The water was 90 feet deep over what had been land. Approximately 500,000 cubic yards of material had slumped about 100 feet. (This same point of land had slumped into Yakutat Bay in the 1899 earthquake.) At the "Mill Pond" about 300 yards northeast of the eastern end of the Yakutat airport runway, large logs were thrown up on the bank four feet above water level. This is the second independent tsunami generated by this earthquake and was due to a submarine landslide. There were reports that the island had risen about 20 feet but this probably was a confusion with the fact that water at this point had temporarily fallen about this amount due to the landslide.

In Disenchantment Bay, two men were about one-quarter mile from the Turner and Haenke Glaciers when their canoe quivered from the earthquake. They were tossed about for an hour by 20 foot waves radiating from the glacier from where many tons of ice fell into the bay. A second party of three men (camped on the shore between Haenke and Osier Islands) also experienced the earthquake. Two fled to their boat and spent several hours riding out the swells. The third man tried to save their equipment but lost much to 5-foot waves (Davis and Sanders, 1960). These were probably small tsunami waves generated by the falling ice from the glacier.

At Dry Bay, a collapse of the bank at the mouth of the Alsek River caused a wave (bore) three to six feet high that spread up-river at 12 miles per hour. This was a submarine landslide tsunami. The calving of ice from the Alsek Glacier caused an ice dam to be formed at the point where the Alsek River leaves the trace of the Fairweather Trench. Fishermen on the lower reaches of the river noted a drop of 3.5 feet in the river level within half an hour of the earthquake. Flooding followed within a few hours when the dam gave way (Davis and Sanders, 1960, p. 225). There was a similar account reported for the 1854–1855 tsunami.

Davis and Sanders (1960) report a slump on the Dohn River in Dry Bay, closing off the river mouth, and causing a water-level rise that lasted several hours. Edith Renner, at Strawberry Point at the estuary mouth of the Situk River just south of Yakutat Bay, was knocked down by the earthquake. She saw waves several feet high moving up the river. A family on the Ahrnklin River on the same estuary saw waves moving down the river toward Strawberry Point, probably the same waves seen there. Other estimates give the heights as 2 to 5 feet. Two miles upstream, where the railroad trestle crosses the Situk River, a family observed waves going up and down the river for some minutes after the shaking stopped but they rapidly decreased in height.

Brazee and Jordan (1958) report that mariners about 20 miles off Icy Point likened their experience to "riding on top of a big explosion." From their vantage point they were able to hear loud roars as the mountainside was breaking away. As the ice and rocks hit the water a "wall" seemed to appear from below.

In Dixon Harbor waves of 1 to 3 feet high were observed several minutes after the earthquake.

A tide of more than 3 feet struck Inian Island (off the north coast of Chichagof Island) breaking the mooring of several small boats. Seiche continued in Cross Sound for minutes or hours. Rocks falling from steep cliffs in Glacier Bay caused small waves that broke on the shore with heights of 2 to 3 feet. Many crab pots were lost.

Slight traces of waves were reported on the tide gage at Sitka beginning at 23:25, 70 minutes after the earthquake, with a period of 18 minutes and a maximum amplitude of 2 inches. At Yakutat the gage registered a maximum amplitude of 8 inches and a period of 27 minutes.

The Alaska communication system had two cable breaks, one and three miles from the Skagway Beach terminal, caused by silt movement carried out into Lynn Canal from the Skagway River. Subaqueous slides in Taiya Inlet are blamed for 25 foot waves at Skagway that, coming at low water, caused no damage (Yehle and Lemke, 1972, p. 84). Tocher (1960) reports that these waves were augmented by subaerial slides from the steep-sided fjords. There were two other breaks south of the Katzehin River delta with the cables deeply buried.

Three cable breaks occurred between Flat (Mud) Bay and Kataguni Island in Lynn Canal, in which the cables were buried for that distance, about 17 miles. The break was probably due to sediments from the Katzekin River. Another cable break occurred about 15 miles south of Eldred Rock in Lynn Canal, burying the cable too deep for the cable ship to hook. The break occurred off Brenners Bay which is fed by three glacial rivers. A seventh break occurred near Wrangell where the Stikine River discharges a large quantity of silt (Hatch, 1959). These indicate four probable episodes of submarine slumping and unobserved or unreported waves.

The Juneau-Skagway cable was broken in four places. Richards (1959) reports on the cable break near Shikosi Island which is near Kataguni Island. In attempting to recover the cable, about one mile of the south end of the cable was found coiled in a small area near the southern tip of Kataguni Island. This indicates either high velocity currents sweeping the cable there, or cable recoil after breaking under high tension stretching caused by the current. This cable was not recovered and was abandoned. The break near the Katzekin River was buried under tons of sand, mud, and gravel. Significantly, there was a buoy at the mouth of the river which was being used by a fisherman to maintain his boat's position. Immediately after the earthquake he noticed that the buoy had disappeared. No trace of the buoy was found, but the fisherman did not mention any wave action.

At Hilo, Hawaii, the tsunami was recorded 6.7 hours after the earthquake with an amplitude of 4 inches and a period of 15 minutes. This was a multiple tsunami event of at least eight observed separate waves, two of which caused fatalities. Validity 4 for tsunamis at Lituya Bay and Yakutat Bay and validity 3 for tsunamis at Disenchantment Bay, Dry Bay, Glacier Bay, Inian Island, Skagway, and Dixon Harbor. There may have been up to four other tsunamis associated with the cable breaks, and others that were not reported.

1958, November 6, 22:58 GMT. A magnitude 8.1 earthquake in the southern Kuril Islands, Russia, produced a tsunami that was recorded at Massacre Bay, Attu, with an amplitude of 8 inches, and at Sweeper Cove, Adak, with an amplitude of less than 4 inches. Validity 4.

1958, November 12, 20:23 GMT. A magnitude 7.0 earthquake in the southern Kuril Islands, Russia, may have been recorded at Massacre Bay, Attu and Sweeper Cove, Adak. The maximum amplitudes of 8 and 4 inches respectively are near the detection threshold and these are doubtful recordings. Validity 2.

1959, May 4, 07:16 GMT. A magnitude 8.0 earthquake in the northern Kuril Islands, Russia, was recorded at Massacre Bay, Attu, with an amplitude of 6 inches. Validity 4.

1960, May 22, 19:11 GMT. The great Chilean earthquake with a magnitude of 8.6 generated a wave that caused considerable damage around the Pacific. In Alaska, it was recorded at Massacre Bay, Attu, with an amplitude of more than 5.5 feet, at Sweeper Cove, Adak, with an amplitude of 3.5 feet, and at Yakutat with an amplitude of 2.1 feet. At Womens Bay (Kodiak), Dutch Harbor (Unalaska), and Seward recorded amplitudes of 2.3 feet. Sitka had an amplitude of 1.5 feet and Skagway had an amplitude of 7 inches. It was observed on the records of Juneau, Kake, and Ketchikan (Berkman and Symons, 1964).

Cox and Pararas-Carayannis (1976) report some ice cracking in the afternoon, but did not give a location. This occurred near Point Hope on the Chukchi Sea near the mouth of the Kukpuk River in the early afternoon of May 23. Some Eskimos were on the ice and returned to shore when they heard the cracking. There was a U.S. Geological Survey team at the mouth of the river, including George Moore, who reported this event. Curiously, if this was caused by the Chilean tsunami it would have had to traveled under the still-frozen ice to reach and crack the thinner coastal ice as its amplitude increased in the shallower water. It could not have been caused by the seismic wave which would have arrived within minutes of the origin time.

At Cape Pole, Kosciusko Island, a log boom was broken by strong currents associated with this tsunami. The runup there was about 3.25 feet. A 14 to 15 foot wave was reported at Montague Island by the MacLeod Harbor radio operator. The wave caused minor damage to some pilings. It was followed by a dozen swells of between eight and ten feet (*Anchorage Daily Times*, May 24, 1960, p. 1). These would have been ranges. The fishing vessel *Swift* near Cape Decision reported unusual tidal action of 1½ to 4 feet (range?) at 10 to 30 minute intervals. Cape Decision is a point of land on the south end of Kuiu Island sixty miles west of Wrangrell. Waves 8 to 10 feet high were reported at Kosciusko Island off the northwest end of Prince of Wales Island. Another fishing vessel, the *Jenny B*, reported to the Coast Guard that it was experiencing 4-foot tidal variations but the location was not reported in the press (*Daily Alaskan Empire*, May 24, 1960, p. 1).

At Valdez no change in the tides were noticed (*Valdez Breeze*, May 28, 1960, p. 1). Joe Leahy (personal communication), now director of the Valdez museum, reported that as a Coast Guard Seaman he and several of his shipmates on the Buoy Tender *White Holly* had been dropped off to paint day markers for the channel at El Capitan Pass, northwest of Craig, at low tide. A sudden rise in the water of 3 to 4 feet forced them to climb the markers. The Captain, Lee Groves (personal communication), confirms the account but puts the event at Klakas Inlet near

Klinkwan on the southwest coast of Prince of Wales Island.

Clam diggers at Kanak Island (at the west end of Controller Bay), had to run for higher ground, abandoning their clam boxes and nearly losing their truck. On Egg Island the tide came and went three times during low tide. Some "inside" diggers noticed the tide coming in too soon and the water getting dangerously high around their skiff. They ran to the boat and climbed in, but when they tried to push off they found they were high and dry again. Some of the diggers reported digging three low tides in an hour. A fisherman on the bar had to run as big breakers came in and the fishing gear was alternatively afloat and dry all over the flats (*Cordova Times*, May 26, p. 1). This is the largest teletsunami to have affected Alaska. Validity 4.

Table 11. Amplitudes for the May 22, 1960, Tsunami Recorded in Alaska

Location	Amplitude
Massacre Bay, Attu	1.7 m
Sweeper Cove, Adak	1.1 m
Womens Bay, Kodiak	0.7 m
Dutch Harbor, Unalaska	0.7 m
Seward	0.7 m
Yakutat	0.6 m
Skagway	0.2 m
Juneau	trace
Kake	trace
Ketchikan	trace

1963, October 13, 05:17 GMT. A magnitude 8.1 earthquake in the southern Kuril Islands, Russia, generated a wave at Massacre Bay, Attu, with an amplitude of 8 inches. Validity 4.

1964, March 20, 16:00 GMT. A wave with an amplitude of about 3 inches and a period increasing to about 1 hour and continuing for more than 12 hours was recorded on the Seward marigram but a source of this not known. There were no storms or unusual weather reported in Alaska in March. Validity 2.

4.3 The Prince William Sound Tsunami: March 28, 1964

1964, March 28, 03:36 GMT. At about 5:36 P.M. local time the largest earthquake to affect the North American Continent struck the Prince William Sound area of Alaska. It also generated the most destructive tsunami observed in Alaska and the west coast of the United States and Canada. It was extensively studied, notably by the National Academy of Sciences Committee on the Alaska Earthquake (1970–1973), the Coast and Geodetic Survey (Liepold, 1966–1969), and by Wilson and Tørum (1968).

The earthquake was noteworthy in that it was a subduction zone event occurring within the islands of Prince William Sound. This allowed for an unusual degree of observation. Usually such earthquakes are mainly located in deep, oceanic areas well off shore.

Tsunamis accounted for 106 of the 115 fatalities directly associated with this event. There were two types of tsunamis generated—a major tectonic tsunami accounting for 25 of the tsunami fatalities, and about 20 local submarine and subaerial landslide tsunamis which accounting for 81.

The tectonic tsunami was probably generated in the trench area and affected all of the communities observing a tsunami in Alaska and around the Pacific Basin. This wave caused $10 million in damage to the Canadian Pacific coast. It caused about $20 million in damage and 16 fatalities on the United States west coast. It was the source of tsunami damage in Alaska outside of the Prince William Sound and caused some of the tsunami damage and 5 of the fatalities there. It reached the shores between 20 and 45 minutes after the earthquake began.

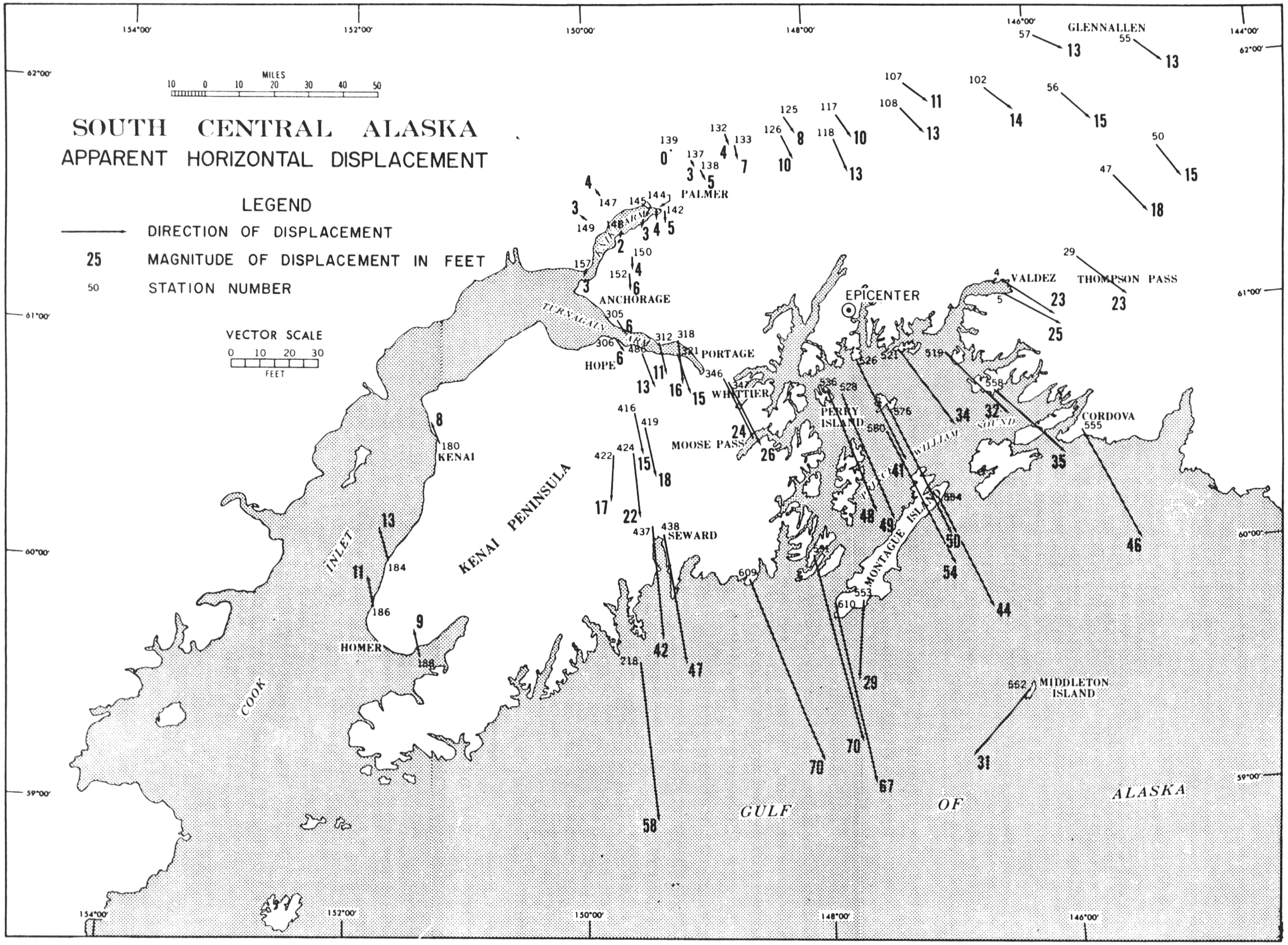


Figure 28. Horizontal displacement, south-central Alaska. (Leipold and Wood, Vol. III, 1969)

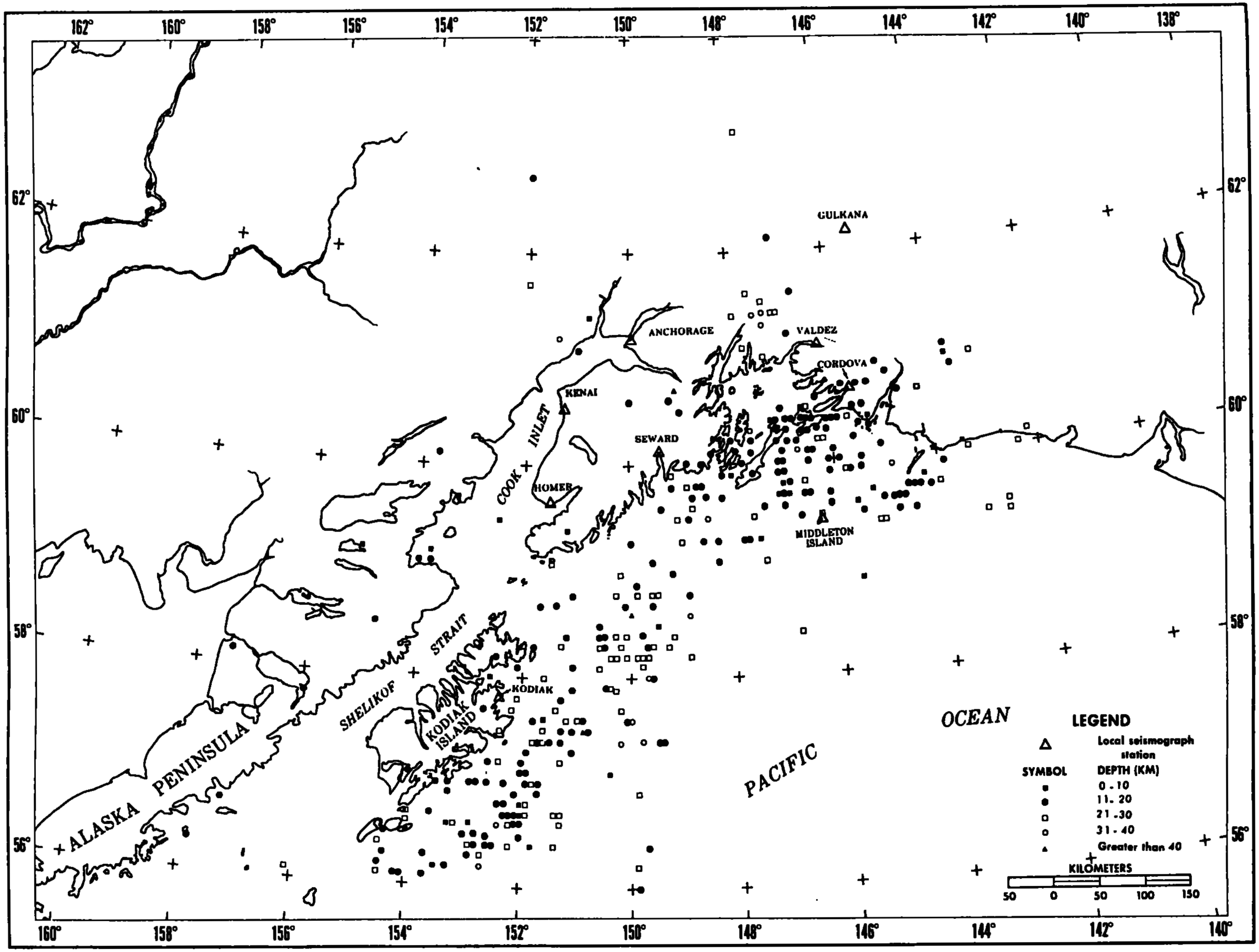


Figure 29. Focal depths of selected aftershocks, March 28 to October 30, 1964. (Leipold and Wood, Vol. II, 1969).

The often destructive, locally-generated submarine and subaerial landslide tsunamis arrived in 2 to 5 minutes and caused most of the damage. This type of tsunami is limited to the bay of generation and accounted for most of the fatalities and damage. They originated during the earthquake shaking, which destabilized the uncon-solidated glacial sediments and unstable land masses on fjord walls. The tsunamis reached great heights as a 170 foot runup at Shoup Bay, Valdez, demonstrated.

This source of tsunamis, and their inclusion in the definition of tsunamis, was not well known outside of the field in the 1960s, leading to considerable confusion in the reports of these waves in the literature of that time. They were sometimes called "water waves," tides, and seiche. Their source has been ascribed to the tectonic tilting—horizontal and vertical movements of the shores and sea floor—and the passage of seismic waves.

Regional tilting would give rise to low amplitude waves, probably not discernible above tidal changes. Their amplitude would be the same as the uplift, and in a glacial bay such as Seward and Valdez would be only a few inches in differential uplift from one end or side of the bay to the other. Such waves arising from regional uplift and subsidence may have higher amplitudes equivalent to the differential change in elevation but the period would be about an hour.

The passage of seismic waves are a known cause of seiche at great distances from the source where the waves have had time to disperse. The seismic waves caused water to slosh out of swimming pools as far away as New Jersey and caused some damage to boats in Puget Sound and along the Gulf of Mexico. However, this phenomenon is not observed in the epicentral area for several reasons. The seismic waves have passed from the epicentral area in four or five minutes, not enough time to set up sympathetic oscillations. In addition, the waves have not had time to separate into phases with common frequen-cies, and all frequencies coexist. This also inhibits the development of resonance.

There are statements in the literature that the damage would have been greater except that it occurred at low tide. This is true for the tectonic tsunami, but only partly true for the landslide tsunamis that caused most of the damage. At low tide more of the water-logged delta is above the supporting water and is more prone to fail under seismic shaking. Had the earthquake occurred at high tide probably some of the submarine landslides would not have occurred or would have been smaller, but those that did occur would have had a greater flooding effect.

The vast amount of data for this event makes it necessary to present only a summary here. The information selected concentrates on the circumstances of injuries, damage, and fatalities that may be helpful in mitigation planning, the timing and size of the waves, and new or reevaluated information.

The order of presentation is from west to east for communities directly observing the waves, with instrumental data at the end. Almost all of the effects are from the zone of deformation as shown by the aftershocks and areas of uplift or subsidence.

The uplift was probably due to the continental plate moving up the subduction boundary and the subsidence would be due to the release of strain. The vertical motions received more attention due to their impacts on ports by either deepening harbors (making docks unusable) or shallowing them (making dredging necessary to maintain port facilities). The vertical motions were also more obvious. This regional tilting fits the traditional theory that tsunamis are caused by uplift or down-drop of the ocean floor.

The whole block shifted horizontally to the southeast by at least 70 feet. (See Figure 28.) This thrusting of the whole plate into the trench was the likely cause of the initial rise in water for the tsunami, a situation not readily observable in most subduction-type tsunamis, since the whole area is under the ocean.

Another observation of thrust-type earthquakes effects is the relatively low intensity of the earthquake for an earthquake of this magnitude. Intensity VII and VIII were the predominate intensities even though these communities were riding on the moving plate that had ruptured directly under them. Figure 29 shows the boundary of the plate motion as outlined by aftershocks.

The communities within this area experienced similar shaking as the rupture passed directly under them. There were variations due to local geology but the distance to the epicenter is not relevant. As the tectonic tsunami did not arrive immediately with the regional deformation, its source was at some distance, and probably near the trench. This accounts for the variation in arrival times from about 30 minutes at Kodiak to about 45 minutes at Valdez.

The count of fatalities for this event is higher by three in this account than that usually given. The additional fatalities counted in this report includes the third mate of the *Chena*, Ralph Thompson, who died of a heart attack suffered on the bridge of the wildly plunging and rolling vessel, Emil Elbe who died of a heart attack running away from the wave at Seward, and the infant washed into a snow bank at Whittier and who died after being found. Other fatalities were not counted here include Charles Byer, Sr., a heart attack victim and Bill Joy, both at Cordova (*Petersburg Press*, April 3, 1964, p. 1) as the circumstances of their deaths were not available. An infant died in Akhiok of exposure after being evacuated but before the tsunami arrived. Also in Kodiak one man was killed during the clean-up. The criteria for including fatalities as due to the tsunami is whether the tsunami directly led to the fatality.

Perryville. Cloud and Scott (1969) report that high tides or tsunamis affected the area about 4½ hours after the shock. Three or four waves about 10 feet high were reported. The late time probably identifies these as waves from the tectonic tsunami. The waves arrived with the rising tide.

Chignik. Tsunami waves were reported arriving about two hours after the main earthquake shock and were 10 feet high and twelve in number. In the lagoon the waves were reported at three hours after the earthquake and only 3 feet high. About midnight a 10-foot wave raised the water level from low, to one to two feet above high tide (Cloud and Scott, 1969).

Aleknagik. This village, north of Bristol Bay, reported seeing two waves about 1 foot high and 150 feet apart on Lake Aleknagik in the open water near the mouth of the lake (Cloud and Scott, 1969). This would have been a separate landslide tsunami in the lake.

4.3.1 Kodiak Island Area

Akhiok. Griffin and Swarthout (1996) give the following account. Norman Nault and his partner had finished a trapping trip to Tugidak Island, a low island in the Trinity Islands just south of Kodiak. They cached some of their pelts on the island, and then were picked up by airplane for their next destination. The pilot took the rest of their furs to Kodiak for later reshipment to Anchorage. The men built a log cabin on Fox Island in Deadman's Bay. On March 26, after a day of hunting, they tied up their dory at Akhiok where they were staying in the school. When the earthquake struck the next day the school was badly shaken. The two men elected to stay in the new school even though other people shouted warnings of the tsunami as they ran for higher ground. The radio carried warnings of the coming wave. The school was sixty feet above the sea level. Nault reports:

> I can't begin to tell you the shock I got when I saw the wave. A wall of water forty or fifty feet high was suddenly in the bay and racing toward

> the village . . . This was a wall of ferocious, foaming, "monster" water and it seemed to be traveling at jet speed. . . . I thought the school would shake apart as the giant wall of water slammed into the beach with thundering momentum and blasted the houses. . . Some of the houses, sheds, shacks and boats were just lifted up and smashed together until they were splintered like kindling. . . . I saw a small amount of water flooding underneath me around the pilings that held the building up. . . . Then I heard a sucking sound as the water began to race back toward the ocean taking masses of debris and rubble with it.

The bay was filled with debris; nine waves came and went but none as high as the first. One baby died among the evacuees, probably of exposure. This fatality is not counted as directly due to the tsunami.

It was two days before people felt safe in returning to the village. Nault's losses extended to his cabin (on Fox Island) which was washed away, his dory tied up at the harbor at Akhiok, the cache of furs left on Tugidak Island, and furs that had been shipped to a warehouse (in Kodiak) which was also destroyed (Griffin and Swarthout, 1996).

Kaguyak. Located near the southeastern end of Kodiak Island, Kaguyak was a small fishing village of 36 people in residence at the time of the earthquake. There were twelve houses, two Russian Orthodox churches, and other structures on a spit of land about 200 feet wide between the ocean and a fresh water lake. The first wave was observed at sea, and word-of-mouth warnings alerted the villagers who evacuated to a nearby hill. The wave arrived about 20 minutes after the earthquake and flooded up to the church. A villager called on the radio and gave the first warnings that a tsunami had been generated. He contacted Old Harbor and the Shearwater cannery which relayed the message to Chiniak station near Kodiak. These early warnings were responsible for evacuations and reduced fatalities on Kodiak Island. The next two waves were not as large and just reached the beach berm. The largest wave struck at 9:00 P.M. It was 32 feet above the post earthquake MLLW level and washed all of the houses off of the spit and into the lake. They were carried back across the spit and into the bay.

After the first wave, there was a flare from the camp of a geologist, Donald Wyatt from Los Angeles, and his wife, about two miles from the village. Walter Cohen from the village went to see what was wrong. He raced through town between the second and third waves. He attempted to convince them to stay on the hill

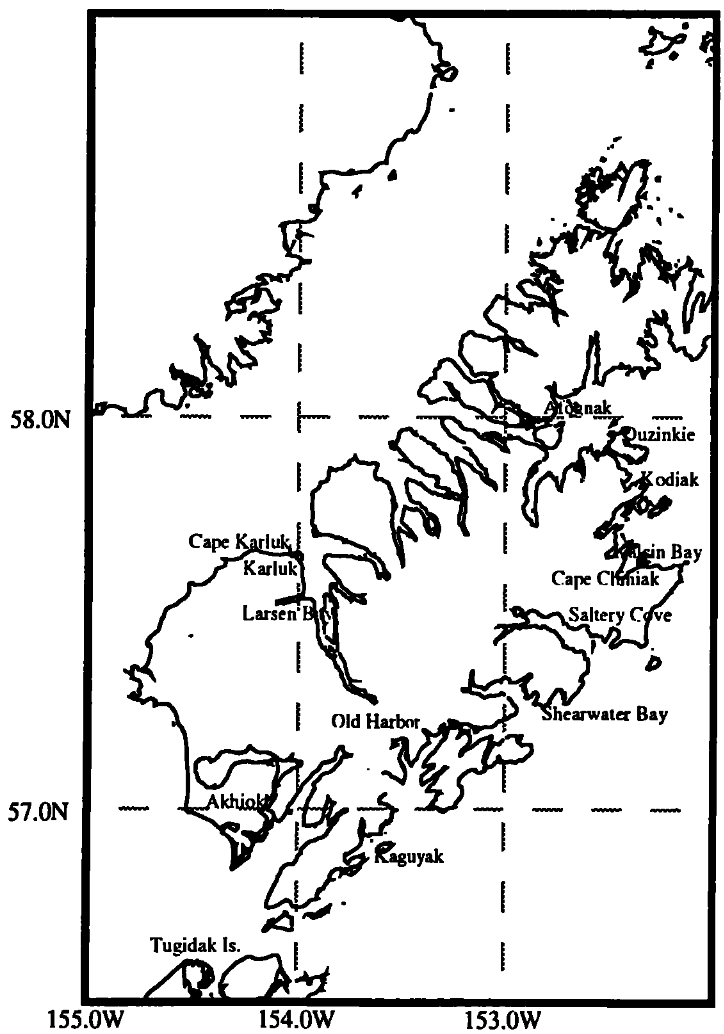


Figure 30. Location map, Kodiak Island.

and not to try to cross the low land separating them from the villagers. They insisted and loaded up their heavy gear for the crossing. Wyatt was wearing a heavy back pack, flare gun, gun belt and pistol, a knife, and hatchet which he refused to take off even when it was difficult for him to keep up with Walter Cohen. They were caught by a wall of water near the church but were rescued by three villagers in a dory. When the dory approached the lake shore, Wyatt pitched his wife out of the boat; she landed face down and did not move. Cohen jumped out onto an ice floe and reached the woman. He managed to carry her up the hill to the other villagers. The dory tipped over and the three villagers and the geologist fell into the water. Donald Wyatt was not seen again.

Two villagers were also killed—Anakenty Zeedar, whose body was found in the rafters of a building and probably died of exposure, and Simmie Alexanderoff, whose body was not found. The survivors were relocated to Akhiok and Old Harbor; Kaguyak was abandoned (Davis, 1971). All of the fatalities occurred when people who were in safe places left to seek the compan-ionship of others or save a valued boat.

Karluk. A native fishing village on the western coast of Kodiak Island, Karluk experienced the tsunami as low tide changes beginning 1½ hours after the earthquake. It did not cause any damage.

Larsen Bay. A native fishing village on the west coast of Kodiak on Uyak Bay, Larsen Bay suffered a 2.5 foot subsidence. A wave 4 feet over the high tide level at 1:00 A.M. caused two feet of water in the Alaska Packers Association warehouse. There was little significant damage. Rancher Dewitt Fields reported he lost a few head of cattle and some small buildings.

Old Harbor. At the time, Old Harbor was a village of 193 people and thirty-eight residences, two churches, a school, a store, a theater, and a number of out-buildings built on a narrow strip of land about 500 feet wide and 1,500 feet in length. It was only a few feet above tide level. The earthquake only caused minor damage. The radio warnings of a tsunami caused the villagers to begin evacuation. The first wave began at 6:24 P.M., 48 minutes after the earthquake and at extreme low tide to four or five feet above normal high tide, flooding some of the homes on the back side of the village.

The fishing boat *Kiska* was returning to home port and was in the channel between the Islands of Sitkalidak and Kodiak. The crew anchored the boat and went ashore to check on their families. The second wave was not as high as the first but did start to move some of the houses. When the wave receded, the current broke the *Kiska's* anchor and it started to drift into the channel. The water receded until the 1½ mile-wide channel between Old Harbor and Sitkalidak Island was almost dry. Two men retrieved the boat and kept it up right, fending off houses floating in the channel. When the third wave went out the boat was left on its side.

The fourth and highest wave was 17.7 feet above pre-earthquake MLLW or 12 feet correcting for a 2-foot elevation rise and a 3.8 foot tide above MLLW at the time (Kachadoorian and Plafker, 1967). It partially flooded the school and church. It carried away almost all of the houses, leaving only eight of the thirty-eight houses, and those were damaged too much to repair. In addition to the *Kiska,* four other boats were lost. This fourth wave came in after 11:00 P.M.

An elderly man named Jay Manson lived alone on Sitkalidak Island with his dog. They had been seen in a row boat after the second wave, but not since. Manson was counted among the fatalities (Davis, 1971).

Shearwater Bay. The Kodiak Fisheries cannery at Shearwater Bay, a tributary to Kiliuda Bay south of Cape Chiniak was almost completely destroyed. Waves 24.5 feet high lifted the cannery off its pilings (Wilson and Tørum, 1968). Ed Pestrikoff of Old Harbor and his family were caretakers at the cannery but escaped unharmed by racing uphill when the wave came in. Thirty-one fishing boats that had been stored on the beach were reported lost.

Saltery Cove. In Ugak Bay, a rancher, Ron Hurst, lost half of his herd. He lived for four days on the hillside at Saltery Cove after the tsunami washed away his home and other structures (Jones, 1964).

Cape Chiniak. Cape Chiniak, about 20 miles south of Kodiak, observed the first tsunami wave about 30 minutes after the earthquake (Chance, 1973, p. 134). A technician at the Air Force satellite-tracking station used ham radio to report the arriving waves.

Kalsin Bay. Many ranchers lost cattle—up to 70 to 80 head. Jake Blanc's house was moved one-half mile inland but left intact. The Art Vosgien family had been on an outing with the Currys when the earthquake hit. They decided to return to the Naval Station. On the way to Kalsin Bay there was a big rush of water over the road. The Vosgiens and Currys waited for the water to recede and believed that the tsunami had come and gone (*Kodiak Daily Mirror*, March 28, 1994).

The road was blocked by trees and debris. Richard Vosgien, 12 years old, and Maurice Curry began walking down the beach road toward a house 1½ miles away while the others sought help nearby. Eugene Schultz and his wife, Rose Marie, attempted to get through the debris with their Jeep. At this time also, Airman Gordon Wallace, his wife Arlene, and son Jackie Buscher were coming from an outing at Chiniak. The Wallaces found the road flooded and had gotten out of the car when a big wave hit them, knocking Airman Wallace unconscious. When he regained consciousness he frantically searched for his family along the shore, even by riding a log in the icy water. He followed a fence to the Stratman house where he collapsed. He was saved, but his wife's body was found in the car and his son's nearby. The Schultz' Jeep was found in a deep water-filled hole and both were killed. Mr. Curry and Richard Vosgien were also killed (*Kodiak Daily Mirror*, March 28, 1994, p. 1, 6, 7).

Kodiak. Earthquake damage to Kodiak, and the Kodiak Naval Station five miles south on Womens Bay, was slight. However, the Mayor feared a tsunami and, as the civil defense siren was out of operation, he ordered the fire department to have the fire trucks sound their sirens. As people came out to see what the problem was the police herded them up Pillar Mountain. Not everyone heeded the warnings and one family stayed on a point of land just 30 feet above sea level for the whole series of waves even though the point was completely surrounded by water three times. Six people died in Kodiak, all on boats or trying to get to their boats. Virgil Layton died on August 29 while doing salvage work but is not counted as a tsunami fatality (Jones, 1964). There were only three injuries requiring hospital care; the three were fishermen (National Academy of Science, 1970, p. 294–296).

The Naval Station received word from the Pacific Tsunami Warning Center of the possibility of a tsunami. The early warnings undoubtedly saved lives. There were no casualties at the Naval Station due to evacuations to higher ground before the first wave, but six people from the station were drowned along the coastal highway at Kalsin Bay (see "Kalsin Bay" section, above).

At least 10 waves inundated the Naval Station, with the maximum high water occurring with the fifth wave at 11:35 P.M. It reached 25 feet above post earthquake MLLW at the Crash Boat Harbor, 23 feet at the runway, 21 feet at 5th St., and 18.8 feet at the hangar. The tide level at the time was 7.4 fee; tthe wave was 15.6 feet high at the maximum (Kachadoorian and Plafker, 1967, p. F12). The first crest at 6:35 P.M., coming near MLLW, was 10.8 feet high, the second at 7:00 P.M. was 12.8, the third at 8:30 P.M. was 8.6 feet, and the fourth at 10:00 P.M. was 9.4 feet at the Crash Boat Harbor.

Figure 31. Aerial view of Kodiak, showing damage from the March 28, 1964, tsunami. The picture was taken in August, 1964. (Photo credit: U.S. Department of the Interior)

The first wave knocked out the electrical power and steam heat, and broke the water mains. It arrived as a rapidly rising tide. The second wave appeared as a breaking wave at the southwestern shore of Womens Bay. Elsewhere, it was described as a three foot wall of water followed by a series of surges. A ten-ton mooring buoy was torn free from its anchorage, carried a quarter of a mile inland and was deposited on the runway at an elevation of about 16 feet by the fifth wave.

There was about $10.9 million in damage done to facilities including the replacement of the marginal pier, generators, and repair to roads, family housing, runways, warehouses, and many other facilities. The tide gage was destroyed so there was no instrumental record of the wave. Some of the damage resulted from a 5.4 foot subsidence which caused the marginal pier to be flooded at high tides. A novel secondary hazard was the scattering of radioactive nuclides. The contamination was contained in the Ground Electronics Building and of low concentration. It posed no threat to the station personnel.

Waves with periods of 4, 7, 13, 14, 19, and 22 minutes were also observed. These were probably tsunami-generated seiche, in contrast to the tectonic waves which had periods of 50 to 75 minutes. In Kodiak, the tsunami caused about $31.3 million in damage. It destroyed 215 structures, leaving 600 people homeless out of a population of 2,658. About 101 boats moored in the Small Boat Harbor were destroyed, damaged, or missing. Six people were reported missing and presumed dead in the harbor in addition to three on the *Spruce Cape* which sunk near Spruce Cape. A group of children were removed by boat from the small boat harbor wharf moments before it collapsed (*Kodiak Mirror*, April 3, 1964, p.1).

There are relatively few first-person observations of the waves actions as most people fled to higher ground with the warnings or early waves. One observer was Jerry Tilley, who was working on the shrimp fishing vessel *Fortress*. The

Figure 32. Damage at Kodiak from the March 28, 1964, tsunami. (Photograph credit: NOAA)

Fortress was tied up to the City Dock when the shaking began. The shaking was violent, snapping some of the pilings and shaking the dock. A hugh boil of reeking black water arose under the boat. The water level was 12.5 feet above its predicted level. The men cut loose their lines shortly after 5:50 P.M.

Immediately after this, the water receded rapidly, leaving the 85-foot boat sitting on the bottom of the harbor. The water level was estimated to be 10 feet below MLLW. Tilley reported that the first tsunami wave reached the boat at 6:15 P.M. and the water level rose 15 feet in 5 seconds [*sic*]. The report of black, reeking water may indicate a locally-generated wave; its coming during the shaking rules out a tectonically-generated wave. The shallow water and gentle slope generally would argue against a landslide source. However, it is possible that some part of the fill behind the dock or some accumulation around the pier was agitated by the vibrating pilings or stirred up by the seismic waves, causing the reported effect. As this is the only report it probably was very local. The subsequent rise in water of about 12.5 feet and its receding until the boat was sitting on the bottom was probably the first tsunami arrival with an error in time admittedly estimated. Kachadoorian and Plafker (1967) speculate that the first rise in the water was due to seismic seiche or regional tilting, neither of which are possible (as discussed earlier).

The second wave reportedly came in as a six foot surge, then rose to 14 feet. It moved to the northeast at an estimated 20 to 25 knots. It swept the Alaska Packers Association, Donnelley and Acheson, and Standard Oil structures away. Ironically, it uncovered an old Russian stone wharf built in the late 18th Century, still intact and undamaged.

The wave patterns were complex as Kodiak is sheltered by several islands including Near Island, Woody Island, and several smaller islands. This led to refracted waves and waves coming from several directions. The highest wave probably was at Potatopatch and Mission Lakes, several miles northeast of Kodiak. Here debris was found at a height of 29 to 30 feet above MLLW or about 22.6 feet above tide level. The waves destroyed 32 homes in this area, pushing most into the lake and damaging 8 to 10 more.

Ouzinkie. A fishing village of 214 inhabitants is located on the southwestern end of Spruce Island which is immediately northeast of Kodiak. Ouzinkie suffered extensive damage, with loss of the cannery, post office, company store, three private homes and cannery superintendent's quarters. The waterfront was extensively damaged and fishing gear was destroyed. The maximum wave height was reported to be 30 feet (Leipold and Wood, 1969, p. 31). One villager, Ted Panamarioff, and his boat, the *Spruce Cape* were lost between Kodiak city and Spruce Island along with John Larsen and another crewman.

Afognak. This community of about 190 inhabitants located on the southeastern side of Afognak Island suffered extensive damage due to the tsunami and to subsidence of 4½ to 5½ feet. The town is built along a two mile stretch of the coast. Twenty-three of the 28 structures, including the grocery store and community hall, were extensively damaged or destroyed. Two bridges and 26 automobiles were also destroyed. The time of the initial wave is estimated at one-half to one hour after the earthquake and the successive waves were higher due to the rising tide. The highest wave was the third or fourth arriving at 9:27 P.M. It was 14.5 feet above MLLW or 10.8 feet above the tide level at the time. There were no fatalities or injuries, but the town was abandoned and relocated on the north coast of Kodiak Island, at Port Lions (named for the Lions International Organization which donated $1 million to its construction).

West Coast of Cook Inlet. There was a slight submarine landslide in Tuxedni Bay, west and north of Homer. An observer reported that part of the tidal flat slid into the deep channel but did not mention any wave being formed. Tsunamis were observed as rapid tide changes, but no damage was done.

4.3.2. Kenai and Cook Inlet Area

Homer. Most of the tsunami-related effects observed in the Homer area were in the vicinity of the Homer Spit, a bar extending 4 miles southeast into Kachemak Bay. The effects began within three minutes after the onset of the earthquake (Chance, 1973, p. 130). The water rose over the floors of houses near the beach at Barabara Point and MacDonald spit on the East side of Kachemak Bay with little force causing only minor damage (*The Cook Inlet Courier*, March 30, 1964, p. 1). The owners of the Porpoise Room Restaurant which had been recently moved to Homer Spit saw a great vortex of water about 1 to 2 minutes after the earthquake began. About 500 feet of the outer breakwater slid away and boats in the harbor were pulled into the "funnel-like pool." The majority of the boats were pulled out into the bay but none were lost. One boat suffered considerable damage to its hull when it was hung up on rocks (*Cheechako News*, Kenai, April 3, 1964, p. 2). The wave surged back to shore in no more than one minute, flooding the restaurant to a depth of six feet. The Salty Dawg, a saloon on the spit, was flooded to a depth of four feet, although the tide was low and falling. Low tide was expected at 7:30 P.M. The water moved from east to west. However, the dock remained serviceable.

Most of the damage was due to a regional tectonic subsidence of about 3.5 feet. This was determined by the Coast and Geodetic Survey from outside the deformed region. The Alaska Highway Department determined a further subsidence of 2.5 feet at the end of the spit, using a bench mark on the mainland. The latter would be due to compaction and possibly lateral spreading (Waller and Stanley, 1966, p. D22). This made the Lands End Hotel flood at high water causing extensive salt water damage; $40,000 was later raised to save the building. The area on the shore west of the Salty Dawg sank ten feet (*Homer News*, April 1, 1964, p. 1). The Inlet Inn and Hotel was reported to be a total loss and the Porpoise Room Restaurant was abandoned due to the continuing high water. There was salt water damage to two seafood processing plants and the Standard Oil Company tank farm (Waller and Stanley, 1966, p. D9). It is probable that there was locally variable compaction or subsidence due to lateral motion as well as a regional tectonic subsidence of about 1 meter.

Seven to fourteen waves were seen in **Kachemak Bay** breaking on the tide flats. One wave was seen in the bay coming from the south side of the bay cresting white and about 3 miles long. Crests were about 40 feet apart (Chance, 1973, p. 131). On the west side of the of the spit, about five minutes after the shaking started, the water withdrew from the beach on the Cook Inlet side and a 9-foot wave returned from the west. An observer reported a wave a mile long and cresting, coming in from the southeast, the direction of Seldovia. Another wave came in from the northeast. The two waves gave the impression of an inverted V that was not connected. A third observer from the spit reported a wave at ten minutes after the earthquake (Chance 1973, p. 131).

Seldovia. The water barely went over the boardwalk (*Homer News*, April 1, 1964, p. 5). The jetty of the small boat harbor collapsed and disappeared (*The Cook Inlet Courier*, March 30, 1964, p. 3) and the pilings that hold boat floats were nearly all gone (*Cheechaka News*, April 3, 1964). Joel Moss, a mining engineer from Seldovia, reported that a 12- to 15-foot wave swept on shore about 1 to 2 minutes after the beginning of the earthquake. A similarly timed, 15-foot wave was reported by William Ekloff at **Pederson Bay**. This is possibly the source of the waves reported seen coming from the direction of Seldovia at Homer. Moss reported that many waves came at close intervals during the first hour and continued later at longer intervals until morning. Ekloff reported that two more waves arrived in the first hour, one 10 feet high and the other lower. No damage occurred; the waves arrived at low water. The boat floats were washed away at 9:10 P.M.

High tide occurred at 1:39 A.M. at 25 feet, 5.5 feet higher than the forecast. Between 4:00 and 5:00 A.M. the water was 26 feet high causing flooding to the warehouse, Polar Bar, Beachcomber Hotel, and Seldovia House (Chance, 1973, p. 131). A wave came in at 7:00 P.M. like a very strong tide, and successive waves came in at about 45 minute intervals. At about 11:00 P.M., the water surged with 3 to 4 foot heights and 15 minute periods. At about 02:00 A.M. on March 28th, the water level reached the floor level of the Beachcomber Hotel (Berg et al., 1970, p. 20). The waves arriving after about two hours were probably from the tectonic tsunami source.

At **Ninilchik** there was no appreciable rise in the water reported (*Homer News*, April 1, 1964, p. 9). The tides were very erratic at Pederson Bay on the southeastern shore of Kachemak Bay, opposite the end of Homer Spit and **Kasitna Bay**, the next bay to the southwest towards Seldovia. The water level dropped 6–8 feet in fifteen minutes and would vary 1–2 feet between the bays. It came in one bay and went out the other. The water was four feet over the end of

Homer Spit at the crest of the tide, about 1:40 A.M. The *Homer News* (April 8, 1964, p. 2) reports that in Kasitna Bay "there is now a deep channel at the Ekrens Packing Company that was not there before." A large rock disappeared and a clam bed was completely wiped out.

Port Graham. A minor tsunami was noticed about nine minutes after the earthquake but reached only half tide level (Plafker et al., 1969, p. G37).

A 28-foot wave hit **Perl Island** at 8:40 P.M. at the southwestern tip of the Kenai Peninsula and a 30-foot wave arrived at 2:30 A.M. The low lying part of a ranch was inundated, drowning nine head of cattle. There are no reports of observed waves from other Cook Inlet communities but the tectonic tsunami almost certainly would have been observable at some of them. Possibly the late hour, lack of significant damage, and earthquake concerns contributed to the lack of reports from these other communities.

The waves in the first hour were due to slumping in perhaps five locations. A wave seems to have been generated on the eastern shore of Kachemak Bay, with the collapse of the pier at Seldovia, or possibly from the Grewingk Glacier delta (Waller and Stanley, 1966, p. D4). There were probably waves generated with the collapse of the boat harbor breakwater, possibly waves generated by slumping off the end of Homer Spit, or from the collapse west of the Salty Dawg. There appears to have been a slump-generated wave from Munson Point, west of the spit. The tectonic tsunami would have been generated from the main area of deformation, probably the Alaskan trench. Reference of the distance to the epicenter are irrelevant since it only shows where the rupture began. The zone marked by the pattern of the aftershocks and overlying the thrust plate would have almost equal intensities. Seiche generated by seismic waves are not known to generate tsunamis in the epicentral area. They are undifferentiated by frequency, and have dispersed within the time of shaking, about 3 or 4 minutes. Seiche are resonances requiring several cycles of a frequency equal to a mode of the natural period of the body of water. There were no reports of deaths or injuries in this area.

4.3.3. Prince William Sound Area

Rocky Bay. Plafker et al. (1969, p. G10) report that the first wave to reach the logging camp at Rocky Bay, just east of the southern tip of the Kenai Peninsula, arrived within 30 minutes. The first wave came as a withdrawal of 18 feet. The highest run-up occurred with the high tide after midnight and left marks 11 feet above the extreme high tide. These would be waves from the tectonic tsunami.

Aialik Bay. Aialik Bay is an uninhabited glacial bay south and west of Seward. An underwater landslide-generated tsunami was reported to have originated near Pederson Glacier, reaching an estimated 95 feet on adjacent Holgate Peninsula and 100 feet on the opposite shore of Aialik Peninsula (Plafker et al., 1969).

Kenai Lake. Kenai Lake is a long narrow lake in the central part of the Kenai Peninsula, about 23 miles long and about 1.33 miles wide. It occupies a narrow glacier-carved valley, with a maximum depth of 570 feet, 135 feet below sea level. It is made up of several segments meeting at abrupt angles. It is fed by a number of streams that drop rapidly from the steep rock walls of 3,000 to 4,000 feet, carrying coarse gravel and sand that forms small protruding deltas into the lake. These deltas offer some of the only level ground for building. The earthquake triggered failure in a number of these and at least five of these produced small tsunamis. These were studied in detail by McCulloch (1968) and are the only lake tsunamis studied in detail.

At Lakeview, the delta of Victor Creek collapsed, creating waves 35 feet high on the opposite shore. The return or back-fill wave was 25 feet high. Trees 2.5 feet in diameter were felled; some were broken and others uprooted. A block of frozen sediment estimated to weigh 50 tons was carried 40 feet from the scarp. A log house was carried 200 feet and the walls were demolished.

At Lawing, at the first right angle bend of the lake, the delta of the Trail River and Ptarmigan Creek collapsed, producing waves of 20 feet on the far side and 30 on the delta side. A shed and boat house were demolished. A second, smaller wave was observed about 1 minute later. Ice was seen breaking as the waves passed under the frozen lake surface.

The largest wave was produced by the delta at Ship Creek, reaching heights of 72 feet on the opposite shore and 30 feet on the near shore. The slide area was completely submerged. The delta material traveled an estimated 7,000 feet into water 540 feet deep.

At Meadow Creek, delta waves of 20 feet were measured on the far side and 25 feet on the near side.

At Porcupine Creek, near the upper end of the lake, a 15-foot wave was detected on the near side.

Other slides were observed which apparently did not produce waves at Rocky Creek (where 260 feet of the Alaskan Railroad bed was lost) and at Quartz Creek. Some evidence of smaller waves may have been lost when the lake which had subsided about 5.5 feet filled, covering evidence of smaller waves.

A gage at the Chugach Electric Association plant near the middle of the lake measured continuing water activity, but the gage was out of operation for more than two hours after the earthquake due

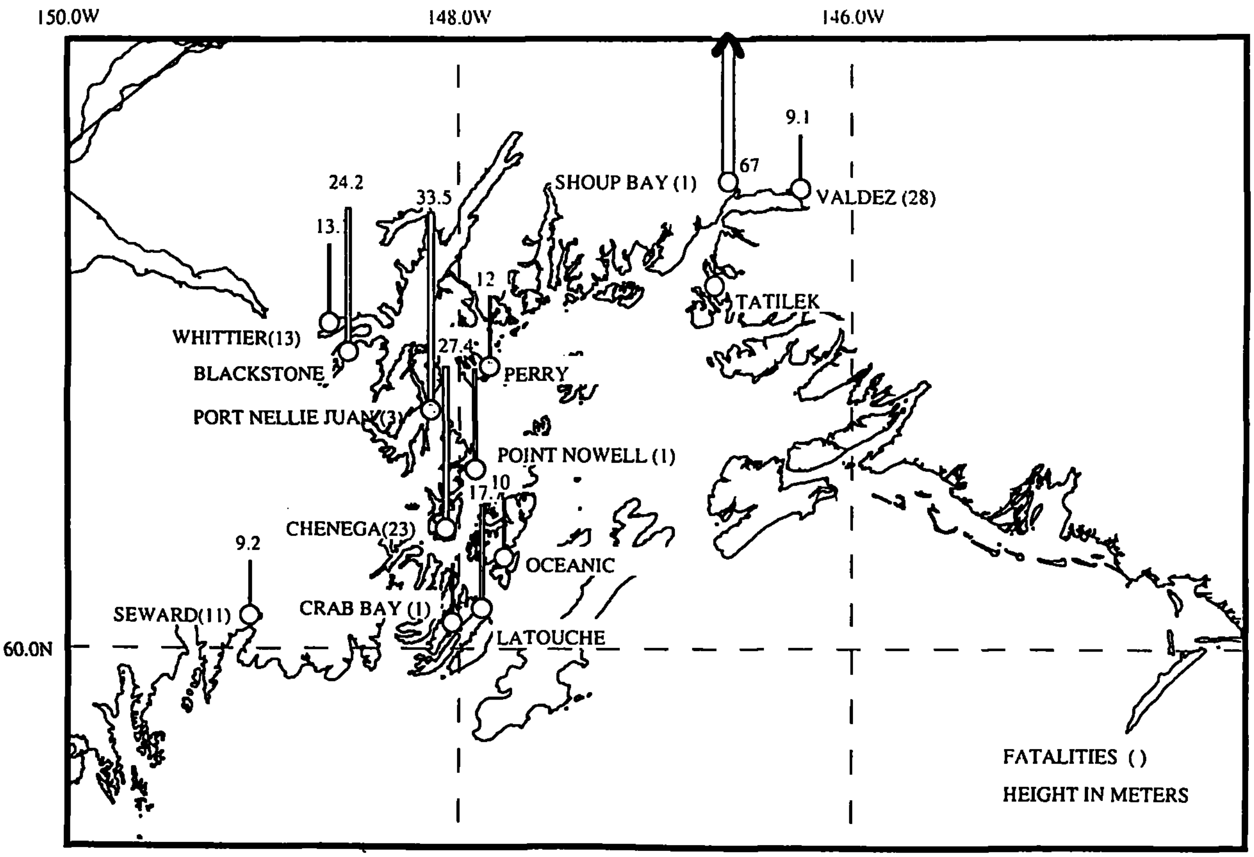


Figure 33. Fatalities and selected runup heights in the Prince William Sound area.

to a power failure. It recorded true seiche with periods of 1.4 minutes to periods of 36.36 minutes, the calculated fundamental mode of the lake. There were nine modes recorded, representing higher level normal modes and perhaps other modes for segments of the lake acting independently and for waves transverse to the main axis.

The seiche could have been generated by the tilting of the lake with the western end being about 3 feet lower than the upper end. Waves about 7 feet high were measured near the western end at Kenai River and about 8.5 feet at the upper end, where the Snow River enters the lake. Waves estimated to be 20 feet high were reportedly seen as gentle rises (not as breaking waves) but this may have been the range. The Kenai River was reported to have run backwards into the lake for a distance of 150 yards down stream. Waves and seiche were much higher where the water depth became shallow abruptly, or where they were funneled between land masses. In the channel between Porcupine Island and the north shore of the lake, the waves reached heights of 20 feet.

McCulloch concluded that larger slides and deeper water caused the slide materials to be carried further and also caused the waves on the opposite shore to be larger. He also concluded that as the lake surface was lower by 10 feet than it was later in the spring, the danger may be greater at times of high lake level. However, it is known that in areas where the tide level may be a factor, the larger exposed mass at low tide is more likely to fail than if it were supported by the water column. The higher lake levels may increase the level of flooding if a wave is formed, but decrease the likelihood that one would be formed. He also cautions that buildings on deltas may be subject to being carried away by the slide, damaged by fractures of the delta surface, or swept away by the waves. In planning to build on a delta by a lake or bay, it may be prudent to attempt to learn past wave heights as determined from debris lines, tree trim lines, or other such evidence.

Seward. Seward (population 1,730 in 1964) is located on a delta formed by Lowell Creek near the head of Resurrection Bay, a 25 mile long fjord. The bay is about two to four miles wide and the water depths drop off sharply from the shore to a maximum of 978 feet. The topography rises rapidly land-ward of the delta, affording no access inland. The city was connected by road with other Alaskan communities only by a single highway—this crossed a lagoon at the head of the bay by way of a causeway. The principal income for the community was from longshoring and other marine-related work. At the time of the earthquake most businesses were closed. Also, the city had just been selected as an All American City. The mayor, Perry Stockton, and Civil Defense Director and City Manager, Bill Harrison, had left that day to fly to Anchorage to appear on television in regard to the upcoming celebration scheduled for April 4th and 5th. They were able to return on the first flights back to Seward Saturday morning.

A freighter, the *Chena,* which had a prominent role in the tsunami effects at Valdez, had just unloaded and departed. The cargo-moving equipment was stored in the Berth One warehouse as it was the beginning of a three day (Easter) holiday. There were petroleum storage tanks on the waterfront at two places, at the Standard Oil Company and Texaco docks. The citizens' fear of an eventual disastrous fire or explosion of the tanks was instrumental in speeding their spontaneous evacuation.

At the time of the earthquake, the tanker *Alaska Standard* was at the Standard Oil Company dock taking on petroleum products. Harold Solibakke was the captain. One seaman, Theodore Pederson, was on the dock on hose watch when the earthquake hit. The tide was near low and predicted to reach minus 0.7 feet at 6:08 P.M. Stove oil, and two grades of gasoline had been loaded and diesel fuel was being loaded. The ship was connected with the dock by five hoses and seven mooring lines. The shock was followed in about 30 seconds by the ship heeling sharply to starboard (bay side).

An observer on shore reported seeing the *Alaska Standard* disappear from sight (Lantz and Kilpatrick, undated) probably due to the drop in water level and the roll.

Captain Solibakke (1964) reported that the ship first heeled suddenly and dangerously to starboard then rose, breaking the hose connections or pulling them out with the risers, pipelines, and pilings. Fire followed almost immediately, as did the slump-generated tsunami. Fourteen storage tanks were completely destroyed by the slumping and ensuing fire, and four more were badly damaged, leaving just five of the twenty-three tanks intact.

Figure 34. Damage to the rail yard at Seward resulting from the March 28, 1964, tsunami. Charred remains from the fires are in the foreground. (Photo credit: NOAA)

Although the Civil Defense team arrived quickly, there was little they could do as the water lines and power lines were cut. They were forced to cut a hole in the ice at First Lake a mile away for water for their pumper trucks. The fire, a fairly common secondary hazard from tsunamis, was mainly confined to the water and waterfront area. There was an 80-car train on the railroad tracks ready to leave but it was caught in the wave and fire. The last 40 cars were filled with petroleum products that exploded serially toward the Texaco tanks. Tank cars and boxcars were moved as far as a quarter of a mile from the track by the following tsunami. A 75-ton switching locomotive overturned and moved 300 feet. A 120-ton locomotive was carried 100 feet and left sticking up through the rubble (*Petticoat Gazette*, April 2, 1964). The Texaco tanks continued to burn for two days. Emil Elbe, an engineer for the Alaskan Railroad, died of a heart attack while running from one of the waves.

The time of arrival of this first wave is not definitely known but could not have been more than six to eight minutes after the onset of the earthquake, which lasted about four minutes. About 30 to 45 seconds after the shaking began, the dock area began to slide into the bay. Slice after slice followed until a strip 50 feet wide and 500 feet long disappeared into the bay. The area that had been the dock became water 40 feet deep.

The *Alaska Standard* got power in about five minutes and was already surrounded by flames on the water, an unenviable situation for a ship full of petroleum products. The ship skirted the flames on the starboard side; the flames were almost to the vessel's side. The ship was turned and pointed toward the bay entrance. Captain Solibakke noticed a large circular area in the middle of the bay that was muddy, roiling, "boiling," and turbulent. He believed this was responsible for the wave that had hit the dock earlier. This was probably about 2,400 to 3,000 feet almost due east of the Standard Oil dock, where post earthquake surveys show a pronounced bulging of the bathymetric lines. The wave-generating slump probably saved the ship by cutting its ties with the dock and allowing it to quickly move into the middle of the bay. Had it remained tied to the burning dock with its load of gasoline it almost surely would have been lost.

The wave had another beneficial effect for the vessel. It washed a mass of debris from the dock and warehouse up on the foredeck, including the Coast and Geodetic Survey tide gage. Seaman Pederson also ended up on the foredeck. When the earthquake started he had seen the ship buck and slam into the dock. He ran about 100 feet up the dock toward the shore as all the hoses to the ship broke, shooting oil into the air. He saw pilings shoot into the air and the 200 foot warehouse sink down. The ship pitched and dropped vertically 20 to 30 feet, hitting the bottom according to some accounts. Pederson found himself in the water when the dock collapsed about one minute after the shaking started. He was trying to stay afloat close to where the dock and warehouse had been. About 30 seconds to 1 minute later, he saw a huge wave filled with debris from the dock coming down on top of him. He was about 20 feet below the deck on the *Alaska Standard* when he was hit on the head and knocked unconscious. When he regained consciousness he was on the tanker's catwalk eight feet above the deck. He extricated himself from the debris but had suffered a

Figure 35. March 28, 1964, tsunami—destruction of the dock at Seward. (Photo credit: NOAA)

broken fibula in his left leg and lacerations of the scalp and left hand. The dock on which he was standing was completely destroyed (Chance, 1973).

Another member of the crew, Donald Herrington, Jr., was believed to have been on board but was missing after the wave. Crew members reported seeing a man clinging to a barrel astern of the vessel, but there was nothing they could do. He is counted as a fatality in the coroner's inquest. Several soldiers were able to get a small boat off the mud flats after the waves had ended, and ferried Pederson to shore Saturday morning at 6:30 A.M. for transfer to the Seward General Hospital. The *Alaska Standard* remained in the bay until Sunday, unable to land but acting as a communications link. The road to Anchorage was cut in numerous places due to bridge failures, and all aircraft at the airport were destroyed. The *Alaska Standard* departed Sunday for Cordova and Ketchikan.

The badly damaged marigraph was recovered at Ketchikan and the record salvaged. It shows a beginning drop in the water level at about 5:41 P.M. before the trace no longer shows water motion.

At the time of the first shock, Dean Smith was in the operator's cabin of the gantry crane on Berth No. 1, one of the two gantries on the dock and fifty feet above the dock. As the shaking intensified, the gantry whipped back and forth and the wheels came off the track. It was "walking around like some stiff-legged spider." By the time he got down there were cracks in the pavement and the office and dock coffee shop had started to settle toward the water. Gantry No. 2 had bounced off its tracks and fell into the bay about 45 seconds after the shaking had started (Chance, 1973).

Mr. Lambertson was in his office at the Standard Oil Company when the shaking started. As he ran he heard the tanks, pipes and warehouse banging and the ground began to open up in fissures. When he reached the city power plant he looked back and saw the dock, one tank farm, the office he had just vacated, and the power plant sinking into the bay. It was followed by a roaring fire.

Patrolman Dale Pickett saw the Standard Oil tanks explode and drove toward the docks. He saw the wave coming over the tracks near 6th and Washington Streets. His patrol car was surrounded by the wave and he was unable to open the driver's side of the car due to the force of the water. It threw him against the window and door causing cuts to his head. A boxcar was being swept towards him as his car was pushed into a driveway. He escaped as the debris-laden wave flooded the car's interior. Another patrolman, Ed Endresen, was also injured. He had abandoned his patrol car when it was damaged by a falling chimney. He ran to the railroad crossing near the small boat harbor. He fell into a fissure estimated to be 30 to 40 feet deep but held on to the edge. As the fissure began to close it forced water up which helped his escape. The fissure closed on his foot. He wrenched his back in twisting it free. Historical accounts of people being swallowed by fissures during earthquakes have largely been discounted, but may indeed be possible. The list of injuries at Seward was small, numbering about five, and mostly minor.

Waves were spreading from the source of the wave that had hit the Standard Oil dock and soon reached the small boat harbor. There were about 150 boats in the harbor (Lantz and Kirkpatrick, 1964). The first wave began to fill up the harbor in 30 to 45 seconds after the earthquake started. The water rose straight up so that the boats pulled up the dolphins. Fred Watson was on board one of the fishing boats that was carried over the breakwater. Three other people were in the *Unga* and after a wild ride ended with the stern on Bay Road at the head of the bay. The occupants made their way through water and debris to higher ground. Six people died in the vicinity of the Small Boat Harbor. These included Alfred Brosson, and Lester Fowler on the *Vicky Lynn*, Robert and Louise Oukuk Ellanna on the *Alameda*, and Victor Moe and Frank Spadero who were visiting the harbor when the quake struck. Only Moe's body was recovered. A total of 30 fishing boats and 40 pleasure craft, valued at $2 million, were lost (Norton and Haas, 1970). There were reports of a possible third person on the *Alameda*, perhaps Ellanna's mother, but this was found not to be the case and no other person is known to be missing.

The first wave overtopped the causeway, filling the lagoon with debris from boats and houses before the first citizens began to evacuate the city.

At Lowell Point, about 1½ miles south of the city, three men were finishing their work when the earthquake struck. They saw the Standard Oil tanks explode and a "second" wave that quickly followed that looked as tall as a "liberty ship" (30 feet). The "second" wave formed southeast of the Standard Oil dock and was coming ashore about 1 minute and 45 seconds after the first earthquake shock. Two of the men got into a car and the third got into a pickup truck. The truck was started but was promptly swamped and the driver, John Eads, abandoned it. He was swimming in six feet of sand and debris-filled water. He went under several times. He was able

Figure 36. March 28, 1964, tsunami—debris at the north end of Resurrection Bay near Seward. (Photo credit: U.S. Department of the Interior)

to finally get on shore and vomited salt water and sand. The other two men fared better as they sped south. They had traveled about half way to Spruce Creek before the wave picked up their car and carried it 50 feet into the brush to the southwest. They all survived (*Petticoat Gazette*, April 2, 1964, p. 7; Chance, 1973).

The Army Docks, a new barite plant opened just one month at the San Juan Dock, and the city's Halibut Producer's Coop all slid into the sea as did the old cannery at Lowell Point. The destruction accounted for 95% of the industrial base of Seward. Eighty six houses were completely destroyed and 269 homes were heavily damaged, about 15% of Seward's residences (Lemke, 1967, p. E13).

Figure 37. Destruction of a house at Seward, due to the March 28, 1964, tsunami. (Photo credit: NOAA)

Many of the people began to flee the city with the first shaking, as they had a fear of a possible explosion of the petroleum tanks. The causeway was the only way out of town, to the airport, and to residences at the head of the bay. Those who did not cross before the third wave were stuck until later in the evening when bulldozers cleared the road. The road to Anchorage was blocked by damaged bridges, about 2½ miles beyond Seward. Some debris had washed over the causeway with the first wave. Two fatalities occurred here due to a late arriving wave from the main tectonic tsunami arriving at high tide. Three men—Win Corbin, Michael Osmonovich, and James Holben—were leaving town after 10 P.M. (The causeway had been opened by city workers using a tractor.) They were caught by a large wave about two-thirds of the way across. A log smashed into the side of the vehicle and jammed the passenger's door closed. They abandoned the vehicle and tried to make for a headland jutting into the lagoon. Only Corbin made it. Holben, encumbered by a heavy overcoat and boots, tried to help Osmonovich who was a poor swimmer. Osmonovich grabbed a crate floating by and the men became separated. Holben felt himself being sucked back to the bay, and struggled to keep afloat in the dark, icy, and debris-laden water. He had to duck under the water to escape the fire burning on the surface. Finally, numb and exhausted, he was able to reach shore and eventually, the hospital. Osmonovich was never found and was presumed drowned. The second fatality occurred when a wave arrived about 10:30 P.M. and washed away Alvin Wisdom, a city employee working to clear the causeway.

There were numerous close calls. One group of eight people spent the night on the roof of a floating house near the airport. Having climbed on the roof of the garage, they jumped higher, to the main roof. The wave carried away the garage, the porch, and the attached bedrooms, leaving only the central part of the house. Later waves reached the eaves. The people chopped a hole in the roof and used the insulation for warmth. Later they were joined by two other people who had spent several hours in a tree. The house floated several hundred yards and came to rest in a grove of trees. It snowed during the night. Four times one of the men tried to build a fire only to have returning waves put it out (Lantz and Kirkpatrick, 1964).

Two young men, Frank Walunga and Jessie Lee Hatch, had left earlier in the morning to go seal hunting in a 14-foot wooden skiff with an outboard motor. They were last seen about 12 minutes after the earthquake by Bob Hayes and Dr. Starr. Walunga and Hatch were in the middle of the bay heading home; they declined to be picked up. They had a seal carcass on board. Apparently they were caught by a later wave *en route* to shore and were never found. (This information came from notes in the records in Seward City Clerk's Office file on "Missing Persons.")

About 25 minutes after the initial shaking, the first tectonically-generated tsunami arrived. The exact time is not known but is estimated to have been between 20 and 30 minutes later. Many observers reported that the earthquake began with moderate shaking and intensified greatly about 25 seconds later. The first shaking would have been P phases, the fastest of the seismic wave types, arriving from the epicentral area. The more violent waves would have been from the S phase and P phases generated along the fault, which propagated directly under the city. The fault movement is believed to be at the velocity of the S phase and spreads from the epicenter through the area defined by the aftershock pattern.

The sequence of waves began with the collapse of the delta near the Standard Oil dock at about 30 seconds after the first shaking was felt. The water would have been pushed away from the shore as a bow wave until it reached a point where the landslide came to rest. Here the wave paused, and formed a mound of water. This then returned as a tsunami arriving at the dock about 1½ to 2 minutes after the shaking had started and was the "second wave" observed at Lowell Point. It was reportedly 30 feet high. There possibly were other lesser sources in submarine slumps from the Fourth of July Point, Lowell Point, and at the head of the bay. There was reportedly one other cycle of this wave before the tectonically-generated tsunami appeared. This wave had an amplitude of 30–40 feet and reached across the bay. Plafker et al. (1969) report that a wave at about 11 P.M. had an amplitude of nearly 70 feet, but this would have been the height (twice the amplitude) of the wave. It continued to cycle with a period of about 55 minutes until 4:20 A.M. The third wave was reported to be the highest.

Of the 12 tsunami fatalities, including the death due to a heart attack while trying to run to safety, eight appear to have been due to the earlier slump-generated waves and there was little or no time for evasive actions. The four fatalities attributed to the tectonically-generated wave could have been prevented had the individuals stayed away from the shore until all wave activity had died down, about twelve hours. These include the two young men who were seal hunting, the city employee attempting to open the causeway, and the man lost trying to cross the causeway prematurely. The husband of a clerk at the post office was killed on a fishing vessel in Kodiak; he is counted in Kodiak's total. The remarkable fact is the low loss of life considering the number of people who were in

Figure 38. The waterfront at Seward a few months after the March 28, 1964 earthquake, looking North. Note the "scalloped" shoreline left by underwater landslides. (Photo credit: U.S. Geological Survey)

the water or on floating buildings, cars, boats, or trees or in other risky situations.

There were few serious injuries. The Red Cross lists ten as seriously injured and 190 as having minor injuries. Approximately 100 were treated for minor cuts and bruises at the hospital as out-patients. Eighty five were hospitalized. Hundreds suffered from exposure from the snow and cold. Emergency meals were prepared for 1,600 to 2,000 people per day; sanitation was poor and many were infected with gastroenteritis, diarrhea, and upper respiratory infections (Joyce, 1964).

The effect of the tide level was important in the damage to Seward. As it was low tide, the pore pressure in the delta was high. The loaded train (mentioned on page 95) would have added to the weight of the overburden. The water-saturated mass of the delta was unsupported and more prone to fail when the shaking initiated liquefaction. However, the low tide mitigated the effect of flooding. One of the most destructive waves that resulted in two of the fatalities occurred at near high tide at 10:30 P.M. Reports of the wave heights is further complicated by the fact that the land subsided 3.5 feet. There are reports that tilting may have contributed to the wave but this is not possible. The regional tilt was only a few meters in several hundred kilometers. Any difference from one end or side of the bay to the other would have been at most several inches and not enough to create a noticeable wave.

A separate landslide-generated tsunami occurred at **Thumb Bay** about seven miles south of Seward and on the opposite shore. Plafker et al. (1969) reports heights of 25 to 30 feet inside the bay.

Whidbey Bay. Plafker et al. (1969, p. G10) report that waves reached the logging camp at Whidbey Bay about 19 to 20 minutes after the earthquake began. Water withdrew for 10 to 12 minutes, exposing the bay bottom for a distance of a mile and depth of 50 feet. The second wave was the highest, arriving about 10 to 12 minutes after the first, and reached 35 to 40 feet above the tide level. The logging camp was destroyed. Waves continued until the next morning. These were probably tectonic tsunamis.

Puget Bay. Waves struck the head of the bay about 20 minutes after the earthquake, with the first wave reaching a height of 18 feet above the pre-earthquake lower low water. As the tectonic uplift was about 5 feet, and a minus tide was predicted, the wave height would have been 23 to 24 feet. The second wave arriving 10 to 15 minutes later was a little smaller. The third and highest wave arrived at about 8:00 P.M. and reached a height of about 28 feet above mean lower low water. This wave washed away or destroyed about $8,000 of logs and machinery. There had been a large subaerial landslide that traveled about 1¼ miles and dropped 3,931 feet, partially filling the northwestern end of the bay. Whether or not that caused the early waves is not known. Effects were reported also from **Johnson Bay** to the west, but no run-up heights were reported (Plafker et al., 1969, p. G41).

Sawmill Bay. Sawmill Bay is located on the southeastern coast of Evans Island and protected from the open Prince William Sound water by Elrington and Latouche Islands. There are settlements at the San Juan Cannery, Port Ashton, and Crab Bay. The water first began to rise smoothly at **Crab Bay** for about 1 minute, 2 minutes after the beginning of the earthquake. It withdrew to the minus 20-foot level in a few seconds, exposing the whole bottom of Crab Bay and large expanses of Sawmill Bay. The returning wave was 10 feet above the extreme high tide line. This happened before the end of the earthquake shaking, and was due to several submarine landslides as suggested by the pattern of inundations. The tectonic tsunami was observed later with the highest run-up coming at high tide at 1 A.M. The waves demolished one dock, damaged pilings under some structures, and beached or carried away a number of vessels including two that were carried up into the forest at San Juan Cannery and **Port Ashton**. Two residents of Port Ashton were swept into the bay but escaped. Another man at Crab Bay, Alfred Blendheim, drowned trying to secure his skiff. One unoccupied house opposite Sawmill Bay on Elrington Island was destroyed. Waves reached heights above the tide level of up to 49 feet.

Latouche. The abandoned mining settlement of Latouche had its piers and waterfront buildings damaged or destroyed. At **Port Crawford,** 1.3 miles northeast of Latouche, an abandoned sawmill was displaced. Waves there reached 48-feet elevation, and 58 feet about 1 mile further along the coast (Plafker et al., 1969, p. G23).

Port Oceanic. Located on the southern tip of Knight Island on Thumb Bay, a shallow inlet off of Mummy Bay, Port Oceanic has an abandoned cannery. At the time of the earthquake there were two caretakers there who reported that within 2 to 3 minutes after the earthquake began a wave of local origin entered the bay destroying the dock, several boats, and knocked out some of the cannery's pilings. There was a landslide at the head of Mummy Bay which came down from an elevation of 1,800 feet. Plafker et al. (1969) believe that the water was too shallow for it to have been the source of the wave at Oceanic, but subaerial landslides carry more energy than submarine landslides and the shape of Thumb Bay is such as to constrict an incoming wave. This is the likely source of the wave in the two bays. The elevation reached 39 feet at Oceanic.

Chenega. Chenega is located at the south end of Chenega Island. This community of 75 people experienced, proportionally, the greatest disaster. Only one house and the school survived of the 8 to 10 homes, the store, and the church that comprised the community. Twenty-three of its inhabitants were lost including many of the church elders who had taken refuge in the church, and three others who were on a nearby island (*Anchorage Daily News*, March 28, 1989). Only one body was recovered. Two people were reported injured (Lantis, 1972). One was a woman rescued from part of a floating house by the fishing boat *Marpet*. She was badly bruised and feared she had broken her leg. This is the only account of someone being saved from the water although a number of people were washed into bays and managed to save them-selves.

One man, Mike Kompkoff, was carrying two young daughters and accompanied by his 9-year old daughter when the wave overtook them. He was thrown across a creek and into a snow bank. The youngest, Norma Jean, age 3, and Julia, the oldest, were swept away and lost.

The houses were either washed to sea or carried into the forest and broken. The reinforced concrete school was built on higher ground at 70 feet above post-earthquake mean sea level. All of the boats were lost except for three—one in port at the time and two that were out on the water with hunting parties.

About 60 to 90 seconds after the beginning of the earthquake a small wave rose half way up the rocky beach, but rapidly receded exposing the whole cove bottom for a distance of 300 yards from shore and to an estimated depth of 120 feet. The returning wave arrived in about 4 minutes, and before the shaking had ceased. It was about 35 feet high and breaking. It surged up to the school's foundation at an elevation of 70 feet. The survivors spent the night in the snowy woods above the school, fearing another and larger wave.

The wave was of local origin, given the short time after the beginning of the shock to its appearance. It probably was the result of submarine landsliding into Knight Passage where the water depth reaches over 1,000 feet within a mile of shore. However, fathometer surveys did not find any evidence of major submarine landsliding. An alternate explanation was that the movement of the island about 55 feet to the south (Plafker, 1969, p. I-27) on the general thrust plate would cause a wave due to the inertia of the water if the movement was rapid enough. Such an explanation would be at odds with the observation that the water receded from the coast for 300 yards. Also, if such an explanation was true for Chenega, it would have been a phenomenon that would have been generally observed on all of the coasts.

The survivors eventually relocated to a site 20 miles away above Crab Bay at a site now called Chenega Bay.

Point Nowell. Point Nowell is the site of a small fishing camp at a low peninsula on the mainland near the northern entrance to Knight Island Passage. At the time of the earthquake there was one person at Point Nowell—Frank Henry Erb. The man disappeared and was presumed drowned. Waves 37 feet above mean lower low water swept over the peninsula, displacing several buildings and smashing some in the woods. Trees 12 to 18 inches in diameter were broken off. The wave apparently entered from the south although its source is not known. It presumably was a local wave as were the waves that affected Chenega and Perry Island.

Port Nellie Juan. An inoperative cannery site known as Port Nellie Juan is located at the mouth of McClure Bay, an inlet off a larger body of water also called Port Nellie Juan. At the time of the earthquake there were three resident caretakers of the cannery—Alex and Annie Chimovsky, and their son Emanuel. All three disappeared and were presumed drowned. The cannery dock was washed away by 30-foot waves. A 60-foot barge, moored at the mouth of a small creek on the north shore of the body of water called Port Nellie Juan, was washed 200 feet into the forest and 30 feet above mean lower low water. Further to the west the same body of water is known as **Kings Bay**; a submarine landslide there caused a wave of 113 feet. At several points along Port Nellie Juan waves of over 70 feet occurred.

Perry Island. The Comstock brothers, Carl and Milton, occupied a two-story house on Perry Island. There was also a storage house and a boat house at the settlement. Immediately after the earthquake, an 8 to 10 foot wave came ashore and receded in 2 minutes, taking their skiff out. The receding wave bared the bay floor for an estimated 200 yards or a depth of 8 feet below low tide. The returning wave was seem coming from the direction of the Meares Point Lighthouse, flooding the beach bar to a height of 25 feet above mean lower low water. The Comstocks were washed into a slough behind the beach bar and nearly drowned. The boathouse was washed away but the other two buildings were undamaged.

Whittier. At the time of the earthquake, Whittier was a community of about 70 people built on a glacial outwash delta of the Whittier Creek into Passage Canal. It had been constructed by the army during World War II as a rail and port transportation hub to Anchorage.

On the afternoon train were Mrs. Francis Damon, her 16 year old son Larry from Soldotna, and David Barnes, an employee of the Two Brothers Lumber Company who was returning from a week's absence. Larry was planning to help Lewis Mickelson, another employee of the lumber company, to get his boat ready for the fishing season. The Barnes and Mickelsons were friends in nearly identical situations, both raising three small children, two boys and a daughter, each being 6 years old and younger, without the mothers. Both lived in company housing near the waterfront. As the 27th was Lewis Mickelson's birthday, all ten had gathered at his house for a birthday dinner by 5:30 P.M.

Another couple—Leonard Day, a caretaker at the lumber company, and his wife, Alberta—also lived in company housing. He was retiring and they expected to leave in a week for the "Lower 48." (Norton and Haas, 1970, p. 312).

Within 45 seconds of the onset of the earthquake shaking that had started slowly and quickly became violent, the first oil storage tank failed as its bottom moved away. About 1 minute after the shaking started the first wave rose glassy-smooth over the bank. A returning breaking wave flooded the lower part of town to a height of 25 to 26 feet above lower low water, the water level at that time. Low tide was predicted for 6:16 P.M. at -0.6 feet. About one minute later a second breaking wave hit at a height of about 40 feet causing great destruction to the railroad yards. The maximum height reported in Whittier was 43 feet near the small boat harbor location at that time. A witness reported seeing a wall of water coming ashore. Offshore the water had the appearance of something having exploded underneath the canal about 50 yards off shore. A third breaking wave hit about a minute later with a height of 30 feet (Chance, 1970, p. 122). The ten people at the Michelson's home and the Day's were washed away and never found. These were all due to local landslide tsunamis.

At the time of the initial shock and first small wave, Jerry Ware, a railroad maintenance man, was standing at the car-barge dock. He drove to his house trailer near the depot for his wife and six-month-old daughter. A wave came in the window and smashed the trailer, throwing Mrs. Ware clear but washed away Geriann, the infant. Ware was swept through the porch wall and rode and swam with the porch door. He found his wife in the mud and water clear of the trailer. She had serious injuries, with pieces of wood embedded in her body, a fractured ankle and an injured shoulder. She was airlifted out of Whittier the next afternoon on the first flight out and eventually evacuated to Seattle where she recovered. Her baby was found alive in a snow bank but died shortly afterwards. Mrs. Ware was the only serious injury from the tsunami or earthquake at Whittier (Norton and Haas, 1970, p. 312).

Figure 39. March 28, 1964—A surge wave left a two-by-twelve inch (5.2 x 31 cm) plank in a tire at Whittier. (Photo credit: U.S. Geological Survey)

The fire that started immediately after the shock burned for three days, covering 3 square miles of the bay and obscuring the town for a time. Among the debris were giant boulders weighing up to 2 tons and covered with barnacles which were pushed 125 feet inland and left on the railroad tracks at an elevation of 30 feet.

The landsliding that caused the waves occurred at several points along the southern and western ends of the canal. The unconsolidated sediments had submarine slopes of 20 to 30 degrees. The highest run-up occurred on the north side and reached 104 feet (Kachadoorian, 1965, p. B16). It reached 82 feet near the FAA station, which was also reached by the waves. Several unoccupied homes in the area were destroyed. The waves destroyed the small boat harbor, the stub pier, the car-barge cargo slip, the Alaskan Railroad depot waiting room, the Columbia Lumber Company structures, the DeLong Dock, the Army and Union Oil tank farms, the Two Brothers Lumber Company buildings, and other waterfront facilities.

There is little reported for what happened after the first three waves that occurred during the first minutes. Chance (1973, p. 122) mentions a report of an "extra high tide at 2:00 A.M." which would have been near high tide, and a later wave from the main tectonic tsunami.

Hobo Bay. On the west side of Port Wells, John Edward Brenner operated a mine near Hobo Bay. After the earthquake he noted small waves coming every 2 to 5 minutes, decreasing in height. Shortly after darkness the sea rose about 9 feet above the high tide level. He estimates that it took 1½ hours to reach this height. There were three successions of waves in two hours.

Inakwik Inlet. The epicenter of the main earthquake has been placed in Inakwik Inlet, east of Valdez. Irving Wedmore of Valdez was fishing in the inlet about 1 mile from the mouth at the time of the earthquake. Although in 50 fathoms of water, he thought his boat had run aground. (This is a common reaction to the seismic waves passing through the water column and is known as a seaquake.) Water surged high on the north shore with periods of about 1 minute and exposed the beach to considerable distances during the draw-down. Immediately following the earthquake, the water began to recede from the inlet very rapidly. On the mainland opposite Fairmont Island, the water reached a height of 25 feet shortly after the earthquake.

Tatitlek. The village of Tatitlek near the south end of Valdez Arm reported that the water receded immediately after the earthquake and the wave returned 17 to 18 feet above normal mean lower low water but did not reach the extreme high water line which had been elevated 4 to 5 feet by the earthquake. Berg et al. (1970) give an amplitude of 13.5 feet. High and erratic waves continued for several hours but did not cause any damage. The short time after the earthquake indicated a local landslide source.

Jack Bay. Off Valdez Arm on the east side is uninhabited Jack Bay which had a 600 foot section of forest cleared to a height of 39 feet. This area and a nearby cove were the only areas on the north shore of Jack Bay to show signs of wave action. (Plafker et al., 1969, p. G9). This most likely was due to a local landslide-generated tsunami.

Valdez. The community of Valdez was built on the outwash delta of the Lowe and Robe Rivers and Valdez Glacier. At the time of the earthquake it had about 1,200 inhabitants. Valdez had a history of small failures from the front of the delta which caused repeated cable breaks in the early part of the century (see 1908) and one failure which caused some damage to the waterfront in 1926. Its sources of income were shipping into the interior of Alaska via the Richardson Highway. It is the most northern ice-free port in Alaska. Other industries include fishing and canning, tourism, the operation of a state mental hospital, and a highway department maintenance complex.

The 400-foot freighter *Chena* arrived in port at 4:12 P.M. from Seward, and nine local longshoremen were taken on board to transfer the cargo.

Figure 40. Tank fire at the Union Oil tank farm, Valdez, Alaska, following the tsunami of March 28, 1964. (Photo credit: Earthquake Engineering Research Institute)

Figure 41. Aerial view of Valdez, showing the extent of inundation along the coastline from the March 28, 1964, tsunami. (Photo credit: U.S. Department of Interior)

By the time of the earthquake there were 28 adults and children on the dock watching the operation. The crew occasionally would throw candy down to the children.

The earthquake hit with great force. The people on the dock had little chance to escape as 500 feet of the dock and 98-million cubic yards of the supporting delta slid into the bay. The breakup began within 20 seconds of the onset of the earthquake (Chance 1973). The *Chena* rolled alarmingly and was pitched 53 degrees to port, endangering the vessel. The incoming wave (about 45 seconds after the onset of the earthquake) raised the ship 30 feet and above the warehouse. Its propeller was visible to people on shore. None of the people on the dock survived.

Shifting cargo in the hold killed longshoremen Howard Krieger and Phil Gregordoff, and seriously-injured Jack King in hold #3. King was taken to the hospital in Cordova where both of his feet were amputated. Ralph Thompson, 3rd Officer of the *Chena,* suffered a massive heart attack and died at 7:45 A.M. having been evacuated to shore earlier. His death is not counted in the official list of fatalities, but is counted here as the ship's extreme motions, the crashing of the dock and cargo, and the attack by huge waves, no doubt caused the heart attack. Bosun Christ Hurst suffered a broken elbow and fingers.

The return of the wave turned the *Chena's* bow out to the open bay and it was able to gain the safety of the open water. The wave reached beyond McKinley Street two blocks inland. Berg et al. (1970) put the maximum wave at about 20 feet above tide level at the time.

The cannery had collapsed into the bay within the first two minutes. Fortunately no one was on board any of the 70 boats in the harbor as 68 were destroyed. A second smaller wave came in about 10 minutes later. The Union Oil tanks leaked and caught fire (Figure 40). By 10:30 P.M. the whole waterfront was on fire. It burned for two weeks.

Two more waves entered the town, one at 11:45 P.M. and another at 1:45 A.M. The latter came at high tide and flooded the town to a greater depth than any of the other waves. Waves 2.5 high were reported inside the Valdez Hotel on McKinley Street after 11:00 P.M. (Migliaccio, 1964). These would have been waves from the main tectonic tsunami.

There was one additional fatality. Earlier, Harry A. Henderson had taken his boat to his cabin on **Anderson Bay**. A separate tsunami was generated by subaerial landslides on the opposite side of Port Valdez at Cliff Mine and into **Shoup Bay**. Also, Shoup Bay is nearly blocked from Port Valdez by an underwater terminal moraine which possibly contributed to the tsunami generation. A wave 78-feet high destroyed his cabin and nothing was found of him or his boat. The wave reached at least 170 feet high on the Cliff Mine side where driftwood was deposited. Silt and sand were found at the 220 foot level and was probably due to a splash (Plafker et al.,

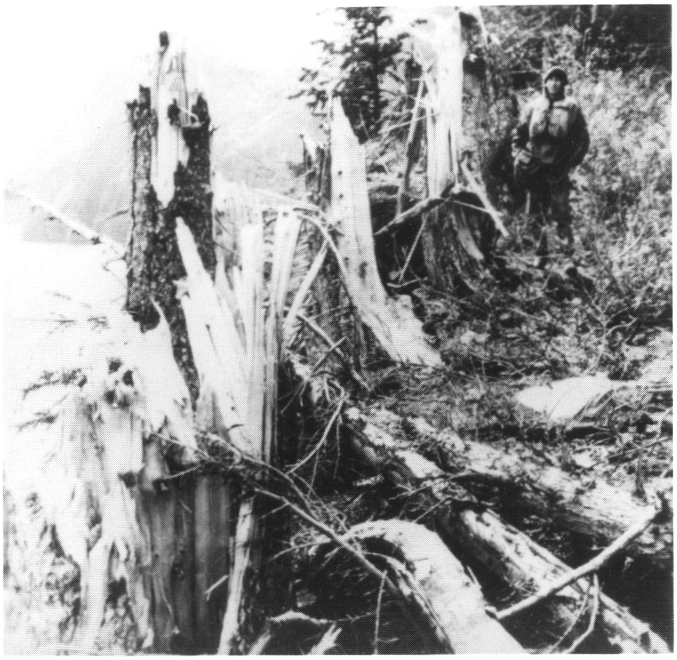


Figure 42. March 28, 1964—Living spruce trees were snapped by a local wave occurring at the western spur of Shoup Bay. (Photo credit: G. Plafker, U.S. Geological Survey)

1969, p. G13). Waves presumably from this slide reached 31 feet at Jackson Point and damaged the abandoned Dayville cannery.

At the western spur of Shoup Bay, a local wave reached between 88 and 101 feet above lower low water, snapping spruce trees 2 feet in diameter (Figure 42). The wave also deposited a barnacle-covered boulder 8 feet above the shoreline. The boulder weighed 1,700 pounds.

Basil "Red" Ferrier and his son Delbert were about 12 to 15 miles west of Valdez just inside the **Valdez Narrows** intending to get a tree for timber. The earthquake triggered a snow slide that split and went into the water on both sides of them. The resulting waves carried their skiff out and back. They jumped in the skiff and reached their boat as the waves swamped the skiff. They saw the wave coming from Valdez and raced their boat for the wider water. The wave overtopped and destroyed the Valdez Narrows navigation light which was on a concrete base 37 feet above the water level.

In town, the earthquake effects were enhanced by the unconsolidated ground. Large waves could be seen in the land and cracks opened. These spouted water as they closed. The sewer and water lines were broken, buildings collapsed and people had difficulty walking. The town was relocated off of the delta to a more protected area to the north.

Hinchinbrook Island. At Boswell Bay, which has an FAA station, satellite tracking station and several homes on the east end of Hinchinbrook Island the first wave arrived at about 6:00 P.M. or about 24 minutes after the earthquake and was about 12 feet high (Plafker et al., 1969, p. G11). This would have been the tectonic tsunami.

Middleton Island. Middleton Island is located about 80 miles southwest of Cordova in the Gulf of Alaska. The island has an FAA navigational facility and an emergency airfield, but no dock or harbor. It experienced an uplift of about 11 feet, but the tectonic tsunami that arrived 20 minutes after the earthquake did not reach above the new elevated high water mark. There was no damage to Middleton Island.

Point Whitshed. Port Whitshed is a small fishing camp at the head of Orca Inlet 8½ miles southwest from Cordova. Ten cabins were washed away and one man was drowned. The first wave was very much like a high tide but was joined by a second wave reflected from opposite sides of the peninsula rushing up behind the cabins. Its return washed the cabins away.

Cordova. The first noticeable wave was a withdrawal about 5 minutes after the earthquake had started; it left the U.S. Coast Guard Cutter *Sedge* grounded. The water withdrew 3 or 4 times in an hour. Each withdrawal left the water about 5 feet below normal and grounded the boats in the small-boat harbor. A wave was reported 10 feet above mean lower low water (Chance, 1973, p. 125).

Many small fluctuations of the water level were observed with the highest occurring at about 12:30 A.M. at high tide. It was 29 feet high on top of a 13-foot tide stage and about 5 feet above the extreme tide level. The city dock was lifted off of its pilings and displaced. One cannery was damaged by having its pilings struck by a free boat.

Several buildings were washed away from the Eyak Lake area and the Cordova sawmill on Orca Inlet was destroyed. A house boat was destroyed as it knocked off the end of the dock. Two boats, the *Amigo* and *North Wind,* were on the Bering River when the first wave lifted the *Amigo* up on the *North Wind.* Both were left on Puffy Slough. A party of clam diggers at Copper Sands on heading for shore after the earthquake saw a house floating by with its lights on but nobody was inside. One man, Charles Beyer, Sr., was found dead of a heart attack in his waterfront home which had been washed off its foundation (*Cordova Times*, April 2, p. 1). Bill Joy was also reported dead but the circumstances are not known unless he was the fatality at Point Whitshed. These two fatalities are not counted in the tsunami fatalities as it is uncertain whether they were caused by the earthquake or the tsunami.

Wingham Island. The fishing boat *Roald* was anchored on the east side of Wingham Island, to the east of Kayak Island. It was buffeted by swift and erratic currents and rapid fluctuations in water level that started about half an hour after the earthquake. The currents were strong enough to move boulders along the shore (Plafker, et al., 1969, p. G8).

Cape Saint Elias. The earthquake was felt for five minutes but did little damage to the U.S. Coast Guard lighthouse and station at Cape Saint Elias on the southwestern tip of Kayak Island. It did cause an uplift estimated at 6 to 8 feet and a rock fall on Pinnacle Rock, an offshore promontory connected to Cape Saint Elias by a gravel bar at low tide. One Coast Guardsmen, Frank O. Reed, had gone to Pinnacle Rock to photograph sea lions and suffered a broken leg from the rock fall. His three comrades were worried that he had not returned and went to look for him at 6:00 P.M. The first tectonically-generated tsunami reached the point at 6:16 P.M., almost an hour after the earthquake. It covered the gravel bar by 4 feet of water, catching the three Coast Guardsmen with chest deep water as they carried their injured comrade on a stretcher. A surge 10 feet high came 10 seconds later and swept all four into the sea. Frank Reed was lost, but the other men survived.

4.3.4 Southeastern Alaska

Yakataga. An FAA station and the home of several trappers and prospectors, located about 75 miles east of Cape Saint Elias, Yakataga experienced shaking strong enough to make standing difficult. The earthquake caused numerous water spouts. The tsunami effects were limited to erratic tides beginning at 6:25 P.M. with a withdrawal of six to eight feet. Waves repeated about every twenty minutes with a maximum range of about 16 feet. None reached the extreme high tide line and no damage was done (Plafker, et al, 1969). Berg et al. (1970) give a maximum height of 12 feet.

Yakutat. An eyewitness reported seeing a peculiar wave curling around the point to the west and along the beach. It boiled and foamed along the shore. She saw only one wave. Another witness reported that a wave surged into the harbor during the earthquake, and tides came in later (Chance, 1973, p. 130). The early arrival would indicate a probable local landslide source for the wave and the later tides could have been the tectonic tsunami. Loud sounds like cannon shots were heard for about 20 minutes after the earthquake and all agreed that the sounds came from the direction of Khantaak Island. Examination from the air the next day showed

Examination from the air the next day showed slumping near Turner Point with much debris in the bays and lagoons—mainly kelp. Turner Point collapsed in the 1899 and 1958 earthquakes.

Disenchantment Bay. Chance (1973) reports that at 10:30 P.M. a seal hunter at Disenchantment Bay noticed that the water in the bay was rising and falling at ten minute intervals. At 10:30 P.M. the water was at minus three feet and rose to plus-ten feet for a rise of 13 feet (range?). It fell to plus-three feet. An 8-foot wave followed about fifteen minutes later; a third wave rose to 19 feet and fell to 3 feet in another 15 minutes. These would be tectonic tsunami waves. The relative greater heights in Disenchantment Bay was due to its smaller size than Yakutat Bay (the entry point for the wave).

Lynn Canal. The marine cable was broken 19 1/5 miles south of Skagway near the delta of the Katzehin River. No visual wave was reported.

Skagway. At Skagway a 17-foot tsunami was reported at approximately 10:30 P.M., more than 3 hours after the earthquake. There were three more waves; the highest was 5 feet. The water inundated about 30 feet, 10 feet above the bay level, but caused no damage (Cloud and Scott, 1969).

Juneau. The tide was 4 to 6 feet higher than normal (Cloud and Scott, 1969). Waves 3.8 feet were measured by the tide gage.

Hoonah. The tide came in a few minutes after the shock was felt and was several feet high. Logging camps located up the bay reported that the water rose several times in the hours after the shock. The tsunami came about 8 P.M., 20 minutes after the shock. A few mooring lines were broken, causing some damage. Two tsunamis 6 to 7 feet high were reported at 9:00 and 11:00 P.M. at **Elfin Cove** northwest of Hoonah.

At **Pelican,** southwest of Hoonah, the first tsunami arrived at 7:40 P.M. and was followed by seven or eight more waves with the highest being 5 feet. Damage was done to several homes. One home was flooded, two scows drifted loose, and the boardwalk was warped (Cloud and Scott, 1969).

Yakobi Island. People heard a roaring sound like steam escaping and noticed that the water in the channel began to race madly back and forth. It rushed out of the bay, leaving the float and boat on the bottom.

Haines. In the small-boat harbor the tides came in and out four [*sic*] times between midnight and 8:00 A.M. Unusually high tides occurred at 1:15 A.M. about 5¾ hours after the earthquake. It was 19 feet high. This was followed by five more waves about 1 hour apart which were at a maximum of 17 feet (Cloud and Scott, 1969).

Sitka. Two floats were reported broken from their moorings and a dock collapsed. A few miles northeast, tsunamis 15 to 20 feet high were reported at about 7:35 P.M. These were followed by four or five other waves causing minor damage to a boat and float in the area (Cloud and Scott, 1969). It was recorded with an amplitude of 7.2 feet.

Petersburg and Wrangell. "A 17 foot high tide was recorded at the island protected ports here (Wrangell) and at Petersburg last Friday but no tidal wave effects occurred. The highest was only three feet above normal" (*The Daily Sentinel* (Sitka), April 1, 1964, p. 3). It is a common error not to recognize that tsunamis often appear as rapid and untimely tides.

Klawock. A 10-foot wave occurred about 9:00 P.M. It was followed by two others about midnight that were 15 feet high. The water inundated 50 feet inland and destroyed three frame dwellings on the city dock (Cloud and Scott, 1969). The waves also damaged the Sand Point dock, the bridge across the Klawock River and the ramp leading to the Coastal-Ellis Airlines. There was a lot of water on the roads (*Craig Newsletter–The Voice of Brotherhood,* April 8, 1964, p. 4).

Craig. On the southeastern side of town the wave came over the road. The new city dock was almost submerged and when the water receded from the dock, and floats were almost fully dry (*Craig Newsletter–The Voice of Brother-hood*, April 8, 1964, p. 4). A 14-foot tsunami was reported about midnight but it caused no damage (Cloud and Scott, 1969).

Annette. A tsunami 3 to 4 feet high was reported about 9 hours after the shock at 4:40 A.M. causing no damage (Cloud and Scott, 1969).

Table 12. Tsunami-Related Fatalities, March 28, 1964

Region	Fatalities
Kodiak area*	
Kaguyak	3
Sitalidak I.	1—presumed drowned trying to reach Old Harbor from home on Island
Kalsin Bay	6
Kodiak, City	9
Seward*	12—includes man who died of a heart attack running away from wave
Evans I., Crab Bay	1
Chenega	23
Point Nowell	1
Port Nellie Juan	3
Whittier	13—includes infant washed into snowbank
Valdez	31—includes heart attack victim on the *Chena*
Anderson Bay	1
Point Whitshed*	1
Cape St. Elias*	1
TOTAL	106

* Fatalities due to main tsunami, including 4 at Seward, total 25

Table 13. Amplitudes for the March 28, 1964, Tsunami Recorded in Alaska

Station Name	Amplitude (meters)
Massacre Bay, Attu	0.4
Sweeper Cove, Adak	0.3
Dutch Harbor, Unalaska	0.4
Homer (local landslide)	0.5
Yakutat	1.2
Sitka	2.2
Juneau	1.2
Ketchikan	0.6

4.4 Recent Tsunamis: 1965–1996

1965, February 4, 05:01 GMT. 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. The earthquake caused minor damage at Adak, Attu, Amchitka, and Shemya Islands. At Sweeper Cove, Adak, the sea level fell 1.2 feet in fifteen minutes. At Massacre Bay, Attu, the water rose 5.2 feet relative to its normal position at that time. It was recorded with an amplitude of 0.8 feet at Dutch Harbor, Unalaska, and 3 inches at Sitka.

On the southern coast of Shemya Island the rise of water was estimated at 35 feet. A warehouse was flooded and part of the coastal road was washed out. Slight damage from the tsunami was reported from Amchitka. A field party noted a line of flotsam that appeared to have been moved about 6.5 feet above the normal high tide line.

The aftershock pattern outlined a block 400 miles by 125 miles (Jordan et al., 1965). (See Figure 43, next page.) Hwang et al. (1972) showed that the maximum energy followed the orthogonal to this block and passed between Hawaii and Japan. Validity 4.

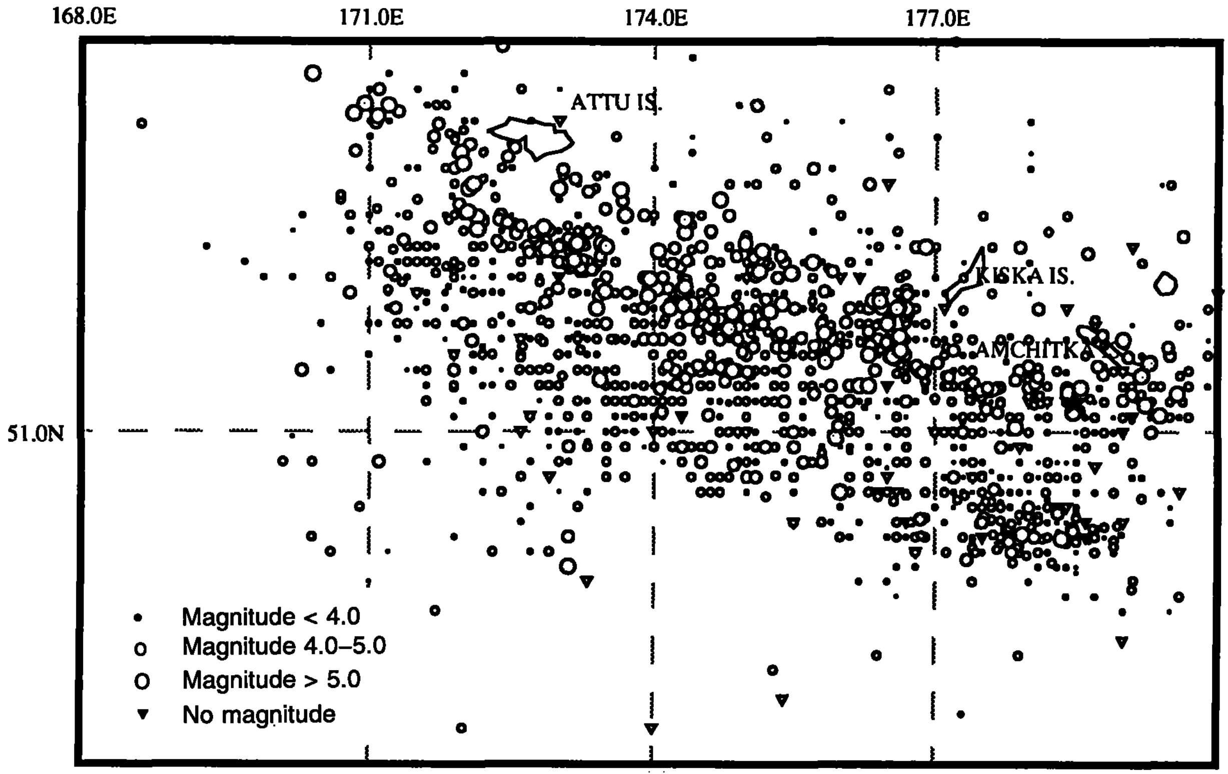


Figure 43. Aftershocks of February 4, 1965, earthquake in the Rat Islands, Aleutian Islands. 1,792 earthquakes were recorded.

1965, March 30, 02:27 GMT. A magnitude 7.4 earthquake felt on Amchitka and Adak Islands caused a tsunami that was registered on the tide gage at Massacre Bay, Attu, with an amplitude of 4 inches. Validity 4.

1965, July 2, 20:59 GMT. A magnitude 7.0 earthquake near Umnak Island caused a tsunami that was recorded at Dutch Harbor, Unalaska, with an amplitude of 3 inches. Validity 4.

1966, October 17, 21:42 GMT. A magnitude 8.0 earthquake in Peru generated a tsunami that was recorded at Snug Harbor, Kenai; Massacre Bay, Attu: Womens Bay, Kodiak; Sitka, and Sweeper Cove, Adak, all with amplitudes of about 2 inches. Validity 4.

1968, April 1, 00:42 GMT. A magnitude 7.5 earthquake in Bungo Strait, between Shikoku and Kyushu Islands, Japan, produced a tsunami recorded at Massacre Bay, Attu, with an amplitude of less than 4 inches. Validity 4.

1968, May 16, 00:49 GMT. A magnitude 7.9 earthquake off the east coast of Honshu, Japan, produced a tsunami with an amplitude of 6 inches at Massacre Bay, Attu, 3 inches at Sweeper Cove, Adak, 2 inches at Dutch Harbor, Unalaska, and 1 inch at Sitka. Validity 4.

1968, August 1, 20:19 GMT. A magnitude 7.3 earthquake on Luzon, Philippine Islands, generated a tsunami with an amplitude of less than 4 inches at Massacre Bay, Attu. Validity 4.

1969, August 11, 21:27 GMT. A magnitude 7.8 earthquake in the Hokkaido, Japan-Kuril Islands, Russia area caused a 4-inch tsunami at Massacre Bay, Attu. Validity 4.

1969, November 22, 23:10 GMT. A magnitude 7.3 earthquake near the east coast of Kamchatka, Russia, generated a 3.6 feet wave at Massacre Bay, Attu, 2.9 feet at Shemya, and 1 foot at Sweeper Cove, Adak. Validity 4.

1971, May 2, 06:08 GMT. A magnitude 7.1 earthquake in the Andreanof Islands, Aleutian Islands, produced a tsunami with an amplitude of about 1½ inches at Adak. Validity 4.

1971, July 14, 06:11 GMT. A magnitude 7.9 earthquake in New Ireland in the southwestern Pacific generated a 1¼ inch wave at Massacre Bay, Attu. Validity 4.

1971, July 26, 01:23 GMT. A magnitude 7.9 earthquake in New Ireland produced a 1¼ inch wave at Massacre Bay, Attu, and at Sweeper Cove, Adak. Validity 4.

1971, November 6, 12:00 GMT. The underground nuclear explosion (code-named "Cannikin") on Amchitka produced a 4-inch wave at Square Bay and a 2-inch wave at Constantine Harbor, both on the north shore of Amchitka. These bays have natural periods of about 20 minutes; these were recorded at about 6 and 10 minutes after the explosion. The energy appeared to be trapped as edge waves on the shelf, since they were not recorded on the south side or at Rat Island (66 miles away) nor on deep ocean gages (Olsen et al., 1972; Willis et al., 1972). These may have been seiche. Validity 2.

1971, December 15, 08:30 GMT. A magnitude 7.8 earthquake off the east coast of Kamchatka, Russia, generated a 2-inch wave at Sweeper Cove, Adak, 3½ inch wave at Massacre Bay, Attu, and at Shemya, and less than one-half inch at Unalaska. Validity 4.

1972, July 30, 21:45 GMT. A magnitude 7.6 earthquake in southeastern Alaska caused some damage to Sitka and was felt over 50,000 square kilometers. It produced a wave recorded at Juneau with an amplitude of 4 inches, and at Sitka with an amplitude of 3 inches. "A Coast Guard spokesman in Juneau said the only apparent result at sea was a sort of confused whitecap throughout Alaskan waters" (*Southeast Alaska Empire*, July 31, 1972, p. 1). A couple spending the weekend at Avoss Lake, 32 miles south of Sitka, rushed from their shaking cabin. At the lake they found their boat had been completely thrown ashore (*Sitka Sentinel*, July 30, 1972). This is a possible landslide tsunami in the lake. Validity 4 for the Juneau recording and 3 for the Avoss Lake event.

1973, February 28, 06:38 GMT. A 7.2 magnitude earthquake in the Kuril Islands, Russia, generated a tsunami that had a maximum amplitude of 5 feet on Shumshu Island, Kurils. There is evidence of this tsunami on the Massacre Bay, Attu, and Shemya marigrams with maximum amplitudes of 4 inches and 3 inches respectively. Validity 4.

1973, June 17, 03:55 GMT. A magnitude 7.4 earthquake on Hokkaido, Japan, produced a tsunami with a maximum amplitude of 2 inches at Massacre Bay, Attu. Validity 4.

1975, June 10, 13:47 GMT. A magnitude 7.0 earthquake in the Kuril Islands generated an earthquake with an amplitude of 1 inch at Sitka and Attu. Validity 4.

1975, November 29, 14:48 GMT. A magnitude 7.2 earthquake on the southern coast of the Island of Hawaii generated a locally damaging submarine landslide tsunami that was recorded at Yakutat with an amplitude of 2 inches and at Sitka with an amplitude of 4 inches. Validity 4.

1979, February 28, 21:27 GMT. A magnitude 7.1 earthquake in southeastern Alaska generated a 6-inch wave at Sitka and a 2-inch wave at Yakutat. An amplitude of 30 centimeters is reported in *United States Earthquakes, 1979* (Stover and von Hake, 1981), but this is in error. Lahr et al. (1980) show that the main shock and aftershocks had epicenters on land north and northeast of Icy Bay and the aftershock zone did not extend into Yakutat Bay, Icy Bay, or the ocean. Therefore it is probable that the small tsunami was caused by local landsliding. Validity 4.

1985, March 3, 22:47 GMT. A magnitude 7.8 earthquake near the coast of central Chile produced a tsunami that was widely recorded around the Pacific Basin. It was recorded in Alaska with maximum amplitudes of 3 inches at Sand Point, Popov Island, Shumagin Islands, 2 inches at Sweeper Cove, Adak, 1 inch at Seward and at Womens Bay, Kodiak, and was observed at Yakutat. Validity 4.

1986, May 7, 22:47 GMT. A magnitude 7.7 earthquake caused minor damage on Adak and Atka and generated a small tsunami that was widely recorded around the Pacific Basin. In Alaska it had a maximum amplitude of 2.9 feet at Adak, 0.4 feet at Dutch Harbor, Unalaska, and 0.15 foot at Sand Point, Popov Island, Shumagin Islands (Pararas-Carayannis, 1986). Validity 4.

1987, November 17, 08:47 GMT. A magnitude 6.9 earthquake in the Gulf of Alaska produced a small tsunami with an amplitude of 2½ inches at Yakutat. This event (and also the two subsequent events) occurred at the junction of the Aleutian arc and the Fairweather transcurrent faulting system of southeastern Alaska (Lahr et al., 1988). Validity 4.

1987, November 30, 19:23 GMT. A magnitude 7.6 earthquake about 75 kilometers south of Cape Yakataga (within the Pacific tectonic plate) produced a tsunami observed at Yakutat. Boats slowly rose and fell without damage. It was recorded at Yakutat with an amplitude of 17 inches and at Sitka with an amplitude of 5 inches. It was also recorded on deep ocean bottom pressure gages (Figure 44) installed off of the Alaskan coast adjacent to the Shumagin Gap region and on a similar gage off the United States west coast with amplitudes of 0.2 inches at AK8, 0.4 inches at AK7, and 0.7 inches at WC9 (Gonzalez et al., 1990). Validity 4.

1988, March 6, 22:36 GMT. A magnitude 7.6 earthquake in the Gulf of Alaska was observed as a seaquake, causing $5,000 in damages to the

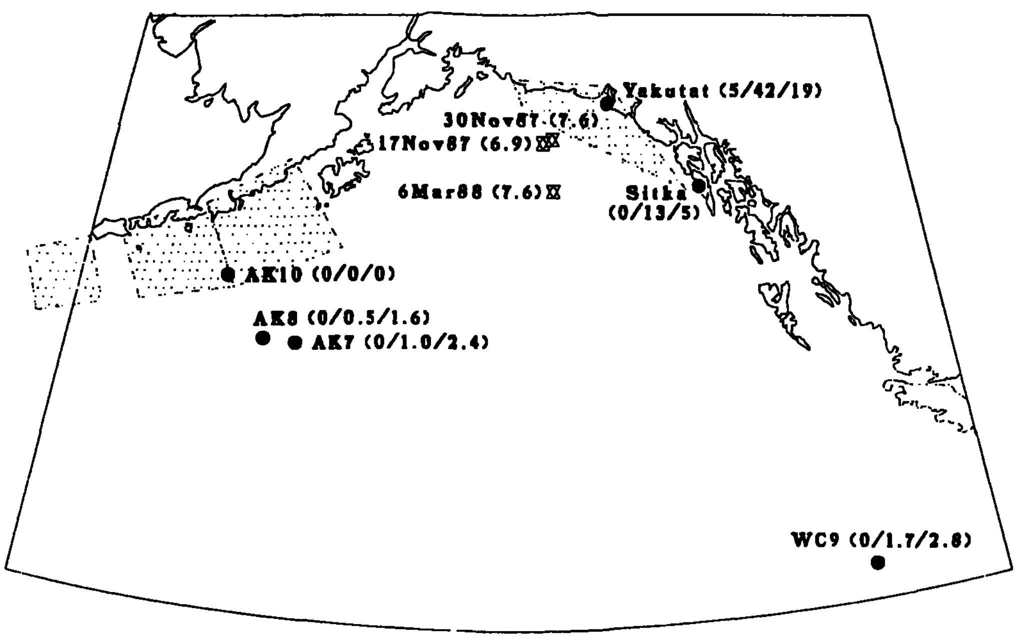


Figure 44. Epicenters for the earthquakes of November 17 and 30, 1987, and March 6, 1988, with magnitudes in brackets. Location of ocean bottom recorders AK7, AK8, AK10, WC9, and tide gages at Sitka and Yakutat, are shown with recorded amplitudes of the three tsunamis. Stippled areas are seismic gaps (Gonzalez et. al, 1990).

the *Exxon Boston,* and *Exxon New Orleans* located at 57°38' N and 142°45' W. The earthquake generated a tsunami that was recorded at Yakutat with an amplitude of 7.5 inches, and at Sitka with an amplitude of 2 inches. The deep ocean bottom pressure gages recorded amplitudes of 0.6 inches at AK8, 0.9 inches at AK7, and 1.1 inches at WC9. It was not recorded by U.S. west coast stations at Alameda, Port Luis, or Monterey. The Fort Point record was not found. Validity 4.

1991, February 21, 02:36 GMT. A rare earthquake in the Bering Sea, with a magnitude of only 6.5, generated a small tsunami that was recorded at Dutch Harbor, Unalaska, with an amplitude of 1 foot and at Sweeper Cove, Adak, an amplitude of 9 inches. It had been felt as an earthquake at Saint Paul Island and Adak. It was not recorded by U.S. west coast tide stations of Alameda, Port San Luis, or Monterey. The Fort Point, California, recording could not be located. Validity 4.

1994, October 4, 13:23 GMT. A moment magnitude 8.2 (determined by the National Earthquake Information Center) earthquake occurred in the southern Kuril Islands, Russia. At least 10 people were killed; there was extensive damage. The earthquake was also damaging at Hokkaido, Japan, and observed widely elsewhere in Japan. It generated a tsunami that was observed with ampli-tudes of 1.3 feet at Kahalui, Hawaii, 1.6 feet at Crescent City, California, and elsewhere at lesser amplitudes. In Alaska, it was recorded with amplitudes of 6 inches at Adak and Shemya, and 3 inches at Unalaska. Validity 4.

1994, November 4, 04:10 GMT. Workmen were about half finished with a $4 million refurbishing of the White Pass and Yukon Railroad Dock on the eastern side of Skagway harbor. There was pile driving equipment on the dock and 9,000 cubic yards of granitic riprap material and soil, rock, and fill material that was used to fill in a 50-foot gap between the railroad embankment and the remaining dock, a distance of 290 to 330 feet. The total weight was approximately 23,350 tons. The riprap was piled on top to a height of 18 feet (Cornforth and Lowell, 1996). At 7:10 P.M. when the tide was at minus 4 feet, an 800 foot section of the 1,300 foot dock slid away. The 50-year-old dock was carried away when the underlying sediments collapsed and slid into deeper water. The flow went to the southwest, scouring the bay bottom to depths of up to 70 feet. Two D7 Caterpillar bulldozers were also lost. The water was ninety feet deep where it had been only forty feet.

Paul Wallen of Homer was in steel caisson cell number 4 with his brother, removing old wooden pilings when the collapse occurred. His brother held on to a piling while debris poured down the

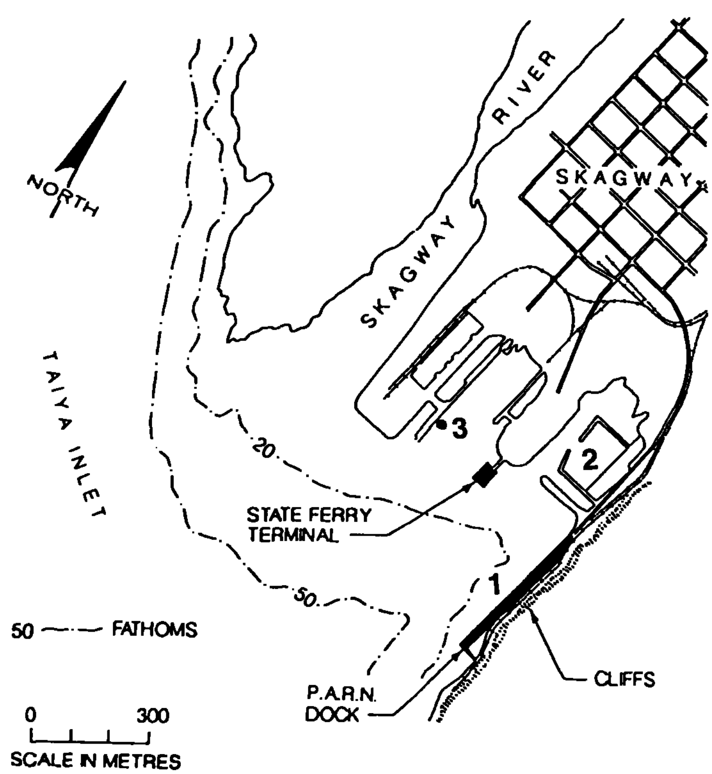


Figure 45. Skagway Harbor. (1) Slide area; (2) small-boat harbor, and (3) tide gage location.

caisson, and climbed ashore before a large returning wave covered the caisson area. Paul Wallen's body was not found until January 24; it had washed under the surviving part of the dock.

A large crack, 50 to 60 feet long and 1 to 2 inches wide in the soil near the shoreline, had been observed a week before, prompting one man to quit out of concern for safety. There was evidence of movement the day before, with a breaking of the brace between cells 1 and 2, and the distortion of the cells.

A 20- to 25-foot wave crossed the harbor and caused $2,000,000 damage to the Ferry Terminal near the middle of the harbor. The waves broke the anchoring chains holding the 4,400 ton floating concrete dock, spinning it into the Broadway dock, and damaging three dolphins there. The passenger ramp twisted free from the terminal dock and the auto ramp sank. The four-inch fuel line parted, spilling 60 to 100 gallons of fuel oil into the harbor (*The Skagway News*, November 11 and 23, 1994).

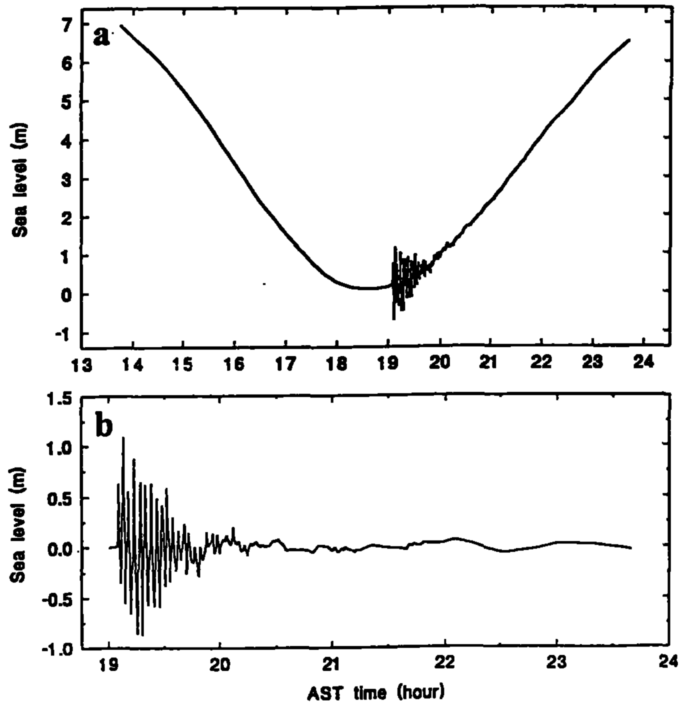


Figure 46. (A) Tide gage record, November 4, 1994, Skagway tsunami. (B) Record with tide removed. Sea level referenced to bottom of gage intake, with the actual tide level at -1.2 m. (Kulikov et al., 1996)

A wave also entered the small-boat harbor and caused about $100,000 damage there. Two men were on a boat in the harbor when they saw a large wave coming into the harbor. The boat hit bottom. Things were chaotic and one boat broke loose and slammed into others. The men crawled out on the rolling and pitching floating dock fingers. One man injured his back and the other aggravated a heart condition.

There was a report that a similar event had occurred in November, 1966, at night, and had left a scoured channel across the bottom of the bay due to the collapse of fill material near the place of this failure. There was no marigraph record for this date and no earthquakes occurred in this area in November. The state of the tides is unknown, and it is not known whether a wave had been generated.

The replacement costs for the Railroad Dock was $15–20 million. The slide was estimated to have been 600 feet wide, 50 to 60 feet thick, and 4,500 feet long (1–3 million cubic yards). This was probably due to the additional weight on the dock and the weight of the riprap on the supporting sediments, the effects of removing the old wooden pilings, and the increased pore pressure due to the minus tide. There was no earthquake. Validity 4.

1995, July 30, 05:11 GMT. A magnitude 7.8 earthquake occurred in northern Chile. It was widely recorded and in Alaska the amplitudes were: 6 inches at Adak; 4 inches at Shemya and Sand Point; 3 inches at Dutch Harbor, Unalaska; and 2 inches at Kodiak, Seward, Sitka, and Yakutat. Validity 4.

1995, December 03, 18:14 GMT. A magnitude 8.0 earthquake in the Kuril Islands was recorded at Shemya with an amplitude of 4 inches, and at Adak with an amplitude of 2 inches. Validity 4.

1996, February 17, 06:00 GMT. A disastrous magnitude 8.1 earthquake in the Jaya Irian, Indonesian area of the island of New Guinea caused waves of at least 23 feet which, with the earthquake caused 40 fatalities and 19 missing. It was widely recorded in the Pacific. There were wave amplitudes of 14 inches at Shemya and 4 inches at Adak.

1996, June 10, 04:03 GMT. A magnitude 7.7 earthquake 60 miles west-southwest of Adak was widely recorded in Alaska, Hawaii, and the United States west coast. In Alaska there was an amplitude of 20 inches at Adak, 3 inches at Shemya, and 2 inches at Kodiak, Unalaska, and Sand Point. Validity 4.

1996, June 10, 15:24 GMT. A magnitude 7.2 afershock created a second tsunami with an amplitude of 5 inches at Adak and not readable at other Alaskan stations. Validity 4.

5.0 Summary of Events

Table 14 (on the following pages) summarizes the events listed in the previous pages of text and observations and lists the quantitative data for each event. The times are given in Universal Time and the amplitude data are in meters. The key to the "Cause" (of event) column is:

L	=	Landslide (subaerial or submarine)
M	=	Meteorological
E	=	Earthquake
V	=	Volcano

References are occasionally given for the origin data. The abbreviations are as follows:

Abe	Abe (1983)
AEC	Atomic Energy Commission
C&L	Cox and Lander (1995)
Cox	Cox and Morgan (1977)
DNAG	Decade of North American Geology Seismicity Data (1991)
EQH	Earthquake History of the United States (1982)
Iida	Iida (1984)
ISC	International Seismological Center
ISS	International Seismological Summary
NEIC	National Earthquake Information Center
PAL	Lockridge (1985)
PAS	Pasadena, California Institute of Technology
PCT	Iida et al. (1967)
PDE	Preliminary Determination of Epicenter, Monthly Listing
S&G	Soloviev and Go (1984)
USE	United States Earthquakes (1968, 1971, 1974, 1979)
USGS	U.S. Geological Survey

Table 15, beginning on page 141, lists Alaska tsunami observations at remote locations. The same codes are used for this table.

The data on Table 14 and data for other areas of the world are available in digital form from the National Geophysical Data Center. For more information, please contact:

National Geophysical Data Center
NOAA, Code E/GC1
325 Broadway
Boulder, Colorado 80303-3328, U.S.A.

Telephone: 303-497-6221
Fax: 303-497-6513
Internet: info@ngdc.noaa.gov

ORIGIN DATA: DATE (GMT)	ORIGIN DATA: Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	ORIGIN DATA: Area	VALIDITY	CAUSE	TSUNAMI DATA: MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1st MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1737 10 16	16:00	Kamchatka, Russia	3	E	4.5	Amchitka Norton Sound	12–15					Driftwood. Driftwood attributed by natives to 1737 event.
1788 07 21	57.0N 153.0W 8.0?	Alaska Peninsula	4	E	3.0	Three Saints Bay, Kodiak	3–10	F				Ship cast on shore; several huts destroyed.
1788 08 06	55.0N 161.0W [USGS] 8.0	Shumagin Islands	4	E	 4.0	Pavlof Village, AK Peninsula Sanak Island Unga Island	5.0 30.0 88.0?					 Waves passed over the village. Many natives drowned.
1790 09 11		E. Aleutian Islands	0	M		Unalaska	OBS					Sea agitated by high winds; later seaquake felt.
1792	57.0N 152.0W [USGS]	Alaska Peninsula	1	M ?		Three Saints Bay	OBS					Agitated and anomalous waves following strong earthquake. Ship damaged.
1796 05 29	54.0N 167.0W [USGS]	E. Aleutian Islands	1	V		Unimak Island						Doubtful report of a tsunami accompanying eruption of Bogoslof volcano.
1820 03 01		E. Aleutian Islands	1	V	0.5	Umnak Island						Eruption of Pogromni volcano caused highly disturbed sea. Probably not a tsunami.
1825 03 21	54.8N 164.0W	E. Aleutian Islands	0	V		Unimak Island						Eruption of Shishaldin volcano caused a debris flow due to snow melt. The sea was agitated for six months.
1826 10 22		E. Aleutian Islands	0	V		Unimak Island						Eruption of Shishaldin volcano. Wild hogs perished from cold and ash on Chernabura Island.

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1st MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1827 08 08		Alaska Peninsula	0	E & V		Chernabura Island						Confused entry for an earthquake in Kormandorski Is., the 1827 eruption in Kamchatka, and the 1826 event, above.
1845–1847	Summer	Southeastern Alaska	3	L	3.0	Yakutat Bay	OBS					"100" natives perished near Haenke I. Date uncertain. Possible erroneous date for 1847 Sitka earthquake or 1853–1854 Lituya Bay event.
1853–1854		Southeastern Alaska	4	L	4.0	Lituya Bay	120.0					Tsunami in bay cleared trees to a height of 120 m. 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 27	18:10 57.0N 152.0W [USGS]	Gulf of Alaska	3	E		St. Paul's Harbor	OBS	R	03.0			Waves in harbor advanced and receded.
1856 07 26	54.6N 165.0W [USGS]	E. Aleutian Islands	1	V		Unimak Island	OBS					Submarine volcanic eruption. Water agitated.
1865 07 16	02:00	E. Aleutian Islands	1	E		Unalaska						Community flooded due to subsidence.
1866 09 05	13:00 58.0N 152.0W [USGS]	Alaska Peninsula	2	E		Kodiak	OBS					Dock demolished on Woody I.

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1868 05 15	55.0N 161.0W [USGS]	Alaska Peninsula	2	E	2.5	Unga Island	6.0					Water agitated and rose 20 feet.
1868 08 14	01:30 18.6S 71.0W [PAL] 8.5	N. Chile	4	E	4.3 3.5	Kodiak Island	2.2				22.0	Rising water forced workers from beach. Earlier great earthquake and tsunami on August 13 at 21:30 not mentioned.
1872 08 23	18:06 52.2N 166.4W [Cox]	Fox Is., Aleutian Islands	4	E		W. of Umnak I.						Recorded at St. Paul I., Pribilof Is., and on U.S. west coast and Hawaii. First instrumental tsunami and earthquake source.
1874 05	4.0	Southeastern Alaska	3	L		Lituya Bay	24.0					Washing and flooding. Height based on tree trim line.
1878 08 29	54.0N 167.W [USGS]	E. Aleutian Islands	1	E & V	1.0 1.5	Makushin, Unalaska	OBS					Village reported destroyed by earthquake and tsunami. Not in contemporary reports.
1880 09 29	04:00 55.8N 155.6W 6.3 [DNAG]	Alaska Peninsula	3	E		Chirikof Island Semidi Islands	OBS OBS					Water inundated land 55 m. Earthquake felt.
1880 10 26	22:20 57.0N 136.0W 6.3 [DNAG]	Southeastern Alaska	3	E & L		Redoubt Lake, Baranof Is. Whale Bay	1.8 OBS					Two separate tsunamis. Debris line on lake shore. Huge wave ran into bay.

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1883 08 27	02:59 6.7S 105.4E	S. Java Sea (Krakatau)	0	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.
1883 10 06	19:04 59.4N 153.4W [C&L]	Cook Inlet	4	V	3.0 3.0	Augustine Island Kodiak Island Port Graham	OBS 0.1 9.1	 R	 05.0		 01.1	Volcanic eruption generated tsunami. Air wave and tsunami recorded. Flooded houses, and ships ran aground.
1897 04 17		Gulf of Alaska	3	L		Hinchinbrook Island	OBS					House and shed washed off of foundation and a second house was damaged.
1899 09 04	00:22 60.0N 142.0W [DNAG] 7.9 [PAS]	Gulf of Alaska	4	E		Cape Yakataga Kayak Island Yakutat	OBS OBS 3.1	F F				Tide from shore pulled ship to limit of anchor chain. Beach elevated 1 m. Water inundated 300 m beyond highest water mark. 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 [PAS] 25.0	Gulf of Alaska	4	E & L	3.0	Disenchantment Bay Glacier Bay Katalla, Controller Bay Lituya Bay	12.0 OBS 1.2 60.0					At least 8 separate tsunamis. 14.5 m vertical uplift. Wave from collapse of Taku Glacier overturned boats 1.6 km away. Probably a slump-generated wave. Local tsunami, date not certain. Native village and saltery destroyed.

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1st MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1899 09 10 (continued)						Logan Coast	12.1					Mature trees uprooted to a height of 12 m.
						Lynn Canal	0.6					
						Russell Fjord	9.1	R				Eight prospectors narrowly escaped local tsunami caused by collapse of glacier.
						Valdez	2.1					Local tsunami.
						Yakutat	4.6					Whirlpools formed.
						W. shore Yakutat Bay	9.0		05.0			Water inundated 1/2 km.
						Yakutat Bay	3.0		08.0			Sawmill damaged, huts flooded. Part of Khantaak Island with Indian graveyard slid into the bay.
1900 08 11	04:40 62.0N 138.0W [USGS]	Southeastern Alaska	4	E & L		Lituya Bay	OBS					Five natives on small island drowned due to waves from ice fall.
1901 12		Cook Inlet	1	V & E		Kenai						Several waves causing much damage reported, but reports confused.
1903 08		Cook Inlet	2	V		Iniskin Bay	OBS					Waves seen in calm bay.
1905 07 04	59.5N 139.8W	Southeastern Alaska	4	L		Disenchantment Bay	35.0					Fallen Glacier collapsed. Loose deposits and bushes cleared off the land.
						Russell Fjord	6.0					
1906 08 17	00:40 33.0S 72.0W [PAL] 8.6 [Abe] 25.0	S. Chile	4	E		Port Chatham, Kenai, Peninsula	0.2		26.0			Recorded.

ORIGIN DATA			VALIDITY	CAUSE	TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area			MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1907 09 24	12:58 59.5N 135.2W [USGS] 5.5 [S&G]	Southeastern Alaska	3	L		Haines S. of Yakutat	OBS					Small temporary change in water level noted. Cable break.
1908 02 14	11:25 61.0N 146.2W [EQH] 6.0	Gulf of Alaska	2	E & L		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] 60.0 [USGS]	Gulf of Alaska	1	L	0.5	Golden Port Wells (Bay)	OBS OBS					Large rock and landslide into bay. Landslides into the bay, water agitated, fish killed. Cables cut and buried. Doubtful tsunami.
1918 09 07	17:16 45.5N 151.5E 8.25	Kuril Islands, Russia	4	E		Craig	<0.1		20			Recorded.
1925 02 23	23.54 60.0N 146.0W [ISS] 6.0	Gulf of Alaska	4	L	 1.0	Petersburg/Wrangell Valdez	 OBS					Cable break; no wave reported. Boardwalk torn up by wave; cable broken.
1927 10 12	08:31	Southeastern Alaska	2	L ?		Ketchikan	<0.1		11			Recorded. Source unknown.
1927 10 24	16:00 57.5N 137.0W 7.1 [Abe] 25.0 [USGS]	Southeastern Alaska	3	L		Cape St. Elias Icy Straits Wrangell, Petersburg, Juneau, Skagway, Ketchikan	OBS					Heavy seas broke towline. Water muddy, and churned. Cables broken.

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1929 03 07	01:35 51.0N 170.0W [DNAG] 7.5 [Abe] 50.0	E. Aleutian Islands	4	E		Cherni Island, Fox Is.	OBS					Recorded in Hawaii and San Francisco. Cherni I. reported over-run, killing all cattle.
1933 03 02	17:31 39.1N 144.7E 8.3 [Iida] 10.0	Sanriku, Japan	4	E		Seward	<0.1		04.0			Recorded seiche.
1936 10 27	15:50 58.6N 137.1W	Southeastern Alaska	4	L		Lituya Bay	150.0	R	02.0		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 [DNAG] 8.3 [Abe] 25.0	Alaska Peninsula	4	E		Dutch Harbor, Unalaska	<0.1		60.0	10-22:30	02.2	Recorded.
						Seward	<0.1		75.0		01.5	Recorded.
						Sitka	<0.1		100	10-22:40	02.4	Recorded.
1944 12 07	04:35 34.0N 137.1E 8.0 [Iida] 30.0	Ryukyu Trench, Japan	4	E	3.0	Massacre Bay, Attu	0.2	F	10.0		05.4	
					2.5	Sweeper Cove, Adak	0.1		12.0		06.4	
1946 04 01	12:29 52.75N 163.5W [DNAG] 7.3 [Abe] 50.0	E. Aleutian Islands	4	E		Adak	0.2		12.0			Tidal fluctuations noted.
						Attu	OBS					Kelp washed on beaches.
						Chignik	0.8		60.0			
						Chirikof I.	OBS					Extremely low tide.
						Cold Bay	6.1					

ORIGIN DATA					TSUNAMI DATA						
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1946 04 01 (continued)						Dutch Harbor, Unalaska	OBS	R		01-15:30		Light damage and small boat landing and ferry barges washed away.
						Ikatan (Akutan), Unimak	OBS					Two houses and two sheds destroyed.
						King Cove	1.5		60.0			Light damage to False Pass cannery.
						Kodiak	0.6					Visible waves.
						Nikolski	12.2?					Bay ran dry, and wave over the bank. Hunting shelters destroyed.
						Sanak Island	6.1				00.2	Houses gutted and carpentry shop, destroyed. Dories washed ashore.
						Sand Point	OBS					Ships rose and fell over a large range.
						Seward	0.1		08.0			
						Sitka	0.4		10.0		02.9	
						Unga	0.8					Two dories and a dock washed away.
						Unimak Island	35.0					Scotch Cap lighthouse destroyed, 5 deaths. Antenna at 33 m washed away. Pankof light also destroyed on southeast Unimak I.
						Yakutat						
							0.4		06.0			Uplift occurred.
1946 11 01	11:14 51.5N 174.5W [USGS] 7.0 [Abe] 40.0	Aleutian Islands	1	E								Not reported in Alaska; doubtful report in Hawaii.
1949 01 27	11:00 55.0N 163.5E [USGS] 5.9	Kamchatka, USSR	4	E		Adak	0.1					Recorded.

DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
ORIGIN DATA					TSUNAMI DATA							
1949 08 22	04:01	British Columbia,	4	E								Multiple tsunamis.
	53.6N	Canada		&		Baranof I. Blue Lake	OBS					Pack and gun washed off lake beach.
	133.3W			L								
	[DNAG]					Ketchikan	0.3					Water receded and rose unexpectedly.
	8.1 [Abe]											
	25.0											Observed wave.
						Knutson Cove	0.3					Waves in Lakes Manzanita and Ward.
						Revillagigedo I.	0.6					
									16.0			Doubtful recording.
						Sitka	<0.1					Cables broken and buried.
						Wrangell						
1949 09 27	15:31 59.8N 149.0W [DNAG] 6.7 [Abe] 50.0	Gulf of Alaska	0	E		Seward	OBS?					Probably "gage shaking."
1952 03 04	01:23	Hokkaido, Japan	4	E	2.0	Dutch Harbor, Unalaska	<0.1		33.0			Recorded only.
	42.2N				2.0	Massacre Bay, Attu	0.2		18.0			
	143.9E					Sitka	<0.1		16.0			
	8.1 [Iida]					Sweeper Cove, Adak	<0.1		21.0			
	45.0											

ORIGIN DATA			VALIDITY	CAUSE	TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area			MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1952 11 04	16:58 52.8N 159.5E 8.2 [Iida] 30.0	Kamchatka Peninsula, USSR	4	E	4.0	Dutch Harbor, Unalaska	0.6	R	58.0	04-20:25	03.5	
						Juneau	0.1		75.0			
						Massacre Bay, Attu	1.2		17.0			
						Seward	0.1		60.0	04-23:15	06.3	
						Sitka	0.2		90.0	04-23:13		
						Skagway	<0.1			05-00:40		
						Sweeper Cove, Adak	1.1	R	48.0	04-19:27	02.5	Low-lying areas flooded.
						Womens Bay, Kodiak I.	0.3	R	62.0	04-22:43	05.8	
						Yakutat	0.2		50.0	04-23:20	06.4	
1953 11 25	17:48 34.0N 141.7E 7.4 [Iida] 60.0	Honshu, Japan	4	E	1.0 1.5	Massacre Bay, Attu	0.2		13.0		04.2	
1956 03 30	06:11 55.0N 160.5E [PCT]	Kamchatka Peninsula, USSR	1	V								Explosion of Bezymianny volcano generated a tsunami or air wave recorded on tide gages.
						Dutch Harbor, Unalaska	0.1		27.0			
						Massacre Bay, Attu	0.3		20.0		01.8	
						Sweeper Cove, Adak	0.1		18.0		02.1	

ORIGIN DATA			VALIDITY	CAUSE	TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	V A L I D I T Y	C A U S E	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1957 03 09	14:23 51.9N 175.33W 8.3 [USGS] 33.0	Central Aleutian Is.	4	E	3.5	Atka Island	9.1					Boat houses washed away. Two damaged. One boat washed away and one damaged. Hunting shelters destroyed. Sheep destroyed.
						Chernofski Island	OBS					
						Dutch Harbor, Unalaska	0.7	R	27.0	09-15:45	01.4	
						Juneau	0.2					
						Massacre Bay, Attu	0.6	R	07.0	09-15:30	01.1	
						Sand Bay, Adak	4.0					Fuel dock structures and pipelines washed away.
						Scotch Cap, Unimak I.	15.0					High wave possibly due to local topography.
						Seward	0.2					
						Sitka	0.4		10.0	09-19:16	04.9	
						Sweeper Cove, Adak	1.9					Structures and two bridges destroyed.
						Trappers Cove, Vsevidof I.	13.7					Four sheep ranches destroyed.
						Umnak Island	2.3					2 moorages and a concrete mixer destroyed.
						Womens Bay, Kodiak I.	0.1		13.0	09-16:32	02.2	
						Yakutat Bay	0.3		09.0	09-19:12	04.8	

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1958 07 10	06:16 58.4N 136.8W [DNAG] 7.9	Southeastern Alaska	4	L	-2.0	Disenchantment Bay	6.0					At least 7 separate tsunamis. Ice fell from glacier; camping gear lost.
						Dixon Harbor	0.5					
						Dry Bay	2.0					Collapse at the mouth of Alsek River caused a 1-2 m wave to spread up a river.
						Glacier Bay	0.5					Landslide-induced waves of 0.5 to 1.0 m.
						Juneau-Skagway	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, a cabin, and mining equipment destroyed. The 525 m value for the runup is a surge and not a true tsunami. (See text, p. 74)
						Sitka	<0.1		18.0	10-07:25	01.2	
						Skagway	7.6					Landslide caused cable breaks.
						Yakutat	0.9		27.0		00.0	Mooring lines torn loose.
						Wrangell	OBS					Underwater cable broken.
1958 11 06	22:58 44.3N 148.5E 8.1 [Iida] 80.0	S. Kuril Islands, USSR	4	E	2.0	Massacre Bay, Attu	0.2		40.0		0.3	Recorded.
						Sweeper Cove, Adak	<0.1		15.0		02.0	
1958 11 12	20:23 44.2N 148.8E 7.0 [Iida]	S. Kuril Islands, USSR	2	E	2.0	Massacre Bay, Attu	0.2		40.0		02.6	Doubtful recording.
						Sweeper Cove, Adak	<0.1		15.0			

ORIGIN DATA			VALIDITY	CAUSE	TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area			MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1959 05 04	07:16 53.4N 159.8E [ISS] 8.0 [PAS] 74.0	N. Kuril Islands, USSR	4	E		Massacre Bay, Attu	0.2		31.0		01.7	
1960 05 22	19:11 39.5S 74.3W [PAL] 8.6 33.0	S. Central Chile	4	E	4.5	Cape Decision, Kuiu I.	0.6		30.0			Tide fluctuations.
					4.0	Cape Pole, Kosciusko I.	1.0					Log boom broken.
						Craig	OBS					Buoy was moved.
						Dutch Harbor, Unalaska	0.7		33.0	23-14:50	19.6	
						Juneau	OBS					Trace recorded.
						Kake	OBS			23-14:00		Trace recorded.
						Kanak Island	OBS					Clam diggers fled.
						Ketchikan	OBS					Trace recorded.
						Klakas Inlet, Prince of Wales I.	1.2					Coastguardsmen climbed to safety.
						Massacre Bay, Attu	1.7	R	45.0	23-15:30	20.3	
						Montague Island	2.3					Minor damage to pilings.
						Point Hope	OBS					Coastal ice cracked.
						Seward	0.7	R	48.0	23-14:40		
						Sitka	0.5	R	27.0	23-13:33	18.4	
						Skagway	0.2		80.0	23-15:00		
						Sweeper Cove, Adak	1.1	R	50.0	23-14:40	19.5	Record clipped; not extrapolated.
1960 05 22 (continued)						Womens Bay, Kodiak	0.7		70.0	23-14:25	19.2	
						Yakutat	0.6	R	30.0	23-14:18	19.1	

DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1963 10 13	05:17 43.8N 150.0E [Iida] 8.1	Kuril Islands, USSR	4	E	2.0	Massacre Bay, Attu	0.2					
1964 03 21			2 ?			Seward	0.8		60.0			Recorded, source unknown.
1964 03 28	03:36 61.1N 147.5W [DNAG] 8.5 23.0	Gulf of Alaska, Alaska Peninsula	4	E & L	4.5	All Alaska						$84 million in damage, 106 deaths. Tectonic and about 20 landslide tsunamis.
						Afognak Island	3.4					23 structures damaged or destroyed. Village abandoned.
						Akhiok, Kodiak I.	3.0					Homes and boat destroyed.
						Aialik	30.0					Landslide tsunami.
						Aleknagik Lake	0.3					Landslide tsunami.
						Annette	1.2					
						Blackstone Bay	24.2					Wave generated by underwater landslide.
						Boswell Bay, Hinchinbrook I.	3.8					
						Cape Chiniak	OBS					
						Cape St. Elias	1.2				00.7	Coastguard man drowned.
						Cape Yakataga	3.7				00.7	
						Chenega	27.4					Village totally destroyed and abandoned. 23 deaths, $100,000 damage.
						Chignik	0.9					Twelve waves.
						Cook Inlet	1.5					
						Cordova	4.2					$1.7 million damage.
						Crab Bay, Evans Island	6.1					1 fatality. Pier and boats destroyed.
						Craig	4.2					
						Disenchantment Bay	4.8					
						Dutch Harbor, Unalaska	0.4	R	36.0	28-06:06	02.5	

ORIGIN DATA				TSUNAMI DATA							
DATE (GMT)	Time (GMT) Area Latitude Longitude Magnitude [authority] Depth (km)	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1964 03 28 (continued)					Elfin Cove	2.1					
					Halibut Cove	7.2					
					Haines	5.8					Probably included high tide.
					Homer	6.0				00.1	Buildings flooded. Submarine landslides caused multiple tsunamis.
					Hoonah	OBS					Mooring lines broken.
					Inakwik Inlet	7.6					
					Jack Bay	12.0					Trees cleared by local submarine landslide tsunami.
					Juneau	1.1	R	81.0	28-06:49	03.2	
					Kachemak Bay	OBS					Waves observed.
					Kaguyak	9.8	R				Village totally destroyed, 3 deaths, $50,000 damage.
					Kalsin Bay	OBS					6 deaths. 60-80 head of cattle lost.
					Karluk, Kodiak	OBS					Low tide; no damage.
					Kenai Lake	10					Landslide tsunami.
					Kenai Peninsula	OBS					Damage to waterfront and boats.
					Ketchikan	0.6	R	29.0	28-06:25	02.8	
					Klawock	4.6					3 houses lost.
					Kings Bay	34.5					
					Kodiak	6.8	R			00.8	9 deaths, $31.3 million damage including 5 blocks of the business district destroyed.
					Kodiak Naval Station	7.6					$10.3 million damage including total destruction of cargo dock and heavy damage to roads and bridges.
					Larsen Bay, Kodiak	1.2					Warehouse flooded, sheds destroyed and cattle drowned.
					Massacre Bay, Attu	0.4	R	72.0	28-07:27	03.8	
					Meares Passage	OBS					Barge beached and broken.
					Middleton I.	OBS					

DATE (GMT)	Time (GMT) Area Latitude Longitude Magnitude [authority] Depth (km)	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1st MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
	ORIGIN DATA			TSUNAMI DATA							
1964 03 28 (continued)					Old Harbor	7.3				00.8	Village nearly destroyed, $150,000 damage, 1 death on Sitkaledak Island nearby.
					Ouzinkie	9.1					$500,000 damage.
					Passage Canal	31.7					Opposite shore from Whittier.
					Pederson Bay	OBS					Tide came and went for 15 hrs.
					Pelican	OBS					Home flooded, boardwalk warped, and 2 scows broken loose.
					Perl Island	9.0					
					Perry Island	7.6					2 men in water escaped. Boathouse washed away.
					Perryville	3.0					Three to four waves.
					Petersburg	0.9					
					Point Nowell	12.0					1 death.
					Point Whitshed	OBS					1 death, 10 cabins washed away.
					Port Ashton	OBS					2 men washed into water escaped.
					Port Crawford	14.6					Sawmill damaged.
					Port Graham	OBS					
					Port Nellie Juan	15.0					3 deaths, dock destroyed.
					Port Oceanic	11.9					Docks and boats destroyed.
					Puget Bay	7.3					$8,000 loss of logs and machinery.
					Rocky Bay, Kenai	5.5	F				
					Saltery Cove	OBS					Cattle, home and buildings lost.
					Seldovia	1.2					$500,000 damage, mostly to boats. Wave amplitude may include tide.
					Seward	8.3	F				Disastrous to town, waterfront, boats, and railroad. $14.6 million in damage. Section of waterfront slid into bay. 12 deaths due to combined effect of local and main tsunamis.
					Shearwater Bay, Kodiak	7.8					Cannery destroyed.
					Shelikof Strait	1.5				01.5	

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1964 03 28 (continued)						Sitka	2.4	R	50.0	28-05:06	01.5	Dock collapsed.
						Sitkalidak Island	OBS					1 death.
						Skagway	3.0					
						Spruce Cape	OBS					1 death.
						Sweeper Cove, Adak	0.3	F	54.0	28-07:00	03.4	
						Tatitlek	4.1					
						Tuxedni Bay, Cook Inlet	OBS					Rapid tide changes.
						Valdez Inlet	67.1					Middle Rock light washed away. A cabin at Anderson Bay was washed away, killing 1 person.
						Valdez	6.1					Disastrous to town, waterfront, and boats. $15 million in damage. Large section of land slid into sea. 31 deaths. Fire burned for 2 weeks.
						Whidbey Bay	15.2					Logging camp destroyed.
						Whittier	13.1–31.7					$10 million in damage. 13 deaths. 2 sawmills and oil tank farm burned. Railroad depot wharf and buildings destroyed.
						Wingham I.	OBS					
						Womens Bay	6.1				00.8	$10.3 million in damage.
						Wrangell	0.9					
						Yakataga	3.7					
						Yakutat Bay	1.2	R	07.0	28-05:00	01.4	
1965 02 04	05:01 51.3N 178.6E 8.2 [DNAG] 36.0	W. Aleutian Islands	4	E	3.0	Amchitka	OBS					Minor flooding damage. Flotsam 2 m above high tide.
						Dutch Harbor, Unalaska	0.2				02.0	
						Kodiak Island	<0.1					
						Massacre Bay, Attu	1.6				03.0	
						Shemya Island	10.7					Warehouse flooded and road washed out.
						Sitka	<0.1					
						Sweeper Cove, Adak	0.4	F	30.0		0.6	

ORIGIN DATA			VALIDITY	CAUSE	TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area			MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1965 03 30	02:27 50.3N 177.9E 7.4 [DNAG] 20.0	W. Aleutian Islands	4	E	-1.0	Attu	0.1					
1965 07 02	20:59 53.0N 167.6W 7.0 40.0	E. Aleutian Islands	4	E	-1.0	Dutch Harbor, Unalaska	<0.1					
1966 10 17	21:42 10.7S 78.8W [PAL] 8.0 40.0	Peru	4	E	1.0 1.5	Kodiak Massacre Bay, Attu Sitka Snug Harbor Sweeper Cove, Adak	<0.1 <0.1 <0.1 <0.1 <0.1			18- 18:30	20.8	
1968 04 01	00:42 32.3N 132.5E 7.5 [Iida] 30.0	Shikoku, Japan	4	E		Massacre Bay, Attu	0.1					
1968 05 16	00:49 40.7N 143.6E 7.9 [Iida] 30.0	Honshu, Japan	4	E	2.0 0.5	Dutch Harbor, Unalaska Massacre Bay, Attu Sitka Sweeper Cove, Adak	<0.1 0.2 <0.1 <0.1					
1968 08 01	20:19 16.5N 122.2E [ISC] 7.3 [USE] 36.0	E. Luzon Island, Philippines	4	E		Attu	0.1					

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1969 08 11	21:27 42.7N 147.6E 7.8 [Iida] 30.0	Hokkaido, Japan Kuril Islands, USSR	4	E	1.0	Attu	0.1					
1969 11 22	23:10 57.7N 163.6E [ISC] 7.3 [USE] 51.0	Kamchatka, USSR	4	E		Adak Attu Shemya Island Unalaska	0.3 1.1 0.9 <0.1					
1971 05 02	06:08 51.4N 177.2W 7.1 [DNAG] 38.0	Andreanof Islands	4	E		Adak	<0.1					
1971 07 14	06:11 5.5S 153.9E [ISC] 7.9 [USE] 43.0	New Ireland	4	E		Attu	<0.1					
1971 07 26	01:23 4.9S 153.2E [ISC] 7.9 [USE] 43.0	New Ireland	4	E		Adak Attu	<0.1 <0.1					
1971 11 06	22:00 51.5N 179.1E 5.7 [AEC] 21.0	Central Aleutian Is. 7.0 m_b (Willis)	2	E		Constantine Harbor, Amchitka	<0.1	R	20.0		00.2	Waves or seiche generated by undersea nuclear explosion "Cannikin."
						Square Bay, Amchitka	0.1	R	10.0		00.1	Same as above.

ORIGIN DATA			VALIDITY	CAUSE	TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area			MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1971 12 15	08:30 56.0N 163.2E [ISC] 7.8 [USE] 39.0	Kamchatka, USSR	4	E		Adak Attu Shemya Island Unalaska	<0.1 <0.1 <0.1 <0.1					
1972 07 30	21:45 56.8N 135.9W 7.6 [DNAG] 0	Southeastern Alaska	4	E & L		Avoss Lake, Baranof I. Juneau Sitka	 0.1 <0.1	 R 	 10.0 10.0			2 tsunamis. Wave on lake threw boat on shore. Coast Guard reported confused whitecaps.
1973 02 28	06:38 50.5N 156.6E [ISC] 7.2 [USE] 62.0	Kamchatka–Kuril Islands, USSR	4	E		Attu Shemya Island	0.1 <0.1		20.0			
1973 06 17	03:55 43.0N 146.0E 7.4 [Iida] 40.0	Hokkaido, Japan–Kuril Islands, USSR	4	E	1.0	Attu	<0.1					
1975 06 10	13:47 42.8N 148.2E 7.0 [Iida] 0	Hokkaido, Japan–Kuril Islands, USSR	4	E	1.0	Adak Sitka	<0.1 <0.1					Doubtful recording. Doubtful recording.
1975 11 29	14:48 19:3N 155.0W 7.2 [Cox] 8.0	Hawaii	4	L		Sitka Yakutat	0.1 <0.1					

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1979 02 28	21:27 60.7N 141.6W 7.1 [DNAG] 16.0	Gulf of Alaska	4	E & L ?		Yakutat Sitka	<0.1 0.1					
1985 03 03	22:47 33.2S 72.0W 7.8 [PAL] 33.0	Valparaiso, Chile	4	E		Adak Kodiak Island Sand Point, Popov I. Seward Yakutat	<0.1 <0.1 <0.1 <0.1 OBS					 Doubtful record; looks like background noise.
1986 05 07	22.47 51.5N 174.8W 7.7 [ISC] 19.0	W. Aleutian Islands	4	E		Adak Sand Point, Popov I. Unalaska	0.9 <0.1 0.1		12.0			
1987 11 17	08:47 58.6N 143.3W 6.9 [PDE] 10.0	Gulf of Alaska	4	E		Yakutat	<0.1					
1987 11 30	19:23 58.7N 142.8W 7.6 [PDE] 10.0	Gulf of Alaska	4	E		AK 7 AK 8 Seward Sitka Yakutat	<0.1 <0.1 <0.1 0.1 0.4					Deep ocean gage. Deep ocean gage. The gage was out intermittently throughout the tsunami. Boats bumped together.
1988 03 06	22:36 57.0N 143.0W 7.6 [PDE] 10.0	Gulf of Alaska	4	E		AK 7 AK 8 Kodiak Sitka Yakutat	<0.1 <0.1 <0.1 <0.1 0.2					

ORIGIN DATA					TSUNAMI DATA						
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1991 02 21	02:36 58.4N 175.5W [PDE] 6.5 20.0	Bering Sea	4	E		Adak Unalaska	0.2 0.3					
1994 10 04	13:23 43.8N 147.3E 8.3 [PDE] 14.0	Kuril Islands, Russia	4	E		Adak Shemya Unalaska	0.1 0.1 <0.1					
1994 11 04	04:10 59.5N 135.3W	Southeastern Alaska	4	L		Skagway	6.1–7.6					Non-seismic landslide at pier being reconstructed during negative tide. 1 killed, 800 feet of pier slid away. Over $25 million damage to pier, ferry terminal, and small boat harbor.
1995 07 30	05:11 23.4S 70.2W 7.8 [USGS] 33.0	Northern Chile	4	E		Adak Kodiak Sand Point Seward Shemya Sitka Unalaska Yakutat	0.15 <0.1 0.1 <0.1 0.1 <0.1 <0.1 <0.1					
1995 12 03	18:14 44.96N 150.47E 8.0 [PDE] 33.0	Kuril Islands, Russia	4	E		Adak Shemya	<0.1 0.1					

ORIGIN DATA			VALIDITY	CAUSE	TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area			MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1996 02 17	06:00 0.8S 137.0E 8.1 [PDE] 15.0	Jaya Irian, Indonesia	4	E		Adak Shemya	0.1 0.35					
1996 06 10	04:03 51.4N 177.8W [NEIC] 7.7 33.0	Andreanof Is., Alaska	4	E		Adak Kodiak Sand Point Shemya Unalaska	0.51 <0.1 <0.1 <0.1 <0.1	R		10-04:33 10-07:25 10-06:42 10-05:45 10-05:15	0.5 3.4 2.6 1.7 1.2	
1996 06 10	15:24 51.3N 177.0W [NEIC] 7.2 33.0	Andreanof Is., Alaska	4	E		Adak	0.1					

Table 15. Alaska Tsunami Observations at Remote Locations

ORIGIN DATA					TSUNAMI DATA							
DATE (GMT)	Time (GMT) Latitude Longitude Magnitude [authority] Depth (km)	Area	VALIDITY	CAUSE	MAG. & INT.	LOCATION OF EFFECTS	MAX. RUN UP/ AMP. (m)	1ST MOTION	PERIOD	ARRIVAL TIME (DAY-HR:MIN)	TRAV. TIME (HRS)	COMMENTS
1872 08 23	18:06 52.2N 166.4W [Cox]	Fox Is., Aleutian Is.	4	E		Hanalei Bay, Kauai	OBS					
						Hilo, Hawaii	1.3					14 oscillations observed.
						Honolulu	0.2					
						Nawiliwili, Kauai	0.5					
1946 04 01	12:29 52.8N 163.5W 7.3 [DNAG] 25.0	E. Aleutian Islands	4	E		California	OBS					1 fatality, $30,000 damage.
						Oregon	OBS					Several boats swept away.
						Washington	OBS					Boats swamped.
						Hawaii	OBS					159 killed, $26 million damages.
						Iquique, Chile	OBS					Boats damaged.
						Isla Juan Fernandez, Chile	OBS					Some damage.
1957 03 09	14:23 51.5N 175.7W 8.3 [DNAG] 33.0	Central Aleutian Islands	4	E	3.5	Hakodate, Japan	OBS					32 houses and 18 boats damaged.
						Hawaii	OBS					$5 million damages.
						California	OBS					$5,000 damage to boats.
1964 03 28	03:36 61.0N 147.5W 8.4 [DNAG] 23.0	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.
						Washington	OBS					2 injured, roads damaged, fishing boats lost, 16 homes and 9 trailers damaged, and 3 cars lost.
						Oregon	OBS					4 children killed; bridges, houses, trailers, cars, and seawalls damaged.
						California						12 fatalities, $17 million damages.
1965 02 04	05:01 51.3N 178.6E [DNAG] 8.2 36.0	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.

6.0 Marigrams for Alaska Tsunami Events

The following figures are marigrams from Alaska tide stations. Alaska tide gages were first installed in 1871. Most stations were operated for only a few months in the summer, in order to get total constants with longer-term operations at Kodiak, Ketchikan, Sitka, Juneau, and Seward.

The time is local time, unless otherwise marked as Universal or Greenwich time. Before 1883, local time was "sun time" and varied from community to community. (See section 1.3.8 for the method of converting local sun time to Universal time.) After 1883, Standard times were used with the Central Alaska zone at 150°W Meridian time, or ten hours behind Universal time. Southeastern Alaska is on 135°W Meridian time, 8 hours behind Universal or Greenwich time.

The introduction of Daylight Savings Time in 1918 moved the Meridian time to 135°W. Daylight Savings Time was gradually adopted by individual States. In February, 1942, year-round Daylight or War time was adopted, and lasted until September 1945. Generally, the time used is clear, but for critical events near a date of conversion some extra precaution should be taken.

The dates are those of the origin of the event in all but a few cases. Records reproduced from earlier sources carry the date as given. Thus, the records from the November 4, 1952, tsunami are dated as November 4, 1952, with local hours for the records copied for this study, and as November 5, 1952, GMT, for the records from Zerbe (1953).

The marigrams typically record at speeds of one inch per hour and with a convenient amplification factor to keep the trace on the width of the paper. A typical scale is 1:12. One inch on the record equals one foot of water change. The instruments are designed to record the approximately 12-hour tide; they perform less well at lower periods. The instruments' performance at the shorter periods can be affected by partial plugging of the hole, bringing water into the stilling well by marine animals, or by deliberately reducing the hole size at noisy sites.

Figure 47 illustrates the reductions of amplitude and shift of the peak by the instruments.

These figures are meant to give a general sense of the record. Where a high degree of accuracy is needed, the user may need to refer to the microfilm collection at the National Geophysical Data Center or the original records at NOAA's National Ocean Survey.

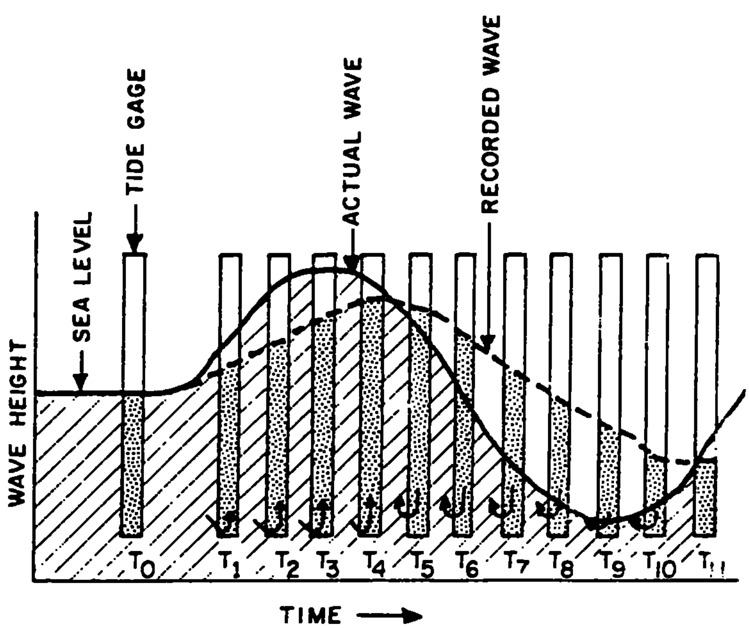
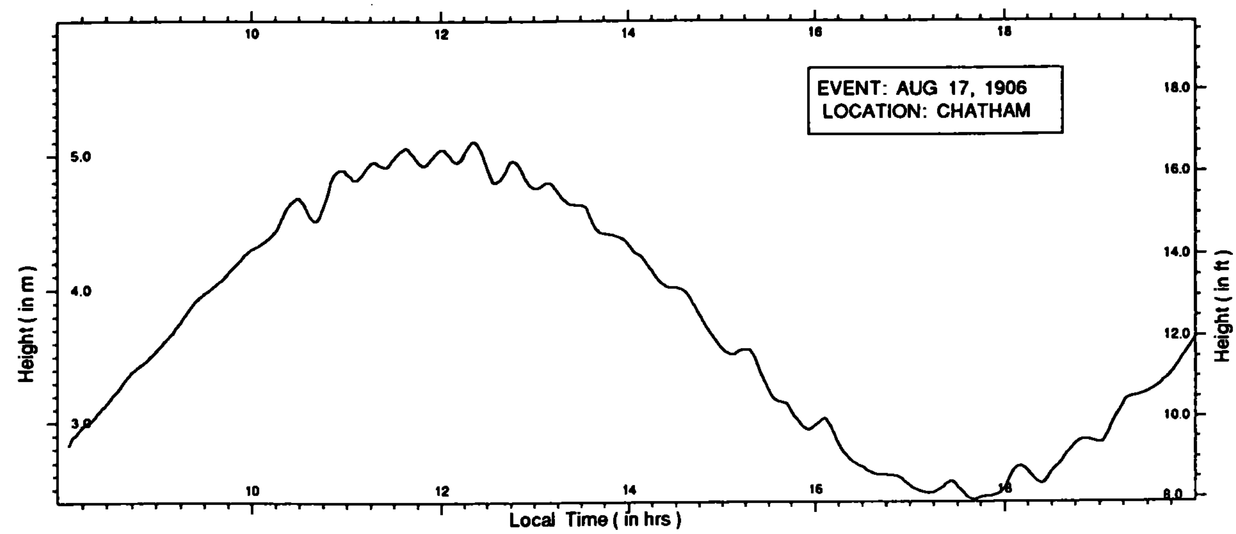


Figure 47. Schematic illustrating how the stilling well in tide gages results in a decrease in recorded wave height and a delay in recorded peak height with respect to the actual wave.

August 23, 1872. Refer to page 44, Figure 14.

October 6, 1883. Refer to page 51, Figure 16.



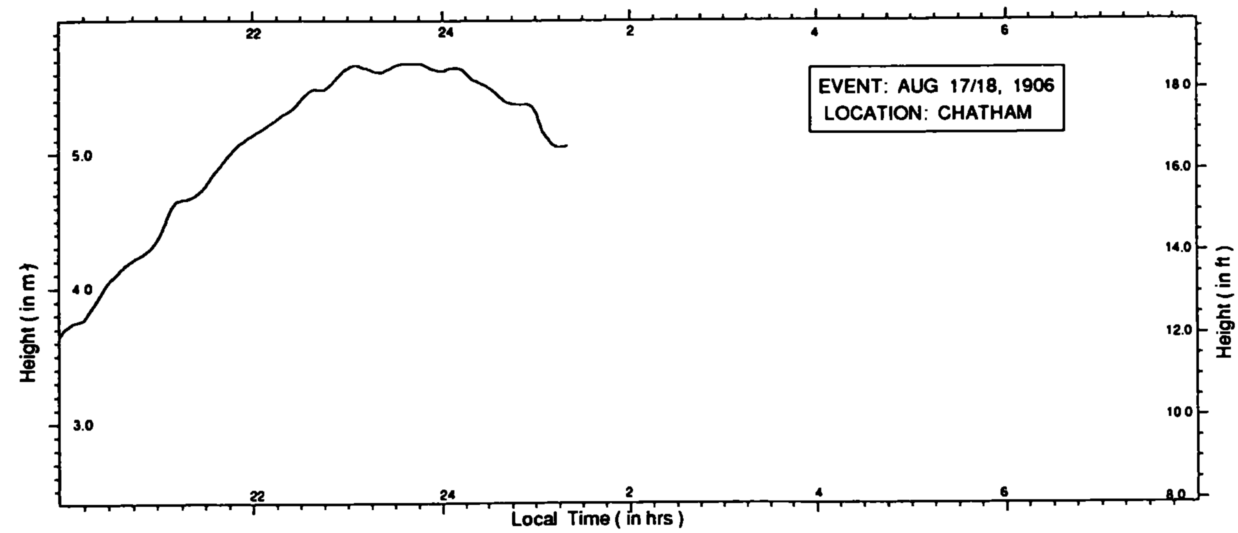


Figure 48.

October 11, 1927. Refer to page 60, Figure 18.

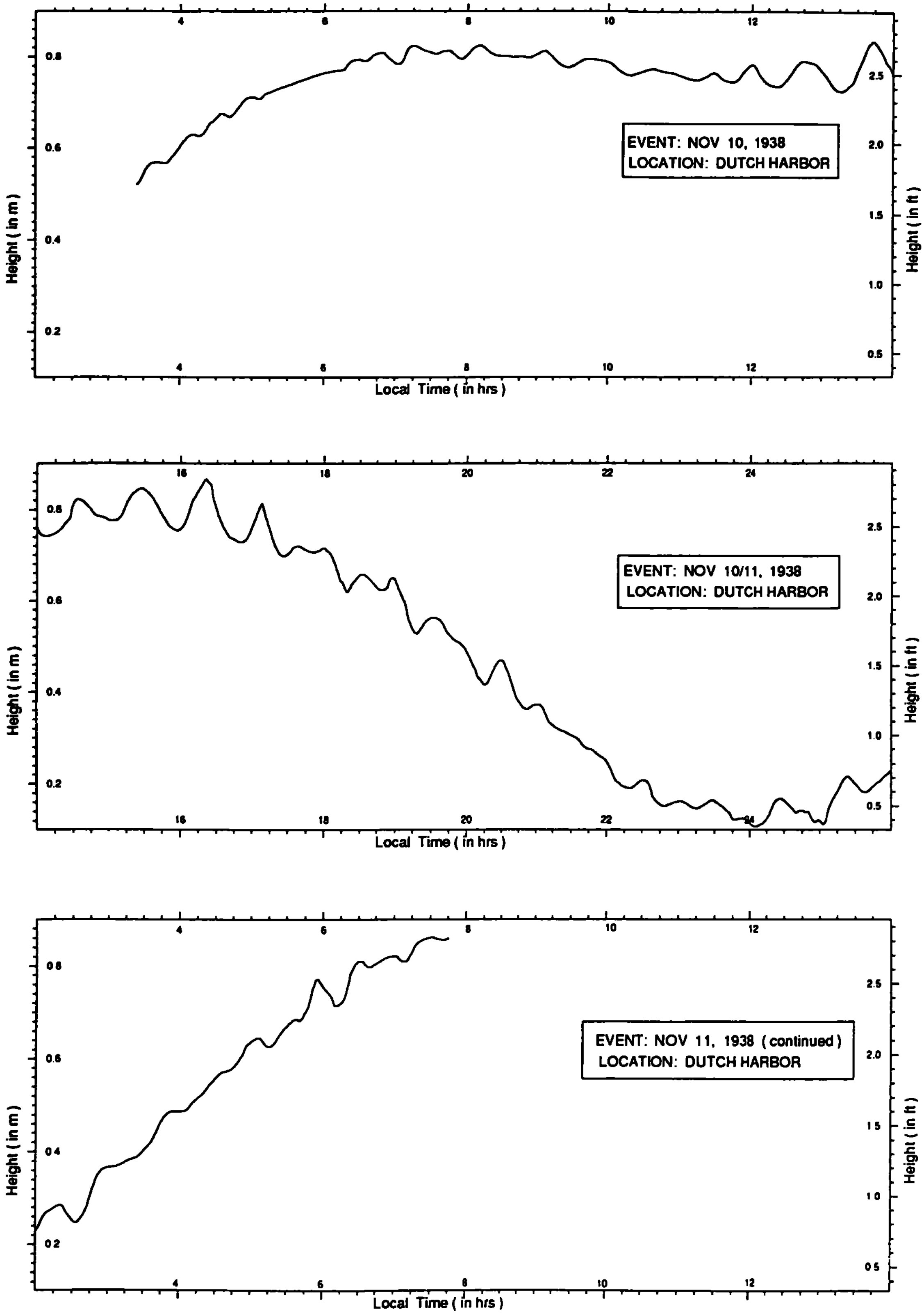

EVENT: NOV 10, 1938
LOCATION: DUTCH HARBOR
Height (in m)
Height (in ft)
0.8
0.6
0.4
0.2
2.5
2.0
1.5
1.0
0.5
4
6
8
10
12
Local Time (in hrs)
EVENT: NOV 10/11, 1938
LOCATION: DUTCH HARBOR
Height (in m)
Height (in ft)
16
18
20
22
24
Local Time (in hrs)
EVENT: NOV 11, 1938 (continued)
LOCATION: DUTCH HARBOR
Height (in m)
Height (in ft)
Local Time (in hrs)

Figure 49.

December 7, 1944. Refer to page 65, Figure 20.

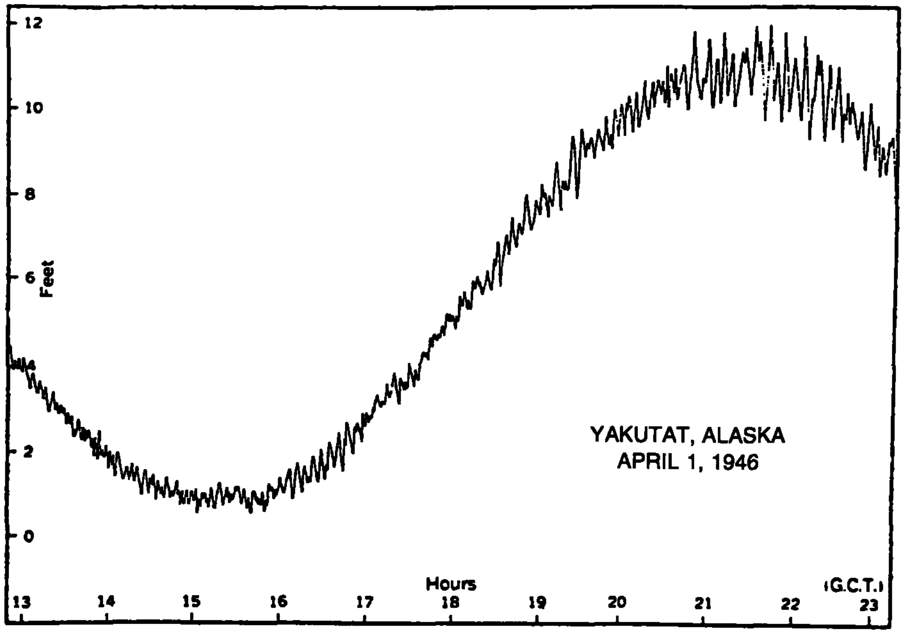


Figure 50. (Green, 1946)

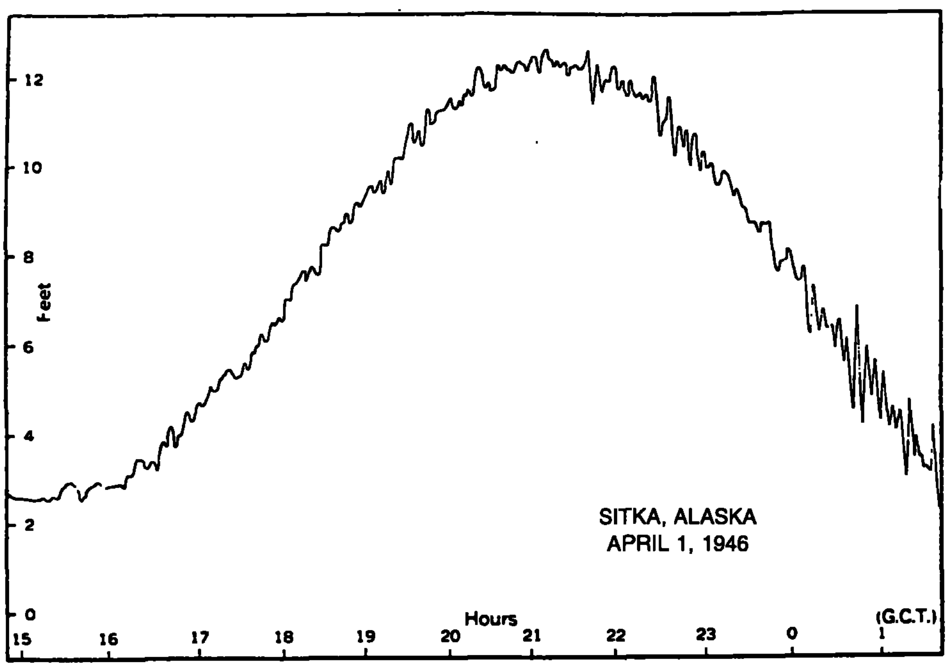


Figure 51. (Green, 1946)

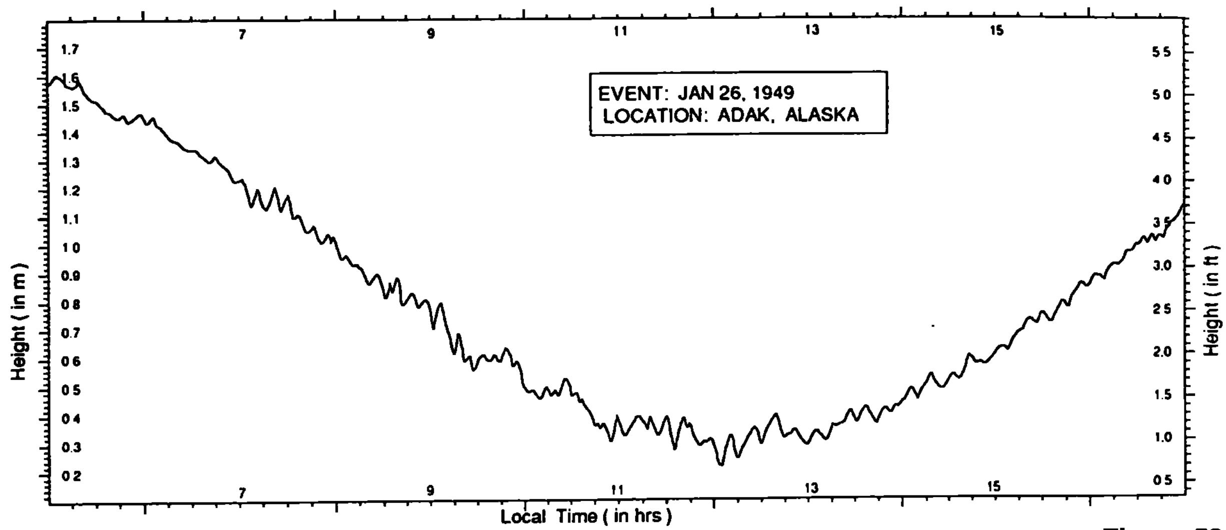


Figure 52.

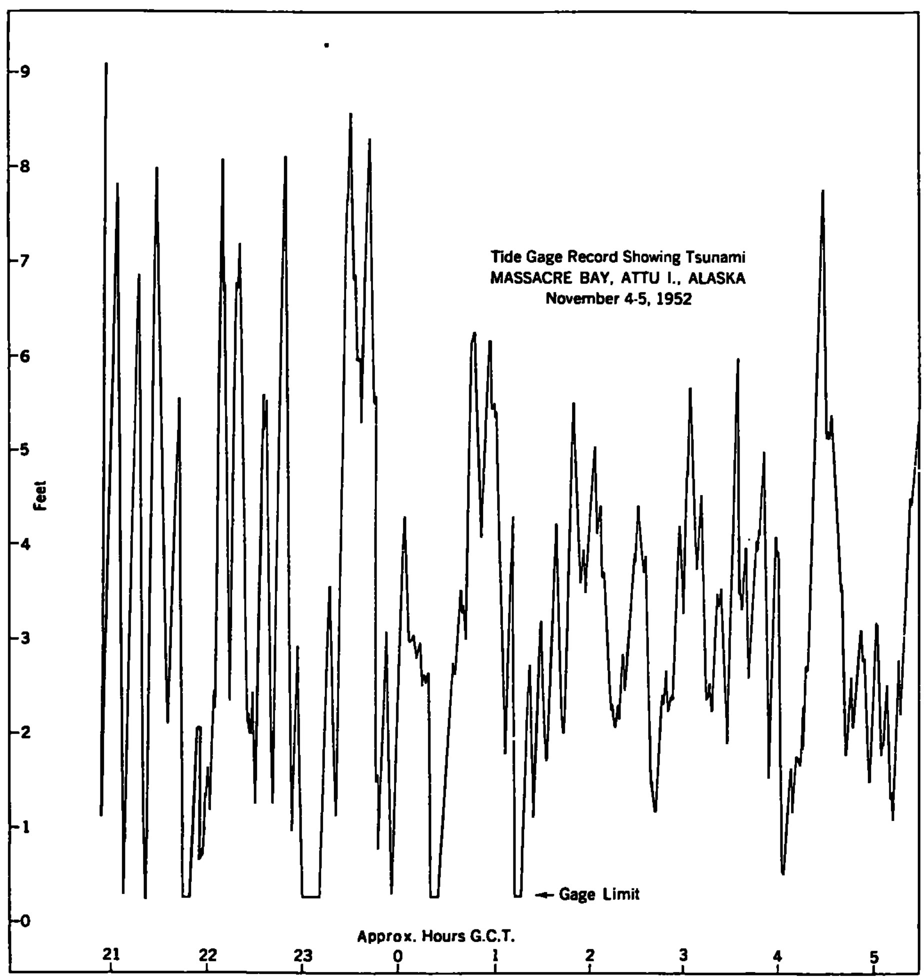
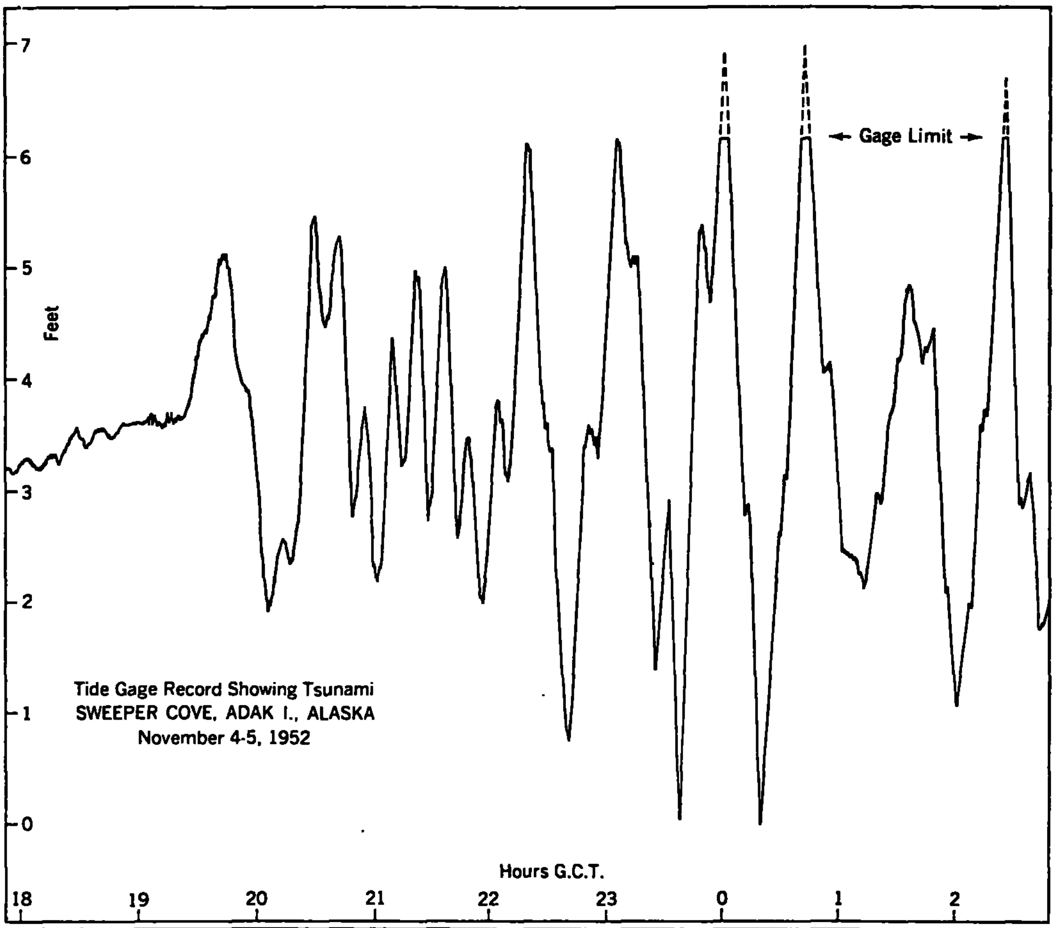


Figure 53. (Zerbe, 1953)



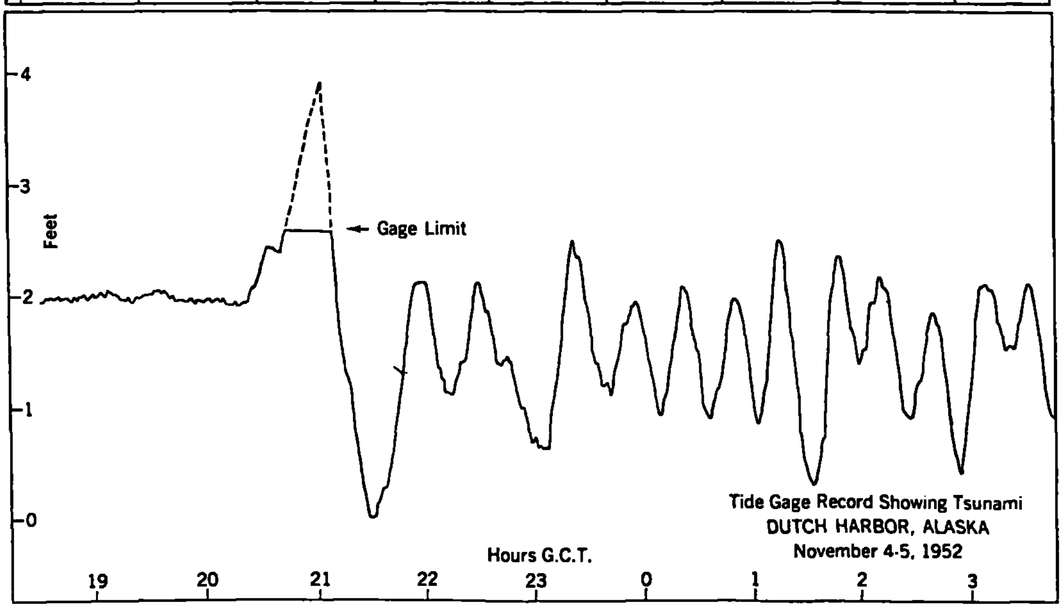


Figure 54, Figure 55. (Zerbe, 1953)

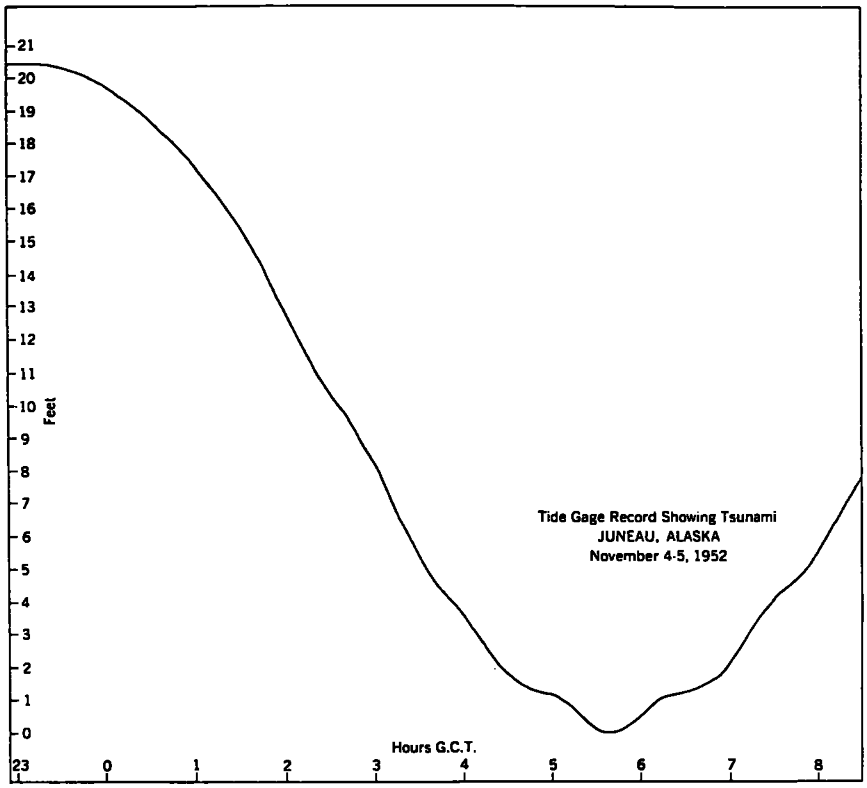


Figure 56. (Zerbe, 1953)

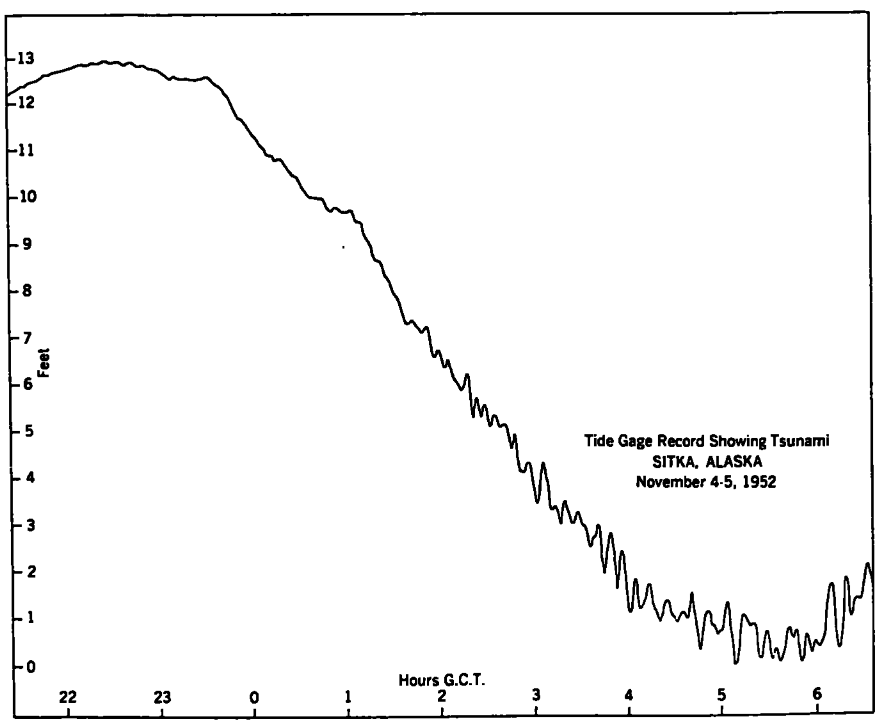


Figure 57. (Zerbe, 1953)

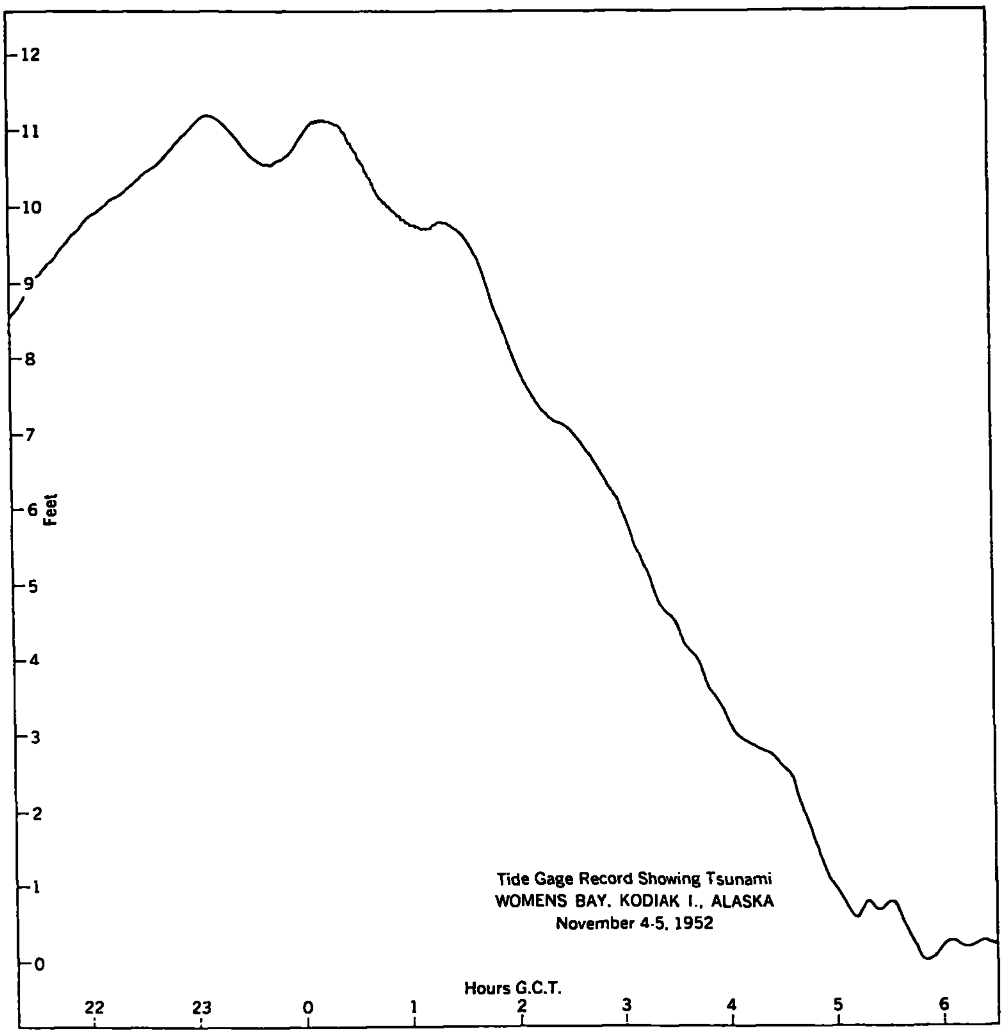


Figure 58. (Zerbe, 1953)

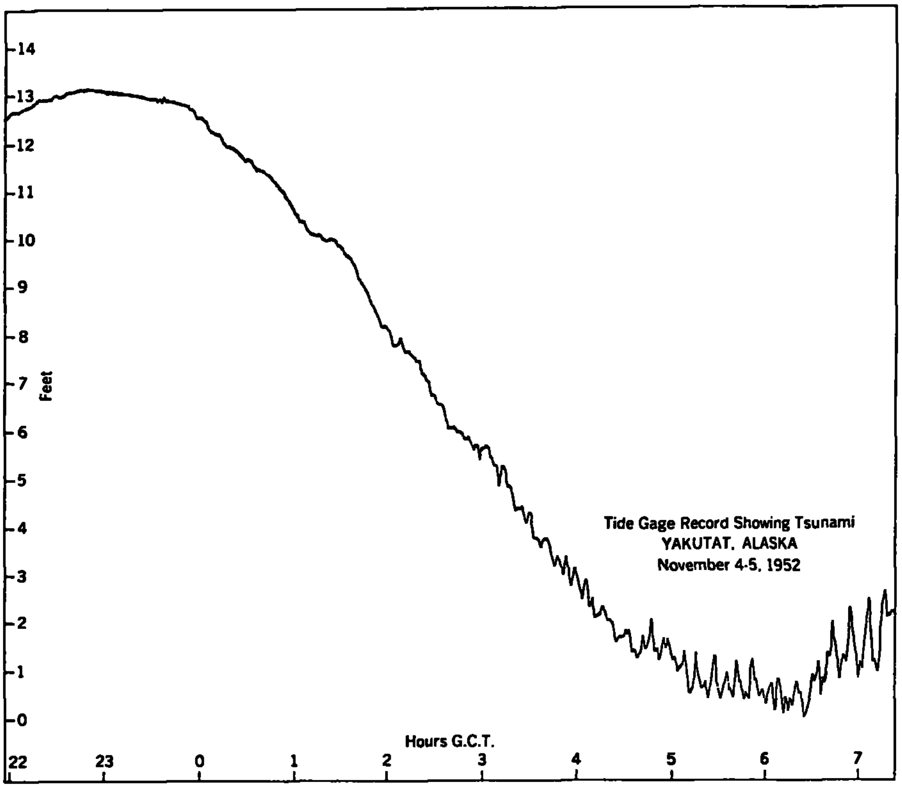


Figure 59. (Zerbe, 1953)

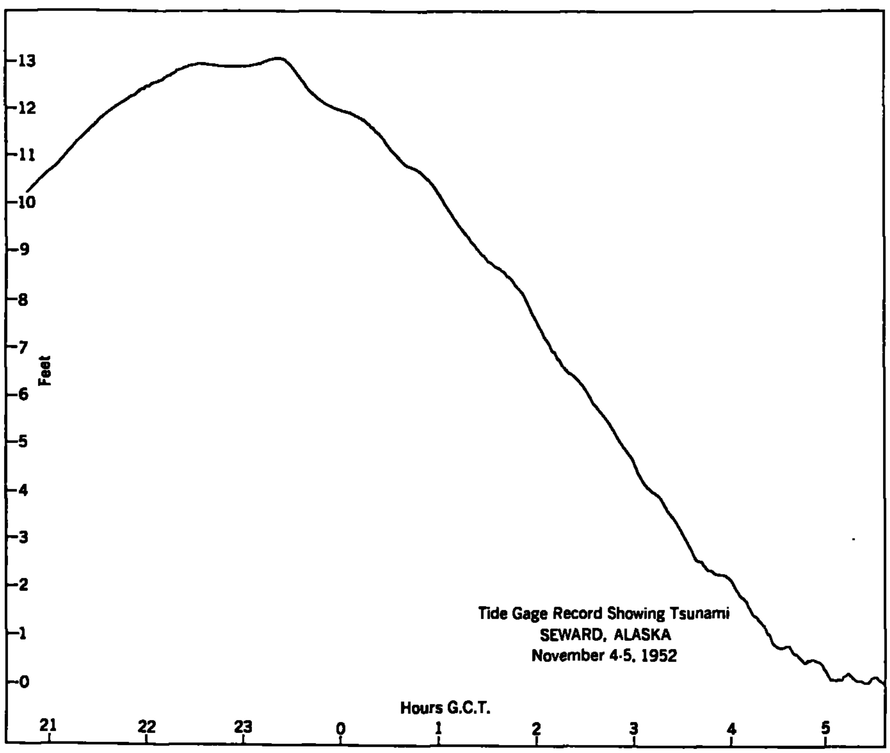


Figure 60. (Zerbe, 1953)

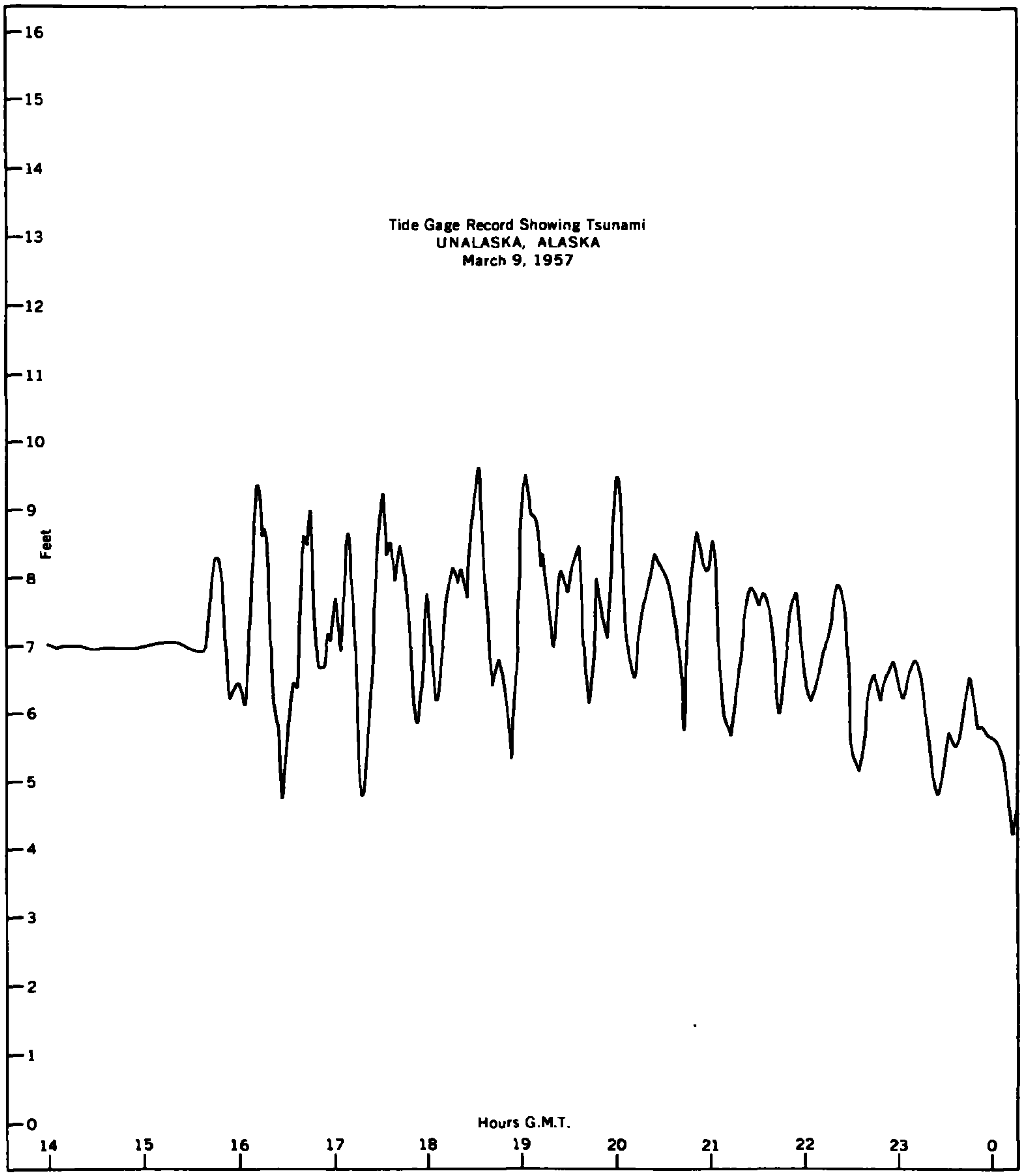


Figure 61. (Salsman, 1959)

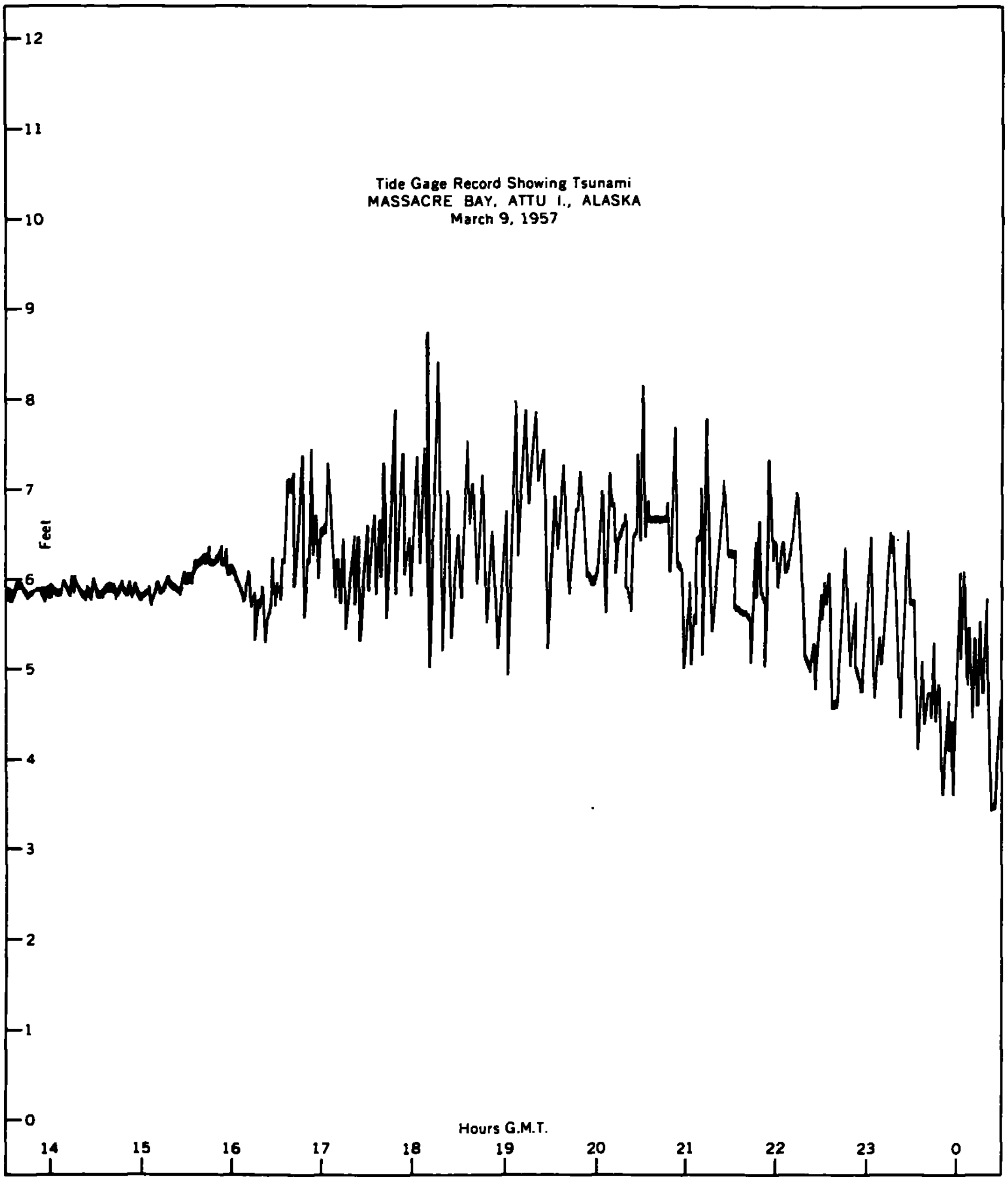
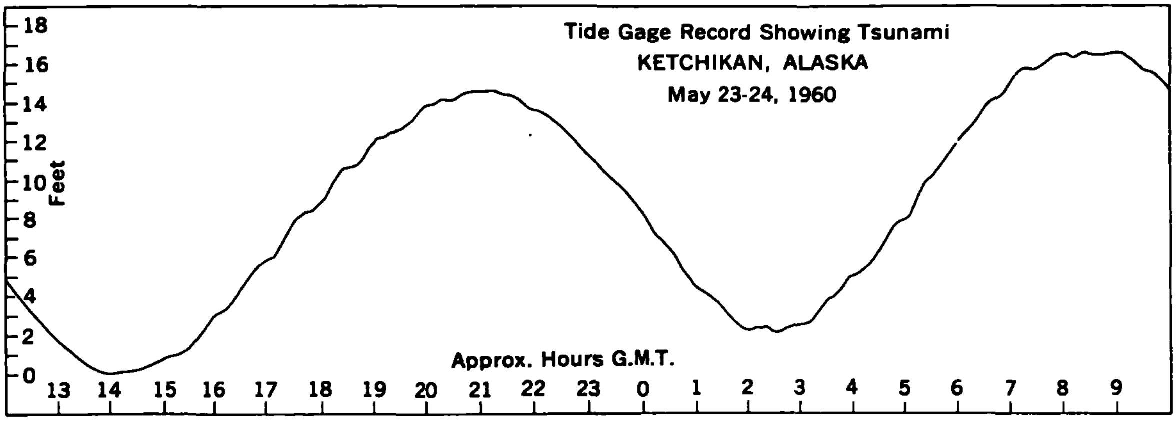
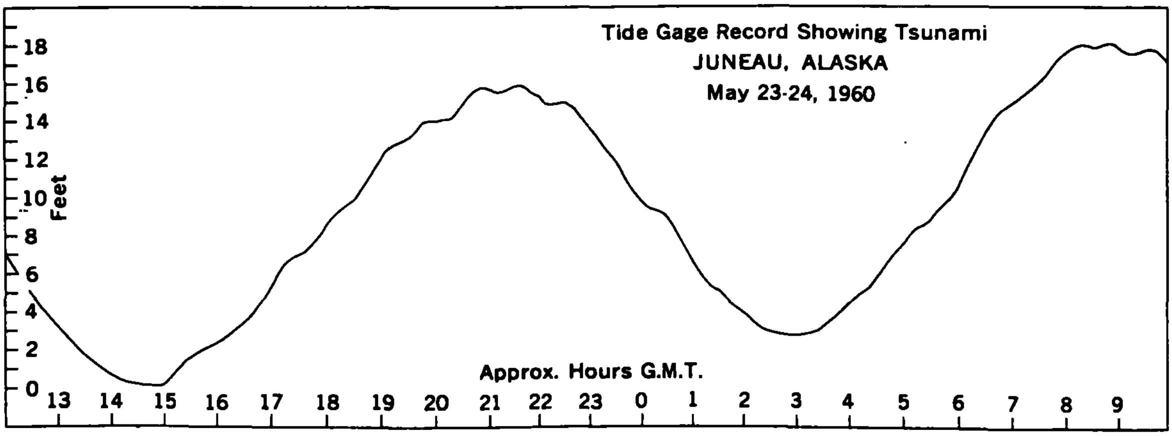


Figure 62. (Salsman, 1959)





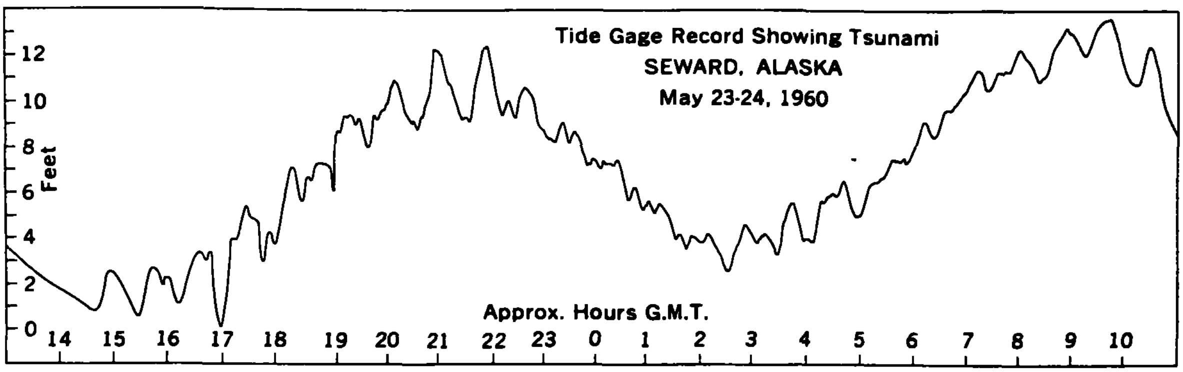
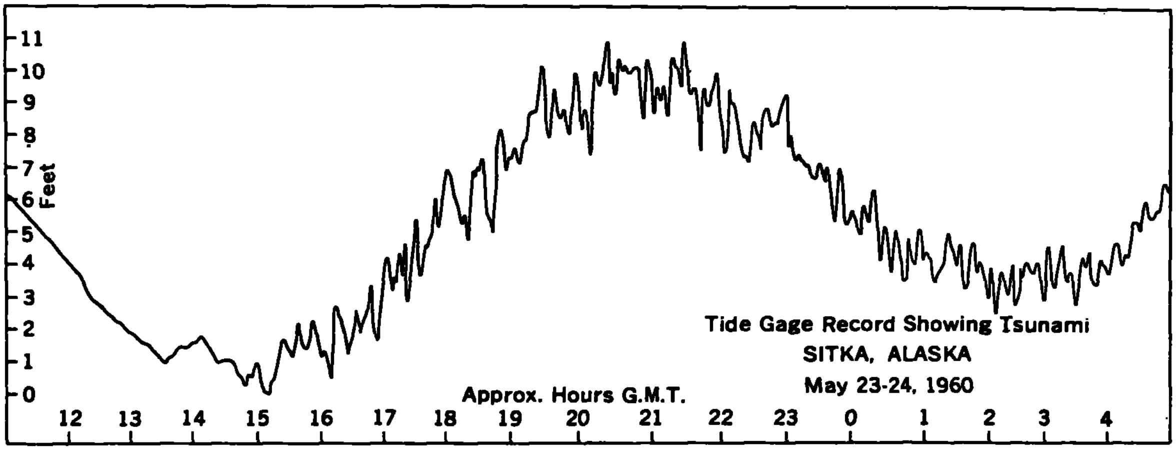
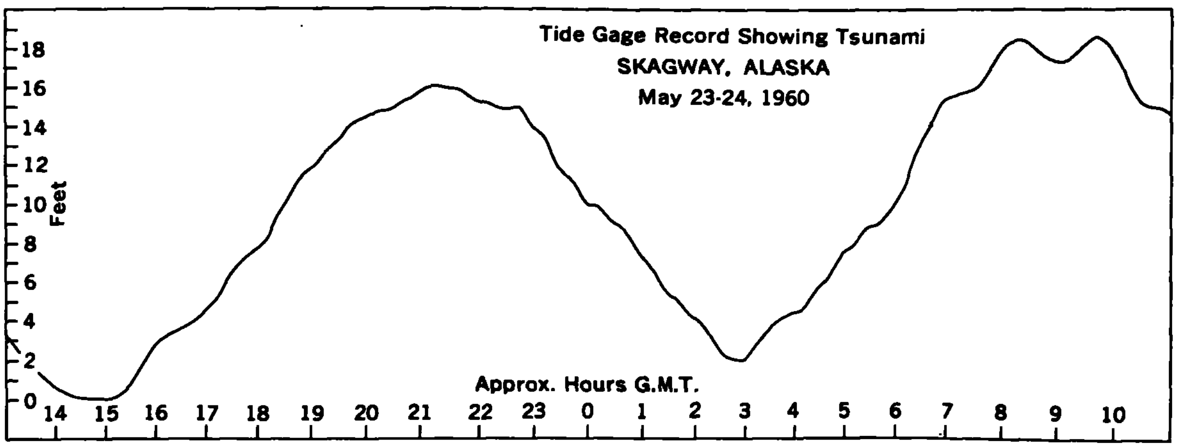


Figure 63, Figure 64, Figure 65. (Berkman and Symons, 1964)





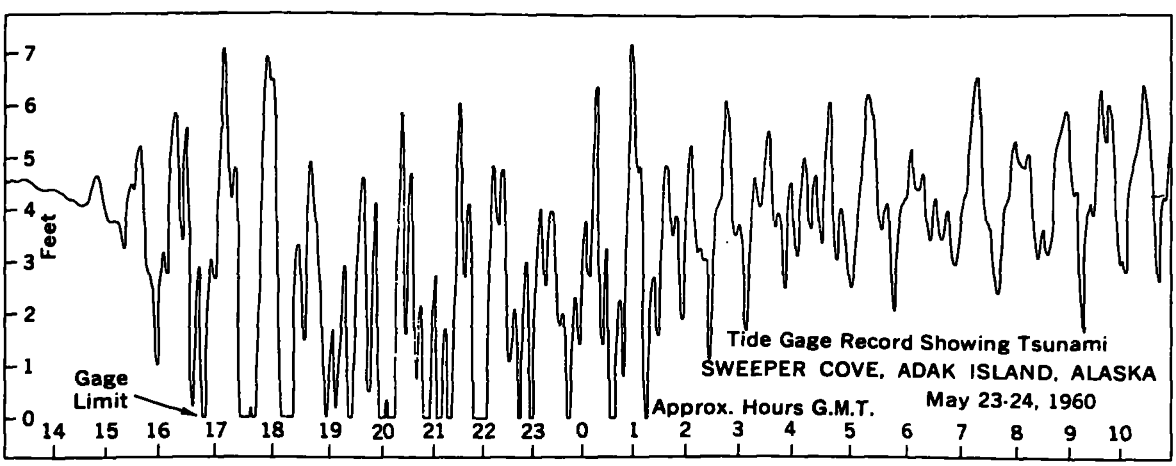
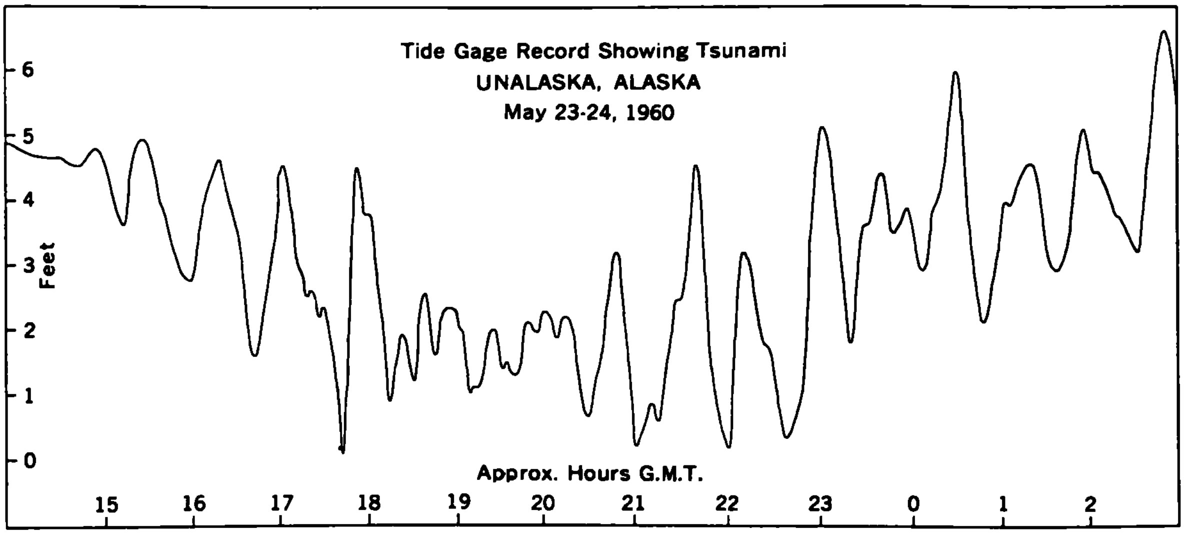
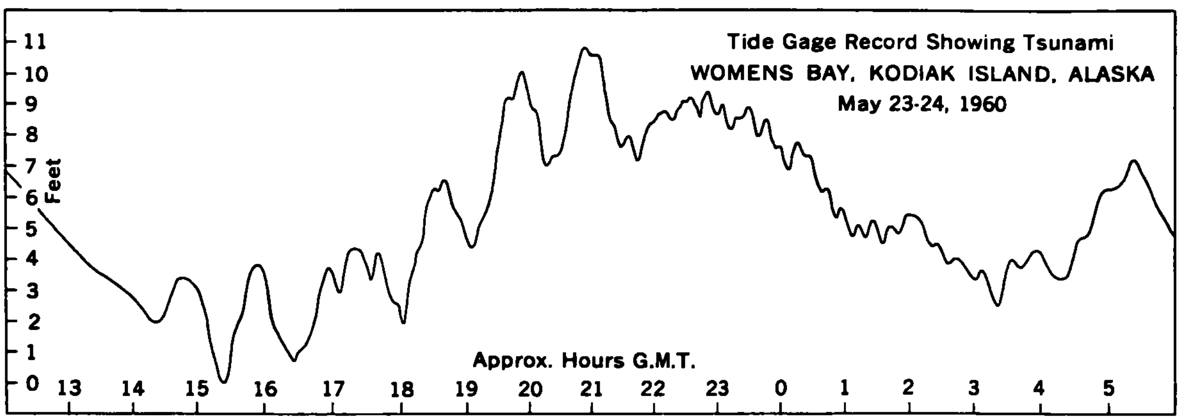


Figure 66, Figure 67, Figure 68. (Berkman and Symons, 1964)





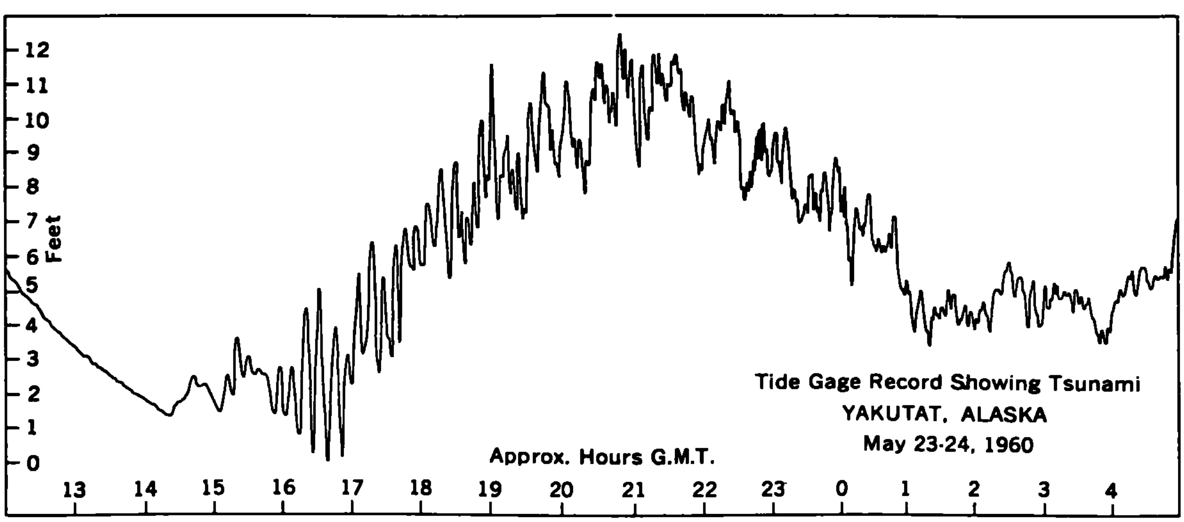


Figure 69, Figure 70, Figure 71. (Berkman and Symons, 1964)

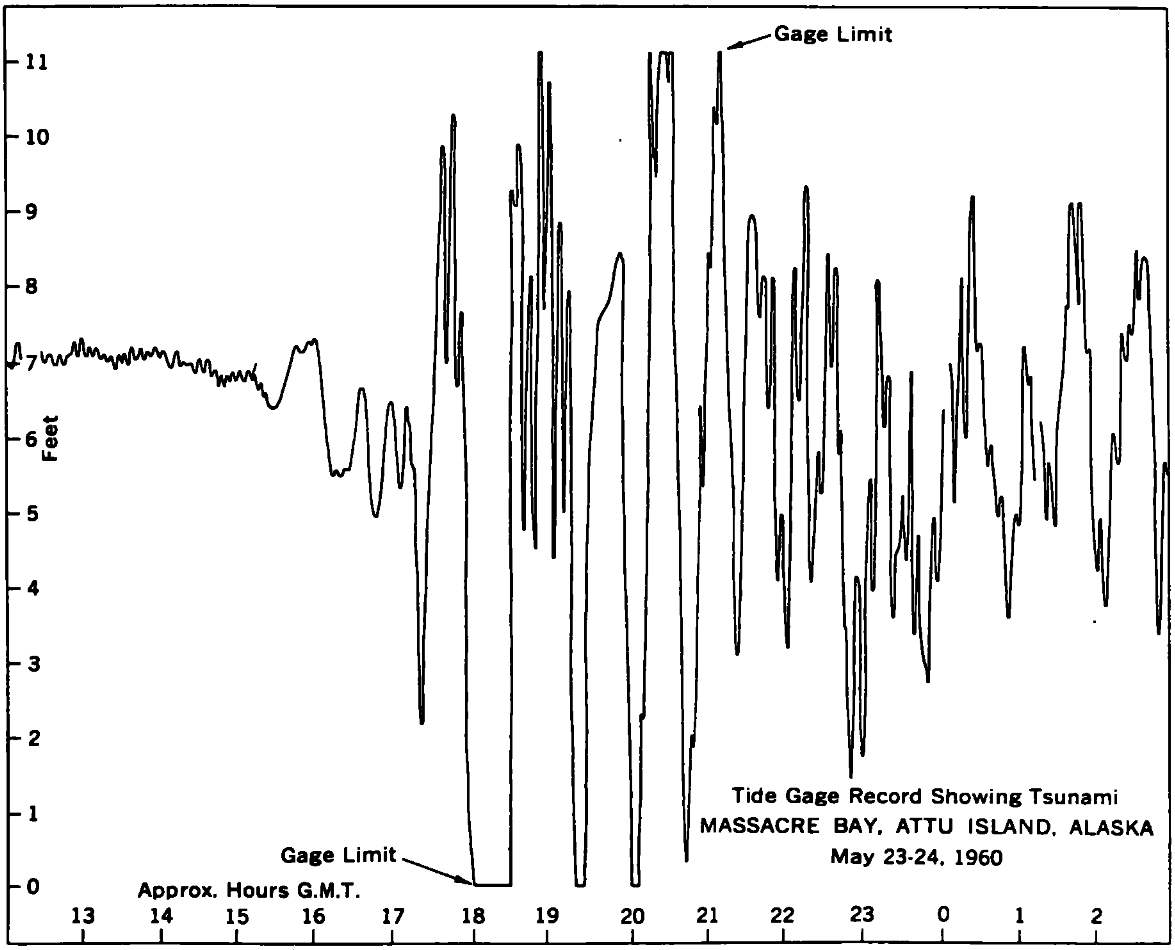
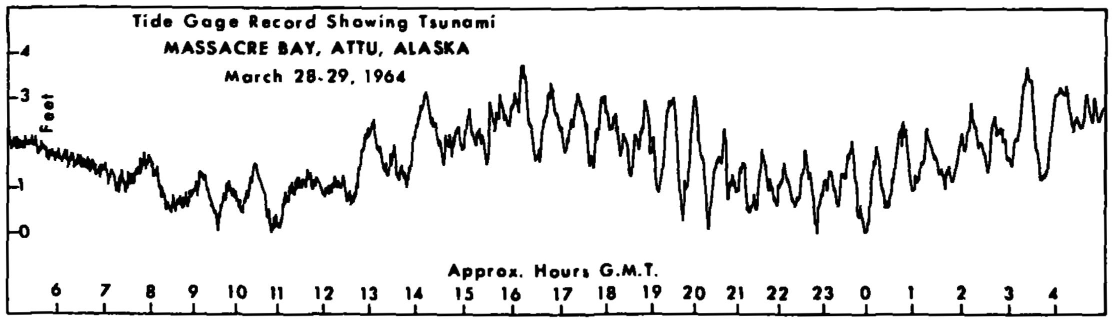
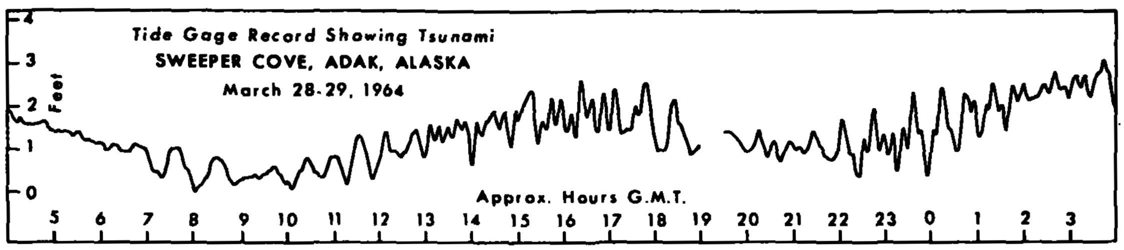
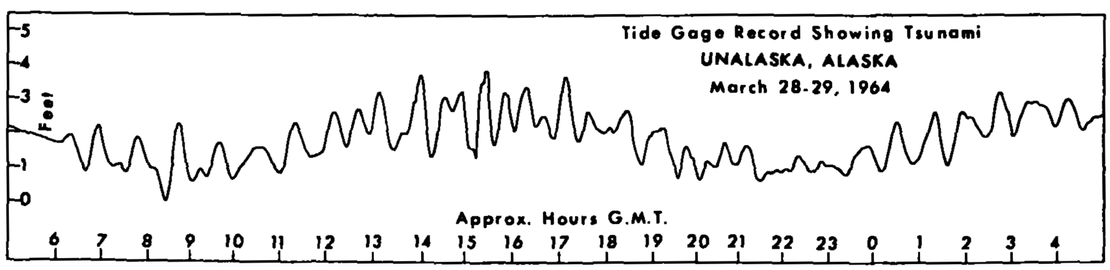


Figure 72. (Berkman and Symons, 1964)







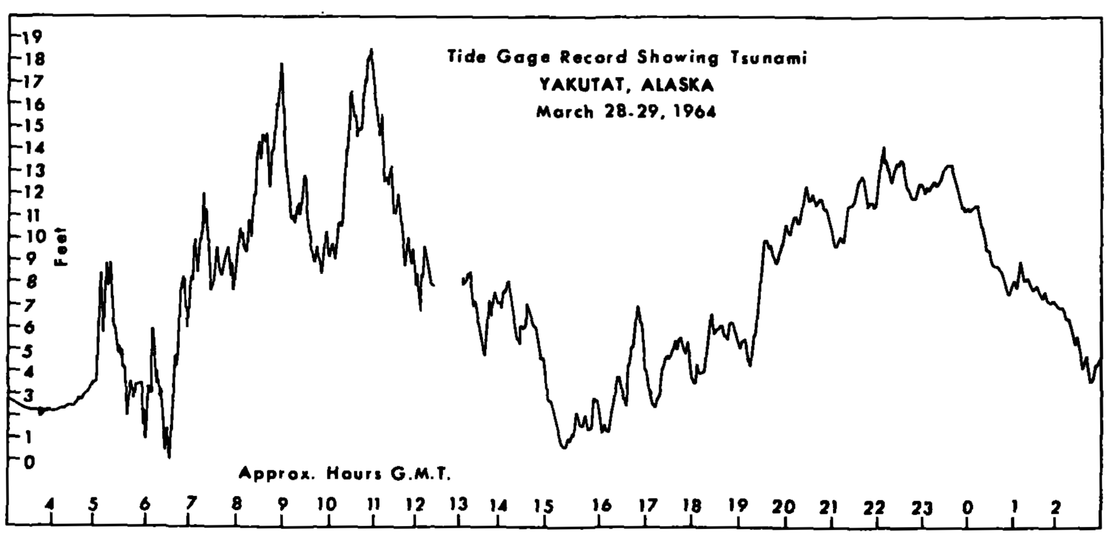
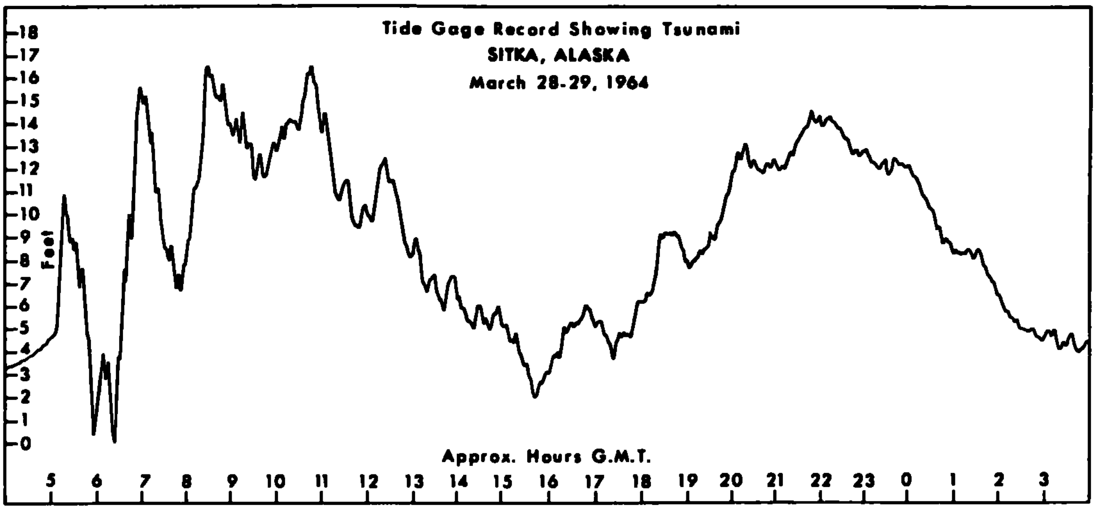
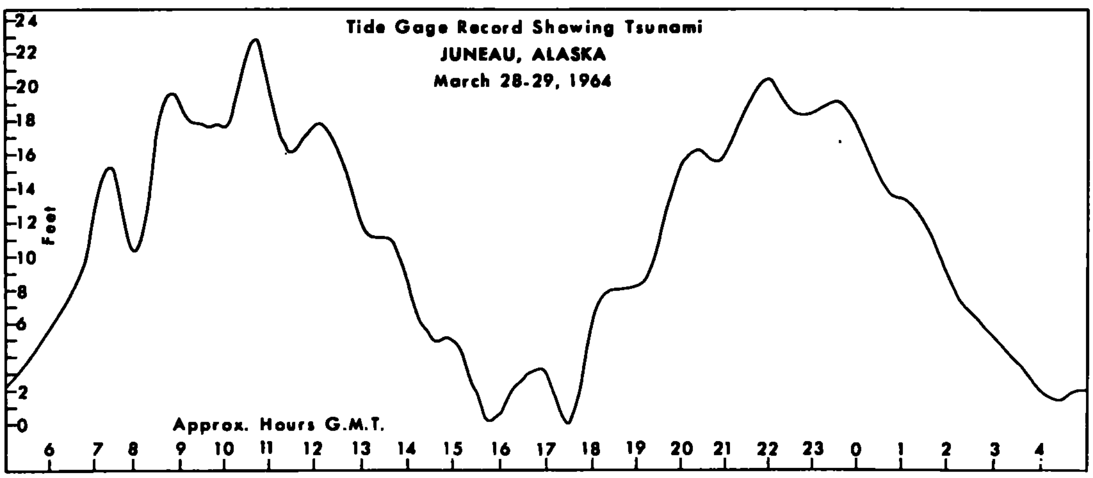


Figure 73, Figure 74, Figure 75, Figure 76. (Spaeth and Berkman, 1967)





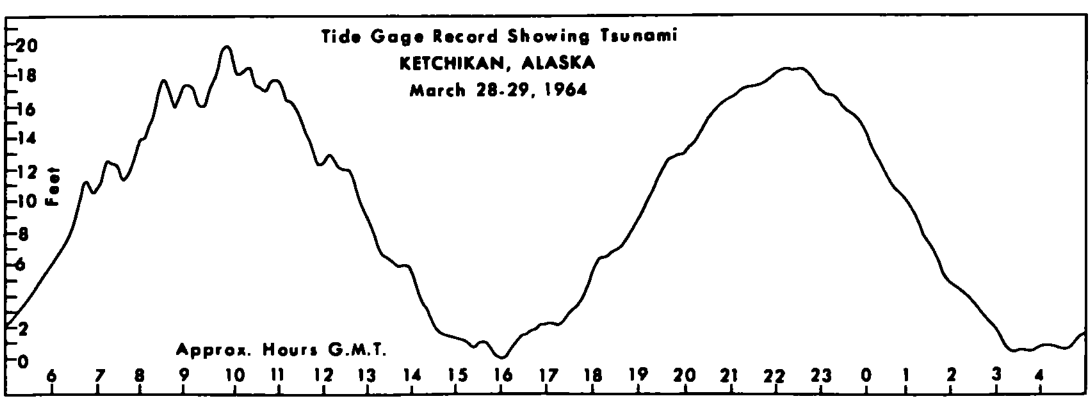


Figure 77, Figure 78, Figure 79. (Spaeth and Berkman, 1967)

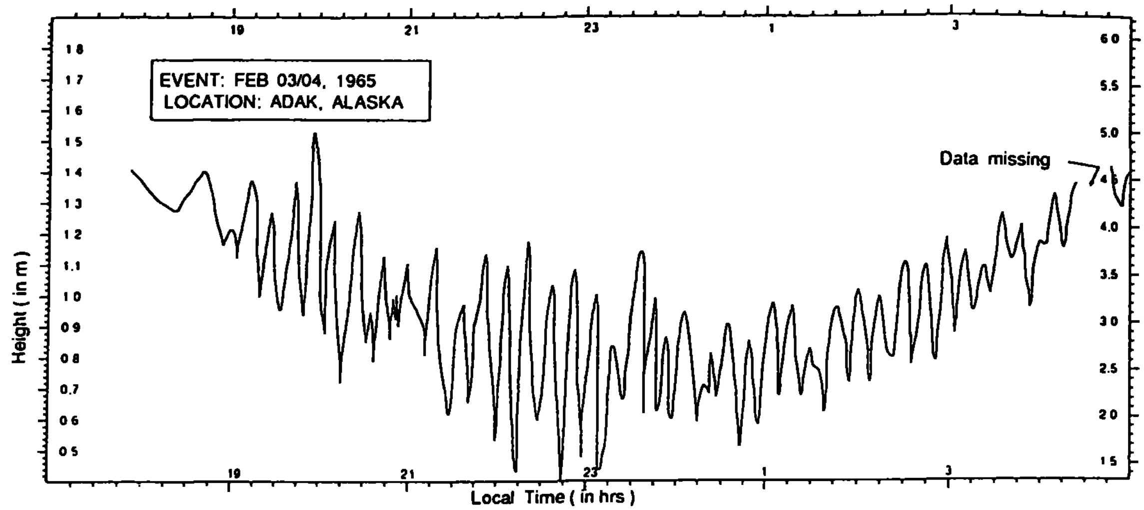
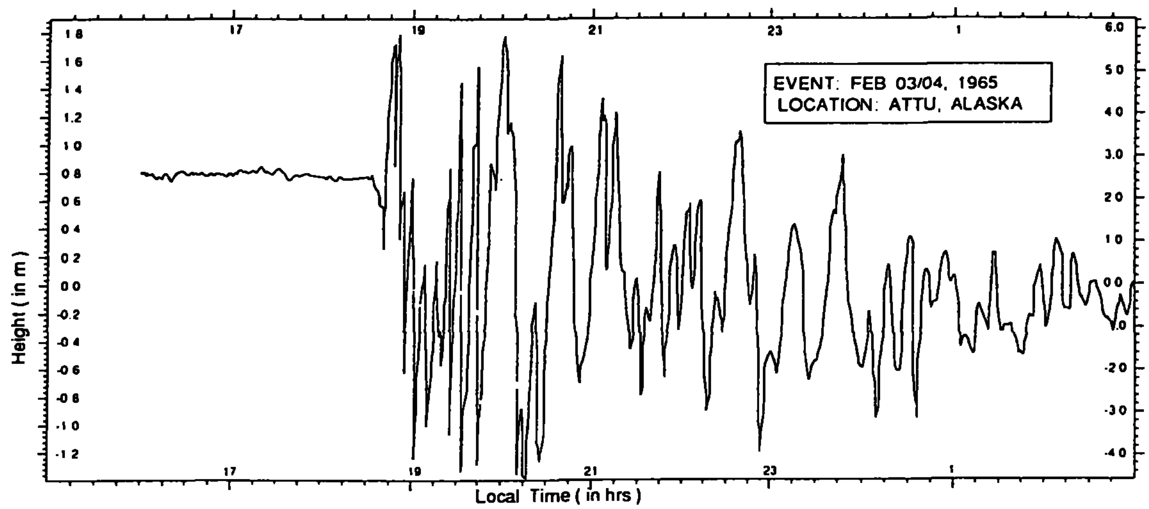


Figure 80.



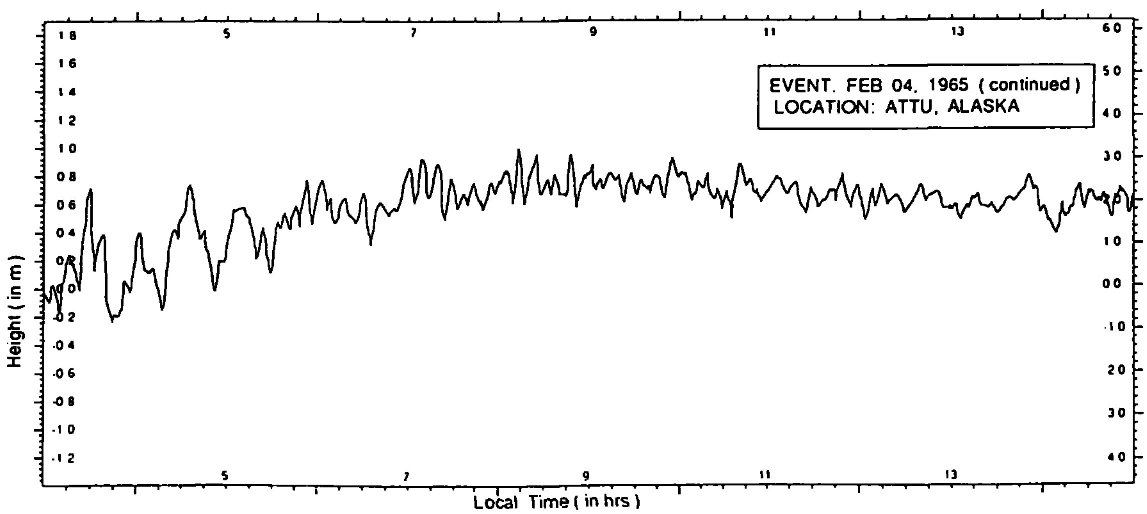
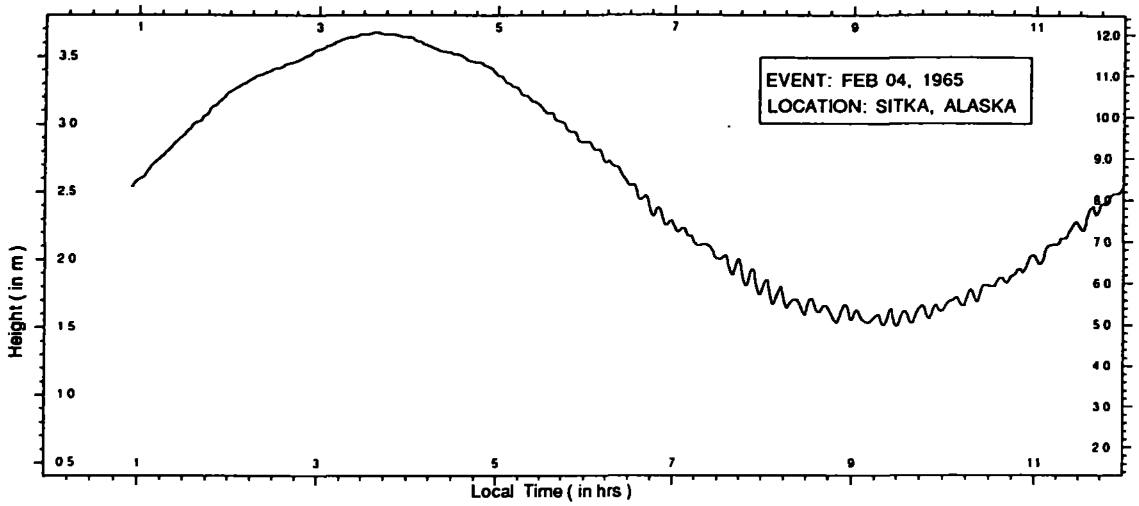


Figure 81.


EVENT: FEB 04, 1965
LOCATION: SITKA, ALASKA
Height (in m)
Height (in ft)
Local Time (in hrs)

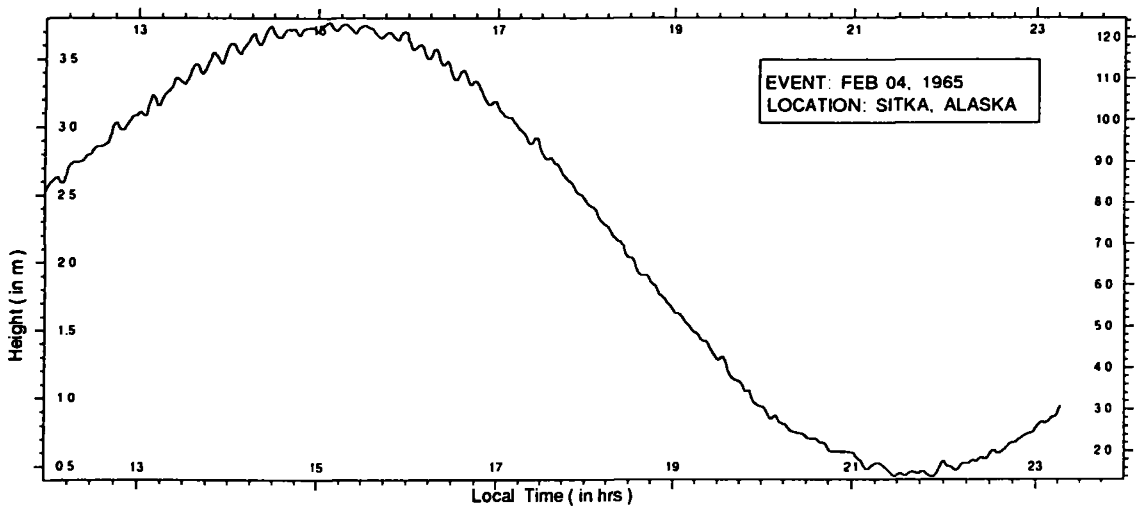

EVENT: FEB 04, 1965
LOCATION: SITKA, ALASKA
Height (in m)
Height (in ft)
Local Time (in hrs)

Figure 82.

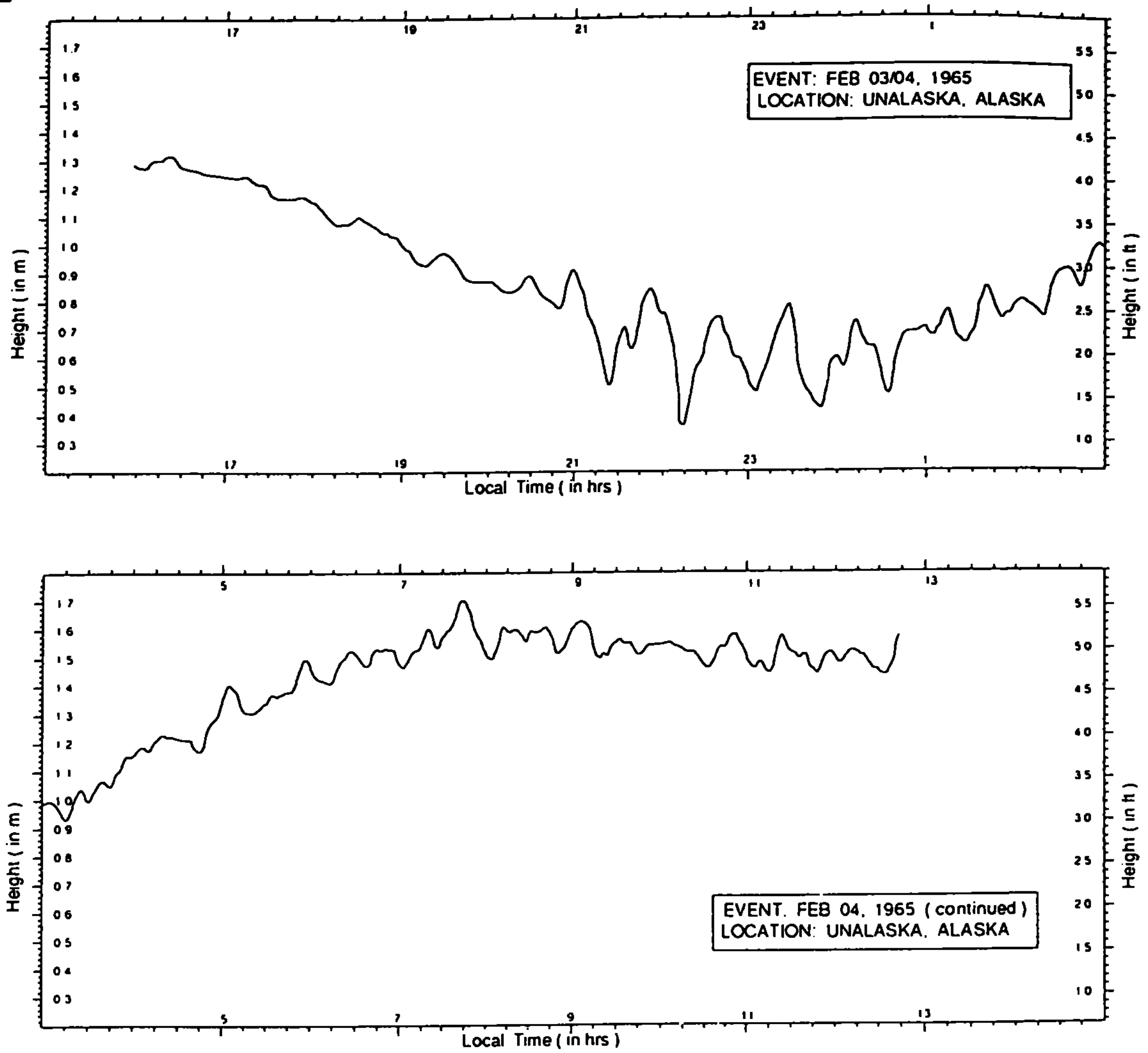


Figure 83.

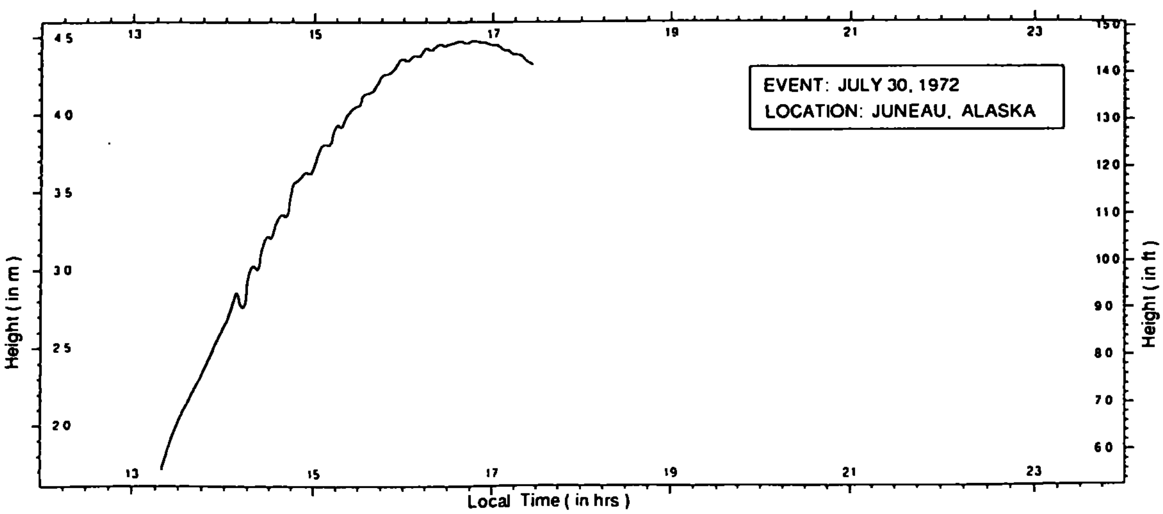


Figure 84.

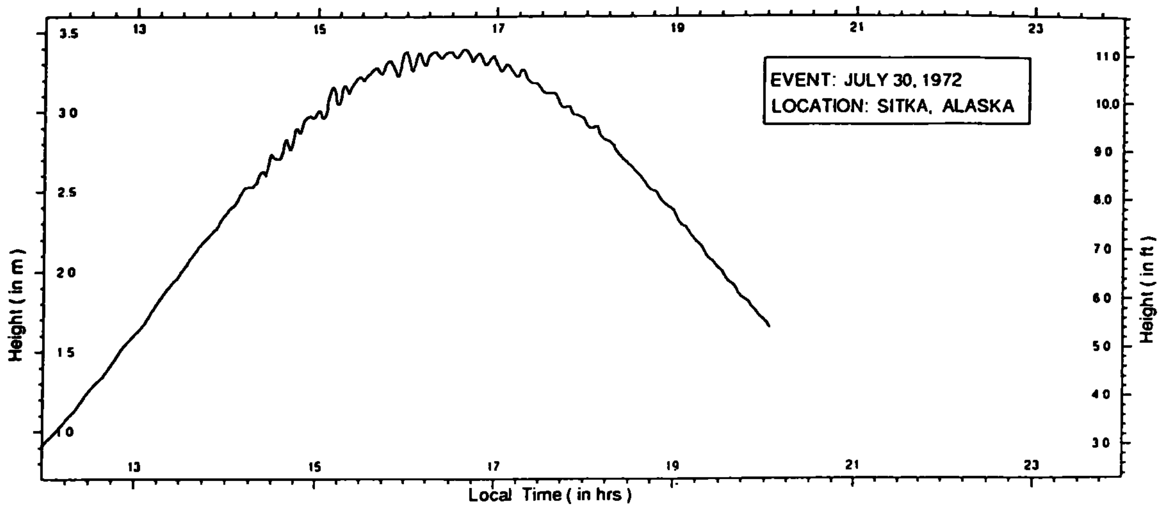


Figure 85.

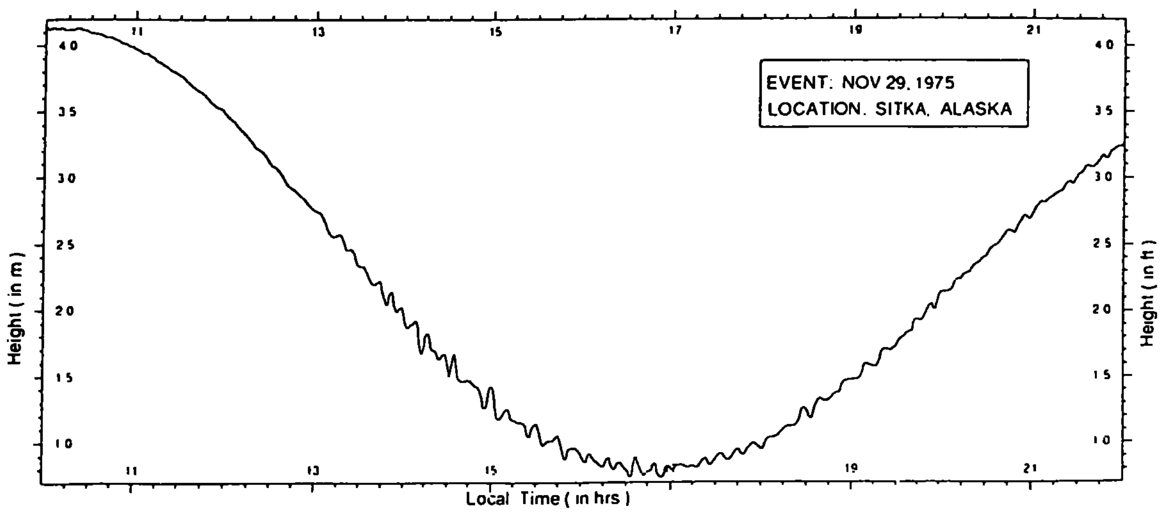


Figure 86.

Marigram at Adak after Aleutian Event May 7 22:47 UT 1986

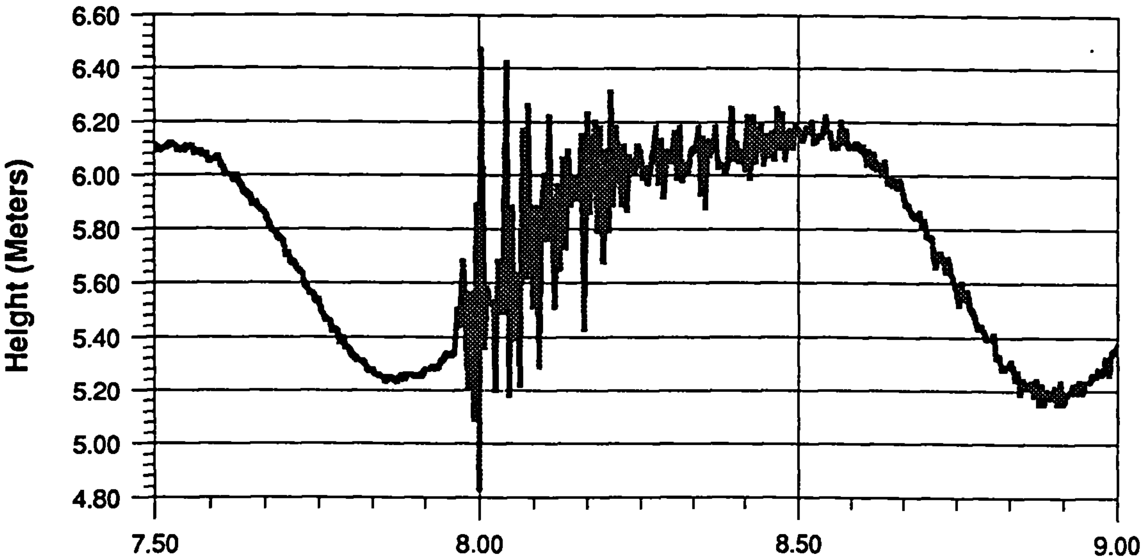


Figure 87.

Marigram at Unalaska after Aleutian event May 7 22:47 UT 1986

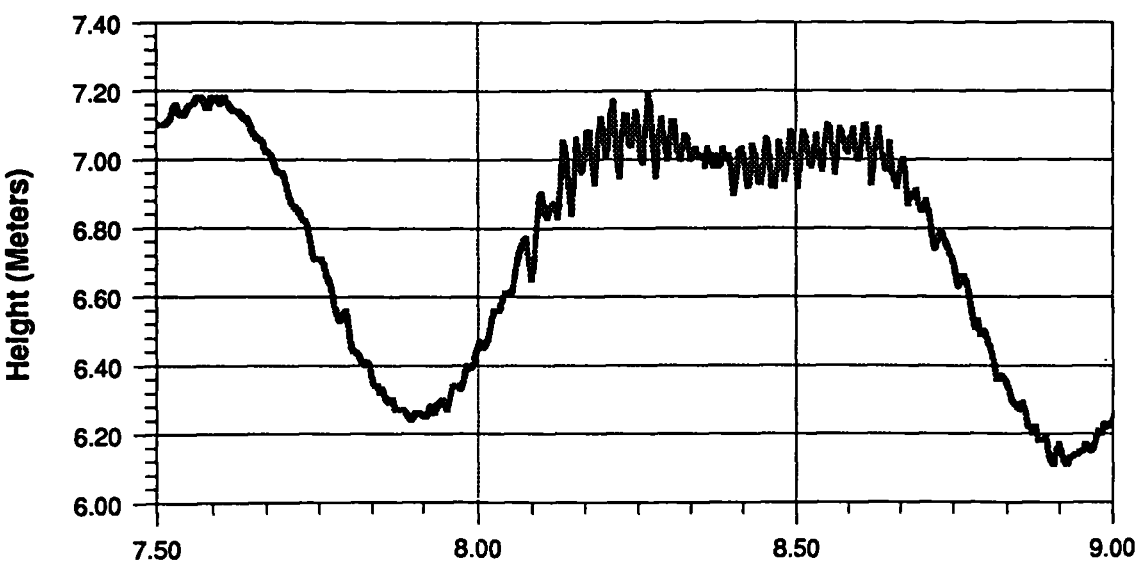


Figure 88.

Marigram at Adak After Bering Sea event February 21 02 UT 1991

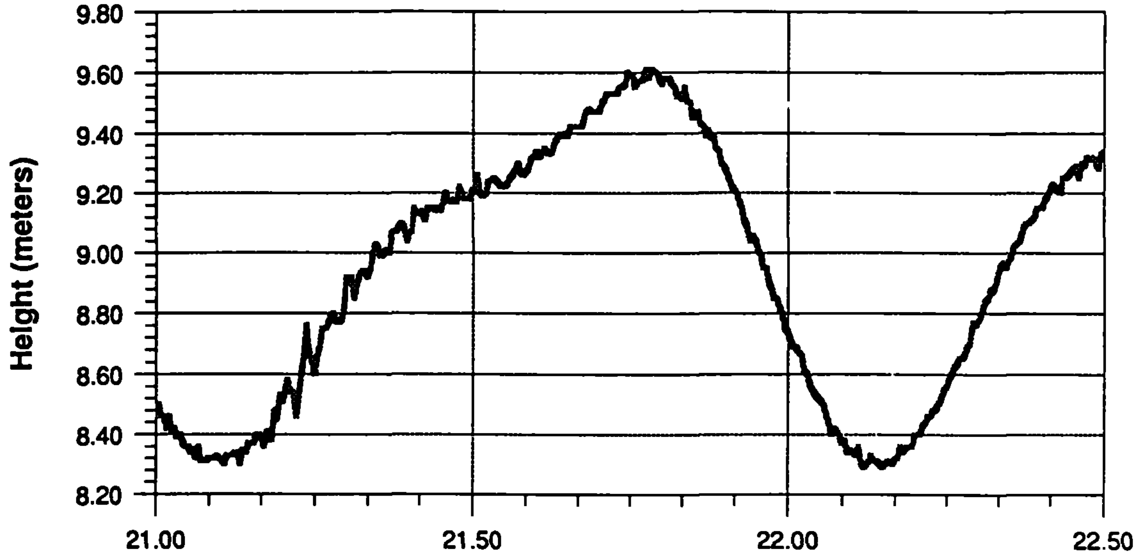


Figure 89.

Marigram at Unalaska after Bering Sea event Feb. 21 02 UT 1991

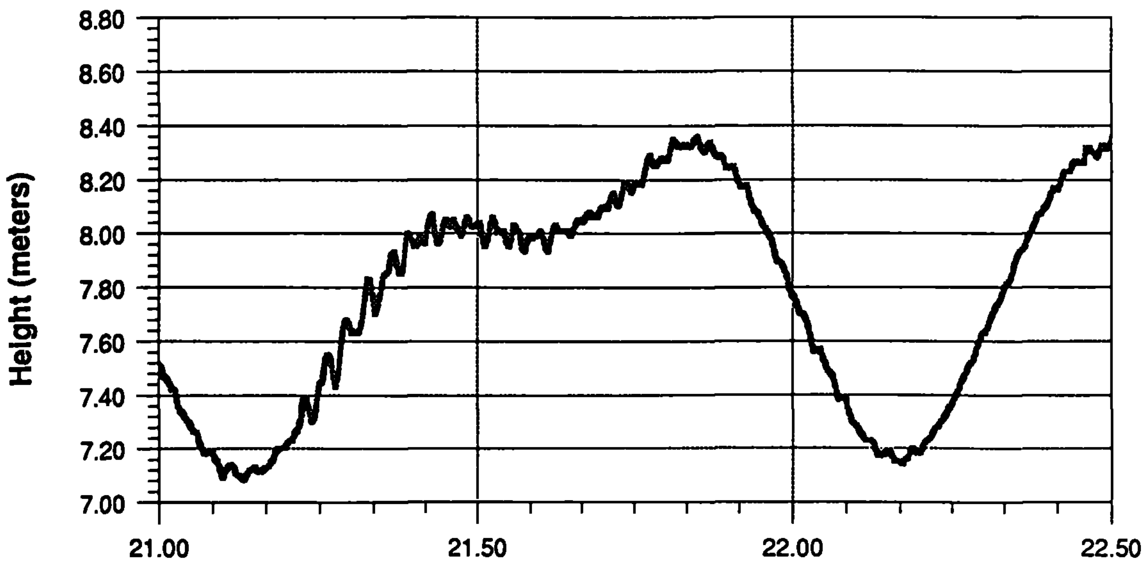


Figure 90.

November 3, 1994. Refer to page 114, Figure 46.

7.0 Tsunami Travel Time Charts

This section includes eight tsunami travel time charts prepared for Alaska locations:

The charts originally appeared in *Tsunami Travel-Time Charts for Use in the Tsunami Warning System* (U.S. Department of Commerce, 1971).

Given an epicenter or tsunami source, the number of hours it would take a tsunami to reach the location can be determined. Knowing the origin time of the earthquake or disturbance, the time of the first arrival of the tsunami can be approximated. For example, the southern Chile tsunami of May 22, 1960 occurred at 39.5°S, 74.5°W at 19:11 GMT. From the chart the travel time would be about 19.3 hours and the first wave would be expected at about 19:29 GMT on May 23 or 9:29 A.M. AST.

For localities other than the eight given here the time can be approximated by interpolation between the values of nearby localities with charts.

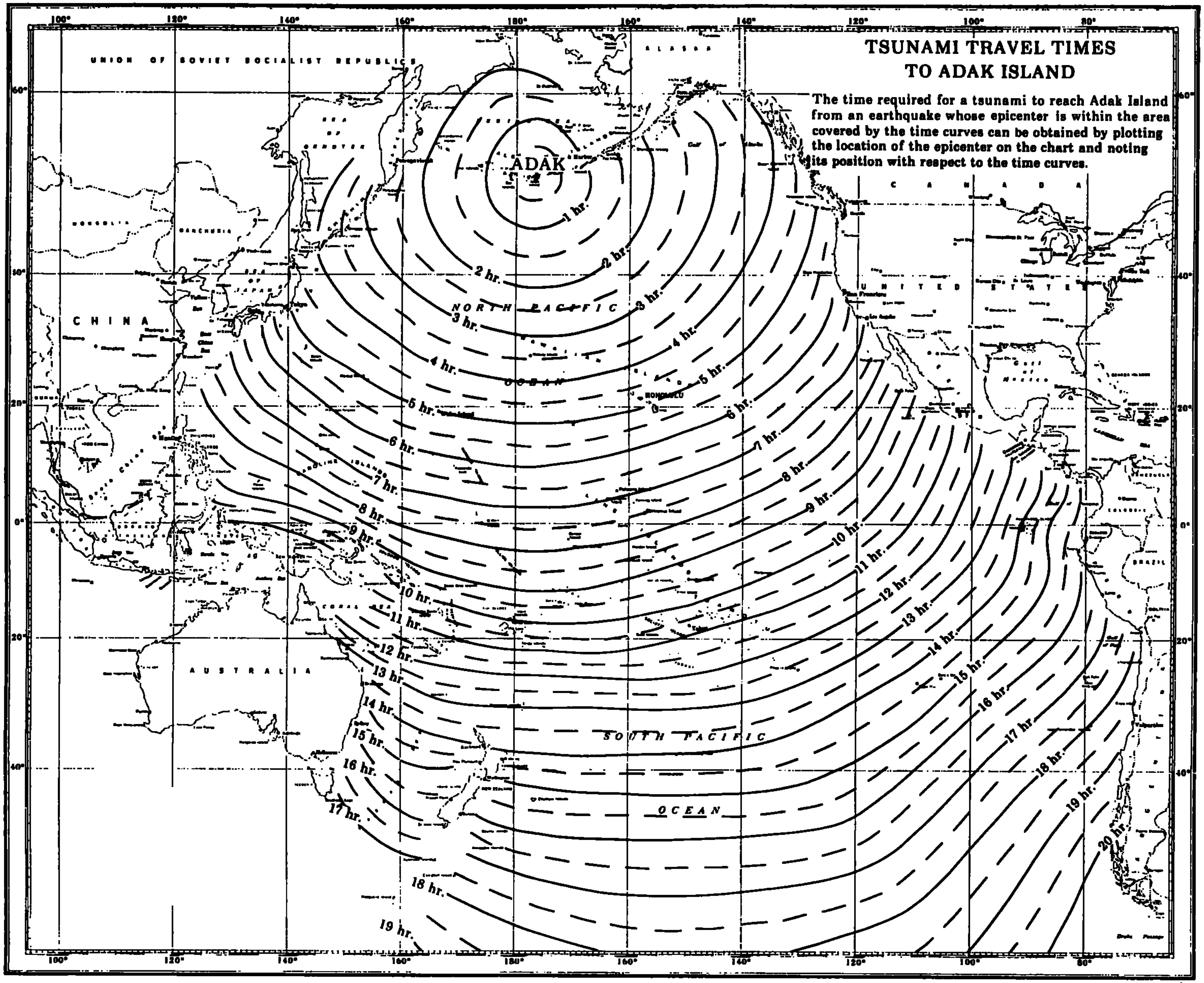
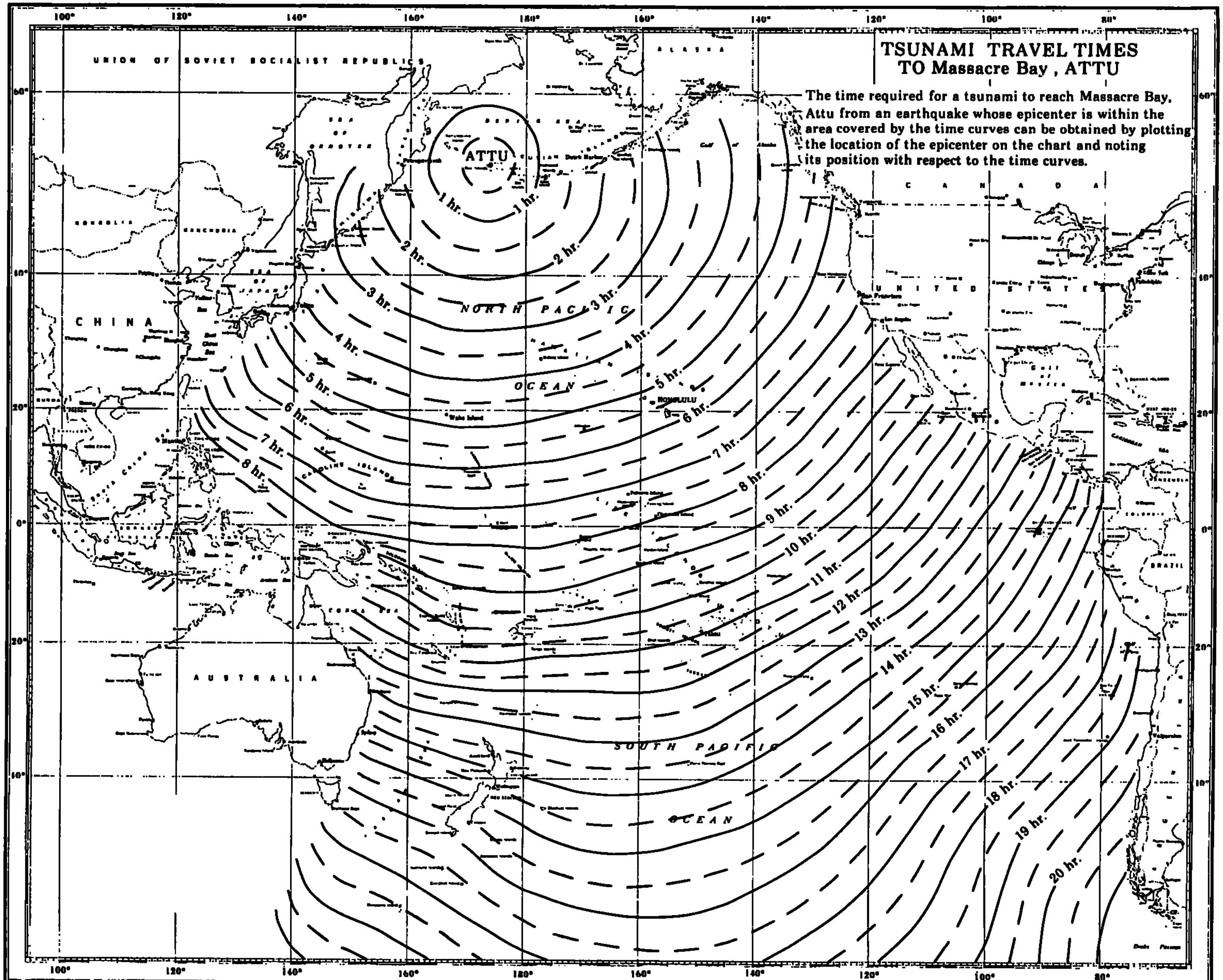

TSUNAMI TRAVEL TIMES
TO ADAK ISLAND
The time required for a tsunami to reach Adak Island from an earthquake whose epicenter is within the area covered by the time curves can be obtained by plotting the location of the epicenter on the chart and noting its position with respect to the time curves.
ADAK
UNION OF SOVIET SOCIALIST REPUBLICS
ALASKA
CANADA
UNITED STATES
CHINA
AUSTRALIA
NORTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
HONOLULU
1 hr.
2 hr.
3 hr.
4 hr.
5 hr.
6 hr.
7 hr.
8 hr.
9 hr.
10 hr.
11 hr.
12 hr.
13 hr.
14 hr.
15 hr.
16 hr.
17 hr.
18 hr.
19 hr.
20 hr.
100°
120°
140°
160°
180°
160°
140°
120°
100°
80°
60°
40°
20°
0°
20°
40°

Figure 91.



TSUNAMI TRAVEL TIMES
TO Massacre Bay, ATTU
The time required for a tsunami to reach Massacre Bay, Attu from an earthquake whose epicenter is within the area covered by the time curves can be obtained by plotting the location of the epicenter on the chart and noting its position with respect to the time curves.
ATTU
UNION OF SOVIET SOCIALIST REPUBLICS
ALASKA
CANADA
UNITED STATES
CHINA
AUSTRALIA
NORTH PACIFIC
OCEAN
SOUTH PACIFIC
OCEAN
HONOLULU
1 hr.
2 hr.
3 hr.
4 hr.
5 hr.
6 hr.
7 hr.
8 hr.
9 hr.
10 hr.
11 hr.
12 hr.
13 hr.
14 hr.
15 hr.
16 hr.
17 hr.
18 hr.
19 hr.
20 hr.

Figure 92.

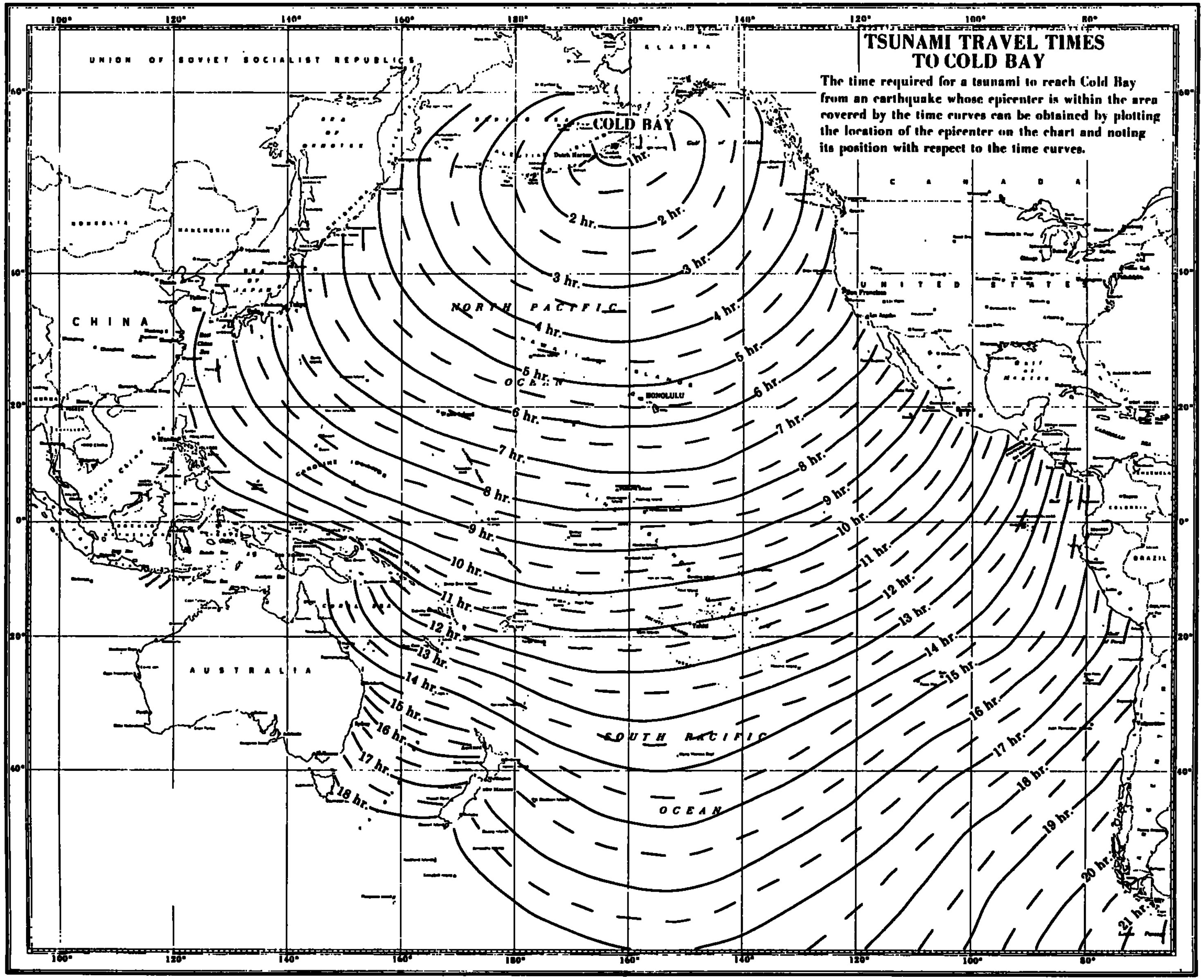

TSUNAMI TRAVEL TIMES
TO COLD BAY
The time required for a tsunami to reach Cold Bay from an earthquake whose epicenter is within the area covered by the time curves can be obtained by plotting the location of the epicenter on the chart and noting its position with respect to the time curves.
COLD BAY
UNION OF SOVIET SOCIALIST REPUBLICS
ALASKA
CANADA
UNITED STATES
CHINA
AUSTRALIA
NORTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
HONOLULU
BRAZIL
1 hr.
2 hr.
3 hr.
4 hr.
5 hr.
6 hr.
7 hr.
8 hr.
9 hr.
10 hr.
11 hr.
12 hr.
13 hr.
14 hr.
15 hr.
16 hr.
17 hr.
18 hr.
19 hr.
20 hr.
21 hr.
100°
120°
140°
160°
180°
160°
140°
120°
100°
80°
60°
40°
20°
0°
20°
40°

Figure 93.

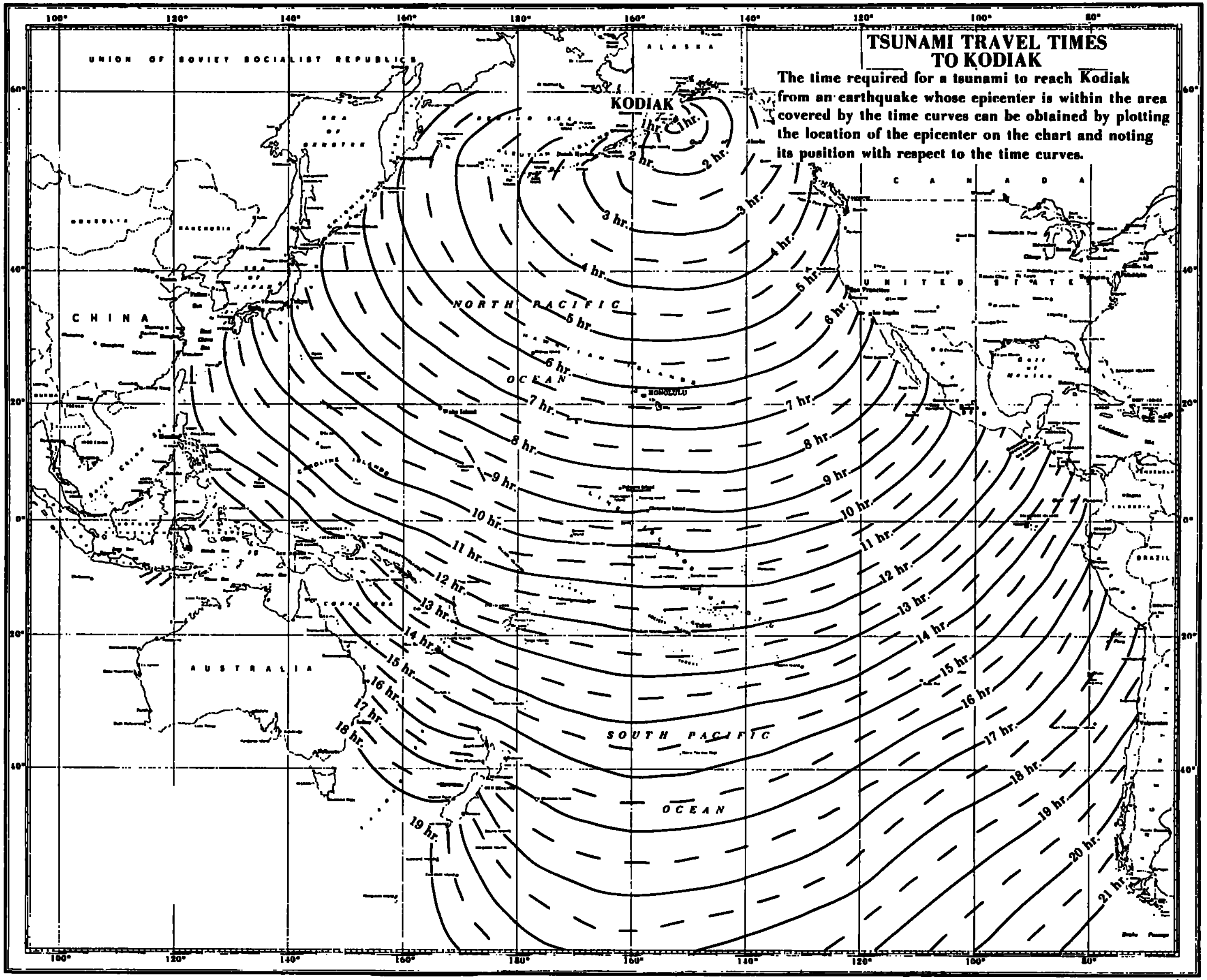

TSUNAMI TRAVEL TIMES
TO KODIAK
The time required for a tsunami to reach Kodiak from an earthquake whose epicenter is within the area covered by the time curves can be obtained by plotting the location of the epicenter on the chart and noting its position with respect to the time curves.
KODIAK
UNION OF SOVIET SOCIALIST REPUBLICS
ALASKA
CANADA
UNITED STATES
CHINA
AUSTRALIA
BRAZIL
NORTH PACIFIC
OCEAN
SOUTH PACIFIC
OCEAN
HONOLULU
1 hr.
2 hr.
3 hr.
4 hr.
5 hr.
6 hr.
7 hr.
8 hr.
9 hr.
10 hr.
11 hr.
12 hr.
13 hr.
14 hr.
15 hr.
16 hr.
17 hr.
18 hr.
19 hr.
20 hr.
21 hr.
100°
120°
140°
160°
180°
160°
140°
120°
100°
80°
60°
40°
20°
0°
20°
40°

Figure 94.

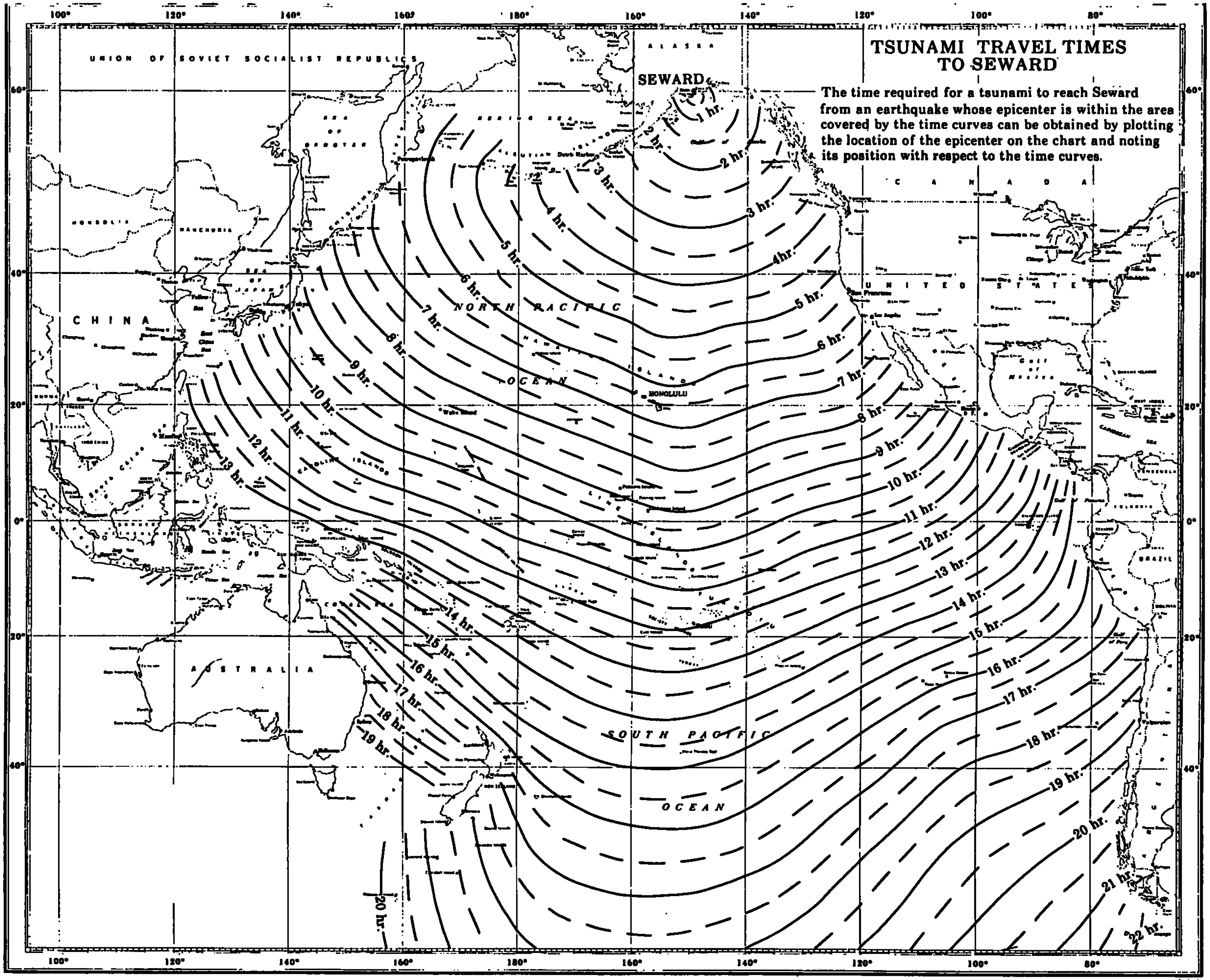

TSUNAMI TRAVEL TIMES TO SEWARD
The time required for a tsunami to reach Seward from an earthquake whose epicenter is within the area covered by the time curves can be obtained by plotting the location of the epicenter on the chart and noting its position with respect to the time curves.
SEWARD
UNION OF SOVIET SOCIALIST REPUBLICS
ALASKA
CANADA
UNITED STATES
CHINA
AUSTRALIA
NORTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
HONOLULU
1 hr.
2 hr.
3 hr.
4 hr.
5 hr.
6 hr.
7 hr.
8 hr.
9 hr.
10 hr.
11 hr.
12 hr.
13 hr.
14 hr.
15 hr.
16 hr.
17 hr.
18 hr.
19 hr.
20 hr.
21 hr.
22 hr.
100°
120°
140°
160°
180°
60°
40°
20°
0°

Figure 95.

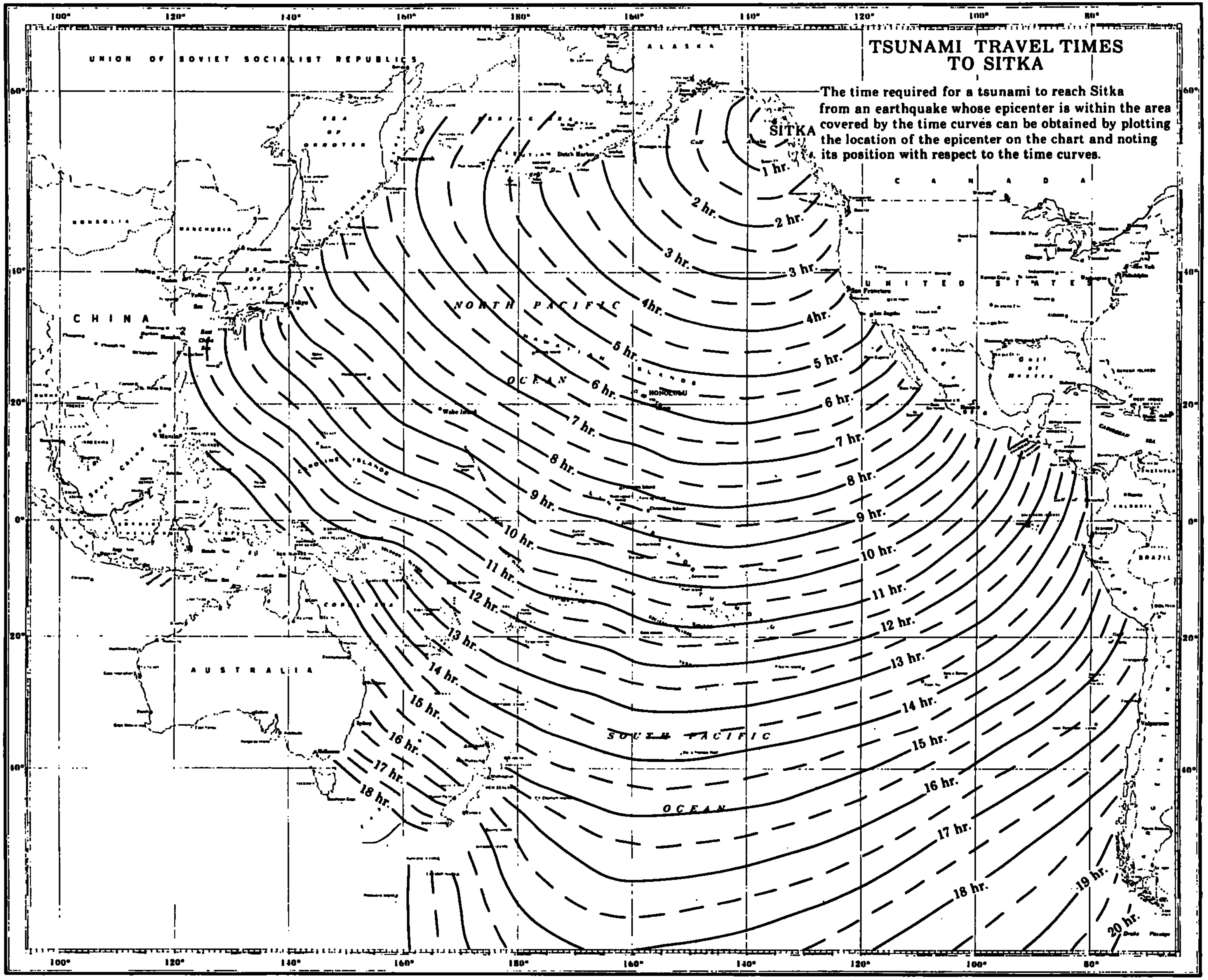

TSUNAMI TRAVEL TIMES TO SITKA
The time required for a tsunami to reach Sitka from an earthquake whose epicenter is within the area covered by the time curves can be obtained by plotting the location of the epicenter on the chart and noting its position with respect to the time curves.
SITKA
UNION OF SOVIET SOCIALIST REPUBLICS
ALASKA
CANADA
UNITED STATES
CHINA
AUSTRALIA
BRAZIL
NORTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
HONOLULU
1 hr.
2 hr.
3 hr.
4hr.
5 hr.
6 hr.
7 hr.
8 hr.
9 hr.
10 hr.
11 hr.
12 hr.
13 hr.
14 hr.
15 hr.
16 hr.
17 hr.
18 hr.
19 hr.
20 hr.

Figure 96.

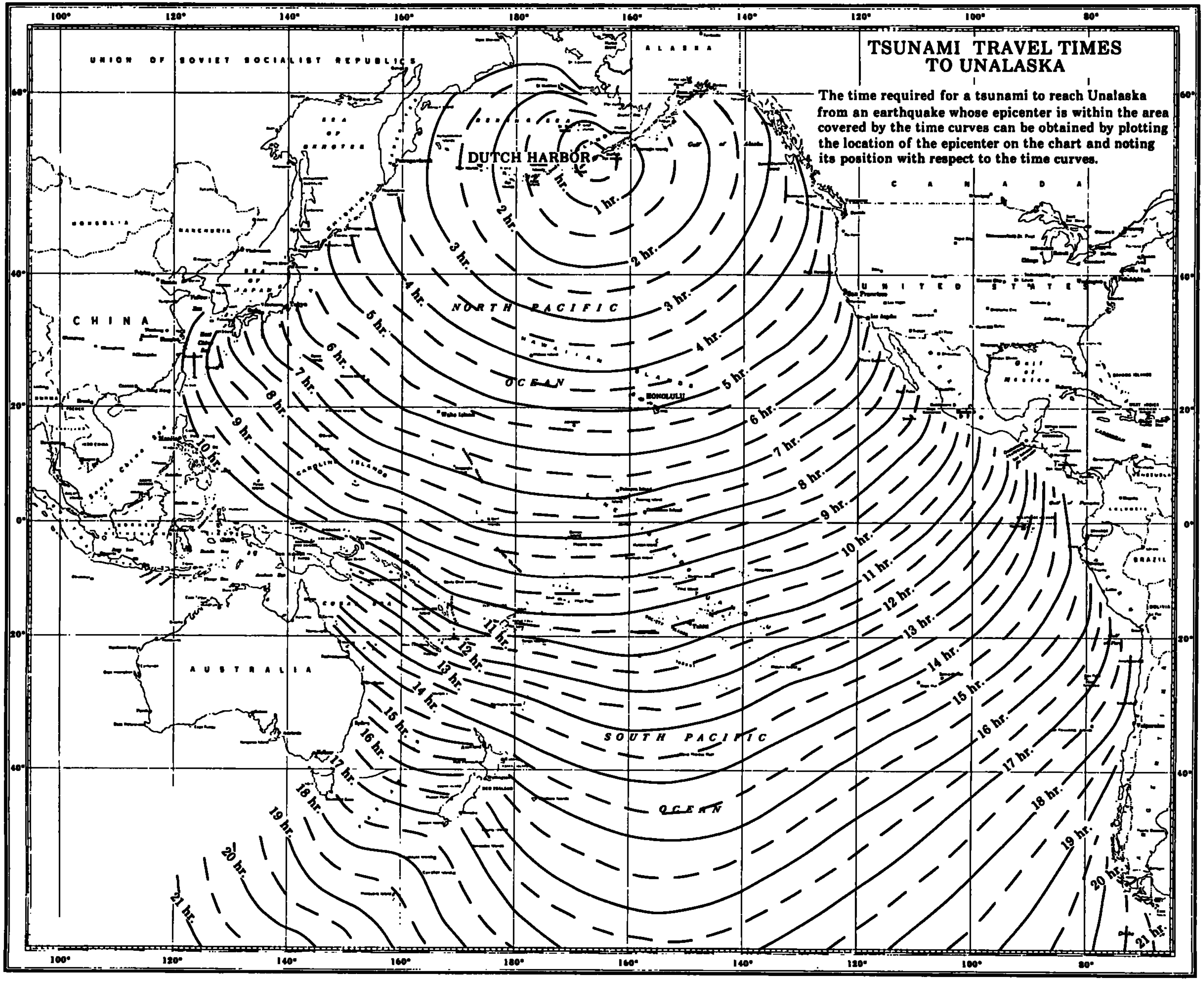

TSUNAMI TRAVEL TIMES
TO UNALASKA
The time required for a tsunami to reach Unalaska from an earthquake whose epicenter is within the area covered by the time curves can be obtained by plotting the location of the epicenter on the chart and noting its position with respect to the time curves.
DUTCH HARBOR
HONOLULU
UNION OF SOVIET SOCIALIST REPUBLICS
ALASKA
CANADA
UNITED STATES
CHINA
AUSTRALIA
NORTH PACIFIC
OCEAN
SOUTH PACIFIC
OCEAN
1 hr.
2 hr.
3 hr.
4 hr.
5 hr.
6 hr.
7 hr.
8 hr.
9 hr.
10 hr.
11 hr.
12 hr.
13 hr.
14 hr.
15 hr.
16 hr.
17 hr.
18 hr.
19 hr.
20 hr.
21 hr.
100°
120°
140°
160°
180°
160°
140°
120°
100°
80°
60°
40°
20°
0°
20°
40°

Figure 97.

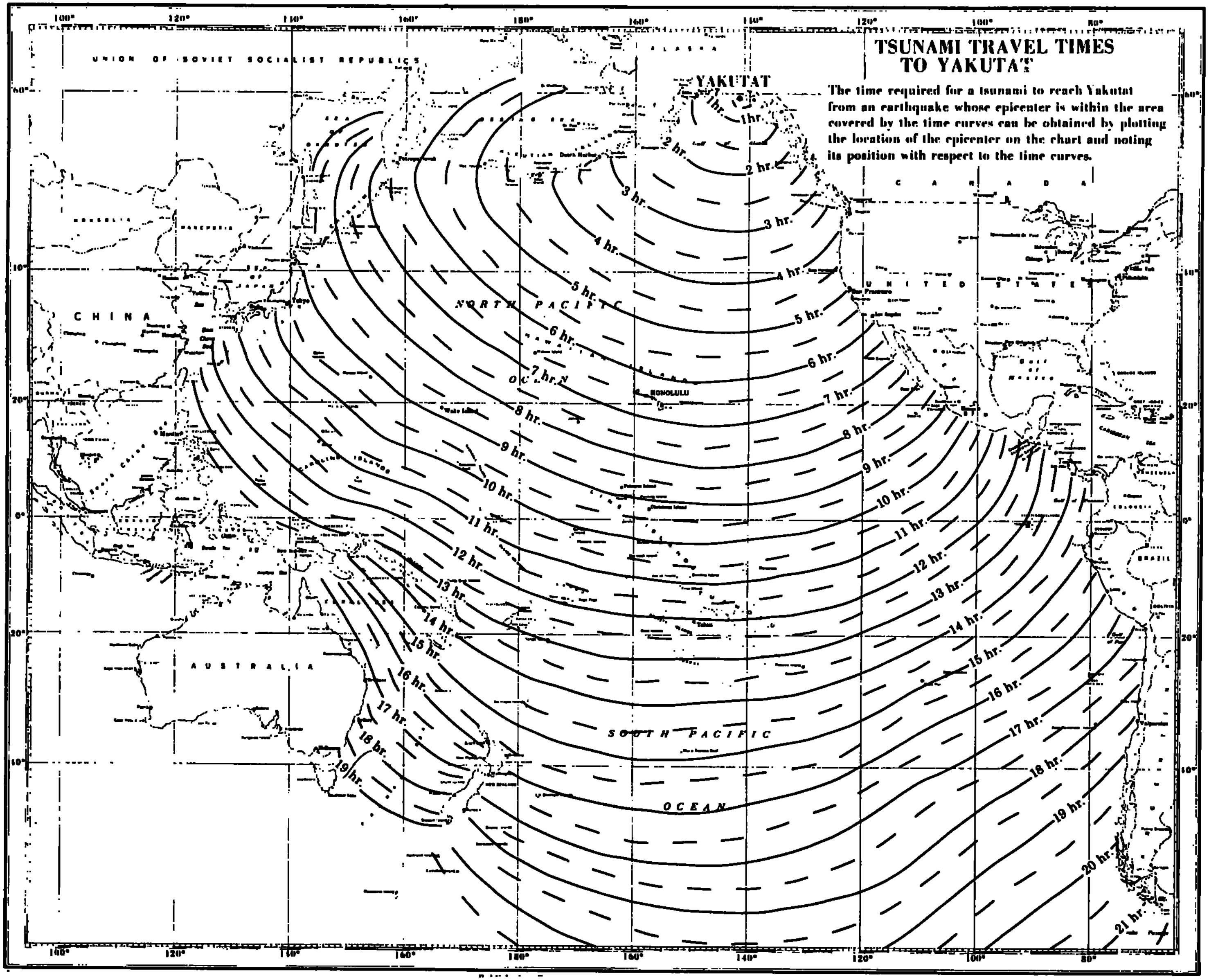

TSUNAMI TRAVEL TIMES
TO YAKUTAT
The time required for a tsunami to reach Yakutat from an earthquake whose epicenter is within the area covered by the time curves can be obtained by plotting the location of the epicenter on the chart and noting its position with respect to the time curves.
YAKUTAT
UNION OF SOVIET SOCIALIST REPUBLICS
ALASKA
CANADA
UNITED STATES
CHINA
AUSTRALIA
NORTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
HONOLULU
1 hr.
2 hr.
3 hr.
4 hr.
5 hr.
6 hr.
7 hr.
8 hr.
9 hr.
10 hr.
11 hr.
12 hr.
13 hr.
14 hr.
15 hr.
16 hr.
17 hr.
18 hr.
19 hr.
20 hr.
21 hr.

Figure 98.

References

Abe, Katsuyuki and Shin-ichi Noguchi, "Revision of Magnitudes of Large Shallow Earthquakes 1897–1912," *Physics of the Earth and Planetary Interiors,* Vol. 33, Aug. 1983, p. 1–11.

Beget, James E. and Juergen Kienle, "Cyclic Formation of Debris Avalanches at Mount St. Augustine Volcano," Letters to Nature, *Nature,* Vol. 356, April 23, 1992, p. 701–704.

Berg, Eduard, Doak C. Cox, Augustine S. Furumoto, Kinjiro Kajura, Hirosi Kawasumi, and Etsuzo Shima, *Field Survey of the Tsunami of 28 March 1964 in Alaska, and Conclusions as to the Origin of the Major Tsunami,* HIG-70-2, Hawaiian Institute of Geophysics, University of Hawaii, January, 1970, 60 p.

Berkman, S.C. and J.M. Symons, *The Tsunami of May 22, 1960 as Recorded at Tide Stations,* U.S. Department of Commerce, Coast and Geodetic Survey, Washington, D.C., 1964, 79 p.

Bodle, Ralph R., "Note on the Earthquake and Seismic Sea Wave of April 1, 1946," *Transactions of the American Geophysical Union,* Vol. 27, No. 4, August 1946, p. 464–465.

Bodle, R.R., "Aleutian Earthquake and Sea Wave of April 1, 1946," *Earthquake Notes,* Eastern Section of the Seismological Society of America, Vol. XVII, No. 4, June 1946, p. 6.

Bois, C., "Chronique Sismologique," *Materiaux pour l'Etude des Calamites,* No. 16, Geneva, Switzerland, 1928, p. 384.

Boyd, Thomas M. and Arthur L. Lerner-Lam, "Spatial Distribution of Turn of the Century Seismicity along the Alaska Aleutian Arc," *Bulletin of the Seismological Society of America,* Vol. 78, No. 2, April 1988, p. 636–650.

Brazee, R.J. and James N. Jordan, "Preliminary Notes on Southeastern Alaska Earthquake," *Earthquake Notes,* Eastern Section of the Seismological Society of America, Vol. 29, 1958, p. 36–40.

Brennan, Ann M. and James F. Lander, eds., *Proceedings, 2nd UJNR Tsunami Workshop, Honolulu, Hawaii, November 5–6, 1990,* National Geophysical Data Center, Boulder, Colorado, March, 1991.

Brown, Delmer L., *Tsunami Activity Accompanying the Alaska Earthquake of March 27, 1964,* U.S. Army Engineering District Alaska, Anchorage, Alaska, April 23, 1964, 89 p.

Chance, Genie, "Perceptions of Earthquake-Related Physical Events in Coastal Communities," *The Great Alaskan Earthquake of 1964, Summary and Recommendations,* National Academy of Sciences, Washington, D.C., 1973, p. 117–135.

Chief Signal Officer, "Miscellaneous Phenomena: Earthquake," *Monthly Weather Review,* War Department, No. 51, January 1881, p. 999–1000.

Cloud, William K. and Nina H. Scott, "Distribution of Intensity, Prince William Sound Earthquake of 1964," *The Prince William Sound, Alaska Earthquake of 1964 and Aftershocks,* U.S. Dept. of Commerce, Environmental Science Services Administration, Coast and Geodetic Survey, Special Publication 10-3, Fergus J. Wood, Editor-in-Chief, Washington, D.C., 1969, p. 5–40.

Coan, Titus, "Recent Eruption of Moana Loa," *American Journal of Science,* Ser. 3, Vol. 2, No. 23, 1872, p. 406–407.

Coffman, Jerry L. and William K. Cloud, editors, *United States Earthquakes, 1968,* U.S. Department of Commerce, 1970, 111 p.

Coffman, Jerry L. and Carl Stover, editors, *United States Earthquakes, 1974,* U.S. Department of Commerce and U.S. Department of the Interior, 1976, 125 p.

Coffman, Jerry L. and Carl A. von Hake, editors, *United States Earthquakes, 1971,* U.S. Department of Commerce, 1973, 176 p.

Coffman, Jerry L., Carl von Hake, and Carl W. Stover, editors, *Earthquake History of the United States,* plus supplements, U.S. Department of Commerce and U.S. Department of Interior, 1982, 208 p. plus 50 page supplement.

Commander, Alaskan Sea Frontier, Press Release, 042221, Kodiak, Alaska, April 4, 1946 [in National Geophysical Data Center files].

Comstock, Carl C., Letter to Wally Norenberg, Alaska Department of Fish and Game, Cordova, Alaska, April 23, 1964.

Comstock, Carl C. and Milton B. Comstock, Letter to Heffron's of April 23, 1964.

Cornforth, Derek H. and James A. Lowell, "The 1994 Submarine Slope Failure at Skagway, Alaska," *Proceedings of the Seventh International Symposium on Landslides, Trondheim, Norway, June 17–21, 1996,* 1996.

Coulter, Henry W. and Ralph R. Migliaccio, *Effects of the Earthquake of March 27, 1964 at Valdez, Alaska,* U.S. Geological Survey Professional Paper, 542-C, Washington, D.C., 1965, 36 p.

Coulter, H.W. and R.R. Migliaccio, *Effects of the March 27, 1964 Earthquake at Valdez,* U.S. Geological Survey Professional Paper 542-C, Washington, D.C., 1966, 36 p.

Cox, Doak C., "Fatalities Due to Tsunamis and other Causes Associated with the Alaska Earthquake, March 22–28," Table 1 in Weller, *The Great Alaskan Earthquake of 1964; Human Ecology,* 1972, p. 227.

Cox, Doak C., "Probable Central Aleutian Source of the Tsunami Observed in August 1872 in Hawaii, Oregon, and California," *Science of Tsunami Hazards; The International Journal of the Tsunami Society,* Honolulu, Hawaii, Vol. 2, No. 2, 1984, p. 79–94.

Cox, Doak C., Kumizi Iida, S.L. Soloviev, and George Pararas-Carayannis, "Pacific Tsunami Historic File," National Oceanic and Atmospheric Administration, Boulder, Colo., unpublished manuscript.

Cox, Doak C., and James F. Lander, "Revised Source of the Tsunami of August 23, 1872," *Science of Tsunami Hazards; The International Journal of the Tsunami Society,* Honolulu, Hawaii, Vol. 12, No. 2, 1995, p. 117–126.

Cox, Doak C. and Joseph Morgan, *Local Tsunamis and Possible Local Tsunamis in Hawaii, HIG-77-14,* Hawaiian Institute of Geophysics, University of Hawaii, November 1977, 118 p.

Cox, Doak C., and George Pararas-Carayannis, *Catalog of Tsunamis in Alaska,* with revisions by Lt. Jeffrey P. Calebaugh, SE-1, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Boulder, Colo., March 1976, 43 p.

Crawford, Peter L., "Tsunami Predictions for the Coast of Alaska," *Proceedings, Coastal Zone '87,* p. 3332–3345.

Dall, W.H., *Alaska and Its Resources,* Lee and Shepard, Boston, Mass., 1870, 627 p.

Dall, W.H., *Alaska and Its Resources,* 2nd ed., Lee and Shepard, Boston, Mass., 1897.

Dall, W.H., *United States Coast and Geodetic Survey Pacific Coast Pilot,* Part I, 1883, p. 202–204.

Davidson, Art, "Home of the Giant Wave," *Alaska Magazine,* November 1989, p. 27–30.

Davidson, G., "Notes on the Volcanic Eruption of Mount St. Augustine, Alaska, on October 6, 1883," *Science,* Vol. 3, No. 54, 1884, p. 186–189.

Davies, John N. and Jerome B. Kisslinger, Untitled manuscript of Alaskan Earthquakes through 1880, personal communication with James F. Lander, August 5, 1987.

Davies, John N., L. Sykes, L. House, and K. Jacobs, "Shumagin Seismic Gap, Alaska Peninsula: History of Great Earthquakes, Tectonic Setting, and Evidence for Higher Seismic Potential," *Journal of Geophysical Research,* Vol. 86, No. B5, May 10, 1981, p. 3821–3855.

Davis, Nancy Yaw, "The Effects of the 1964 Alaskan Earthquake, Tsunami and Resettlement on Two Koniag Eskimo Villages," PhD Dissertation, University of Washington, 1971, 434 p. [Available from University Microfilms, Ann Arbor, Mich., Catalog No. 7124028 03600.]

Davis, Phyllis, *A Guide to Alaska's Newspapers,* Gastineau Channel Centennial Association and Alaska Division of State Libraries and Museums, Juneau, Alaska, 1976, 92 p.

Davis, T. Neil, *A Table of Alaskan Earthquakes 1788–1961,* University of Alaska Geophysical Institute, Report 8, 1961.

Davis, T. Neil and Norman K. Sanders, "Alaska Earthquake of July 10, 1958: Intensity Distribution and Field Investigation of Northern Epicentral Region," *Bulletin of the Seismological Society of America,* Vol. 50, No. 2, 1960, p. 221–252.

Davydov, Gavriil I., *Two Voyages to Russian America, 1802–1807,* St. Petersburg Morskaia Tipografiya, Vol. 224, 1812, 154 pages. English translation by Colin Bearne, edited by Richard Pierce, The Limestone Press Kingston, Ontario, Canada, 1977.

de Laguna, Frederica, *Archeology of the Yakutat Bay Area, Alaska,* U.S. Government Printing Office, Washington, D.C., 1964, 245 p.

de Laguna, Frederica, *Under Mount Saint Elias: The History and Culture of the Yakutat Tlingit,* Smithsonian Institution Press, Washington, D.C., Part One, 1972, 547 p.

Digree, Sig J., *Kodiak Seismic Wave: Earthquake Pictorial,* Island Publishing Company, Kodiak, Alaska, undated, 32 p.

Doroshin, Peter, "Some Volcanoes, Volcanic Eruptions and Earthquakes in the Former Russian America," *Verhandlungen der Russisch-Kaiserlichen Mineralogischen Gesellschaft zu St. Petersburg,* Ser. 2, Pt. 5, p. 25–43, 1870. Translated by Jerome B. Kisslinger in *Pacific Northwest Quarterly,* Vol. 74, No. 2, p. 59–68, April 1983.

Dowl Engineers, *Old Town Hazards Assessment, Valdez, Alaska,* prepared for the City of Valdez, March 1983.

Eckel, Edwin B., *The Alaskan Earthquake March 27, 1964: Lessons and Conclusions,* U.S. Geological Survey Professional Paper 564, Washington, D.C., 1970, 57 p.

Engle, Eloise, *Earthquake: The Story of Alaska's Good Friday Disaster,* John Day Co., New York, N.Y., 1966, 217 p.

Ewing, Maurice and Frank Press, "Tide-gage Disturbances from the Great Eruption of Krakatoa," *Transactions of the American Geophysical Union,* Vol. 36, February, 1955, p. 53–60.

Foster, Evelyn, "Tidal Wave," *The Alaska Pen,* Unga High School Newspaper, Unga Alaska, April, 1946, p. 6.

Fuchs, C.W.C., "Die Vulcanische Ereignisse des Jahres 1878," *Mineralogische und Petrographische Mittheilungen,* G. Tschermak, Band 2, Vienna, Austria, 1879, p. 115.

Fuchs, C.W.C., "Die Vulcanische Ereignisse des Jahres 1883," *Mineralogische und Petrographische Mittheilungen,* Band 6, No. 3, Vienna, 1885a, p. 218–219.

Fuchs, C.W.C., "Statistik der Erdbeben von 1865–1885," *Sitzungsber Kgl. Akad. Wiss. Math—Naturwiss,* Kl. Abt. I, Band 92, 1885b, p. 593, 604, 605, 611, 612.

Furumoto, Augustine S., "Expectation of Destructive Far-Field Tsunamis from the Aleutian-Alaska Subduction Arc," *Science of Tsunami Hazards; The International Journal of the Tsunami Society,* Vol. 11, No. 1, 1993, p. 7–24.

Furumoto, Augustine S., "Source Parameters of Destructive Tsunamis," *Science of Tsunami Hazards; The International Journal of the Tsunami Society,* Vol. 9, No. 2, 1991, p. 95–113.

Galaktionoff, Nick, "Nick Galaktionoff on Makushin: Early Memories, Four Villages Abandoned in the Aleutian Islands during the Twentieth Century," *Cuttlefish Two*, Unalaska High School, Unalaska, Alaska, Vol. 2, 1978, p. 25–29.

Gonzalez, F.I., E.N. Bernard and M.C. Eble, "Deep Ocean Measurements of Three Alaskan Tsunamis," *Tsunamis: Their Science and Hazard Mitigation; Proceedings of the International Tsunami Symposium, July 31–August 3, 1989*, V.K. Gushiakov (ed.), Novosibirsk, Russia, 1990, p. 216.

Grantz, Arthur, Reuben Kachadoorian, and George Plafker, *Alaska's Good Friday Earthquake, March 27, 1964; A Preliminary Geologic Evaluation,* U.S. Geological Survey Circular 491, 1964, 35 p.

Green, C.K., "Seismic Sea Wave of April 1, 1946, as Recorded on Tide Gages," *Transactions of the American Geophysical Union*, Vol. 27, No. 4, August 1946, p. 490–500.

Griffin, Joy, and David Swarthout, eds., *Alaskan Earthquake 1964: Where Were You?*, Homer, Alaska Public Library, manuscript for publication in 1996.

Hatch, Carl H., Col. Signal Corps, Headquarters, Alaska Communication System, Seattle, Letter (SIGAK-PE-3) to Coast and Geodetic Survey, Attn. James N. Jordan, dated May 1, 1959.

Heck, N.H., "List of Seismic Sea Waves," *Bulletin of the Seismological Society of America*, Vol. 37, No. 4, 1947, p. 269–286.

Heezen, Bruce C., and G. Leonard Johnson, "Alaskan Submarine Cables: A Struggle with a Harsh Environment," *Arctic*, Vol. 22, No. 4, 1969, p. 413–424.

Hilgard, J.E., "Earthquake Waves of the Aug. 14, 1868 and Depth of the Pacific Ocean," *American Journal of Science and Art*, Series 3, Vol. 6, 1873, p. 77–78.

Huggins, Eli Lundy, "Kodiak and Afognak Life 1868–1870," *Alaska History*, No. 20, The Limestone Press, Kingston, Ontario, Canada, 1981.

Hwang, L.S., H.L. Butler, and D.J. Divoky, "Tsunami Model: Generation and Open-Sea Characteristics," *Bulletin of the Seismological Society of America*, Vol. 62, No. 6, 1972, p. 1579–1596.

Iida, Kumizi, *Catalog of Tsunamis in Japan and Its Neighboring Countries*, Department of Civil Engineering, Aichi Institute of Technology, Japan, 1984, 52 p.

Iida, Kumizi, "Magnitude, Energy and Generation Mechanisms of Tsunamis and a Catalogue of Earthquakes Associated with Tsunamis," *Proceedings, Tsunamis Meetings Associated with Tenth Pacific Science Congress*, International Union of Geodesy and Geophysics Monographs, 1963, p. 7–18.

Iida, Kumizi, Doak C. Cox, and George Pararas-Carayannis, *Preliminary Catalog of Tsunamis Occurring in the Pacific Ocean*, Data Report No. 5, HIG-67-10, University of Hawaii, Honolulu, August 1967, 274 p.

Jaggar, T.A., "The Great Tidal Wave of 1964," *Natural History*, Vol. 55, No. 6, 1946, p. 263–268, 293.

Johnson, Jean M. and Kenji Sataki, "Rupture Extent of the 1938 Alaskan Earthquake as Inferred from Tsunami Waveforms," *Geophysical Research Letters*, Vol. 21, No. 8, April 15, 1994, p. 733–736.

Johnston, David A., and Robert L. Detterman, "Revision of the Recent Eruption History of Augustine Volcano—Elimination of the '1902 Eruption'," *The United States Geological Survey in Alaska: Accomplishments During 1978*, Kathleen M. Johnson and John R. Williams, eds. U.S. Geological Survey Circular 804-B, 1978.

Jones, Ralph S., Kodiak City Manager, *Kodiak Tsunami, First 29 Days*, Kodiak, Alaska, 1964. [A collection of 25 City Hall Emergency Bulletins issued approximately daily.]

Jordon, James N., James F. Lander, and Rudolph A. Black, "Aftershocks of the 4 February 1965 Rat Island Earthquake," *Science*, Vol. 148, June 4, 1965, p. 1323–1325.

Joyce, Patricia, *Narrative Report: Alaskan Earthquake—Seward,* April 21, 1964, 4 p.

Kachadoorian, Rueben, *Effects of the Earthquake of March 27, 1964 at Whittier, Alaska,* U.S. Geological Survey Professional Paper 542-B, Washington, D.C., 1965, 21 p.

Kachadoorian, Reuben and George Plafker, *Effects of the Earthquake of March 27, 1964 on the Communities of Kodiak and Nearby Islands,* U.S. Geological Survey Professional Paper 542-F, Washington, D.C., 1967, 41 p.

Kienle, Juergen and Samuel E. Swanson, "The Hazards of St. Augustine," *The Northern Engineer*, Vol. 15, No. 3, 1983, p. 10–14.

Kienle, Juergen, Zygmunt Kowalik and T. S. Murty, "Tsunamis Generated by Eruptions from Mount St. Augustine Volcano, Alaska," *Science*, Vol. 236, June 12, 1987, p. 1442–1447.

Kirsch, E.H., Captain, U.S. Coast and Geodetic Survey Ship *Explorer*, Memo to Director, U.S. Coast and Geodetic Survey, 27 May, 1957 [in National Geophysical Data Center files].

Kodiak Historical Society, *Ashes and Water*, Kodiak Alaska, 1976, 40 p.

Kreutzer, Judy and Frank Gallant, Interview with Basil "Red" Ferrier, July 12, 1979, Valdez, Alaska.

Kulikov, Evgueni A., Alexander B. Rabinovich, Richard E. Thomson, and Brian B. Bornhold, "The Landslide Tsunami of November 3, 1994," *Journal of Geophysical Research*, Vol. 101, No. C3, March 15, 1996, p. 6609–6615.

Lahr, J.C., H.S. Hasegawa, and John Boatwright, "Alaska Seismic Gap only Partially Filled by 28 February 1979 Earthquake," *Science*, Vol. 207, 21 March, 1980, p. 1351–1353.

Lahr, J.C., R.A. Page, C.D. Stephens, and D.H. Christensen, "Unusual Earthquakes in the Gulf of Alaska and Fragmentation of the Pacific Plate," *Geophysical Research Letters*, Vol. 15, No. 13, 1988, p.

1483–1486.

Lander, James F., and Patricia A. Lockridge, *United States Tsunamis (including United States Possessions), 1690–1988,* Publication 41-2, National Geophysical Data Center, Boulder, Colo., 1989, 265 p.

Lander, James F., Patricia A. Lockridge, and Michael J. Kozuch, *Tsunamis Affecting the West Coast of the United States, 1806–1992,* NGDC Key to Geophysical Record Documentation No. 29, National Geophysical Data Center, Boulder, Colo., 1993, 242 p.

Lantis, Margaret, "Impact of the Earthquake on Health and Mortality," *The Great Alaskan Earthquake of 1964, Human Ecology,* National Academy of Sciences, Washington, D.C., p. 77–89.

Lantz, Bill and Mildred Kirkpatrick, *Seward Quake, Good Friday, 1964*, Kirkpatrick Printing Co., Seward, Alaska, undated, 54 p.

La Perouse, J.F. de G., *The Voyage of La Perouse Round the World in the Years 1785, 1786, 1787, and 1788,* arranged by M.L.A. Milet-Mureau, John Stockdale Printers, London, England, 1898, 290 p.

Leipold, Louis E., Editor-in-Chief, and Fergus J. Wood, Scientific Coordinator, *The Prince William Sound, Alaska, Earthquake of 1964 and Aftershocks,* Publication 10-3, U.S. Coast and Geodetic Survey, Washington, D.C., 1966–1969 [three volumes].

Lemke, Richard W., *Effects of the Earthquake of March 27, 1964 at Seward, Alaska*, U.S. Geological Survey Professional Paper 542-E, Washington, D.C., 1967, 43 p.

Lemke, Richard W. and Lynn A. Yehle, *Reconnaissance Engineering Geology of the Haines Area, Alaska, with Emphasis on Evaluation of Earthquake and Other Geologic Hazards*, U.S. Geological Survey Open File Report 72-229, 1972.

Lemke, Richard W. and Lynn A. Yehle, *Regional and Other General Factors Bearing on Evaluation of the Earthquake and Other Geologic Hazards to Coastal Communities of Southeastern Alaska,* U.S. Geological Survey Open File Report 72-230, 1972, 109 p.

Liapunova, R.G., and S.G. Fedorova, *Russkaia Amerika v Neopublikovannykh Zapiskakh Kirila Khlebnikova* (Russian America in the Unpublished Notes of Kiril Khlebnikov), Nauka, Leningrad, 1979 [in Russian].

Lockridge, Patricia A., *Tsunamis in Peru-Chile*, World Data Center A for Solid Earth Geophysics, Report SE-39, Boulder, Colorado, 1985, 97 p.

Martin, Lawrence, "Alaskan Earthquake of 1899," *Bulletin of the Geological Society of America*, Vol. 21, July 9, 1910, p. 339–406.

Martinson, Charles Richard, "Aleut Settlements of the Makuskin Bay Area," a dissertation to the Graduate School of the University of Oregon, June 1973.

McCartney, Alan M., personal communication with James F. Lander, University of Arkansas, Fayetteville, Ark., Mar. 1, 1994.

McCulloch, David S., "Slide-Induced Waves, Seiching, and Ground Fracturing at Lake Kenai," *The Great Alaskan Earthquake of 1964: Hydrology,* The National Academy of Sciences, Washington, D.C., 1968, p. 47–81.

Migliaccio, Ralph R., "Earthquake of March 27, 1964," Memo to R.G. Sherman, Chief Geologist, dated April 10, 1964, 6 p.

Miller, D.J., "Catastrophic Flood Wave in Lituya Bay, Alaska," *Geological Society of America Bulletin,* Vol. 65, 1954, p. 1346.

Miller, D.J., *5th Alaskan Science Conference, Sept. 7–10 1954, Proceedings*, Anchorage, Alaska, 1957, p. 56–57.

Miller, Don J., *Giant Waves in Lituya Bay, Alaska,* U.S. Geological Survey, Professional Paper 354-C, Unites States Government Printing Office, Washington, D.C., 1960, 86 p.

Moore, George W., "Geology of Chirikof Island, Alaska," *U.S. Geological Survey Technical Letter, Aleutian 1,* Oct. 11, 1962, 10 p.

Mushketov, I.V. and A.V. Orlov, "Katalog Zemletriasenii Rossiiskoi Imperii" (Catalogue of the Earthquakes of the Russian Empire), *Zapiski Imperatorskago Russkago Geograficheskago Obshchestva* (Records of the Russian Geographical Society on General Geography), Vol. XXVI, St. Petersburg, 1893 [in Russian].

Nance, John J., *On Shaky Ground—An Invitation to Disasters*, William Morrow and Company, Inc., New York, N.Y., 1988, 416 p.

National Academy of Sciences Committee on the Alaska Earthquake, *The Great Alaska Earthquake of 1964: Geology, Part A,* National Academy of Sciences, Washington, D.C., 1971, 834 p.

National Academy of Sciences Committee on the Alaska Earthquake, *The Great Alaska Earthquake of 1964: Human Ecology*, National Academy of Sciences, Washington, D.C., 1970, 510 p.

National Academy of Sciences Committee on the Alaska Earthquake, *The Great Alaska Earthquake of 1964: Oceanography and Coastal engineering*, National Academy of Science, Washington, D.C., 1972, 556 p.

National Academy of Sciences Committee on the Alaskan Earthquake, *The Great Alaskan Earthquake of 1964: Summary and Recommendations*, National Academy of Sciences, Washington, D.C., 1973, 291 p.

National Archives, Alaska Region, "Annual Report," *General Correspondence of the Office of the Alaskan Communications System, 1909–1939,* Record Group 111 (Records of the Office of the Chief Signal Officer), Box 8, Anchorage, Alaska.

National Archives, Alaska Region, "Cable Operations, U.S. Cable Ship *Burnsides*, November 7, 1902 to June 30, 1908," *Communication Service, Alaskan Communications System 1900–1961*, Record Group 342 (U.S. Air Force Command's Archives and Organization), Box 31, Location 10/04/10, Anchorage, Alaska.

Neumann, Frank, *Seismological Report; October, November, December 1927*, U.S. Department of Commerce, Coast and Geodetic Survey Serial No. 503, Washington D.C., 1931, p. 6.

Nishenko, S.P., and K.H. Jacob, "Seismic Potential of the Queen Charlotte-Alaska-Aleutian Seismic Zone," *Journal of Geophysical Research*, Vol. 95, No. 83, March 10, 1990, p. 2511–2532.

Norton, Frank R.B., and J. Eugene Haas, "The Towns and Cities," *The Great Alaskan Earthquake of 1964: Human Ecology*, National Academy of Sciences, Washington, D.C., 1970, p. 245–399.

Olsen, D.J., "General Summary, Alaska," *Climatological Data*, U.S. Weather Bureau, Washington, D.C., Vol. 35, No. 8, August, 1949, p. 86.

Olsen, Kenneth H., John N. Stewart, James E. McNeil, and Martin Velousek, "Long-Period Water-Wave Measurements for the Milrow and Cannikin Nuclear Explosions," *Bulletin of the Seismological Society of America*, Vol. 62, No. 6, December 1972, p. 1559–1578.

Oswalt, Wendell H., compiler, *Alaska Commercial Company Records: 1868–1911*. Unpublished inventory of Elmer E. Rasmussen Library, University of Alaska, Fairbanks, Alaska. Revised by Terry P. Dickey, 1972.

Orthodox Church in America Records, Library of Congress, Washington, D.C. [370 reels of microfilm].

Pararas-Carayannis, George, "The Earthquake and Tsunami of 7–8 May 1986," *Tsunami Newsletter*, International Tsunami Information Center, Honolulu, Hawaii, Vol. XIX, No. 2, August 1986, p. 1–3.

Perry, Alexis M., "Documents sur les Tremblements de Terre et les Phenomenes Volcaniques des Isles Aleoutiennes, de la peninsule d'Alaska et la Cote Nordouest d'Amerique," *Memoires de l'Academie des Sciences, Arts, et Belle-Lettres de Dijon*, Section des Sciences, Vol. 13, 1865.

Perry, Alexis M., "Note sur les Tremblements de Terre en 1871, avec Supplements pour les Annees Anterieures de 1843 a 1870," *Memoires Couronnes et Autre Memoires*, published by l'Academie Royal des Sciences, des Lettres et des Beaux Arte de Belgique, No. 8, Vol. XXIV, Brussels, Belgium, 1875, p. 1–143.

Petroff, Ivan, *Report on the Population, Industries, and Resources of Alaska*, U.S. Government Printing Office, Washington, D.C., 1884, 189 p.

Petroff, Ivan, *Report on the Population, Industries and Resources of Alaska; Seal and Salmon Fisheries and General Resources of Alaska*, Vol. IV, U.S. Government Printing Office, Washington, D.C., 1898, p. 167–452.

Plafker, George, *The Alaska Earthquake of March 27, 1964—Regional Effects, Tectonics*, U.S. Geological Survey Professional Paper, No. 543-I, 1969.

Plafker, George, and V.R. Eyzaguirre, "Rock Avalanche and Wave at Chungar, Peru," *Rockslides and Avalanches, 2; Engineering Sites,* Barry Voight, ed., Elsevier Scientific Publishing Co., New York, N.Y., 1979, p. 276–278.

Plafker, George, Reuben Kachadoorian, Edwin B. Eckel and Lawrence R. Mayo, *Effects of the Earthquake of March 27, 1964 on Various Communities,* U.S. Geological Survey Professional Paper 542-G, Washington, D.C., 1969, 50 p.

Plafker, G. and L.F. Mayo, *Tectonic Deformation, Subaqueous Slides and Destructive Waves Associated with the Alaska March 27, 1964, Earthquake: An Interim Geologic Evaluation*, U.S. Geological Survey Open File Report, Menlo Park, California, 1965, 21 p.

Ponyavin, I.D., *Tsunami Waves*, Hydrometeorology, Leningrad, 1965.

Reid, H.F., Manuscript catalog collection microfilm, National Geophysical Data Center, Boulder, Colo., undated.

Richards, Eugene W., Captain, U.S. Coast and Geodetic Survey Ship *Patton*, Letter to Director, U.S. Coast and Geodetic Survey, June 24, 1959.

Richter, Charles F., *Elementary Seismology*, W.H. Freeman and Company, San Francisco, Calif., 1958, 768 p.

Roberts, Elliott B., "History of a Tsunami," *Smithsonian Report for 1960*, Smithsonian Institution, Washington, D.C., 1961, p. 327–340.

Rockwood, C.G., "Notes on Recent American Earthquakes No. 8," *American Journal of Science*, Vol. XVII, Article XXI, 1879, p. 161.

Rockwood, C.G., "Notes on Recent American Earthquakes No. 9," *American Journal of Science*, Vol. XIX, Article XVI, p. 295–299.

Rockwood, C.G., "Notes on Recent American Earthquakes No. 10," *American Journal of Science*, Vol. XXI, Article XXIII, 1881, p. 198–202.

Rubottom, Ira R., Captain, U.S. Coast and Geodetic Survey, Seattle, Memorandum on Seward Tide Marigram, to the Director U.S. Coast and Geodetic Survey, April 9, 1964.

Russian-American Company Records of 1802-1867, M 11, National Archives, Washington, D.C.; 77 reels of microfilm in old-style Russian script. In this publication, the following materials are quoted: Vol. 6, No. 13 (Folios 7–9, 18 January 1828); Vol. 47, No. 297 (Folios 106v–107, 29 October 1865); and Vol. 48, No. 280 (Folios 102–102v, 18 November 1866).

Russian Orthodox Missionary at Kenai, *Annual Report*, 1883 [in the University of Alaska archives at Fairbanks, Alaska].

Rutherford, Don, "Disaster at Scotch Cap," *The Keeper's Log*, Winter 1986, Vol. 2, No. 2, San Francisco, Calif., p. 12–14.

Salsman, Garrett G., "The Tsunami of March 9, 1957, as Recorded at Tide Stations," *Technical Bulletin No. 6*, U.S. Coast and Geodetic Survey, Washington, D.C., July 1959, 18 p.

Sanford, H.B., "Log of Coast Guard Unit 368, Scotch Cap DF Station Relating to the Scotch Cap Station Tragedy of 1946, April 1–28, 1946," U.S. Coast Guard, Washington, D.C., 1946.

Sartyschew, Gawrila [Gavriil Sarychev], *Account of a Voyage of Discovery to the North-east of Siberia, the Frozen Ocean, and the North-east Sea,* J. G. Barnard, Translator, Richard Philips, London 1806, reprinted by Da Capo Press, New York, N.Y., 1969.

Scidmore, Eliza Ruhamah, *Appletons' Guide-Book to Alaska and the Northwest Coast,* D. Appleton and Co., New York, N.Y., 1897.

"Seismological Notes," *Bulletin of the Seismological Society of America, Vol. XVII,* 1927, p. 237.

Shepard, F.P., G.A. MacDonald, and D.C. Cox, "The Tsunami of April 1, 1946," *Bulletin of the Scripps Institution of Oceanography of the University of California,* University of California Press, Berkeley, Calif., Vol. 5, No. 6, 1950, p. 391–470.

Siebert, Lee, Harry Glicken, and Juergen Kienle, "Debris Avalanches and Lateral Blasts at Mount St. Augustine Volcano, Alaska," *National Geographic Research,* Vol. 5, No. 2, 1989, p. 232–249.

Simkin, T., L. Siebert, L. McClelland, D. Bridges, C. Newhall, and J.H. Latter, *Volcanoes of the World,* Smithsonian Institution, Washington, D.C., 1981, 232 p.

Sokolowski, Thomas J., personal communication with James F. Lander, June, 1994.

Sokolowski, Thomas J., "Regional Tsunami Potential," *Earthquake Alaska—Are We Prepared?: Proceedings of a Conference on the Status of Knowledge for the Earthquake Hazard in Alaska,* Combellick, R.A., R.D. Head and R.G. Updike, eds., U.S. Geological Survey Open File Report 94-218, in Cooperation with the Alaskan Geological and Geophysical Surveys Department, 1994, p. 43–54.

Solibakke, Harold, Captain, *Alaska Standard,* Letter to "Virg," April 8, 1964. [A copy of his report of the 1964 tsunami effects on his vessel at Seward to the Standard Oil Company of California; at Seward Community Library, Alaska.]

Svetlana, Fedorova, *Russian Population in Alaska and California, Late 18th Century through 1867.* Translated by Richard P. Pierce and Alton S. Donnelly, The Limestone Press, Kingston, Ontario, 1973.

Soloviev, S.L., "The Sanak Kodiak Tsunami of 1788," *The Tsunami Problem,* Moscow, Nauka, 1968, p. 232–237. Translated in *Science of Tsunami Hazards,* Vol. 8, No. 1, 1990, p. 34–38.

Soloviev, S.L. and M.D. Ferchev, "Summary of Data on Tsunamis in the USSR," *Bulletin of the Council for Seismology Academy of Science of the USSR,* No. 9, 1961, 37 p. Translation by W.G. Van Campen, Hawaii Institute of Geophysics, Translation Series 9, 1961.

Soloviev, S.L. and Ch.N. Go, *A Catalogue of Tsunamis on the Eastern Shore of the Pacific Ocean*, Academy of Sciences of the USSR, Nauka Publishing House, Moscow, 1975, 204 p. Translation by Canada Institute for Scientific and Technical Information, National Research Council, Ottawa, Ontario, Canada, 1984, 285 p.

Soloviev, S.L. and Ch.N. Go, *A Catalogue of Tsunamis on the Western Shore of the Pacific Ocean*, Academy of Sciences of the USSR, Nauka Publishing House, Moscow, 1974, 310 p. Translation by Canada Institute for Scientific and Technical Information, National Research Council, Ottawa, Ontario, Canada, 1984, 439 p.

Soloviev, S.L., Ch.N. Go and Kh.S. Kim, *A Catalog of Tsunami in the Pacific, 1969–1982*, Moscow, 1986, 214 p. Translation by Amerind Publishing Company, Pvt, Ltd., New Delhi, India, 1988.

Spaeth, M.G. and S.C. Berkman, *The Tsunami of March 38, 1964 as Recorded at the Tide Station*, ESSA Technical Report LGS33, U.S. Department of Commerce, Rockville, Maryland, 1967, 86 p.

Spurr, J.A., Field Notebook, 1898 [in the U.S. Geological Survey archives in Menlo Park, Calif.].

Steinbrugge, Karl V., *Earthquake, Volcanoes, and Tsunamis: An Anatomy of Hazards*, Skandia America Group, New York, 1982, 392 p.

Steward, M.D., Captain, *Pilot House Log Book—S.S. Chena*, March 19–April 4, 1964 [in Alaska State Archives, Juneau].

Stover, Carl W. and Carl A. von Hake, eds., *United States Earthquakes, 1979*, U.S. Department of the Interior and U.S. Department of Commerce, 1981, 170 p.

Stroh, A., Jr., "Navy Operations at Kodiak," *The Military Engineer*, No. 372, 1964, p. 254–255.

Strum, C.G. and W.B. Strum, *Good Friday Nightmare*, Strum Publishing, Portland, Oregon, undated, 64 p.

Swanson, Chas., Nuchek Station, Letter to M.L. Washburn, Esq., Superintinent, Alaskan Commercial Company, Kodiak, Alaska, May 6, 1897.

Sykes, Lynn R., Jerome B. Kisslinger, Leigh Howe, John N. Davies, and Klaus H. Jacobs, "Rupture Zones of Great Earthquakes in the Alaska-Aleutian Arc, 1784–1980," *Science*, Vol. 210, December 19, 1980, p. 1343–1345.

Symons, J.M. and B.D. Zetler, *The Tsunami of May 22, 1960 as Recorded at Tide Stations, Preliminary Report*, U.S. Department of Commerce, Coast and Geodetic Survey, Washington, D.C., 1960, 29 p.

Tarr, Ralph S., *The Yakutat Bay Region, Alaska: Physiography and Glacial Geology*, U.S. Geological Survey Professional Paper 64, Part 1, Washington, D.C., 1909, 144 p.

Tarr, Ralph S. and L. Martin, *The Earthquakes at Yakutat Bay, Alaska, in September 1899*, U.S. Geological Survey Professional Paper 69, Washington D.C., 1912, 135 p.

Tidball, Jno. C., "Letter to Superintendent," *Report of the Superintendent of the United States Coast Survey, 1869,* Appendix 13, Washington, D.C., 1870, p. 233.

Tikhmenev, P.A., *History of Russian American Company*, Volumes I and II, St. Petersburg, Russia, 1861 and 1863. Translated by Richard A. Pierce and Alton S. Donnelly, University of Washington Press, 1978, 522 p.

Tocher, Don, "The Alaskan Earthquake of July 10, 1958: Giant Wave in Lituya Bay," *Bulletin of the Seismological Society of America,* Vol. 50, 1960, p. 253–266.

Tudor, W.J., *Tsunami Damage at Kodiak, Alaska, and Crescent City, California, from the Alaskan Earthquake of March 27, 1964,* U.S. Navy Civil Engineering Laboratory, Port Hueneme, Calif., 1964, 128 p.

United States Department of Commerce, *Tsunami Travel-Time Charts for Use in the Tsunami Warning System,* Revised, 1971 Edition, National Ocean Survey, Rockville, Maryland, 1971, 50 p.

United States Department of Commerce, *United States Coastal Pilot,* National Oceanographc and Atmospheric Administration, Washington, D.C., 1994, 310 p.

United States Fleet Weather Central, "Resume of Activities Commencing March 27, 1964, Kodiak, Alaska."

United States National Archives and Record Service, "History of Outages and Storm Damage, 1900–1949, Anchorage, Alaska," File, Record Group 342, Box 5.

United States War Department, Secretary of War, *U.S. Signal Corps Annual Report for 1882,* Misc. Phenomena, Part 2, 1883, p. 120.

Veniaminov, Ivan, *Notes on the Islands of the Unalaska District,* Translated by Lydia Black and R.H. Geoghegan, edited by Richard A. Pierce. Published jointly by the Elmer E. Rasmuson Library translation program, University of Alaska and The Limestone Press, Kingston, Ontario, Canada, 1984, 512 p.

Von Huene, Roland, and Doak C. Cox, "Locally Generated Tsunamis and Other Local Waves," *The Great Alaskan Earthquake of 1964: Oceanography and Coastal Engineering*, National Academy of Sciences, Washington, D.C., 1972, p. 211–221.

Waller, Roger M. and Kirk W. Stanley, "Effect in the Homer Area," *The Great Alaskan Earthquake of 1964, Geology Part A*, National Academy of Sciences, Washington, D.C., 1971, p. 461–488.

Waller, Roger M. with Kirk W. Stanley, *Effects of the Earthquake of March 27, 1964 in the Homer Area, Alaska*, U.S. Geological Survey Professional Paper 542-D, Washington, D.C., 1966, 28 p.

Whitmore, Paul, Alaskan Regional Tsunami Warning Center, personal communication with James F. Lander regarding Alaskan tsunamis, January 20, 1988.

Williams, Jay, "Lituya—the Bewitcher," *The Alaskan Sportsman*, February, 1938, p. 6, 18, 19.

Willis, D.E., G. George, K.G. Poetzl, C.E. Saltzer, A.F. Shakal, R. Torfin and T.L. Woodzick, *Final Report: Seismological and Related Effects of the Cannikin Nuclear Explosion, Report No. C002138-9,* prepared for the U.S. Atomic Energy Commission, University of Wisconsin, Milwaukee, Wisc., July, 1972.

Wilson, Basil W. and Alf Tørum, "Runup Heights of the Major Tsunami on North American Coasts," *The Great Alaskan Earthquake of 1964: Oceanography and Coastal Engineering,* National Academy of Sciences, Washington, D.C., 1972, p. 138–180.

Wilson, Basil W. and Alf Tørum, *The Tsunami of the Alaska Earthquake, 1964: Engineering Evaluation,* U.S. Army Corps of Engineers, Coastal Engineering Research Center, Technical Memo 25, May, 1968, 401 p.

Yale, C.G., "Proceedings, Regular Meeting of October the 7th, 1872," *Proceedings of the California Academy of Science*, Ser. 1. Vol. 4, p. 267–269.

Yehle, Lynn A. and Richard W. Lemke, *Reconnaissance Engineering Geology of the Skagway Area, Alaska, with Emphasis on Evaluation of Earthquake and Other Geologic Hazards,* U.S. Geological Survey Open-File Report 72-454, Washington, D.C., 1972, 108 p.

Zerbe, W.B., *Tsunami of November 4, 1952, as Recorded at Tide Stations*, Coast and Geodetic Survey Special Publication No. 300, U.S. Department of Commerce, Washington D.C., 1953, 62 p.

Place Name Index