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Catalogue of TSUNAMIS on the EASTERN SHORE of the PACIFIC OCEAN

S.L. SOLOVIEV & CH.N. GO

Canadian Translation of Fisheries and Aquatic Sciences

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S. L. Soloviev and Ch. N. Go

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S. L. Soloviev and Ch. N. Go

Translated from Russian by the
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1984

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Preface to English Edition

The catalogue of Pacific tsunamis was prepared mainly in 1964-1974. A definite stimulus to undertake this work was the appearance of the "Annotated Bibliography on Tsunamis" compiled with my participation and edited by the International Union of Geodesy and Geophysics in Paris in 1964. The bibliography was an important clue to many previously unknown publications on tsunamis dispersed in different national and international editions.

The desire to have under hand all original descriptions of tsunamis in a compact form is experienced by every investigator of tsunamis. My first step in this direction was the compilation of all actual data on tsunamis observed on the Pacific shores of Kamchatka and Kuril Islands, which was done by the end of the 1950s.

The present edition is the product of double translation; at first from English, French, German and Spanish into Russian and then from Russian into English. Of course the better way would be the translation directly from original languages into English, or citation English texts, because a danger always exists in accumulation of errors during each translation. But recompilation of the catalogue in such a manner would require several years of hard work and it would be almost impossible.

I have had the opportunity to read the manuscript of the English translation and my impression is that the general sense of description is passed correctly, although there are some minor inexactitudes. Some errors found in the Russian text have been removed during the translation. But the catalogue itself is still open to discussion and additions.

My sincere thanks to the staff of the Institute of Ocean Sciences, Sidney, Canada, and especially to Mr. Sydney O. Wigen for efforts to realize this English edition of my, together with Mr. Ch. N. Go, book, and I hope that this edition will be useful in further investigations of such important problems as tsunamis.

Prof. S. L. Soloviev

Moscow, 1982

Foreword and Acknowledgement

In their two-volume catalogue,

Catalogue of tsunamis on the western shore of the Pacific Ocean (1974)

and

Catalogue of tsunamis on the eastern shore of the Pacific Ocean (1975)

S. L. Soloviev and Ch. N. Go have assembled the most complete descriptive summary of tsunamis that have struck the shores of the Pacific Ocean. Their records embrace both localized and ocean-wide destructive occurrences, and in some cases go back more that 1000 years. Knowledge of these past events is essential in making an authentic evaluation of tsunami hazard.

In order to make this body of knowledge more generally available to tsunamists, the Institute of Ocean Sciences has undertaken to have these works translated into English, and to publish them for free distribution to researchers.

We express our great appreciation to the authors, Soloviev and Go, for the work they have done in the compilation, and also the time and care they have taken to review and correct the translations; to The Copyright Agency of the U.S.S.R. for permission to publish; and to the Translation Bureau of the Secretary of State, Ottawa, for its concern and diligence in seeking to provide an accurate translation in a specialized technical field.

In the listing of References in the original edition, papers published in Russian were listed first, followed by papers published in other languages. Titles of papers in Japanese were given in English translation and sequenced alphabetically into the second section. The same sequence is retained in this translation, but with Russian titles and sources translated into English.

I would like to thank the many tsunamists who have given encouragement and guidance in the production of this work; to express particular appreciation to W. Hamilton, preliminary translator of the Eastern Pacific; G. Daze, principal translator; and Mary Lane, Marilee Nugent, and Partricia Straub for their sustained effort and enthusiasm in preparing these works for publication.

For any errors that remain I accept responsibility.

Sydney O. Wigen 1983

Academy of Sciences of the USSR

Interdepartmental Council on Seismology and
Earthquake Resistant Construction

Sakhalin Integrated Scientific Research Institute
Far East Scientific Centre

Abstract

A Catalogue of Tsunamis of the Eastern Shore of the Pacific Ocean (1513-1968). S.L. Soloviev and Ch. N. Go, Moscow, published by "Nauka" 1975

This monograph contains descriptions of about 300 tsunamis and related phenomena which have occurred in the southern and eastern Pacific. The monograph also describes earthquakes and other processes which have generated tsunamis. As far as possible, estimates were made of the intensity of all tsunamis, according to a special scale, as well as of coordinates of epicentres and of the energy (magnitude) of earthquakes that generated the tsunamis.

The book will be of interest to seismologists, oceanographers, tectonic geologists, volcanists, geographers, and to inhabitants of the Pacific shores of the USSR and persons involved in various operations in coastal areas of the Pacific.

The book contains 77 illustrations, 14 tables and 344 bibliographic references.

Editor-in-chief, Corresponding Member of the USSR
Academy of Sciences,

E.F. Savarenskii

INTRODUCTION

This catalogue is a continuation of the work of the authors Soloviev and Go, (1974) and includes all known factual information on tsunamis that have occurred in the southern and eastern Pacific up to 1968.

In preparing the catalogue, wide use has been made of reports of earthquakes and tsunamis that have occurred anywhere in the world (Montbeillard, 1761; Hoff, 1840; Perrey, 1847, 1850, 1852, 1854 a-c, 1862 a,b, 1864 a,b, 1865, 1867, 1870 a,b, 1872 a,b, 1873, 1875 a,b; Mallet, 1853-1855; Fuchs, 1866-1870, 1872, 1874, 1878, 1879, 1881, 1883 a,b, 1885 a,b, 1887 a,b; Rudolph, 1905; Milne, 1912 b; Sieberg, 1932; Heck, 1934, 1947; Iida et al., 1967), as described in the preceding catalogue and in national earthquake catalogues (Montessus de Ballore, 1888, 1911 a, 1912, 1916; Orozco y Berra, 1888; Holden, 1898; Polo, 1899 a,b; Bobillier, 1934; Flores, 1934; Townley, Allen, 1939; Milne, 1956; Silgado, 1968; Lomnitz, 1970; and others) and in special publications. The material pertaining to this part of the Pacific was, for the most part, selected and translated into Russian by S.L. Soloviev.

The catalogue includes hardly any information on the extremely severe Chilean tsunami, which occurred on May 22, 1960, owing to the great volume of factual data on it and on the earthquake which caused it. The Chilean tsunami deserves a special monograph. Limited descriptions are given on the well-known California earthquake of April 18, 1906; however, the data on the very weak tsunami that accompanied that quake are reproduced in full.

As in the previous book, the descriptions in the catalogue are presented in chronological order by separate zones, which are arranged counter-clockwise starting with the islands of Fiji, Samoa, Tonga, and Kermadec and finishing with Canada and the Hawaiian Islands. In addition to the documented tsunamis, the catalogue includes descriptions of several solitary waves in the ocean and of long waves of unknown origin, descriptions of which are encountered in the literature.

For each zone an overall map is given, on which are shown first, the geographical locations referred to in the descriptions, and second, the centres of the tsunamis - to the extent to which it was possible to establish them on the basis of the material gathered in the cataolgue. In researching this material, the archives from the following institutions were used: Moscow and Leningrad libraries, Main Geodetic and

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**Numbers in the right-hand margin mark commencement of corresponding pages in the original text - Transl.

Cartographic Administration, Chief Administration of Cartographic Production of the Navy, Sakhalin Complex Scientific Research Institute, Far East Scientific Centre, and Academy of Sciences of the USSR.

The material presented for each occurrence is given, as a rule, in the same format: first the year and time (local) of the earthquakes are shown, then the earthquake is described, and finally, data on the tsunamis are given. Descriptions of earthquakes, and particularly of tsunamis, are reproduced as far as possible in a form unchanged from that of the original source.

Local time, which is used as standard for both earthquakes and for tsuamis, is given in the usual symbols: hr (hour), min (minute), sec (second), [or numerically in translation, e.g. (10:46)]. These same designations are also used for indicating the duration of a period of time. The designations h,m,s are used respectively for Universal (Greenwich) Time.

The local intensity of earthquakes, as found in the original sources, has been recalculated for the 12-degree MSK-64 scale, which is practically identical with the scale adopted by the USSR as a standard. As a check, the original value of the intensity is given in brackets. The 10-degree scale of Rossi-Forell is abbreviated to R.F. The 10-degree Mercalli scale is abbreviated to M. /4

All values in the descriptions are given in metric designations, but as a check, the original value is sometimes also given in brackets (see Appendi

In the complilation of the catalogues, special attention has been given to data concerning the height and other dynamic parameters of tsunamis. The authors of the catalogue have used the term "height of tsunami" for designation of the difference of levels of the crests and troughs of the waves, as is accepted in oceanography. Sometimes (first of all in the tables) this value is also called the range of the level. However, it should be kept in mind that in some original sources "tsunami height" apparently refers to half range; that is, the magnitude which might have been determined as the conventional amplitude of the tsunami. Moreover, in several descriptions the term "tsunami height" refers to the height of the rise of the water on the shore, which is, generally speaking, a magnitude different in meaning and value.

For an evaluation of the height of a tsunami or the height of the rise of the water on a shore it is necessary to know the ocean level before the arrival of the tsunami. In the original descriptions the rise of water is frequently estimated without reference to the undisturbed water level. The authors of the original descriptions were frequently concerned only with the practical side of the matter; that is, how far the rise of water exceeded ordinary flood tides. In such cases, the height of tsunami can be estimated on the basis of A.I. Duvanin's scheme of high tides for the Pacific - a scheme which was presented in the preceding catalogue. It is useful also to note that in the practical work of the U.S. Coast and Geodetic Survey, the so-called gauge "mean lower

low water" (that is, the mean level of extreme spring ebb tides) serves as the basic datum level for estimating the rise of water.

The original sources from which the descriptions of earthquakes and tsunamis are borrowed, and also more recently compiled reports in which reference to the events is made, are shown at the end of the quoted texts. The primary sources containing the original information about the occurrence, (or where the primary sources were unavailable, the most complete data from compiled reports) are listed in a widely spaced format. Where necessary, the year of the work is underlined.

Since many descriptions of tsunamis are contained in little-known publications, the libraries of the country in which the publication was found are shown in the list of references. The conventional abbreviations of the published data and of the libraries are given at the end of the bibliographical list.

If a given occurrence is referred to in "Seismological Notes" (SN), which are regularly published in the Bulletin of the Seismological Society of America, the pertinent data are put directly in the text. A similar method is used for references to tsunamis in the "Newsletter" of the International Tsunami Information Center (NL).

The descriptions of tsunamis of the twentieth century are followed by a summary of basic earthquake parameters, obtained from instrument readings and contained in any of the main seismological bulletins of the world.

The commentaries from the original sources and the remarks of the authors of the book are enclosed in square brackets.

The final section of the catalogue lists all the tsunamis described and their main parameters. Here, the tsunamis are grouped according to the way they were generated. The first basic group comprises tsunamis generated by earthquakes. The second group includes tsunamis generated by volcanic eruptions, also certain instances of underwater eruptions that affected the ocean's surface even though they did not cause tsunamis as such. The third group comprises some tsunami and other gravitational waves caused by large-scale avalanches, landslips, and turbidity currents caused by earthquakes or resulting from some other occurrence. The fourth group consists of tsunami-type waves of meteorological or unknown origin and of solitary waves that occur in the open ocean. It is possible that some of these phenomena are actually tsunamis generated by distant earthquakes. /5

Tsunamis of seismic origin are grouped by zones according to the plan of S.L. Soloviev (1972), which is more detailed than in the main text of the book. Tsunamis of volcanic origin are given according to the geographic location of the volcanoes "in counter-clockwise order." Waves from avalanches are listed chronologically for the southern and western parts of the Pacific. Waves of meteorological and obscure origin are given by zones as listed in the text of the book.

Table 1

Approximate relation between the magnitude of an earthquake and its duration.

Duration	Magnitude M										
	3½	4	4½	5	5½	6	6½	7	7½	8	8½
Maximum	25	50	1½	2	2½	3½	4½	6	7	8	9
Average	1	3	8	20	40	1	1½	2	2½-3	3-3½	4
Minimum				1	3	8	20	40	1	1½	2
		Seconds							Minutes		

The dates on which tsunamis were recorded are given in local times and according to the Gregorian Calendar.

In the listing of tsunamis generated by earthquakes, in the column "coordinates of the epicentre," the following values are shown:

a) for the occurrences in the twentieth century: coordinates of the epicentre of the corresponding earthquakes as determined by seismological station observations;

b) for earlier occurrences: coordinates of earthquake and tsunami source centres located on the basis of macroseismic reports. In the absence of data on the location of the macroseismic epicentre, only the location of the occurrence of the tsunami is shown.

The readings in "a" are based, as a rule, on the monograph of Gutenberg and Richter (1954), or on the authors' data. The accuracy of the epicentre varies from 1-2° for earthquakes of the beginning of the twentieth century to 0.1-0.3° for earthquakes of recent years. The "b" values were determined by the authors. Individual errors in estimating the coordinates are not listed for technical reasons. The average errors

of these determinations are of course high, varying from 1/2-3°.

Points of the compass (north, south, east, west) are indicated only for the first earthquake of the list. For all epicentres they are listed for only zones traversed by the equator or by the 180° meridian. Unfortunately, the data referring to the depth of seismic foci are not very precise. This applies to old earthquakes, the focal depth of which was established by the method of N.V. Shebalin (1968), and to earthquakes of recent years for which the focal depth is found by trial of hodography for different depths with the help of computers.

For earthquakes that occurred between 1907 and 1968, the value of the magnitude of an earthquake M, determined on the basis of displacements in the earth's surface caused by seismic surface waves, were borrowed from the report of Gutenberg and Richter (1954) or directly determined by the authors. The magnitude of old earthquakes for all zones was estimated by S.L. Soloviev on the basis of the surface effect of earthquakes and with the aid of Shebalin's measuring grids (1968). In individual cases the magnitude was estimated on the basis of the duration of the earthquake with the aid of an empirical relation discovered by Soloviev (1970) and presented in Table 1. The average accuracy of the estimates equals $\pm 1/4$ for the first category, $\pm 1/2$ for the second, and ± 1 for the last.

It is noteworthy that in this catalogue, as in the previous one (Soloviev, Go, 1974), the earthquake magnitudes were borrowed mostly from an earlier work of the authors (Soloviev, Go, 1969). These values of /6
magnitude require careful verification and a more precise definition, which is to be carried out at a later date.

The reliability of tsunamis was assessed on a special five-point scale (see list of basic tsunami parameters).

The tsunami intensity was determined according to Soloviev's scale (1972). The generalized intensity (I) referred to that tsunami intensity (io) which the wave would have had at a point on shore nearest to the focus, if the wave energy had been propagated uniformly. The intensity (i) of a tsunami on a coast was determined as the logarithm to the base 2 of the average height of the flood or the average tsunami amplitude, as determined from marigraph readings for given part of the coastline, multiplied by $\pm\sqrt{2}$. The intensities (I) determined by this method differ little from the values of the tsunami magnitude (m) based on the Imamura-Iida scale (Soloviev, 1972). The accuracy of the determination varies from $\pm 1/2$ to approximately $\pm 1\ 1/2$ depending on the completeness of the original data.

In the list of tsunamis of volcanic origin, in addition to the location of the volcano, date and authenticity of the tsunami, the intensity is indicated for the coast closest to the volcano, which in all cases is the maximum known intensity (io).

In the list of tsunamis generated by avalanches on the ocean

floor, the cause of the avalanche is indicated as well as the date, location, authenticity and tsunami intensity.

In the list of waves of meteorological and unknown origin, the date, location, authenticity and intensity (io) of occurrence are shown.

The authors express sincere gratitude to all their colleagues, both in the USSR and abroad, who helped in the preparation of the catalogue.

THE ISLANDS OF FIJI, SAMOA, TONGA & KERMADEC

1853, December, Tonga Islands. The following is an account of Sawkins (Sawkins, 1856; Perrey, 1861; Davis, 1928), about a very severe earthquake which may have been accompanied by a tsunami.

"Several months prior to my arrival on the island of Tongatapu in 1854 (Fig. 1), an earthquake in the area had caused the northeast part of the island to subside, so that the ocean encroached here for 3 1/2 km (almost 2 miles) inland. Flooding occurred also, though to lesser extent, on the southeast coast of the island up to Nukualofa where, in a garden next to a completely demolished house, the water is now washing the roots of trees. The western shore of the island rose approximately one metre (several feet) and one of the springs that had been there previously disappeared underground.

"Noteworthy also is the fact that the inundation of the northern and eastern shores, and the upheaval of the western and southern shores, was accompanied, at roughly the same time, by the appearance of a new island to the west. This fact was witnessed by many, including the captain of a whaling ship who previously had often sailed along that particular route and who, having grounded his ship on a sand bar near the new island, proceeded to land with a boat and crew on its western side. According to his account, the island was elevated about a decimetre (several inches) above the sea for a distance of 130 km (70 miles) and was covered with a black sand, exactly like the sand on the shores of other volcanic islands of this group and of the islands of Haapai. Moreover, hundreds of tons of sand were washing into the sea with each surf. I especially questioned the natives of Tongatapu whether they had previously seen anything similar to land in that direction, to which they replied negatively. The natives reckoned that the island had appeared on the very night when an earthquake had occurred (Christmas Eve, 1853) and when the ocean had inundated the land in Hihifo (Nord Point*)[1].

1865, November 18 (05:40). On the 18th at 04:20 the English ship "John Wesley" ran aground near the small island (a coral reef) of Tau*, but after several earthquake tremors was refloated completely. The ocean raged with such force that waves enveloped the deck.

At 05:40 there was a strong earthquake and the waves became even more dangerous. Twenty minutes later a terrible crack was heard on the ship and it immediately filled with water and sank in a depth of 1 m (3 feet) [sic], but the crew and all the passengers were saved.

---

[1] Points whose locations could not be determined are marked in the text by *.

The earthquake affected a huge area. It was severe on the islands of Haapai and rather severe on the islands of Lifuka and Vavau, where furniture was displaced and the pendulums of clocks were stopped. On the open sea at 24° S. and 173° 30" W., similar vibrations were experienced on the American ship "Siren" on the 18th at approximately 06:00 accompanied by a muffled rumble.

On the Tonga Islands, the earthquake was accompanied by a "sudden and violent movement of the sea," flooding the land and washing away everything in its path (Fig. 1).

By 09:20 of the 18th in Avarua, island of Rarotonga (Cook Islands, /8
see Fig. 77), in good weather with a light south-east breeze and at low tide, the sea had gradually receded to approximately 1 1/4 m (4 feet) below the usual low water mark, almost completely draining the water area of the port. Then the level of the water gradually rose 1 1/4 m (4 feet) above the highest flood tide, but there was no evidence of waves. The rise /9
and fall occurred while the water surface was completely calm. The sea fell and rose to the same levels a second and a third time. Then, in the course of a half hour, the oscillations diminished and the sea became still and assumed its normal level (Fuchs, 1866, 1885 b; Perrey, 1867; Rudolph, 1887; Krummel, 1911; Sieberg, 1932; Iida et al., 1967).

1866, September 12. (Samoan Islands) An underwater volcano erupted in the vicinity of the Manua Islands. The first indications of it were weak shocks, felt on September 7 by the inhabitants of the islands of Tau and Olosega, which are part of that archipelago. These shocks occurred at an average of four per hour, and the vibrations continued into the following day. Thirty-nine shocks occurred during the night of September 9.

After dinner on the 12th a disturbance in the sea commenced at a distance of approximately 3 km (1 1/2 miles) from the island of Olosega and 8 km (4 1/2 miles) from the island of Tau, at a point with coordinates 14° 13' S., 169° 34' W.. The destruction continued all that day and through part of the next. This was followed by an underwater eruption with its usual manifestations. On the 15th of September the eruption was repeated, and each hour approximately 50 eruptions occurred. The sea heaved violently, with high waves following around the centre of the eruption, which continued for three days. During this time large pieces of lava floated up to the surface of the ocean, and tremors were felt on the islands. A column of thick smoke, rising to a height of about 600 m (2,000 feet), completely darkened the sky. Although the eruption did not reveal open flames, gleams of fire could be observed on two or three occasions. The sea was extremely disturbed and for a distance of 20 km (10 miles) glittered with a phosphorescent light. Many dead fish floated to the surface and were cast upon the shore, amongst which were previously unknown monsters 2 to 3 1/2 m long. After three days, the frequency of the eruptions began to abate, although even on the 11th of November three or four explosions per hour could be counted. The products of the eruption were not thrown up to such a significant height as previously, now no higher than 5-10 m (20-30 feet). The condition of

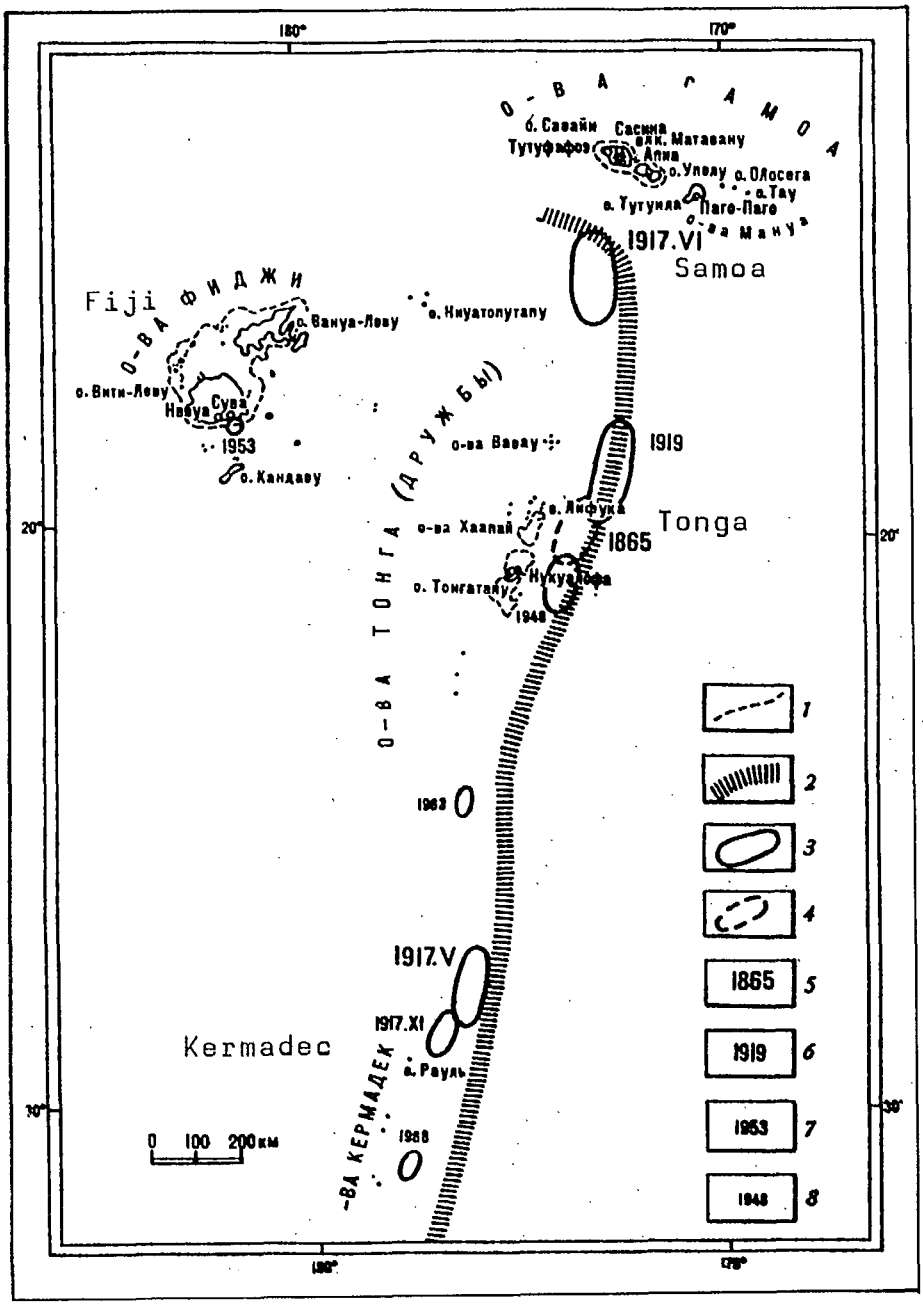


Fig. 1

The islands of Fiji, Samoa, Tonga and Kermadec.

1 - boundary of the shelf;

2 - deep water trench;

3, 4 - epicentres of the tsunami: 3 - definite or probable, 4 - possible;

5-8 - date and intensity of the tsunami I;

5 - I=3; 7 - I=1;

6 - I=2; 8 - I=0;

the vegetation on the Manua Islands suggests that this area had not seen very severe eruptions for at least 80-100 years (Fuchs, 1868; Perrey, 1870; Sapper, 1927).

1881, November 24. There was a strong earthquake on the islands of Tonga and Samoa, one that was felt even on ships in the harbour. On the island of Tongatapu, about 7 1/2 km (4 miles) from Nukualofa, this quake caused a large plain to subside to the point where it was transformed into a deep valley (Fuchs, 1883 a). [Although there is no direct evidence of a tsunami having occurred there, the possibility cannot be excluded.]

1883, March 24. On this day there was a strong hurricane raging in the Samoan Islands and some accounts suggest that an earthquake may have occurred at the same time. But the hurricane was of such ferocity that a clear answer on this point could not be established. However, the consensus was that the hurricane alone could not have caused all the destruction. The vessels that had lain at anchor had suddenly broken loose as if by a special force. In addition, two large tidal waves appeared (Fuchs, 1885 a).

1905-1911. The volcano Matavanu on the island of Savaii (Samoan Islands) was active between August 4, 1905, and November. Huge streams of lava up to one cubic km in volume emerged, one of which moved in a northeasterly direction and reached the ocean shore, a distance of 12 km from the c ıter, on December 6, 1905. Fields and villages situated in the path o. he lava stream were destroyed. From time to time the lava tongues fell into the water and gave rise to small tsunami-type waves (including at the end of 1906 and in 1907). One of the phases of the eruption was observed by the missionary, John Farlong. According to his account, after some periods marked by earth tremors, on August 4, 1908, two yawning fissures appeared from which clouds of steam, illuminated by flames and eruptive material, shot up with explosive force. The streams of lava moved at a rate of 900 m (1/2 mile) in a 24 hour period, and at the points where the lava fell into the sea huge columns of steam rose, which made it difficult to observe the volcano. Tidal waves appeared /10
several times in the same area. They were 450 m (500 yards) in length and inundated the land for a distance of 90-110 m (100-120 yards). According to observers, the appearance of the waves coincided with increasing volcanic activity (Anon., 1908; Sapper, 1927; Richard, 1962).

1908 (1907). Several km (miles) south of Tongatapu Island (21.17° S., 175.73° W.), a submarine eruption occurred, which was accompanied by a strong earthquake on Tongatapu and by a tidal wave. The event generated a large column of steam, along with pumice on the surface of the ocean (Wegener, 1910; Gutenberg, Richter, 1949, 1954). [Possibly distorted information about a previous event.]

1917, May 2. A 12 m (40 feet) tsunami was recorded on the island of Samoa. Well-defined waves were registered in Honolulu and on the west coast of the U.S.A. (Heck, 1947; Ponyavin, 1965).

It is pointed out in the articles of Angenheister (1920, 1923) that the beginning of the tsunami record in Apia coincided with a change in the recorder chart. It took the wave 8 hours and 2 minutes to arrive in Honolulu; 12 hours and 33 minutes to arrive in San Francisco; and 12 hours and 33 minutes to reach La Jolla, California. In the catalogue of Iida and others (1967), the travel time of the tsunami to Honolulu is estimated as 7.9 hours. It is stated that the tidal gauge records in Honolulu showed a tsunami of amplitude of 10 cm and a period of 30 minutes. Doubt was expressed regarding Heck's data on the height of the tsunami on the Samoan Islands. Reference is also made about the tsunami in other catalogues (Shepard et al., 1950; Gutenberg, Richter, 1954; Anon., 1961).

Gutenberg, Richter (1954): 1.V; $18^h26.5^m$; 29° S., 177° W.; M=8.

1917, June 25. There was a catastrophic earthquake with a source between the islands of Samoa and Tonga. On the island of Niuatoputapu (Keppel), a change of relief occurred. One of the lagoons is said to have been raised up and became dry land, while a rocky ridge sank under the water. The quake was felt at a distance of up to 6° from the epicentre, over an area of the order of 1,000,000 square km. The area over which it was felt stretched in a north-south direction.

On the Samoan Islands it was the strongest known earthquake up to that time, and Angenheister gave it a severity rating of 8 degrees. Long-period horizontal oscillations continued for 1 1/2 minutes. The earthquake was more severe in the inner mountains of the island than on the sandy coast. Fragments of the rock rolled down the mountain slopes and numerous cracks appeared in the ground. Trees were uprooted. The piling supports of many huts were torn off, but there was no loss of life. In Apia, the customs building suffered damage. At the same time, a cyclist hastening along a road did not sense the vibrations.

The quake generated a tsunami up to 12 m (40 feet) in height. On the southern shore of the island of Upolu, waves reached a height of 3.1 m and caused destruction in several villages. The tsunami was destructive in Sainili and Pago Pago on the island of Tutuila (Fig. 2).

On the tide gauge record at Apia, the fluctuations of the water level began 5 minutes after the earthquake, having a maximum amplitude of 30 cm and a period of 30 minutes (Fig. 2).

In Honolulu, the oscillations began 7.7 hours after the earthquake, and had an amplitude of under 10 cm and a period of 20 minutes. The tsunami was recorded by tide gauges in California (SN, 1917, vol. 7, N 3; Anon., 1918, 1961; Angenheister, 1920, 1921 a,b, 1923; Sieberg, 1932; Heck, 1947; Gutenberg, Richter, 1954; Shepard et al., 1950; Ponyavin, 1965; Iida et al., 1967). /11

Gutenberg, Richter (1954): 26.VI; $5^h49.7^m$; 15.5° S., 173° W.; M=8.3.

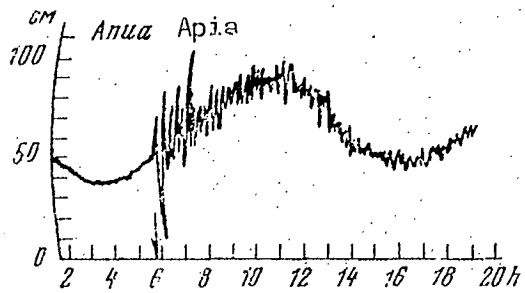


Fig. 2

The recording of the tsunami of 26.VI.1917 by the tide gauge at Apia (Angengeister, 1921a). Here and on the following mareograms, the arrow on the time axis indicates the instant of the earthquake's origin.

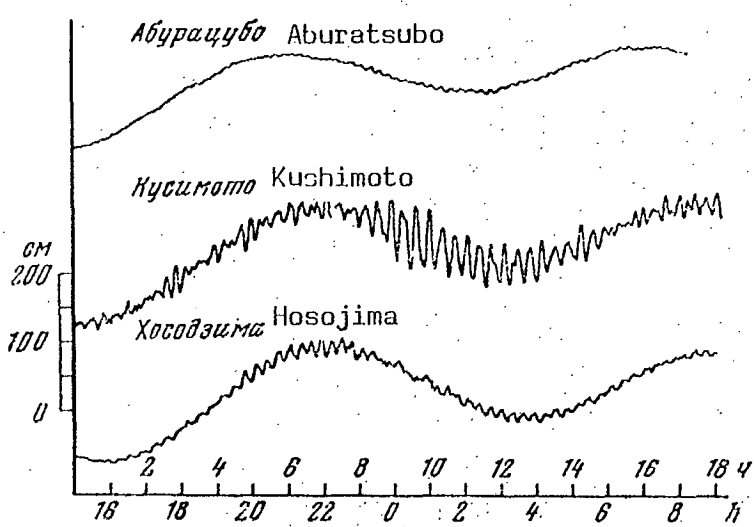


Fig. 3

Records of the tsunami of 1.I.1979 by tide gauges in Japan* (Imamura, Moriya, 1939). On this and the following figures local time is shown above the horizontal axis and Greenwich Time below.

* Points, situated on the western shores of the Pacific Ocean, are set down on the maps of the previous catalogue (Soloviev, Go, 1974).

1917, November 16. A strong earthquake accompanied by tidal waves occurred on the Tonga Islands (Angenheister, 1921 a,b).

Angenheister (1921 a): 16.XI; $3^h19^m28^s$; 29.8° S., 178.7° W.

Gutenberg, Richter (1954): $3^h19.5^m$; 29° S., 177.5° W.; M=7.5.

1919, January 1. An earthquake occurred with the following parameters: Gutenberg, Richter (1954): 1.I; $2^h59^m57^s$; 19.5° S., 176.5° W.; 180 km; M=7.75-8, which, as assumed by Imamura and Moniya (1939) (Imamura, 1949; Gutenberg, Richter, 1949, 1954; Iida, 1956; Anon., 1961), generated a tsunami, recorded in Japan with a height of up to 40 cm (Fig. 3). In the work of Iida et al. (1967), this assumption is perhaps justifiably criticized.

1919, April 30 (erroneously the 9th). On the Ha'apai Islands there was an earthquake lasting 2 1/2 minutes; on the island of Tongatapu there was a weak earthquake of 50 seconds duration. On the islands closest to the epicentre, the quake resulted in many cave-ins, particularly in areas with loose, filled ground, and on the Samoan Islands the quake caused landslides and cave-ins.

The tsunami reached the island of Ha'apai 0.6 hours after the quake began where it had a height of 2.5 m, and it appeared at Apai about 0.9 hours after the quake started, with a height of 0.4 m.

In Punaluu, on the Hawaiian Islands, a bay was completely drained at 7:30. The water gradually returned, but on two occasions it rapidly receded - at about 09:00 and again at 10:30. In Hilo, the tsunami had an amplitude of 0.6 m and a period of 70 minutes. In Honolulu, the tsunami had a height of 0.1 m and a period of 25 minutes.

The tsunami was recorded by tide gauges in California. The time of its passage to San Francisco was 11 hours, 23 minutes; to San Diego, 11 hours, 28 minutes (Angenheister, 1920, 1921 a,b, 1923; Finch, 1924; /12
Sieberg, 1932; Heck, 1947; Gutenberg, Richter, 1949, 1954; Shepard et al., 1950; Anon., 1961; Ponyavin, 1965; Iida et al., 1967).

Gutenberg, Richter (1954): 30.IV; $7^h17^m05^s$; 19° S., 172.5° W.; M=8.3.

1920, August. There was an earthquake and tsunami in Pago Pago, Samoan Islands (Heck, 1934, 1947). Presumably, the information is mistaken for the earthquake and tsunami 21.IX.1920, with its source near the New Hebrides Islands (Iida et al., 1967; Soloviev, Go, 1974).

1926, March (16) or May 12. (The dates are very uncertain). There were tidal waves on Palmerston Island (see Fig. 77). Only one person perished, but all buildings except a church were washed away, and the population, numbering 100 people, were left without shelter and belongings and with very little to exist on (Wilson, 1926; Montandon, 1927 a,b; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967). It was

most likely a storm-generated wave, although there were attempts to connect it with an earthquake on the Tonga Islands: Gutenberg, Richter (1954): 16.III; 17^h32^m; 16.5° S., 171° W.; M=6.

1928, May 18. An earthquake was felt on the island of Lifuka (Ha'apai Island). A tidal wave appeared and pumice was cast upon the shore (Anon., 1931).

Anon. (1931): 19.V; $3^h46^m00^s$.

1948, September 9, (03:30). An earthquake in the area of the Tonga Islands generated a tsunami which was recorded on tidal gauges (Table 2).

TABLE 2

Tide Gauge Data on Tsunami 9.IX.1948

Observation Point	Wave Period (min)	Maximum half range of level oscillations (cm)
Samoan Islands, Pago Pago	17	10
Island Kauai, Port Allen	20	10
Honolulu	12	10
Island Oahu, Waianae	9	10

It took this tsunami 6.6 hours to reach Honolulu (SN, 1948, vol. 38 N 4; Murphy, Ulrich, 1951 a; Anon., 1961; Hamamatsu, 1966; Iida et al., 1967).

Gutenberg, Richter (1954): 8.IX; $15^h09^m11^s$; 21° S., 174° W.; M=7.8.

1953, September 14 (12:17). There was an earthquake and tsunami on the Fiji Islands. The isoseisms of the earthquake are shown in Fig. 4. The macroseismic epicentre was determined at the southern coast of the island of Viti-Levu. Cave-ins and landslides occurred on the steep slopes near shore and bridges were damaged. Considerable material damage was sustained. On loose ground the destruction was noticeably stronger than in bedrock areas. The most frequent cause of the destruction of buildings and bridges was the sinking of filled ground. The dock area of Suva was damaged most of all. The back-filled soil subsided and was displaced one metre towards the water. This resulted in considerable destruction of berthage, supporting walls and access roads. After the earthquake, the caved-in areas had to be filled in. The ground cracked in low places near the shore; numerous small sand and mud volcanoes appeared. Two persons perished, one under a landslide, the other by the

collapse of a building.

The earthquake was followed by a large number of weak aftershocks.

According to eyewitnesses, the water level at the entrance to the harbour of Suva began to recede immediately after the seismic shocks. After approximately 10 seconds there appeared a large brown "bubble" between the channel marker buoys, and a circular wave (in plan) generated by this disturbance rolled up the reef. After 3-4 minutes this same wave /13
reached Suva, where the time of its arrival was sufficiently reliably recorded by three eyewitnesses. The wave height reached 2 m (6 feet). The dock area was devastated; a supporting wall was severely damaged as a result of blows on mooring bollards and wall embrasures, and several yachts and boats were sunk.

In the opinion of Houtz, the wave resulted from currents "descending" from both slopes into the inlet channel and their collision in the channel. Depth soundings carried out after the earthquake indicated (Fig. 5) that the water level along the edges of the inlet, which was flanked by steep coral reefs, had risen by 24 m (80 feet), whereas, in the channel it had dropped by 7 1/2 m (25 feet).

A similar drop in the sea level immediately after an earthquake, with a subsequent surging on the reefs and the pouring over them of large waves of silty water, was observed in the region between Suva and Nagara.

Two waves arrived at the island of Mbengga: one with a height of 0.3 m (1 foot) arrived 30 seconds after the earthquake, the other with a height of 1.2-1.5 m (4-5 feet) arrived 15 minutes after the quake. The first wave was generated apparently somewhere inside the shallow lagoon surrounding the island.

The second wave, like the tidal wave at Nakasaleka on the island of Kandavu, which was observed 12 minutes after the earthquake, and like the wave that approached Navua and Laucala 15 minutes after the earthquake, evidently was generated in an area northeast of the island of Mbengga (see Fig. 4). After the earthquake, variations in the water level of up to 100 m (300 feet) were determined by echo sounding. It is possible that turbidity currents played a part in generating the wave, since underwater cables in the area of the epicentre were displaced, broken and buried under loose alluvium (see Figs. 4 & 5). On the basis of the damage the cables had suffered, the velocity of the bottom currents was estimated to be 10-20 knots. It should be noted that the main tsunami started on the southern coast off the island of Viti-Levu, at low tide, whereas the times of the wave passage referred to above correspond /14
to the high tide which followed.

The tsunami was observed within a radius of approximately 330 km (180 miles) from the indicated centre. On the island of Viti-Levu, reports about the waves were received from various points from Lomeri on the south coast to Cape Tailevu in the northeast. The waves were observed on the island of Kandavu and west of the island of Lau.

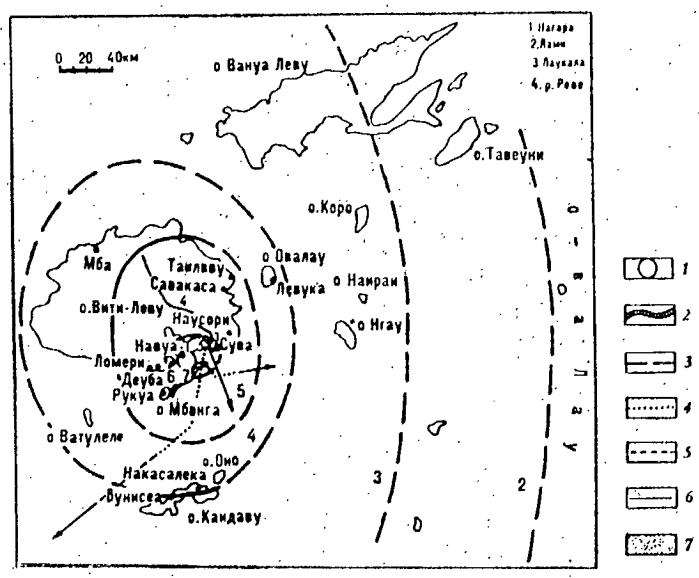


Fig. 4

General map of the Fiji Islands, and the occurrences of earthquakes and tsunamis on 14.IX.1953.

1. macroseismic epicentre of the earthquake;
2. calculated centre of the tsunami, corresponding to a run time of the wave to Nakasaleka in 12 min;
3. isoseists;
4-6. sections of the undersea cable;
   4 - heavily damaged, 5 - lightly damaged, 6 - not damaged;
7. region where subaerial landslides and cave-ins occurred, according to information of Houtz (Houtz, 1963).

TABLE 3
Rise of water 14.1x1953 at individual places.

Point of Observation	Height m.(ft.)	Point of Observation	Height m.(ft.)
Viti Levu, Suva	1.8(6)	Koro	1.5(5)
Dayuba	1.8(6)	Laukala	1.0(3-4)
Lami, suburb of	1.8(6)	Kavahi	1.0(3-4)
Suva, located at		Savakasa	0.9(3)
head of the bay		Vunicaya	0.9(3)
1-2 km from town		Levuka	0.9(3)
Mbengga	1.5(5)	Ostrova Lau	0.6(2)

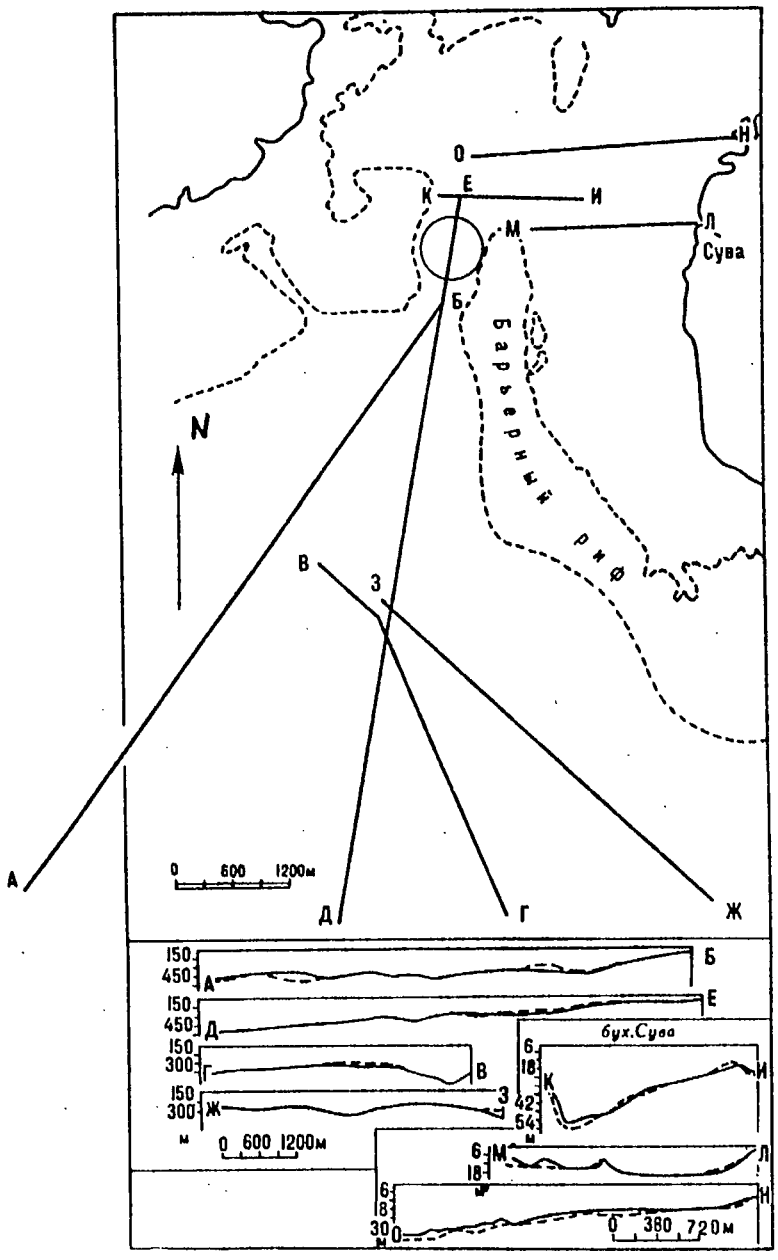


Fig. 5

Changes in the relief of the sea bottom (loose) in Suva Bay as a result of the earthquake of 14.IX.1953. In the upper part of the drawing is the plan, in the lower the profile The circle shows the location of the brown "bubble" (see text). The solid lines are the profile of the bottom before the earthquake, the dotted lines are the profile after it (Houtz, 1963).

The waves had their greatest height, by various estimates, from 3 to 15 m (10-50 feet) at the reefs bordering the southern coast of Viti-Levu. The first wave was the strongest. The approaching waves could be /15
seen at distances of 2-4 km from the beach. Huge pieces of coral reef were thrown up onto dry land.

Estimates of the average rise of the water level at various points are given in Table 3.

In a number of places, coastal villages and individual houses were seriously damaged. In Suva, three persons were drowned in the tsunami waves and two on the island of Kandavu. Twelve persons received serious injuries. The general property damage from the tsunami amounted to approximately one tenth of that caused by the earthquake.

The tsunami was recorded by tidal gauges in Pago Pago, where it had an amplitude of 20 cm (0.7 feet); in Honolulu where the wave had an amplitude of 6 cm (0.2 feet), a period of 16 minutes, and appeared in 7.3 hours after the earthquake; in Port Allen where it had an amplitude of approximately 10 cm; and in Hilo where it had a smaller amplitude (SN, 1954, vol. 44 N 1; Murphy, Cloud, 1955; Rothe, 1955; Hewitt, 1957; Houtz, 1962, 1963; Hamamatsu, 1966; Iida et al., 1967).

Houtz (1963): 14.IX; $0^h26^m36^s$; 18.2° S., 178.3° E.; M=6.75.

196[illegible], December 18. An earthquake occurred with its epicentre near the T[illegible]a Islands. It was felt on the islands of Tonga, Fiji and Kermadec. There was a very strong swell in the Tahiti Islands (NL, 1959, vol. VI. N 4).

(USCGS): $0^h30^m03^s$; 24.8° S., 176.6° W.; 46 km; M=7.25-7.5.

1968, July 25. After an earthquake whose epicentre was near the island of Kermadec, the water level at Suva varied within a range of 10 cm. The quake was felt on the island of Raul (NL, 1968, vol. 1 N 3; Coffman, Cloud, 1970).

(USCGS): 7^h23^m; 30.8° S., 178.4° W.; 60 km; M=7-7.25.

/16

NEW ZEALAND, AUSTRALIA, SOUTHERN PART OF THE PACIFIC OCEAN

1845, July 6 (night). In Wanganui (Fig. 6), a sharp underground tremor awakened all the inhabitants; a rather strong rumbling was heard. The day before, there was a double high tide. High water came up at 01:00; then the tide receded, and at 03:00 the water level was high again (Eiby, 1968).

1848, July 12. On the island of Tahiti (see Fig. 77), an earthquake was followed by a strong tsunami which cast vessels upon the shore. The tsunami was just as strong on the Hawaiian Islands (Perrey, 1862 a).

1848, October 16 (1:40). The first of a series of shocks occurred in the region of Cook Strait. In Karori (vicinity of Wellington) the tremors rocked a wooden villa to such an extent that people found it difficult to remain standing; the pendulums of all clocks stopped; bells sounded. The fire place did not collapse but it was so cracked that it had to be dismantled. These tremors were followed by weaker vibrations which continued until about 06:00, after which their frequency diminished.

In Wellington, many baking ovens were destroyed by the earthquake and even more were cracked. However, brick buildings suffered little damage.

Eight hours after the earthquake, during a high water slack period, the water level in Wellington had risen 0.3 m (1 foot) higher than the mark of the highest flood tide. This effect, however, could have been caused not only by the earthquake but also by a strong southeast wind blowing on the 15th and 16th.

Unusual changes in the sea level were noted also in Nelson and Wanganui (Perrey, 1850; Milne, 1912 b; Heck, 1934, 1947; Laing, 1954; Ponyavin, 1965; Iida et al., 1967).

1848, October 17/18. On the 17th at 15:40, a new earthquake occurred which was more severe than the previous one, and in Wellington almost all brick buildings suffered damage. Even a newly constructed brick building of the hospital was so cracked that it soon had to be demolished. In the Te-Aro block several houses were completely destroyed.

On the 18th there was a very strong flood tide. At the slack, the sea covered a road along the shore and flooded the ground floor of several houses. This flooding caused great alarm amongst the inhabitants although the flood may have resulted solely from the continuous, strong south-easterly winds.

The earthquakes of the 16th and 17th were only forewarning shocks of the still greater earthquake which occurred on the 19th at 05:00 and caused greater damage than the two preceding earthquakes together. The Te-Aro block was turned into a heap of ruins, although all wooden buildings in Wellington remained standing. Three persons were killed in the city.

In Wanganui, which has only wooden houses, all three shocks were felt but there was no damage. In Nelson the shocks were stronger than on Wanganui, while on the Banks Peninsula they were as strong as in Wanganui. The earthquake was recorded in New Plymouth, was very weak in the province of Hawkes Bay, and in Auckland it wasn't felt at all.

The source of the earthquake was apparently located in the valley of the Awatere River where, possibly, movements along surface fractures occurred for a distance of about 110 km (Perrey, 1850; Sieberg, 1932; Davison, 1936; Richter, 1963). M=7-7.5 (Eiby, 1968).

1855, January 23 (after 21:00). There was an earthquake in /18
Wellington and vicinity, lasting for 1 1/2 minutes. All brick buildings collapsed, as did the bridge over the Hutt River (Fig. 7). In certain areas of the Remutaka [sic] Mountain range the vegetation cover slid from the spurs, baring the rock.

Over the course of several days lesser shocks continued with varying int ısity. In Otaki, 250 tremors were recorded during the night.

In Nelson province, in particular in Worcester*, damage was slight and not one brick house collapsed. In Taranaki and Canterbury, the earthquake was weak, and in Auckland and Otago provinces it wasn't felt at all.

In Otaki, many brick ovens were ruined, and people found it difficult to stand upright. Cave-ins and landslides occurred, causing the road to Wellington to become impassable. In Wanganui ovens were damaged.

According to other data (Lyell, 1868; Ongley, 1943), the earthquake was felt over the whole of New Zealand, and at sea, at least up to 280 km (150 miles) from the coast. The area affected by the shock was estimated to be 1,200,000 km^2 (360,000 square miles).

The earthquake was caused by a movement along a fault with a north-easterly strike. The region to the west of the fracture lifted, whereas, along the coast about 30 km (16 miles) north of Wellington no apparent lifting occurred. But from this point to Penkarrow Hill, located to the east of Port Nicholson at the entrance into the bay, the amount of lifting gradually increased, reaching 2.7 m (9 feet) on the western side of the fault, which coincides with the eastern slopes of the Remutaka range. The eastern side of the fault was not disturbed. As a result of the lifting of the shoreline, the flood tide no longer went up the Hutt River.

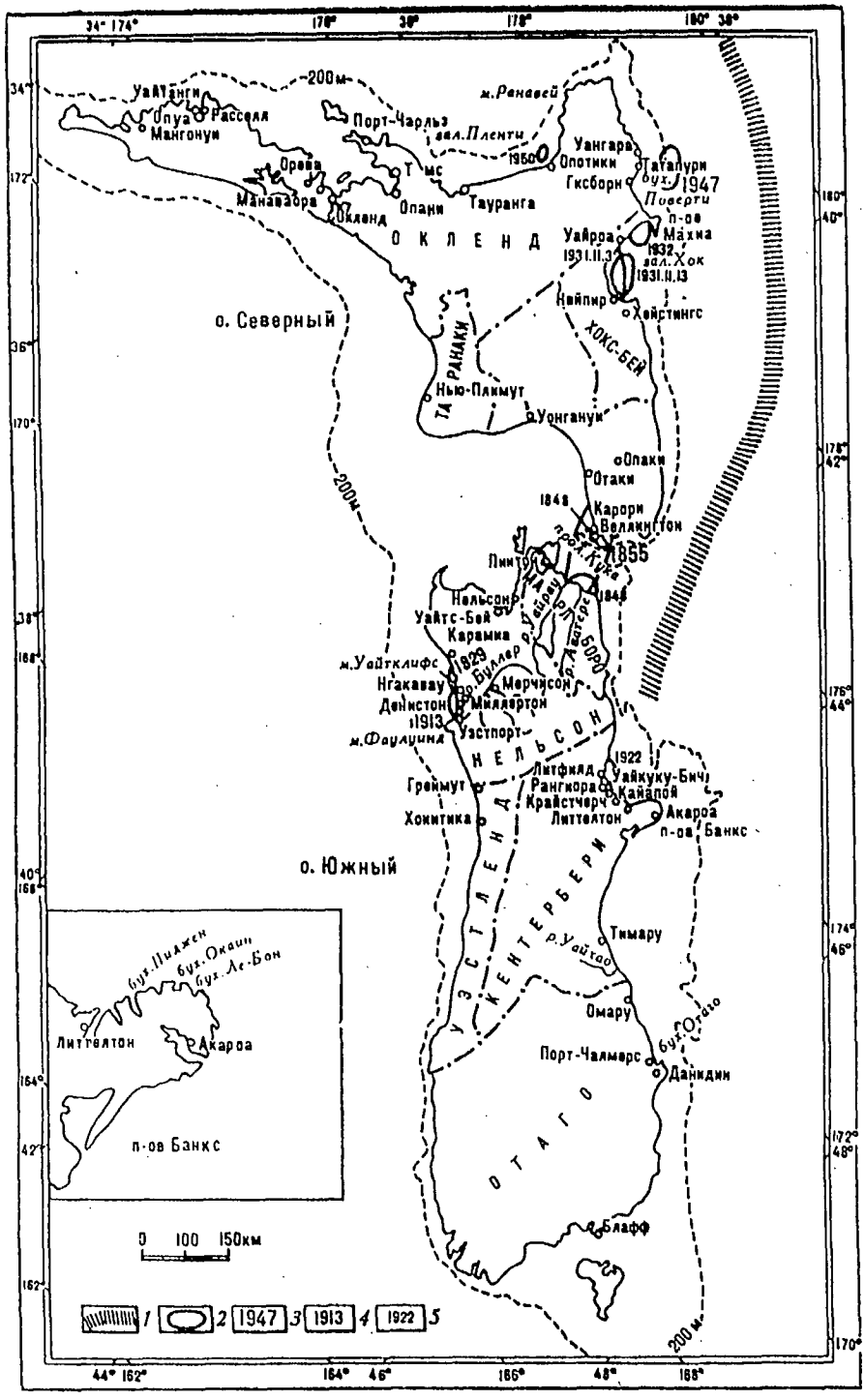


Fig. 6- New Zealand

1-deepwater trench;
2-centre of the tsunami (definite or probable);
3-5-intensity of the tsunami I: 3, I=2; 4-I=5, I=0

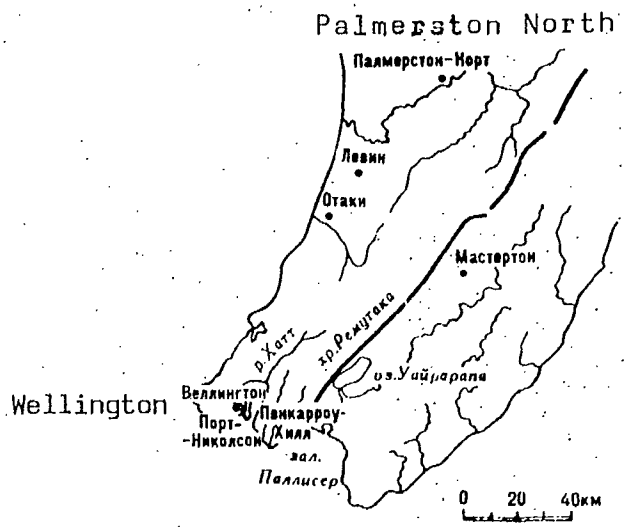


Fig. 7

Direction of the fault (solid line) along which the movements of the earthquake of 23.I.1855 was ass ated (Ongley, 1943).

At the same time, the south coastline of Cook Strait dropped 1.5 m (5 feet) and the flood tide began to go considerably farther up the Wairau River than before the earthquake. At the time of the earthquake huge ocean waves rolled onto the shore (of Cloudy Bay*), and then during the next several weeks the course of the tides was irregular.

The wave left dead fish in its wake on the Wellington racecourse. Many dead fish, among them unknown species, were also found floating in Cook Strait.

In Wellington, the ship "Pandora" was anchored in 11 m (6 fathoms) of water. According to the captain, the shocks that were generated during the earthquake, which lasted over a minute, felt as if the ship was hitting rough bottom. Disembarking with his mate onto the beach, the captain became aware of a rapid succession of ebbs and flows. The waves moved from west-north-west to east-south-east. For a period of 8 hours after the earthquake, the tide rolled onto the shore and receded every 20 minutes. The water level rose by 2 1/2-3 m (8-10 feet) and then dropped to 1 1/4 m (4 feet) below the mark of the spring ebb. The ship seemed to hit bottom four times.

In Palliser Bay, the wave attained a height of 9 m (30 feet) and

displayed a white crest. One family was almost drowned.

The waves were observed for at least 50 minutes, as they rolled over the shore of South Island.

According to some accounts, the water level at Nelson fluctuated somewhat. Davie reports that in the Christchurch area, during the night of 23/24, the noise of the flood on the small river Avon could be heard at a distance of 4 km (2 miles) from the centre of town. In the morning it was discovered that the river bank was littered with seaweed up to a height of 0.3 m (1 foot) above the normal water level (Perrey, 1857; Lyell, 1868; Davie, 1869; Sieberg, 1932; Laing, 1954; Richter, 1963; Ponyavin, 1965; Iida et al., 1967). M=8 (Eiby, 1968). /19

1855, February 14. In Wellington, there were two small earthquakes. During the first, which lasted more than a minute, all the houses collapsed. The vessels riding at anchor in the port were dragged away by the current. A "terrible" tidal wave rushed onto the shore. Numerous bubbles of sulphur dioxide rose from the bottom and many dead fish floated in the water. In areas where the earthquake had been the strongest, the coast had lifted 0.7 m (2 1/4 feet) (Perrey, 1857; Milne, 1913). This information is not correct, for the description refers to the earthquake that occurred on 23.I.1855 (Bastings, 1935; Eiby, 1968).

1856, March. An eyewitness (Stadholm), who happened to be near the shore at the mouth of the river Waihao in the south of Canterbury Province, saw a wave at sea approaching the shore from a southeasterly direction. It reached a height of one metre (several feet) and rushed onto the shore with great force, rolling into nearby lagoons. The observer then proceeded on horseback toward Timaru, and witnessed the effect the wave had had on the shoreline. However, in Timaru itself, the wave had apparently gone unnoticed.

Davie, who at this time was surveying near the low water line at Akaroa, was surprised when he noticed that the water suddenly began to rise. This continued several minutes, after which the water receded again. This was probably the same wave that had been observed by Stadholm (Davie, 1869; Laing, 1954).

1858, September 15 (or 16) (06:00). There was a strong ebb, so that the reef of South Island was completely dry. One quarter hour later it was completely inundated by a large tidal wave. At about 09:00 this occurrence was repeated (Perrey, 1861).

1848-1858. Perrey's report (1862 a), in which he quotes the newspaper "Moniteur" from 23.IX.1858, points out that five unusual tide waves were recorded in Nelson over the eleven years from 1848-1858. (It is possible that these waves included those that occurred on 16 and 18.X.1848, 23/24.I.1855, and the one that occurred in March 1856.)

1866, August 9. Strong water movement was recorded in Sydney harbour (Fuchs, 1885 b).

1866, August 15-21. "Extremely" strong water movement was recorded in Sydney harbour (Fuchs, 1885 b).

1867, August 5-13. Unusual fluctuations in the sea level were recorded at Sydney, particularly from 09:00 to midnight of the 12th (Perrey, 1875 b; Fuchs, 1885 b).

1869, August 11-17. Unusual fluctuations in the sea level were recorded at Sydney (Perrey, 1875 b).

1870, August 12-22. Unusual fluctuations in the sea level were recorded at Sydney. These fluctuations were particularly strong from 17:00 on the 17th to 16:00 on the 18th (Perrey, 1875 b).

1913, February 22 (12:38). A destructive earthquake occurred in Westport, the strength of which was estimated at 7 degrees (VIII according to R.F.). The shock was preceded and accompanied by roaring noises similar to artillery barrages or mine explosions, and they continued for almost a minute. The first vibrations were strong, then abated, increased again for 20-30 seconds, and then subsided. Many ovens cracked, although none were completely ruined. The chimneys had either partially collapsed, cracked or were turned slightly. A brick building had shifted almost 1 cm from its foundation. In stores and houses (wooden houses with sheet metal roofs) objects were generally thrown from their shelves. Several window panes were broken; all the inhabitants fled into the streets, an there were some cases of seasickness.

The earthquake had a similar effect in the narrow coastal zone for a distance of 15 km north of Westport. Here, as in Westport itself, the soil consists mostly of weakly consolidated pebbles and sand lying on rock beds.

At Cape Foulwind, the earth developed cracks from which mud was ejected. South of Westport, the earthquake was still severe even in Greymouth. Here, fireplaces were damaged, objects were thrown from shelves, bells rang by themselves, and most of the inhabitants fled into the streets. Some people had the sensation of being seasick. /20

Further inland, in the mountains on bedrock, the tremors were less severe. Here the earthquake had caused small cracks in the roads which cut across the mountain slopes, and some trees were uprooted. In the coal mines of Deniston and Millerton the tremors were not very strong, but the accompanying roar was deafening.

The earthquake was rather strong in Caramia, and it was felt in Nelson and Hokitika, but not in Wellington. Over the next two or three weeks many weak shocks were recorded in Westport. Moreover, there were about the same number of shocks with rumbling sounds as without, and again as many rumbling sounds without a shock being felt.

The earthquake occurred two hours after an equinoctial-like flood tide hit Westport. Soon after the earthquake, the sea level rose to a

high mark and all the stalls on the beach were flooded. In Ngakavau, the flood tide raised the level 1 m (3 feet), or perhaps 1 1/2 m (5 feet) above the usual spring tides; and from Karamea also the highest flood tides in recent years were reported. On Cape Foulwind, the sea receded after the earthquake (Morgan, 1913; Heck, 1934, 1947; Henderson, 1937; Laing, 1954; Ponyavin, 1965; Iida et al., 1967).

[22.II; 2^h36^m; 41.8° S., 171.5° E.; M=6.8.]

1922, December 25 (15:33). An earthquake occurred in Rangiora with a force of about 7 degrees, which resulted in large fissures appearing on the shore of Waikuku Beach. The earthquake was felt from the province of Taranaki to Dunedin.

An unusual ocean condition was observed after the earthquake in Castlecliff: there were several huge waves and an enormous ebb tide. Near Leithfield, the water came up on shore to a depth of 35-40 cm (15 inches) and flooded a place where people were sitting (SN, 1923, vol. 13 N 2; Laing, 1954; Eiby, 1968).

Gutenberg, Richter (1954): 25.XII; $3^h33^m10^s$; 43° S., 173° E.; M=6.25.

1924, June 26. An earthquake, with its source in the region of the island of Macquarie (see Fig. 77), generated a tsunami which was recorded on a tide gauge in Sydney (Hart, 1931).

Gutenberg, Richter (1954): 26.VI; $1^h37^m34^s$; 56° S., 157.5° E.; M=7.8.

1924, July 21. The steamship "Tease" encountered a tidal wave while proceeding to Chatham Island (see Fig. 77); the impact of the wave resulted in a cracked high-pressure cylinder head. This tidal wave hit the islands during the same night the steamship was damaged and caused extensive losses there too (according to the Record of Unusual Events at Sea, compiled by an English Steamship Company, and reproduced by the Nautical Branch of the Meteorological Service of England) (Malladra, 1925; ISS for 1924).

1929, June 17 (10:48). There was an earthquake with its source in the west of Nelson Province, in Buller county. Murchison, a small town of single-story wooden houses and a population of about 300 persons, was most heavily damaged, for the majority of the houses were twisted or destroyed. Seventeen persons perished. The shocks were felt over a large part of South Island and north of Wellington for a distance of 450 km.

The earthquake was caused by earth movements within a system of fractures and was accompanied by numerous landslides, cave-ins, avalanches, etc. Many landslides occurred on the western shore of South Island. The largest of these was the landslide at Cape White Cliffs (?) (Fig. 8) to the south of Caramia. The tongue of the landslide had risen

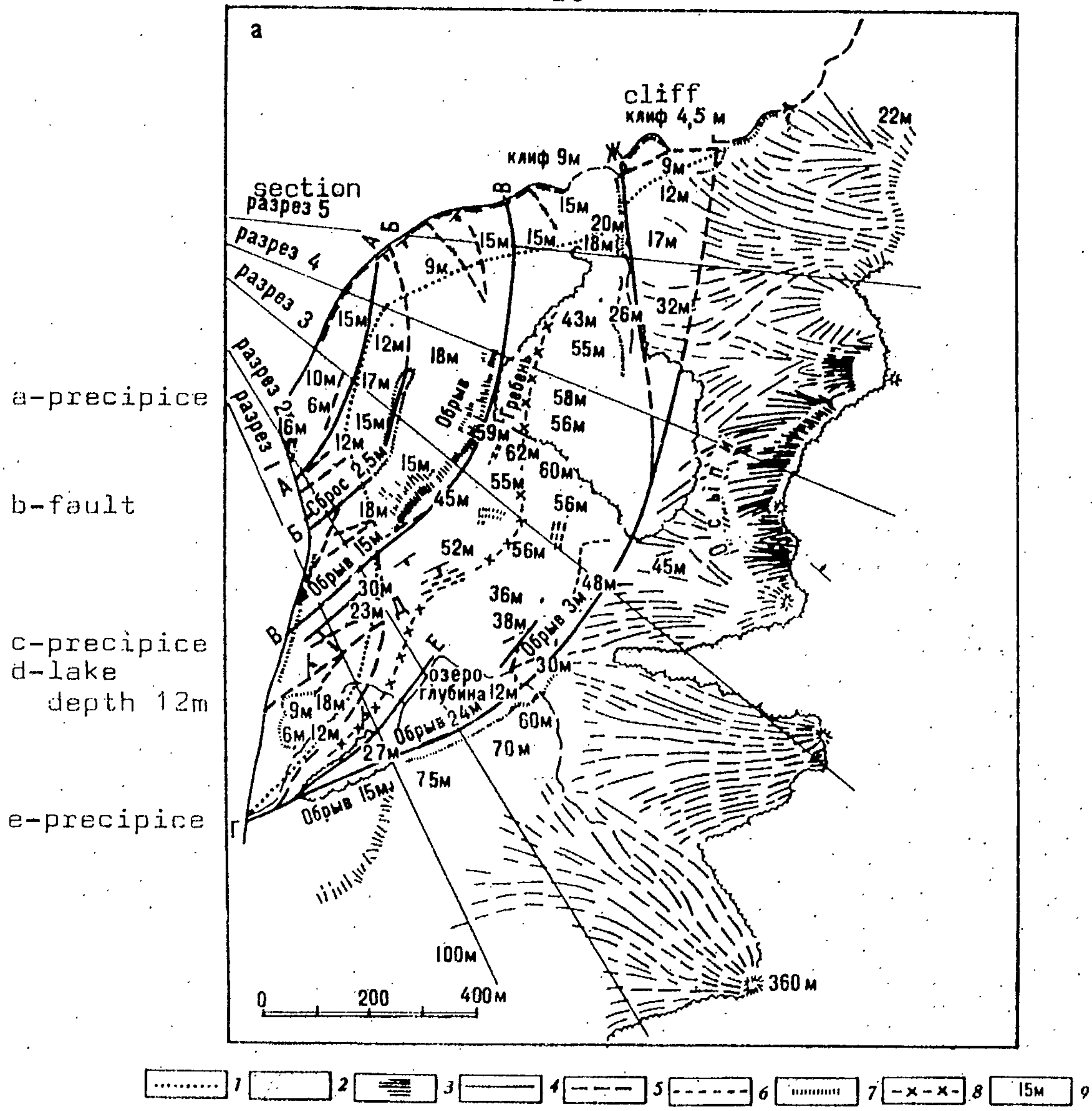


Fig. 8

Diagram of the land-slip at Cape Whitecliffs, caused by the earthquake of 17.VI.1929 (Henderson, 1937).

a - plan:

1 - old shore line

2 - section of the sea bottom which rose

3 - fresh exposure of archezoic sandstone

4 - breaks

5 - supposed (underground) breaks

6 - small breaks and cracks

7 - ruptures

8 - crest of the tongue of the land-slip

9 - height above sea level

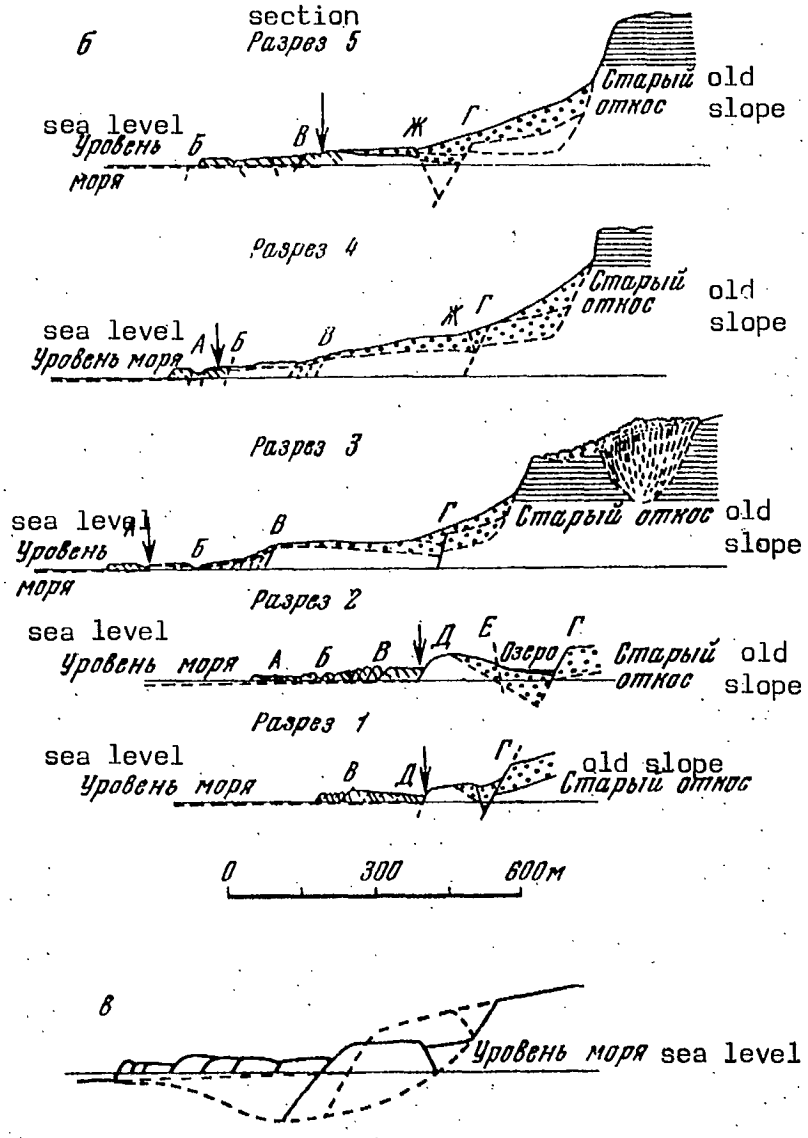


Fig. 8 (continued)

B - vertical section of the land-slip; the arrow shows the old position of the shore.

C - a reconstruction of the land-slip. The positions of the masses which slipped are: the dotted line - before the earthquake; the solid line - after the earthquake.

considerably, and part of the former ocean floor of about 2 km (1 mile) in length and more than 90 m (300 feet) in width, had been lifted 12 m (40 feet).

In Karamea, according to the words of one captain, a tidal wave with a height of 2 1/2 m (8 feet) moved through the area without causing any kind of damage. /21

Sea level fluctuations of up to 10 cm and with periods of about 45± minutes were recorded by a tide gauge at Fort Denison, in Sydney. The most intensive fluctuations were recorded 30-40 hours after the earthquake (Fig. 9) (Hart, 1931; Henderson, 1937; Laing, 1954; Richter, 1963).

Gutenberg, Richter (1954): 16.VI; $22^h47^m32^s$; 41.75° S., 172.25° E.; M=7.6.

1931, February 3 (10:47). There was an earthquake with source in Hawke Bay, which almost completely destroyed Napier and Hastings, and was felt over a considerable area (Fig. 10). In the central region, the quake consisted of two shocks, the second being significantly stronger. Vibrations quickly intensified and continued for 2 1/2 minutes, making it difficult to stand upright. This earthquake turned out to be more severe than all previous quakes in New Zealand. More than 250 people perished in the quake and numerous aftershocks continued for more than a month.

Subsequent geological investigation revealed that the earthquake was apparently caused by a thrust in an easterly direction along a fault or system of faults having a northeastern attitude (see Fig. 10 inset). The shore in the area of Napier lifted up 1.8 m (6 feet), and 18 km (10 miles) farther north the uplift increased to 2.7 m (9 feet). Farther north the lift diminished and in the area of Wairoa there was no uplift at all. The coast south of Napier sank 1/4 to 1 m (1-3 feet). Subsequent depth sounding revealed that the uplift had also affected the bottom of the bay adjacent to Napier. The navigation channel in Napier became shallower by 1.8 m (6 feet). Along the coast of Hawke Bay many cave-ins and landslides occurred.

The sea level changed during and immediately after the earthquake, which basically reflected tectonic displacements of blocks of the earth's crust. There is almost no information about the origin of a tsunami.

Thus in Napier, after the main shock, the water along the coast receded and a considerable strip of the bottom was left dry (Fig. 11). The frightened inhabitants, fearing a tidal wave, climbed a hill (Sind Island), but the wave did not materialize.

In the Port of Ahuriri, adjacent to Napier, the water began to recede from the inner harbour along the canal into Hawke Bay shortly after the main shock. After several hours the harbour was drained, leaving only numerous pools with stranded fish in them. The vessel

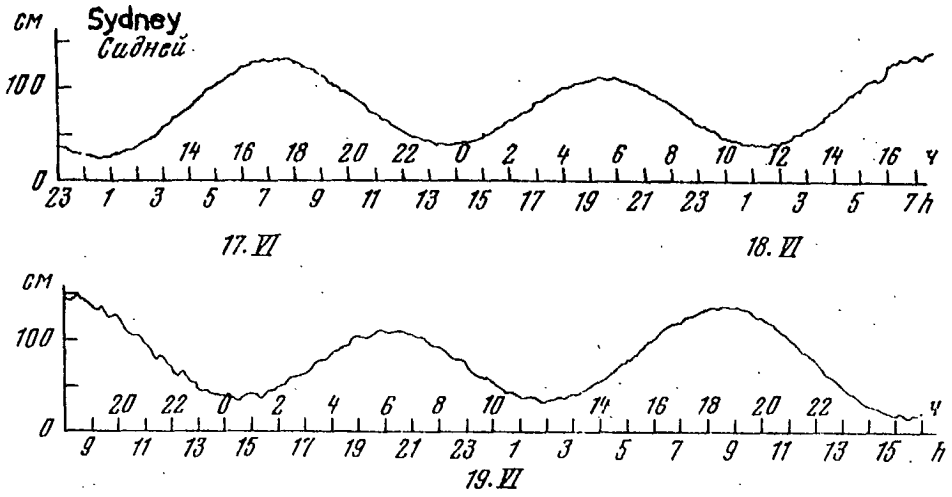


Fig. 9

An Australian tide gauge record of the sea level oscillations caused by the earthquake of 17.VI.1929 (Hart, 1931).

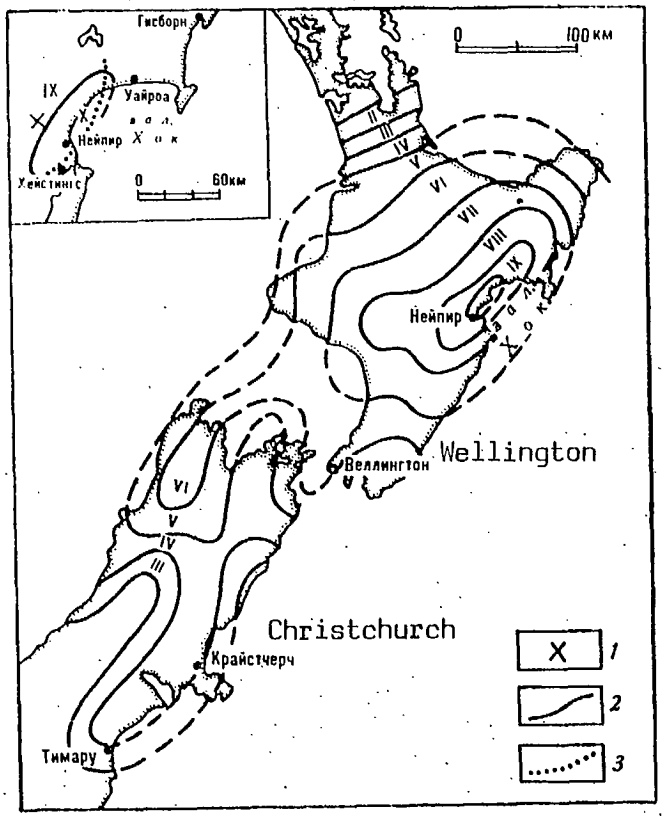


Fig. 10

The surface effect of the earthquake of 3.II.1931 (Callaghan et al, 1933).

1 - epicentre

2 - isoseists on the Rossi-Forell scale

3 - line of zero vertical displacement

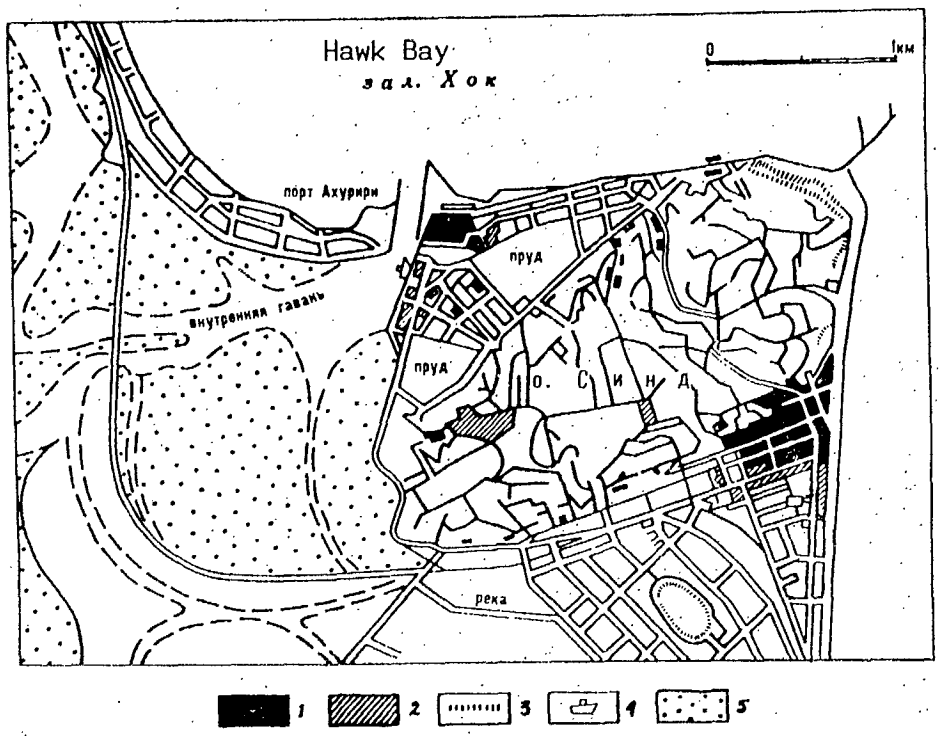


Fig. 11

The cons "iences of the earthquake of 3.II.1931 in Napier (Callaghan et al, 1933).

1 - areas which suffered from the earthquake and the fires which broke out after it;
2 - areas which suffered from the earthquake
3 - locations of landslides
4 - the ship "Veronica"
5 - low-lying areas which became flooded by waves after the earthquake

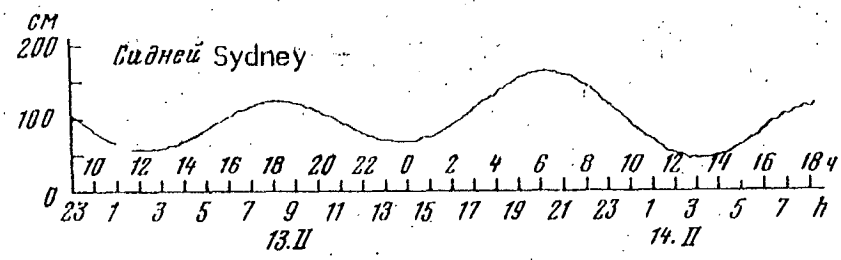


Fig. 12

An Australian tide gauge record of the sea level oscillations resulting from the earthquake of 13.II.1931 (Hart, 1931).

"Veronica," which had recently been launched, ran aground. Other sources reported that a strong ebb had been followed by a moderate flow which had failed to cover the entire bottom of the bay. To some observers on vessels lying at anchor 5 1/2 km (3 miles) from Napier, it seemed as if the city first lifted and then sank after the quake began. The water around the vessels became turbid (SN, 1931, vol. 21, N 1; Bois, 1931 b; Sieberg, 1932; Callaghan et al., 1933; Davison, 1934, 1936; Laing, 1954; Richter, 1963).

Gutenberg, Richter (1954): 2.II; $22^h46^m42^s$; 39.5° S., 177° E.; M=7.75.

1931, February 13 (13:27). A strong aftershock, which was followed by repeated tremors, was recorded in Napier and it had a strength of 7 degrees (VIII according to R.F.) on the coast.

Tsunami-type sea level oscillations were registered on a tide gauge at Fort Denison 28 hours after this shock (Sydney, Australia). The wave had a height of 10 cm and lasted for a period of 35 minutes (Fig. 12). According to the author of this article, this tsunami had reflected from South America (Hart, 1931).

Gutenberg, Richter (1954): 13.II; $1^h27^m16^s$; 39.5° S., 177° E.; M=7.1.

1931, February 19. A severe earthquake in Hawke Bay caused a /22
fluctuation of the sea level, which was recorded by a tidal gauge in Wellington at noon. The reflected wave arrived here approximately 30 hours later. The seismic observatory in Riverview did not record the earthquake (Hart, 1931).

1932, September 16 (1:25). A destructive earthquake occurred on the north shore of Hawke Bay and in the area of Poverty Bay. It was very strong in Gisborne and Wairoa where many buildings suffered serious damage. In Gisborne, several houses were completely ruined and in Wairoa an old bridge, damaged by the earthquake of 3.II.1931, collapsed, as did a newly constructed bridge. Reports from Wairoa told of some subsidence of the ground close to the river. Five inhabitants were seriously hurt, /23
one in Gisborne and four in Wairoa. The earthquake was felt in most areas of the North Island (Fig. 13). It was accompanied by a large series of aftershocks, whose epicentres were located in the sea in a strip extending from Makhia Peninsula (Hayes, 1937).

According to unsubstantiated information, the earthquake generated a large ocean wave (SN, 1932, vol. 22, N 4; SN, 1933, vol. 23, N 3; Laing, 1954; Richter, 1963).

Gutenberg, Richter (1954): 15.IX; $13^h54^m54^s$; 39° S., 177.5° E.; M=6.8.

1948, March 26 (8:33). There was an earthquake with its source in the ocean near Gisborne. The town was damaged. On the north shore of

Hawke Bay the quake had a force of 4 degrees. The quakes generated a tsunami which arrived in Gisborne at 09:20. The largest rise in the water level was observed about 15 km (8 miles) north of Gisborne on the low-lying shore between Whangara and Tatapuri. Eyewitness reports agreed that the second wave was the largest, for it reached a height of 9-10 m (30-35 feet). Houses, roads, and fields were damaged, although only a short distance of the shore was flooded. It is possible that the tsunami resulted from a landslide (SN, 1947, vol. 37, N 2; ISS; Gutenberg, Richter, 1954; Rothe, 1951; Laing, 1954; Richter, 1963; Iida et al., 1967). /24

[25.III; $20^h32^m14^s$; 38 3/4° S., 178 1/2° E., 20 km; M=7.]

1950, March 14 (6:11). An earthquake was felt along the coast of the Gulf of Plenty and north of Hawke Bay with an intensity of 6 degrees. It was preceded by a foreshock of magnitude M=5.25 and followed by aftershocks, all of which generated unusual oscillations of the sea level along part of the shore of the Gulf of Plenty (Hayes, 1952 a,b; Eiby, 1968). /26

[ISS]: 13.III; $18^h10^m41^s$; 37.8° S., 177.2° E.; M=5.75.

1958, November 4. An earthquake with its source within the area of the East Pacific Ridge generated a tsunami which was recorded by a number of tide gauge stations. After 15.6 hours the wave arrived at Midway Island (see Fig. 77) and was recorded there with an amplitude of 10 cm and a period of 12 minutes (Brazee, Cloud, 1960; Iida et al., 1967; Pararas-Carayannis, 1969). The latter source expresses reservations regarding the authenticity of the reports on this tsunami.

[4.IX; $22^h54^m46^s$; 50° S., 115° W.; M=6.1.]

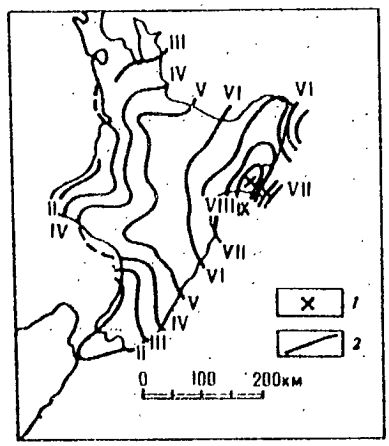


Fig. 13

Epicentre (1) and isoseists (2) on the Rossi-Forell scale of the earthquake of 16.IX.1932 (Hayes, 1937).

CHILE, PERU, SOUTHERN ECUADOR

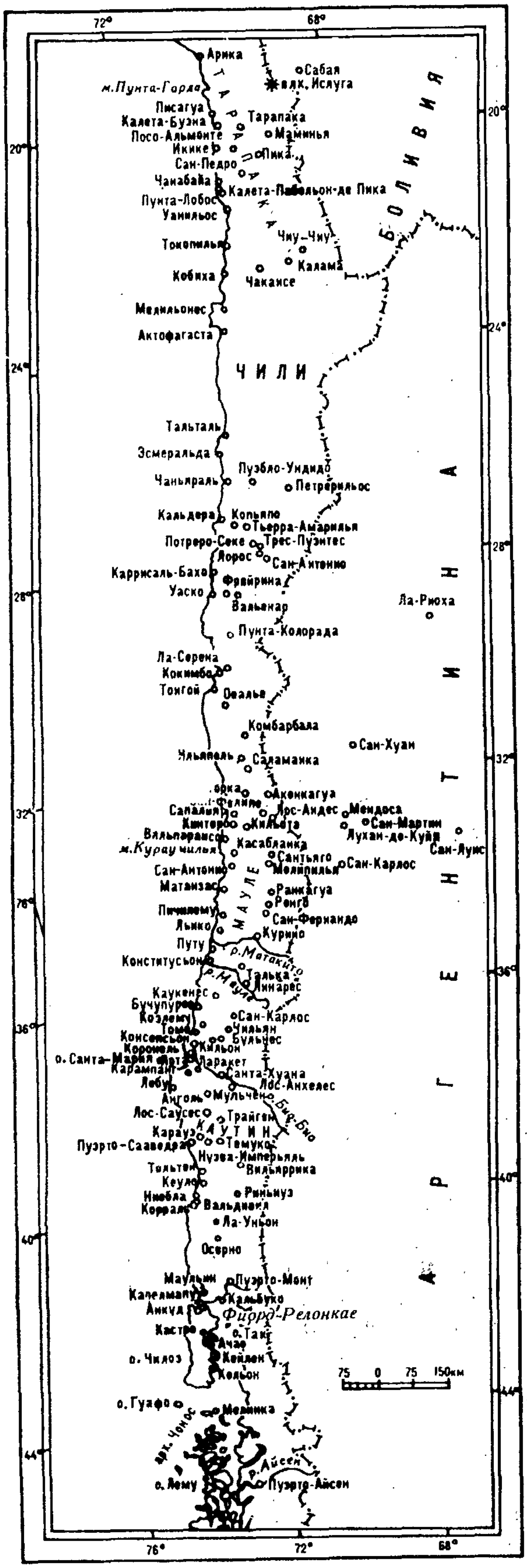
Peruvian Legends. Based on accounts of A. Herrera, who at the beginning of the XVII century had studied the history of the Peruvian Indians, a legend existed according to which there had been a huge flood, many years before the rule of the Incas, at a time when the country was very densely populated. The ocean overflowed its boundaries, dry land was inundated, and almost all the people were drowned. Indians of the Guacas tribe, who lived in Csauska* Valley, and the aborigines of Chiquito* in the province of Callao, related that despite the flood, some people had managed to survive in caves on the high mountains and from them came the people who once again populated the country. The Indians of other mountain tribes maintained that, at the time of the flood everyone had perished except six persons, who had saved themselves on a raft, and it was they who became the progenitors of a new population (Ulloa, 1787; Lyell, 1868).

1513/1515. According to ancient Indian chronicles, Peru has had severe earthquakes in the past - severe enough to cause high mountains to collapse. Coastal inhabitants have reported that, during such earthquakes the ocean level has shown marked fluctuations (Silgado, 1968). [Were such observations recorded in Japan as well?]

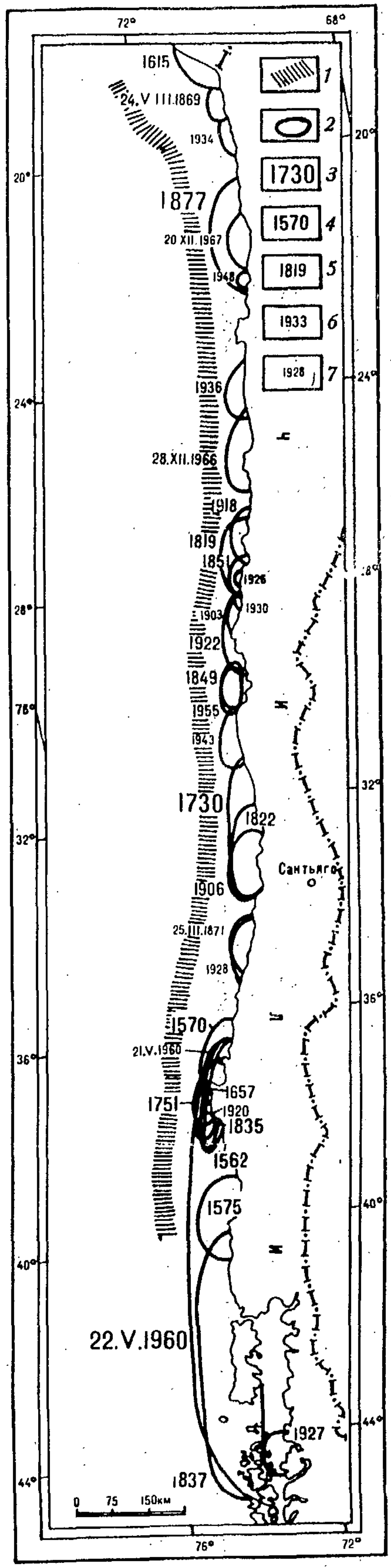
1562. [Usually indicated as October 28, but no reliable data is available.]

A severe earthquake, in which many houses were destroyed, is reported to have occurred in Concepcion and Arauco at dawn (Figs. 14, 16, 17). According to the chronicles, the earthquake caused topographical changes such as the disappearance of some hills and lagoons and the appearance of others. Apparently, the source of the earthquake was situated between 37° and 39° S. (Fig. 15).

The tsunami that followed the earthquake affected the coast for a distance of 1200 km (300 leagues) and caused numerous deaths amongst the Indians.



72°
68°
Арика
м.Пунта-Горда
Сабая
вдк. Исцуга
Писагуа
Калета-Буэна
Посо-Альмонте
Тарапака
Икике
Пика
Сан-Педро
Чанабайа
Пунта-Лобос
Уанильос
Токопилья
Чиу-Чиу
Кобиха
Чакансе
Калама
Мехильонес
Антофагаста
ЧИЛИ
БОЛИВИЯ
Тальталь
Эсмеральда
Пуэбло-Ундидо
Чаньяраль
Петрерильос
Кальдера
Копьяпо
Тьерра-Амарилья
Потреро-Секе
Трес-Пуэнтес
Лорос
Сан-Антонио
Каррисаль-Бахо
Фрейрина
Уаско
Вальенар
Ла-Риоха
Пунта-Колорада
Ла-Серена
Кокимбо
Тонгой
Овалье
Комбарбала
Сан-Хуан
Ильяпель
Саламанка
Аконкагуа
Лос-Андес
Мендоса
Сан-Мартин
Лухан-де-Куйо
Сан-Луис
м.Курау
Касабланка
Сантьяго
Мелипилья
Сан-Карлос
Сан-Антонио
Матансас
Ранкагуа
Ренго
Сан-Фернандо
Курико
Путу
р.Матакито
Конститусьон
Тальна
р.Мауле
Линарес
Каукенес
Бучупурео
Сан-Карлос
Кильон
Булнес
о. Санта-Мария
Карампанге
Лебу
Санта-Хуана
Лос-Анхелес
Мульчен
Лос-Саусес
Трайгвен
КАУТИН
Пуэрто-Сааведра
Темуко
Нуэва-Империаль
Тольтен
Вильяррика
Рининуэ
Вальдивия
Ла-Унион
Осорно
Пуэрто-Монт
Кальбуко
Фиорд-Релонкае
Анкуд
Кастро
о. Чилоэ
Кельон
о. Гуафо
Мелинка
арх. Чонос
р. Айсен
о. Лему
Пуэрто-Айсен
АРГЕНТИНА
75 0 75 150км
76°



72°
68°
1615
24.VIII.1869
1934
1877
20.XII.1967
1948
1936
28.XII.1966
1918
1819
1851
1926
1930
1903
1922
1849
1955
1943
1730
1822
Сантьяго
1906
25.III.1871
1928
1570
21.V.1960
1657
1751
1920
1835
1562
1575
22.V.1960
1927
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1
2
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1570
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1819
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1933
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1928
7
0 75 150км
76°

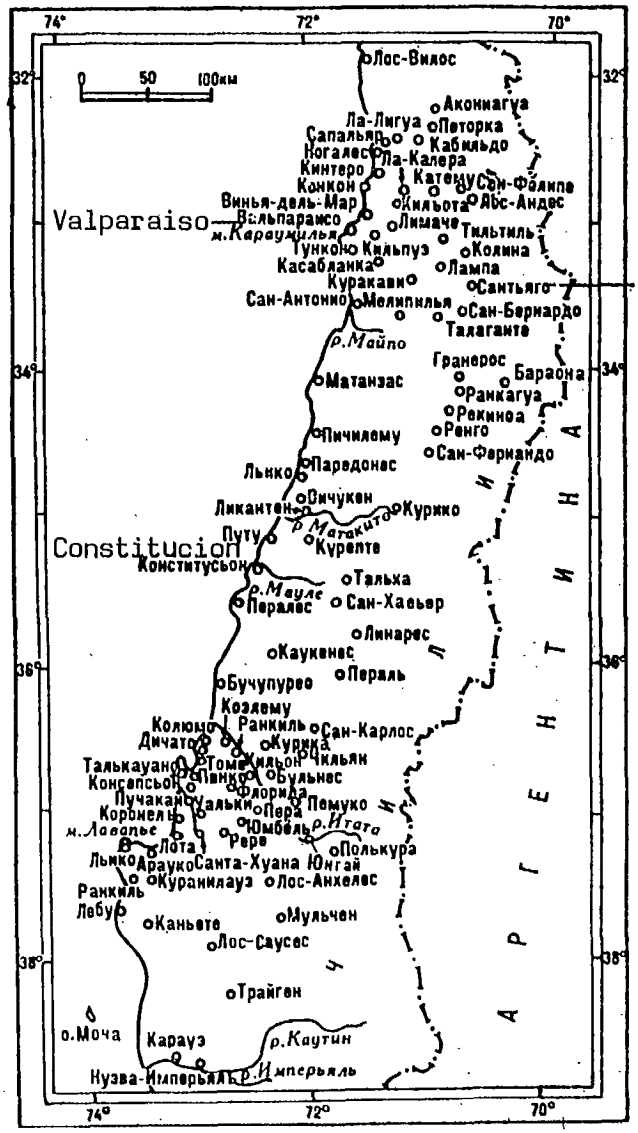


Fig. 16

General map of central Chile.

Fig. 17

General map of the environs of Concepcion.

Opposite page:

Fig. 14 (far left) A general map of Chile.

Fig. 15 (left) Centres of tsunamis in Chile.

1 - deep ocean trench

2 - centres of tsunamis (definite or likely)

3 to 7 - date and intensity of the tsunami I:

3 - I=4; 4 - I=3; 5 - I=2; 6 - I=1; 7 - I≤0

This first known tsunami in Chile occurred in the 21st year after the arrival in the country of the Spanish conquistador, Pedro de Valdivia (Acosta, 1621; Parish, 1836; Perrey, 1854 c; Montessus de Ballore, 1911 b, 1912; Milne, 1912 b; Sieberg, 1932; Bobillier, 1933, 1934; Heck, 1933, 1934, 1947; Navarette, 1933; Gutenberg, Richter, 1949, 1954; Anon., 1961; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967).

1570, February 8 (09:00). A severe earthquake struck the coast between 36° and 38° S. In Concepcion, then situated on the ocean shore in the area of the present city of Penco and consisting of several dozen houses, the majority of structures collapsed. Santiago also suffered damage. "The earthquake toppled mountains and blocked rivers which then began to form lakes." The ground developed cracks from which hot water, mud and sulphurous gases issued forth. The tremors continued for five months.

According to several ancient sources, the ocean near Concepcion receded for ten kilometres (several leagues) and then completely inundated the town, completing its destruction and leaving ships on dry land. Several other settlements were completely washed away. Although the majority of the inhabitants managed to save themselves by moving to higher ground after the first strong ebb, more than 2000 persons perished.

According to Montessus de Ballore and Lomnitz, the tsunami began with the tide that inundated the greater part of the town. Subsequently, the ocean receded further than usual, only to return several times with great onslaught, flooding the town. None of the Spanish apparently lost their lives (Acosta, 1621; Montbeillard, 1761; Parish, 1836; Hoff, 1840; /28
Perrey, 1854 c; Mallet, 1855; Anon., 1877; Goll, 1903; Montessus de Ballore, 1911 a, 1912, 1916; Milne, 1912 b; Sieberg, 1932; Bobillier, 1933, 1934; Navarette, 1933; Davison, 1936; Heck, 1934, 1947; Gutenberg, Richter, 1949, 1954; Anon., 1961; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967; Lomnitz, 1970; Silgado, 1974).

[The descriptions of this and the preceding tsunami are very similar. The information in the above catalogues is based on various and sparsely detailed original sources. Therefore, it is possible that in reality only one catastrophic tsunami occurred in 1570.]

1575, December 16 (approximately 15:00). A severe earthquake caused heavy damage to Valdivia, Angol, Nueva Imperial, and damaged the surrounding areas approximately from Villarica to Osorno. The quake was felt in the area between Castro, which was also destroyed, and Concepcion. The number of deaths were comparatively small (21), because the force of the tremors increased gradually and the inhabitants had time /29
to flee from their homes. The tremors continued for a period of forty days. Sizeable cracks appeared in the ground and landslides were also recorded, a river flowing from Lake Riniue became blocked in its upper reaches. The dam lasted until April of the following year, when after prolonged rains the water level in the lake rose considerably, causing the dam to burst and resulting in much devastation farther downstream; more than 1200 Indians perished and many cattle were lost as well.

The earthquake caused a powerful tsunami in the area of Valdivia, located on a river of the same name about 25 km upstream from its mouth. The earth continued to shake for a quarter of an hour when the water came rushing upstream, reversing the natural flow of the river. The rising water knocked over houses, poles and uprooted trees. Two galleons, riding at anchor in this port were sunk (other accounts said they were washed up on the shore). After the ebb, the inhabitants had time to flee to higher ground. About a hundred Indian fishermen were drowned near the mouth of the Imperial River.

In Concepcion Bay, the tsunami caused no damage. There is no information about the occurrence of this tsunami in other areas (Goll, 1903; Montessus de Ballore, 1911 b, 1912, 1924; Sieberg, 1932; Bobillier, 1933, 1934; Navarette, 1933; Heck, 1947; Gutenberg, Richter, 1949, 1954; Anon., 1961; Berninghausen, 1962; Montandon, 1962; Ponyavin, 1965; Iida et al., 1967; Lomnitz, 1970; Silgado, 1974).

1586, July 9 (19:00). There was a severe earthquake in Peru (Figs. 18, 19), which affected an area along the coast for 1000 km (according to other data, 700 km) and 120 km inland (other data, 200 km). Lima, for the most part, was destroyed, the towers of the cathedral collapsed. Several strong shocks were recorded. Frightened by the ominous rumbles which preceded the shocks, the inhabitants ran from their houses. But not everyone got out in time, for 14 to 22 persons (by various accounts) perished under the wreckage of the houses. Callao, Chancau, Ica, and possibly Cusco and Trujillo were also substantially damaged.

In Callao, the sea level fell by 14 m after the earthquake and then rose 24 m (14 fathoms), inundating the land for a distance of 250 m, destroying everything in its path and washing the dikes away. Trees and bushes were uprooted and carried away by the water. The wave loosened the anchors of ships lying in the harbour.

According to an inscription on a monument in Tokura* (the prefecture of Miyagi), a tsunami arrived at the northeast shore of the island of Honshu, where it reached a height of 1-2 m (Acosta, 1621; Frezier, 1717; Montbeillard, 1761; Parish, 1836, 1838; Hoff, 1840; Mallet, 1855; Perrey, 1858; Anon., 1877, 1961; Sieberg, 1929, 1932; Heck, 1934, 1947; Iida, 1956; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967; Silgado, 1968, 1974).

Not later than 1590. An earthquake in Chile resulted in salt water moving ten kilometres inland, leaving ships stranded on dry land (Parish, 1838; Perrey, 1854 c). [Most likely this refers to the tsunami of the year 1562.]

1590. A severe earthquake in Cusco affected almost the entire southern coast of Peru. Camana was destroyed as a result of flooding from the ocean and from blocked rivers (Silgado, 1968).

1604 (erroneously 1605), November 23 or 24 (erroneously 26 and 29) [13:30]. There was an earthquake and tsunami in Peru and in the

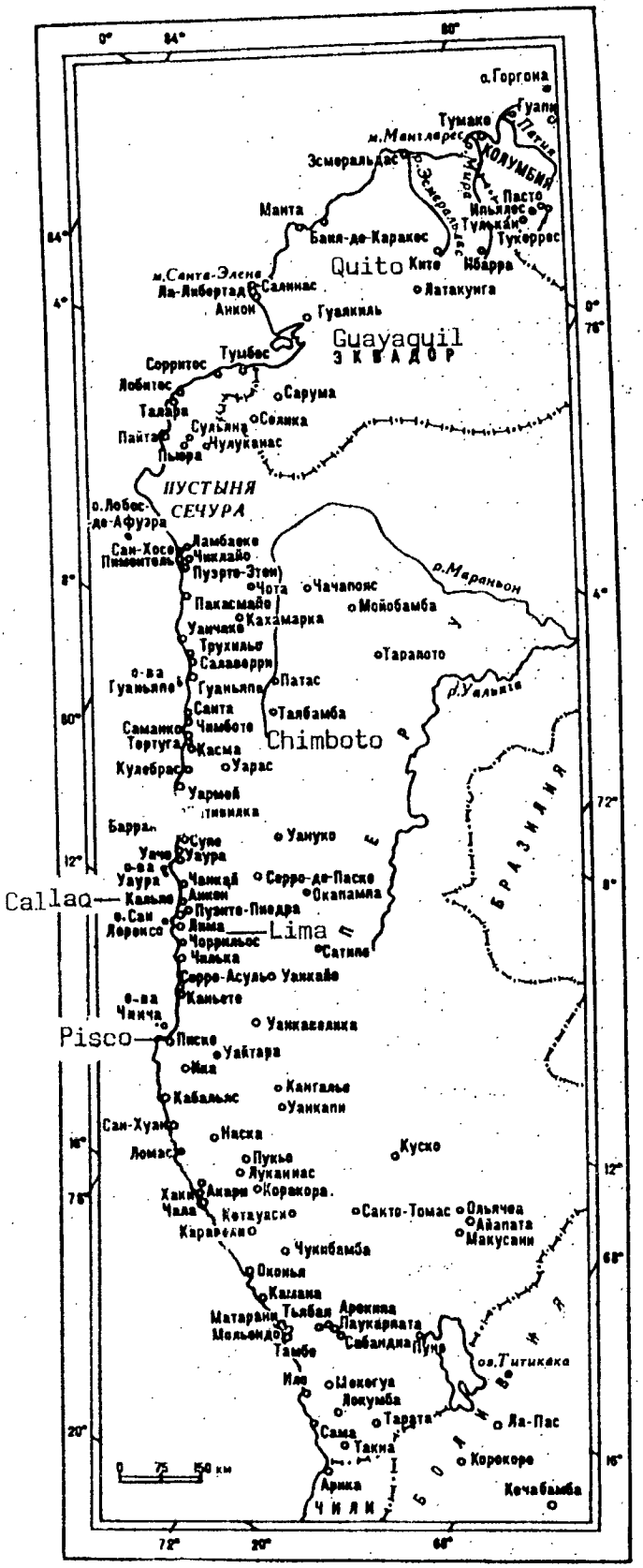


Fig. 18

General map of Peru and Ecuador.

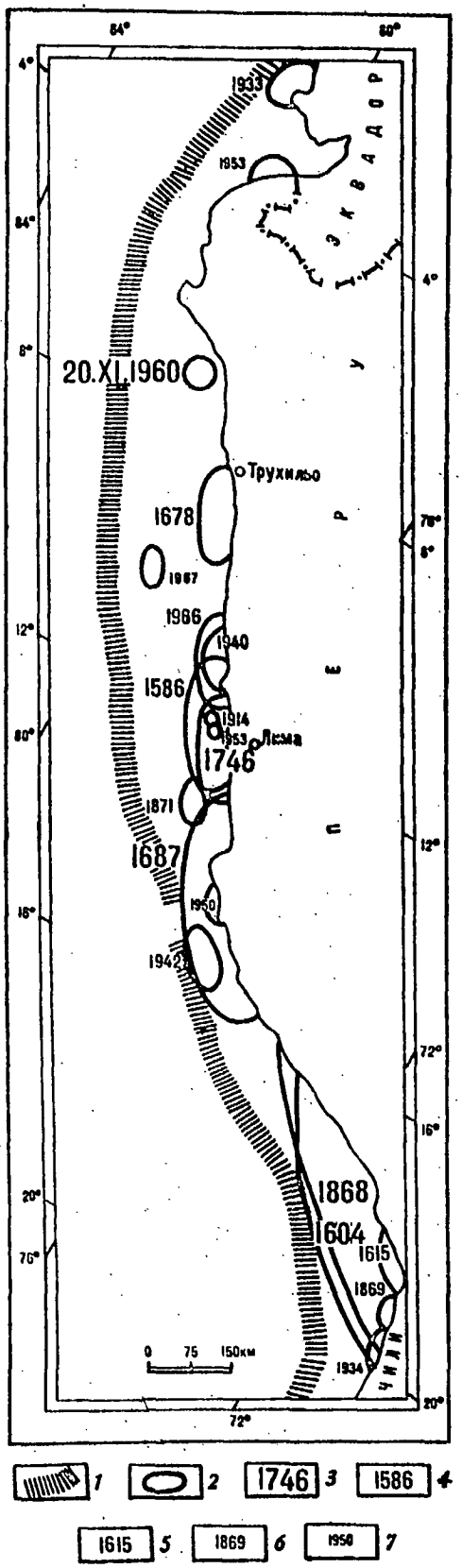


Fig. 19

Centres of tsunamis in Peru and southern Ecuador.

1 - deep ocean trench;

2 - centres of tsunamis (definite or likely);

3-7

- dates and intensities of the tsunamis I:3 - I=4; 4 - I=3; 5 - I=2; 6 - I=1; 7 - I=0.

northern part of Chile.

The source of the earthquake was evidently situated close to Arequipa. The tremors affected an area of 1650 km along the coast (according to other information 1200 km) and 130 km inland (280 km /31
according to other sources). Numerous landslides, avalanches, subsidences, depressions and ground cracks were observed. Arequipa was almost completely destroyed; only San Francisco Monastery was preserved. During the tremors it was impossible to stand upright. The collapsing buildings generated a thick dust which darkened the sky as if night had arrived, and people almost suffocated as they fled the city in fear. Most of the small rivers disappeared because their source dried up. Canals, which had cost the government a great deal of money, collapsed. The shocks continued for about a quarter of an hour. Also destroyed were Ica, San Marcos de Arica, and all the settlements between 16° and 20° S. Estimated losses amounted to more than a million gold pesos.

These problems were compounded by the appearance of a tsunami which flooded the coastline for a distance of 1200 km (300 leagues). Arica suffered most of all. According to a report of the governor of Arica, the ocean receded a distance of two musket shots further than its normal low water point, and then, while the tremors were still occurring, raged with such force that it covered the islet of Alacran*, situated opposite the high part of the city. A barrack-type building (wooden or adobe) was carried away with this first wave. The second shock, which occurred 15 minutes after the first ebb, caused the water to recede again, only to reappear in rising form, sweeping the town and carrying away warehouses, stores, and a large church, and advancing another 100 m inland and destroying all houses. Subsequently, the water receded to the point where the anchors of all ships were exposed.

The turbulence of the ocean generated a mist which obscured the entire coast. Out of this mist came a mountain-like water wave rolling upon Huaiacana* and Chacalluta* districts, about 6 km (1 1/2 leagues) /32
from Arica. The water advanced to the slopes of the mountains, cutting through everything in its path, only to be stopped by higher ground and returned through the town again. Three persons drowned in Arica itself, and more than twenty along the coast. A large part of Arica was washed away, including the fort with all its guns and store of weapons and artillery. Formerly ploughed fields were left strewn with dead fish, some of them previously unknown species. After this disaster the town was moved to higher ground (where, however, it was repeatedly destroyed by new strong earthquakes and tsunamis). Frezier, who visited Arica at the beginning of the 18th century, could still see the ruins of the old town.

In Ilo, the water rose to a point where it advanced almost 2 km (1/2 league) inland along a valley uprooting 100-year old fig trees. Eleven Indians were drowned. An almost completed frigate, of 35 tons displacement standing at the dock, was smashed to pieces.

Three high tides and ebbs were reported to have occurred in

Camana. The water advanced along a valley for more than 2 km (1/2 league), destroying everything in its path. Forty persons were washed away and drowned.

In Pisco, the water receded a considerable distance beyond its usual low point. The inhabitants ran to the beach to witness this unusual occurrence. "However, they immediately noticed that the ocean was swelling, seething and foaming; the waves roaring, mingling with each other, resembling mountains of water which swiftly advanced upon the shore. Any thought of outrunning these giant waves seemed futile." However, when the water reached the dykes, its main thrust was split in two directions, as it were, one branch flowing to the right and the other to the left, thus saving part of the town. The wave had a height of 3 1/2 m (2 fathoms) and it inundated a large section of dry land.

In Callao, the water level did not rise as much as at other points; but here the port, though not inundated, was cut off by the wave from the rest of the town and large pools of water existed for several days between Callao and Lima.

At 17:00, rising water inundated the larger part of Concepcion, destroying several sections of the stone wall that surrounded San Francisco Monastery, which stood 300 m from shore. Huge rocks were carried away like straws. The monks climbed over the wall to escape from the rising flood, which left fish and shellfish on the floors of the monastery. The rising water also destroyed a stone reinforcement whose stones had been carried for up to 5 m (20 feet) (Frezier, 1717; Montbeillard, 1761; Parish, 1936, 1838; Perrey, 1858; Montessus de Ballore, 1911 a, 1916; Sieberg, 1929, 1932; Bobillier, 1933, 1934; Severit, 1933; Heck, 1934; Gutenberg, Richter, 1949, 1954; Anon., 1961; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967; Silgado, 1968, 1974; Lomnitz, 1970).

1615, September (November) 16, evening. Eleven years after the earthquake and tsunami of 1604, Arica was again destroyed by a strong earthquake. The main church and the fort were among the buildings destroyed. Although there was no loss of life, damage was sustained over an area all the way to Tacna. A large number of aftershocks were reported.

The tsunami, which appeared in the same areas as the tsunami of 1604, did not cause serious damage. Two small negro children were almost drowned (Bobillier, 1933; Heck, 1934, 1947; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967; Lomnitz, 1970).

1633, May 14 (at daybreak). The inhabitants of Fort Carelmapu on the island of Chiloe, were awakened by a deafening sound, and at the same time a strong earthquake destroyed the fort. The massive gates, which could be raised only with the help of a large detachment of soldiers, were torn from their supports. Deep cracks appeared in the earth, houses and churches were destroyed, and corpses were hurled from their graves.

Subsequently, the water level rose, carrying away houses and people. Two ships were lost in the harbour.

Thick clouds darkened the sky, culminating in a long hailstorm accompanied by thunder and lightning. A ball of fire seemed to roll slowly from the top of one of the nearby hills into the ocean (Perrey, 1854 c; Goll, 1903; Navarette, 1933).

1647, May 7 (date unreliable).

The catalogues (Perrey, 1854 c; Montessus de Ballore, 1912) /33
contain a detailed description of a catastrophic earthquake on May 13, 1847, in the Santiago and the neighbouring areas of Chile. One of the accounts about this earthquake dated July 12, 1648, refers to other unusual natural occurrences during that year, including the following:

In Cusco (Peru), an earthquake occurred which caused damage in the immediate shore area but not farther inland. On the day of the earthquake, the water level rose with such force at the Callao pier that part of the breakwater was carried away.

On May 7, the vessel "St. Nikolai," which carried cargo from La-Ligua, was smashed in the port of Arica as a result of an unusually forceful rise in the sea level, yet without any evident signs of a storm; 14 persons perished and material losses exceeded 200,000 pesos (francs).

Strange and unusual movements of the sea were reported by fishermen from all ports along this entire coast. The ocean waves were sufficiently high to submerge the highest hills on shore.

Short descriptions of the tsunami are given in the catalogues (Davison, 1936; Montandon, 1962; Iida et al., 1967).

1657, March 15 (20:00 hours). A strong earthquake occurred in Chile between the provinces of Maule and Kautin, approximately between 36° and 39° S. This quake affected an area to the south all the way to Chillan, where the only remaining church of that region was destroyed. Reports of destruction in Santiago apparently were erroneous, for if the earthquake was felt there, it was very weak.

By this time, only Concepcion (all of modern Penco), with a population of 20 thousand, remained in Spanish hands, and it was besieged by insurrecting Indians. The earthquake was accompanied by a frightful rumbling sound, almost as if it were rolling through mountain canyons. People could not stand on their feet. Although the earthquake was weaker than some earlier quakes, most of the buildings were completely destroyed (it is not clear whether from the earthquake or the tsunami), and only one cathedral remained standing. A fire ball is said to have appeared in the sky "bounding about the clouds like a wagon wheel." After the earthquake, the sea level rose and exceeded its normal high mark "with ruthless fury." The tsunami, which may have started with an ebb, affected a considerable section of the shore. In fact, there were at least three

large waves. The largest and most destructive wave occurred in Concepcion two hours [?] after the earthquake and, it appears, unexpectedly for the population. The water inundated the lower sections of the town and reached the centre of the main square. The area along the river in the eastern part of town suffered particularly heavy damage, because here there were fewer houses to break the impact of the wave. One vessel was hurled into the residential area. About forty persons perished from the affect of this tsunami.

After the earthquake and tsunami, the frightened Indians lifted their siege and departed (Montbeillard, 1761; Goll, 1903; Montessus de Ballore, 1911 b, 1912; Milne, 1921 b; Sieberg, 1932; Bobillier, 1933, 1934; Navarette, 1933; Heck, 1934, 1947; Gutenberg, Richter, 1949, 1954; Anon., 1961; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967; Lomnitz, 1970; Silgado, 1974).

1657, July 9. An earthquake partially destroyed Santiago. The sea along the coast near Valparaiso was very turbulent since dawn (Navarette, 1933).

1678, June 17 (other sources give 8 January) [19:45]. An earthquake occurred in Santa (Peru), and the sea receded to within visible range from shore and it remained there for 24 hours, according to an Indian narrator. Then the sea level rose and the waves "rushed and rolled" with such force that three small vessels of 60-100 tons displacement, which were riding at anchor in the open road, were tossed over the hill on which the town was situated. Their hulls were seen in October 1685 by an English traveller (L. Vafer), who also published a story about this event. The town was completely washed away, but later it was rebuilt /34
5 1/2 km (3 miles) from shore and only a solitary sandy hill remains at the former site of the town. The land close to the shore was devastated for a considerable distance.

In Lima, the earthquake was quite severe and partially destroyed the town, including public churches and private buildings. Losses were estimated at three million pesos (Frezier, 1717; Parish, 1836, 1838; Hoff, 1840; Mallet, 1855; Perrey, 1858; Anon., 1877; Milne, 1913; Sieberg, 1929, 1932; Heck, 1934, 1947; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967; Silgado, 1968).

1682, October 19 (about 04:00). The city of Lima was almost completely destroyed by an earthquake. During the 24 hours following the earthquake another twenty shocks were felt.

In Pisco, the ocean receded to a point 2 km from the shore (1/2 league), only to rise with such force that the water advanced almost 2 km (1/2 league) beyond its usual high mark. Many people who had followed the receding tide earlier now perished under the onslaught of the rising sea. The town was rebuilt about 1 km (1/4 league) from the shore (Frezier, 1717; Montbeillard, 1761; Perrey, 1858).

[Evidently, the year must be in error, and this tsunami is the

same as that of 20.X.1687.]

1686. There was "a terrible earthquake in Chile, which affected the country in a north-south direction for 1200 km (300 leagues), toppling mountains, changing the course of rivers and resulting in the inundation and destruction of towns" (Perrey, 1854 c; Milne, 1912 b; Davison, 1936; Anon., 1961; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967).

[Evidently, contradictory information, and the reference is to the tsunami of 20.X.1687.]

1687 (erroneously 1690), October 20. Very strong earthquakes were felt in the Lima area. They began at 04:00 (according to other information, 04:30) and were accompanied by underground rumbling. Many houses were destroyed and many persons perished under the wreckage. Another shock, which was preceded by the same kind of rumbling, occurred at 05:00. At 06:00 (or 06:30), prolonged tremors recurred and they were also accompanied by a terrible boom. Church bells rang by themselves, and the buildings that were still standing were also destroyed. However, this time there were few casualties, since the people, on hearing the rumblings, ran into the streets. A total of 100 persons perished in Lima on this occasion.

Damage from this earthquake was reported from as far away as 700 km south of Lima. Settlements along the rivers Ica, Palca, Nasca* and Camana* suf ed particularly heavy damage. A third earthquake inflicted serious damage to the houses and churches of Arequipa. Large crevasses, many kilometres in length, appeared in the earth between Ica and Canete. The damage in Pisco reflected the strong vibrations the area had suffered. The earthquake was felt practically throughout Peru, and according to Montessus de Ballore (1888), it was even felt in Guatemala.

The vessel on which L. Vafer was sailing, about 600 km (150 leagues) from shore at 12° 30' S., experienced a severe seaquake, during which several sailors were thrown from their hammocks and the usual green color of the sea water appeared to turn white. But when it was scooped up, it became clear that it was mixed with sand.

According to the testimony of Captain Forster of the vessel "Davis," the seaquake was felt even at 1800 km (450 leagues) from shore.

The sea flooded the coast between Chancay and Arequipa. In Pisco the sea receded for a distance of 8 km (2 leagues), or, according to other information, for 2 km. The terrified inhabitants fled to the mountains, but some of the brave ones returned to see what was happening on the shore. While they were there, the sea level rose quickly and advanced "in a frenzy" without giving the observers a chance to escape, and thus they perished. The town was inundated and the sea advanced inland. Where the town once was, is now a bay in which ships lie at anchor. The town was rebuilt one kilometre from the ocean shore. According to other /35
reports, all houses in the town were washed away, but the more solidly

constructed fortifications stood up. In Canete and Chincha, a similar inundation destroyed the warehouses in which 140 tons of mercury were stored and awaiting shipment to Acapulco. Chorrilos and Chancay were also inundated.

In Callao, the sea receded 2 km (1/2 league) from shore, or, according to other data, far enough that the water was hardly visible. After some time the sea level rose, rushing in like a mountain of water, submerging the port and city of Callao and tossing vessels 4 km (1 league) inland. This flood claimed both people and livestock along a coastal area of 200 km (50 leagues). In Callao and vicinity about 500 persons perished.

In all, 5000 persons perished as a result of the earthquake and tsunami.

The area affected by the earthquake failed to produce wheat crops for a long time (40 years), and so the ground had to be planted with lucerne and sugar cane.

The tsunami which was generated at the time of the earthquake reached the northeast shore of the island of Honshu. It was at Kamaishi (Iwate prefecture) on October 22 that 12 or 13 waves with a height of 0.5 m were observed. On the island of Okinawa (Ryukyu Island), three unusual waves were recorded on October 22 between 02:00 and 03:00 in the morning (Sloane, 1694; Anon., 1752, 1877, 1961; Montbeillard, 1761; Parish, 1836, 1838; Hoff, 1840; Mallet, 1855; Perrey, 1858; Milne, 1912 b; Vallaux, 1925; Sieberg, 1929, 1932; Heck, 1934, 1947; Imamura, 1949; Iida, 1956; Montandon, 1962; Ponyavin, 1965; Iida et al., 1967; Silgado, 1968, 1974).

1705, November 26 (or 16). An earthquake occurred in Arequipa and Arica, and the wave generated during that quake flooded and destroyed a large part of Arica (Montbeillard, 1761; Mallet, 1855; Perrey, 1858; Goll, 1903; Milne, 1912 b; Heck, 1934, 1947; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967). (Perrey made the suggestion, with which one must agree, that this information refers to the earthquake and tsunami of 26 November 1605.)

1725, March 27. Shocks were felt along the entire southern coast of Peru right up to Callao. High seas caused much damage in Camana (Iida et al., 1967; Silgado, 1968).

1730, July 8 (04:45). The Valparaiso earthquake. A severe earthquake occurred between 01:00 and 02:00 in Santiago. The inhabitants dressed and hurried into the streets. Then followed three less severe tremors. But at 04:45, the area was struck by a shock so severe that people found it difficult to remain standing. A large part of the city was completely destroyed and clouds of dust arose from the ruins. Since the people had had time to flee into the streets, only two women perished. Between 12:00 and 13:00 there was another earthquake, almost equal in force to the previous one. Innumerable tremors continued during

the next two days, and with diminished frequency over several months.

This was one of the most severe earthquakes in the history of Chile. Severe damage occurred approximately between 30° and 36° S., from La Serena to Chillan.

In La Serena, the parish church was destroyed. In Coquimbo, several houses and churches were slightly damaged. The destructive effects of the earthquake were more apparent in the area north of La Serena, but it is difficult to estimate the northern boundary of the effect of the earthquake because that section of the country was not settled at the time. In Chillan, the damage was less than in La Serena, although several buildings were destroyed and the earthquake greatly frightened the inhabitants. In Valparaiso, some houses were ruined, not only in the low areas, but also on the slopes - something that did not occur even during the earthquake of 1906. Only the house of the governor was saved, although it too was damaged, as well as the arsenal and one auxiliary building. Coquimbo and the moutain villages of Illapel, Petorca and Tiltil were seriously damaged. In the mines the machinery for crushing ore broke down. Strong shocks were also felt in Concepcion but they did not cause any destruction. In Rengo, the church was destroyed. The /36
earthquake was strongly felt as well in three mountain provinces of Argentina, where it terrified the inhabitants of Cordoba (see Fig. 28). The source of the earthquake was probably located close to the mouth of the Aconcagua River.

A destructive tsunami, which enveloped the coast for a distance of over 1000 km, occurred almost simultaneously with the second earthquake. For the first time in its history, the port of Valparaiso was flooded and considerably damaged. In the lower area of Almendral, all houses, fortifications and warehouses were destroyed by the flood. Goods prepared for shipment to Peru were washed away with the warehouses. In particular, 80,000 sacks (fanegas) of wheat were lost.

In Concepcion, the sea receded a great distance, only to "swell" and advance so quickly that it swept everything in its path, inundating the fields and town. There were three large flows, the second of which had the greatest effect. The water level rose higher, perhaps, than in 1657 and inflicted greater damage. Two-thirds of the town was destroyed, including more than 200 houses and buildings located in the lowest part of town adjoining the beach, the palaces of the governor and the bishop, the town hall, churches, monasteries, prisons, barracks, hospitals and stores. However, only two or three persons perished, since the inhabitants, on first noting the receding sea, ran for the hills from where they watched the destruction of their houses and their property. This was the third time Concepcion was destroyed since its founding.

In Valdivia, the river was backed up by the ocean flow. The flood inflicted some destruction but was unable to damage the fortifications on the main square.

In Coquimbo, the tsunami destroyed several ranches on the shore.

In Callao and environs on the 8th of July, it was noted that the sea level slowly rose. It rose to cover the parapet of the walls constructed for protection against storms. Then the water receded very slowly for a few steps. This phenomenon continued all day and part of the next.

The waves reached the northeastern coast of the island of Honshu. In the prefecture of Miyagi, on the Djika Peninsula, on July 9, houses and rice fields were flooded (Montbeillard, 1761; Molina, 1786; Parish, 1836, 1938; Perrey, 1854 c; Mallet, 1855; Lyell, 1868; Anon., 1877, 1961; Goll, 1903; Montessus de Ballore, 1911 a, 1912; Milne, 1912 b, 1913; Sieberg, 1932; Bobillier, 1933, 1934; Navarette, 1933; Heck, 1934, 1947; Davison, 1936, 1949; Imamura, 1949; Iida, 1956; Gutenberg, Richter, 1949, 1954; Hewitt, 1957; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967; Lomnitz, 1970; Silgado, 1974).

1737, December 24. An earthquake destroyed Valdivia and a large part of the settlements on the archipelago (the island of Chiloe and others in the southern part of Chile). This earthquake was even more severe than that of 1633 (Goll, 1903; Lomnitz, 1970). [Included by Goll, with a question mark, in the list of tsunami-generating earthquakes.]

1742, March 23. There was a strong earthquake and tsunami in Concepcion (Navarette, 1933). [Erroneous information?]

1746 (erroneously 1724), October 28 (22:30). In Lima, a rumbling sound was accompanied by strong shocks. This earthquake exceeded all previous quakes that had occurred in this area since the city was founded. In 3-4 minutes the capital was completely destroyed. Of 3000 houses, only about 25 remained standing and even they were seriously damaged. All offices and all 74 churches were destroyed or damaged. The streets were so clogged up with wreckage that it was hardly possible to get through them. Nevertheless, despite the late hour and almost complete destruction of the buildings, of the 60 thousand (by other sources, 30 thousand) population of the city only 1141 persons perished. [Evidently, the vibrations increased in strength, which made it possible for the inhabitants to flee from their homes.]

The disrupted area embraced 44,000 square kilometres. In the north the quake was felt in Guayaquil, that is, about 1100 km from Lima, and at a Jesuit mission situated at the junction of the Maranon and Hualaga Rivers, about 750 km from Lima. A rush of water rose on the Maranon River. In Huancaveliqua, to the south-southeast of Lima, "severe shocks" accompanied by a rumbling sound were observed. /37

Buildings collapsed south of Lima all the way to Canete, and north to Chancay (Fig. 20). About 120 km north of Lima, a new bridge spanning the River Huaura collapsed as well. The roads leading inland were blocked by cave-ins, and landslides and cave-ins occurred near Lucannas. Near Patas, in the Convenciones-de-Cacsa-Marquita* Mountains, new mineral springs appeared. The valleys of Supe, Baranca and Pativilqua were greatly damaged, either by the earthquake or by a

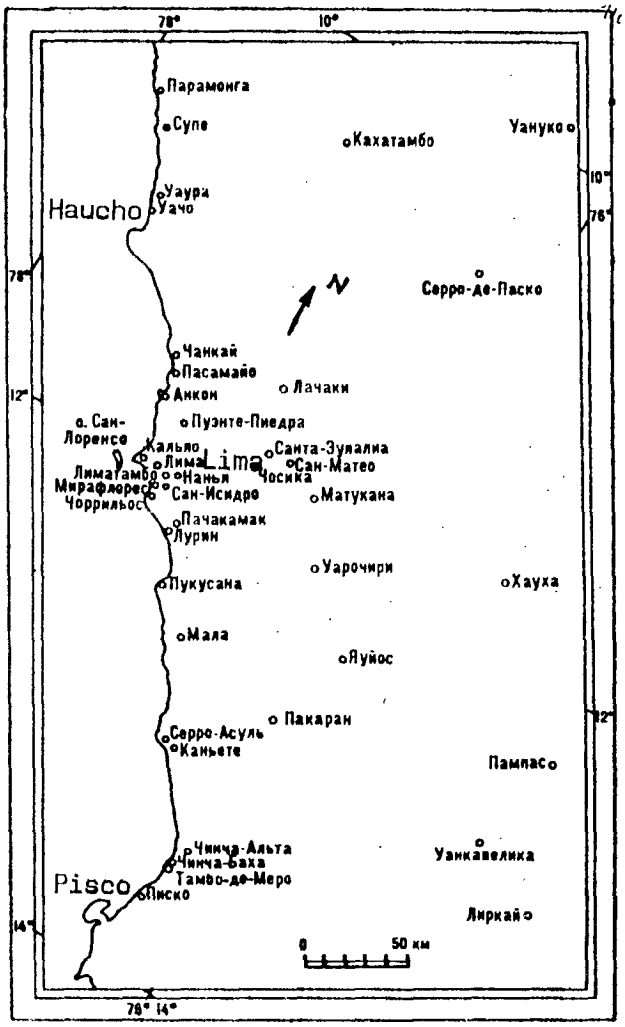


Fig. 20

A general map of central Peru.

tsunami. The shocks were also felt in Cusco, Tacna, and the bordering settlements. According to Sieberg's estimate, the intensity of the earthquake in Chancay, Janja and Pativilqua was 8 degrees and in Tacna, 6 degrees.

Repeated tremors continued in Lima throughout the night, and over a period of 24 hours, no fewer than 200 of them were counted. Up to 24 February, almost 500 subterranean tremors were recorded; however, none of them was so severe as to cause casualties or new serious damage.

The port of Callao suffered most of all from this catastrophe. Like Lima, Callao consisted mostly of single-storey houses on a low terrace, whose height was no greater than 3 m (9-10 feet) above the high water mark. The town was enclosed by a fortress wall, whose base was sometimes washed by the strong ocean tides. Normally, the water level at Callao rises 1.4 m (4-5 feet). Up to 5000 persons lived in the town. /38

The Callao roads were considered to be among the best in South America. On the southwest, it is protected by the islands of San Lorenzo and Callao, and has a smooth clay bottom of considerable depth and plenty of anchorage space. Since the time of the conquest of South America by the Spanish, the port of Callao has been the main port of the vice-monarchy for importing and exporting goods. At the time of the earthquake, 23 vessels lay at anchor in the roads.

Callao was damaged by the earthquake to the same degree as Lima. Approximately one half hour after the earthquake, the ocean "swelled," rose approximately 10 m, smashed the city wall and inundated the city. When the water receded the majority of houses and other buildings were dislodged from their foundations and washed away. A sizable portion of the city wall, including the gate, had been carried away by the water; but one part of the wall remained and for many years it stuck out like a monument to a once-powerful tsunami.

Almost the entire population of the town perished in this disaster. Since the water advanced 4 km (1 league) inland, it overtook even those who had tried to flee to Lima. Only about 200 persons managed to save themselves by clasping onto wooden objects which were being tossed about between the shore area and the island of San Lorenzo, a distance of more than 8 km (2 leagues) away. Those unfortunate souls did not perish, despite their collisions with the wreckage that littered the surface of the water. In the end, they were cast up either on shore or on the island of San Lorenzo. The latter was not nearly as inundated as the continental shore. Twenty-two persons managed to save themselves on the remaining section of the city wall.

Nineteen of the vessels lying at anchor sprang leaks and sank, but four were cast up onto dry land. The vessel "St. Firmin" found itself in Chaquara, about 2 km (1 mile) from its anchorage; and the "St. Antoine" got caught at the same place. A vessel belonging to Cortsa ended up on a site formerly occupied by a hospital in the eastern part of town, and the vessel "Le Secours" was carried all the way to the Cordon* Mountains.

At approximately 04:00, Callao was flooded by another strong wave. The maximum height of the rise of water was estimated at 24 m (80 feet). After the inundation, where once the town had stood there remained only a square covered with ocean clay and pebbles. Only small remnants of walls marked the area where the town had been. During the next few days in the Callao area, those that had survived were pulling bodies out of the water, along with other objects that had been washed away earlier.

News of the tsunami struck panic in Lima and the people fled to the hills.

The tsunami was recorded in many other places along the coast of Peru as well. In the port of Santa, the tidal wave hit the vessel "Concepcion" with such force that it sprang a leak and sank. The crew of

the vessel "Soledad," which was in the vicinity of Nasca, on noticing that the ocean was receding, took precautionary measures and the vessel was saved. Tsunami waves destroyed Caballas, Pisco, Chancay and Guanape.

Near Huacho, the road was completely inundated, and the vehicles that happened to be on the road, along with mules and cargo, were swept away by the receding water. In Huaura (Salinas), the water advanced more than 4 km inland, and drowned mules and drivers.

Near Callao, after the earthquake, part of the shoreline subsided to the point where a new bay was formed. In a space of 6 1/2 hours after the flood in Callao, an ocean wave hit Concepcion; and in Acapulco, a vessel was cast upon the shore (Anon., 1752, 1877, 1961; Seyfart, 1756; Montbeillard, 1761; Parish, 1836; Mallet, 1855; Perrey, 1858; Winslow, 1866; Lyell, 1868; Milne, 1913; Sieberg, 1929, 1932; Heck, 1934, 1947; Jagger, 1946; Berninghausen, 1962; Monandon, 1962; Ponyavin, 1965; Iida et al., 1967; Silgado, 1968, 1974).

1751, May (erroneously March) 24 or 25 (after 01:00). There was a destructive earthquake and tsunami in Concepcion.

The tremors began to be felt on the evening of 23 May. Some of the inhabitants took the precautionary measure of going to bed that evening without undressing. At 00:50 on the 24th (or 25th), a shock of medium strength occurred. Ten minutes later, at 01:00, the city was destroyed by a most severe earthquake. Strong shaking continued for about 6 minutes, including at least six (or three) separate shocks. The shaking was so severe that it was impossible to stand or move about. Almost 11 buildings were either damaged or destroyed. The greatest damage occurred between 36° and 39° S. (at least from Curico to Concepcion) and moderate damage from Valparaiso to Arauco; strong tremors were recorded approximately between 34° and 40° S. In Arauco, no stone was left untouched. Houses, churches and the brick walls of the fortress of Plaza-de-Santa Juana were destroyed. Chillan, Cauquenes and Talca were also destroyed. In Curico, the church and almost all houses were destroyed and much additional damage was caused by aftershocks. On the plain near Curico, a 100 m long crack, from which water spouted, appeared in the ground. In Santiago, people had difficulty keeping on their feet. One of the towers of the cathedral collapsed, several houses and buildings fell down, many walls cracked or began to slant, and for several days the population lived in the streets. The quake destroyed many churches and distilleries in the Central Valley. In Valparaiso, a church which had been restored after 1730, and several barracks were destroyed. It is possible that the earthquake was also destructive on the islands of Juan Fernandez (see Fig. 77). In Concepcion, luminous phenomena were sighted in the sky, such as a ball of fire which appeared to be rolling down the Andes Mountains and into the ocean. Earth tremors occurred on an almost continuous basis for a whole month after the earthquake. The shock that occurred on the 26th was almost as strong as that of the 25th. /39

The ocean began to recede about half an hour after the quake, and soon the half dressed, frozen and frightened inhabitants of Concepcion

climbed the neighbouring hills from where they witnessed the approach of a strong sea wave descending upon the shore. The tsunami flooded the town (then situated in the site of Penco), and washed away the wreckage of buildings and domestic utensils. This lasted several minutes, after which the water receded quite rapidly, draining the bay (which had a length of 12 km). Seven minutes later the ocean returned with great force "the waves crowded one on another," and the water level exceeded its usual limits; the water burst into the town with a speed exceeding that of a galloping horse, completely inundating the town. The water advanced quickly along the river, rising and inundating the adjacent areas and flooding even houses on higher ground. Boats and canoes were hurled into the church of San Francisco, located 400-500 m from shore. Subsequently, the water receded, again quite rapidly, carrying with it walls, some of which were still intact, and household items. Where the town had stood there was nothing but an impassable heap of ruins. And in the Cantarranos quarter, only the piles of the houses were left, all the rest having been washed away. Then the water receded again, just as on the previous occasion, but it rose and inundated the area two more times, the third flooding being the most severe.

The next morning it was established that the water level had varied considerably; in some areas the water had risen more than 3.5 m (4 varas), in others less. Later the fluctuations abated and by noon the sea had calmed down. The receding water had left huge quantities of dead fish within the town precincts. Twenty-five to thirty old persons and invalids (17 persons, according to other accounts) were drowned in the waves of the tsunami - the only victims of the earthquake. Much of what had been washed away, piles, boards, boxes, baskets, icons and other church utensils, were cast up on the island of Quiriquina, where the inhabitants searched for their property on the following days.

The vessel "St. Anthony and Family," loaded with goods and passengers, lay at anchor in the port of Concepcion. The seaquake was very severe and it was feared the vessel might be destroyed, but it survived. With the first strong ebb, the anchor chain broke, and the ship itself was grounded, listing heavily. The returning tide hit the vessel, causing it to list the other way. Then the vessel found itself floating. Subsequently, the sea rose 17 m (9 1/2 fathoms) and the ship was thus refloated. There were three strong tides and ebbs, and each time the vessel became grounded. It required four days to restore the ship to working order.

After this destructive flood - the fourth and most severe in the history of the city - Concepcion was rebuilt farther from the shore, and its old location was eventually used to build the new town of Penco. The tsunami was also recorded in Valparaiso. /40

The waves hit the island of Juan Fernandez, washed away a settlement and sank a vessel anchored in the port. The governor of the island, his family along with 35 other persons perished.

The tsunami reached threatening proportions in Callao; but no one

died because "it was already dawning and so it was possible to flee to a safe location."

There are some reports to the effect that the bottom of Concepcion Bay had risen 7 m (24 feet) during the earthquake; the resulting shoal consisted of hard sandstone rather than sand.

Naturalists who later visited the area of Concepcion, found, in areas of considerable elevation, many mollusc shells which were packed with river sand; such shells normally occur in the littoral zone.

The tsunami reached the southeastern coast of the island of Honshu, flooding the houses on Otsuki* on the Djika peninsula and in Kesennuma to above the floors, but there were no deaths (Seyfart, 1756; Molina, 1786; Parish, 1836, 1838; Cuming, 1840; Petit-Thouars, 1840; Perrey, 1854 c; Lyell, 1868; Goll, 1903; Montessus de Ballore, 1911 a, 1912, 1916; Milne, 1912 b, 1913; Sieberg, 1932; Bobillier, 1933, 1934; Navarette, 1933; Heck, 1934, 1947; Davison, 1936; Gutenberg, Richter, 1949, 1954; Imamura, 1949; Iida, 1956; Hewitt, 1957; Anon., 1961; Berninghausen, 1962; Monandon, 1962; Ponyavin, 1965; Iida et al., 1967; Lomnitz, 1970; Silgado, 1974).

1765. There was an earthquake in Valparaiso, during which boats were tossed up on land by the ocean as far as the Church of San Francisco, which was standing on higher ground (Perrey, 1854).

[Th late is probably incorrect and the reference is to the tsunami of 24.V.1751.]

1799 (?). On September 6, 1799, the newspaper "Moniteur" reported that South America had recently experienced strong earthquakes. The most severe tremors were recorded in Lima, where, over a period of several days, many buildings were damaged beyond repair. Each tremor was accompanied by a rumbling sound. A man on a vessel near Callao reported that he had had a distinct impression of the nearby mountains being raised and lowered, moved toward him and pushed farther back, almost as if by some elastic quality.

According to Hoff's catalogue (1840), a destructive earthquake occurred in Trujillo in the second half of the year. It is possible that Hoff's record refers to a town of the same name in Peru (Perrey, 1858).

[This may be difficult to verify. The more reliable sources (for example Silgado, 1968) do not mention destructive earthquakes in Lima between 1746 and 1828. Also, it is difficult to relate the above events to the tsunami of 1746, because in that disaster all vessels in the Callao area were lost.]

1806, December 1. Lima experienced a severe earthquake at 18:00 hours. At 20:00 the sea rose above the shore at Callao, flooding the town; and at 21:30 a 1 m high wave cast several vessels ashore and damaged others. An anchor of 1 1/2 tons weight, was carried by the water

almost to the house of the port captain and was left in a lagoon (Silgado, 1974).

1811, November 19 (10:15). Valparaiso experienced an earthquake which generated a small tsunami. The ocean receded three times in succession, and a 4 m high wave crashed onto the shore (Silgado, 1974).

1819, April 11. A severe earthquake and tsunami occurred in the area of Copiapo (Chile).

The first shock occurred in Copiapo on April 3 between 08:00 and 09:00. Tremors continued at intervals until the evening of the following day. At 16:00 on the 4th, the ground heaved like a ship in a stormy sea. All the shocks were preceded by strange rumbling sounds, not unlike the sounds of rolling thunder reverberating through mountains. One of the churches and several other buildings collapsed, causing many people to perish under the ruins. The tremors continued for a whole week.

On the 11th at 23:00, an exceptionally severe earthquake, which was preceded by a frightening rumbling sound, completely destroyed the city. Strong vibrations lasted about 7 minutes. Only a few houses, mainly wooden houses, survived the shocks, but even they were badly damaged. Even walls of 1 m thickness, supported by solid buttresses, collapsed. Many cracks appeared in the ground, and displacements were recorded along some of them. The suburb of Chimba, which was about 3 km (1 1/2 miles) from the centre of the city, sustained little damage. The area experienced repeated shocks during the following six months. The earthquake of April 11 caused minor damage to Vallenar. /41

The area in which the earthquake of April 11 had originated, gave rise to a tsunami which was recorded over a distance of 800 km, including in Huasco. At first the ocean receded a little, but it quickly swept back over the land, penetrating in places up to 600 m beyond the high water line. Caldera sustained considerable damage. After the tsunami, the inhabitants went to the shore to dig for copper ingots which had been washed away by the waves.

At Concepcion, the rising waves advanced up the River Bio-Bio (Silgado's record shows this to be at Constitucion); on the 12th at 02:00 the anchorlines of the schooner "La Fortuna" were broken by the ebb and flow currents and the schooner ended up being grounded on rocks.

On the western shore of the island of Hawaii, nine oscillations of the sea level were noted, starting with an ebb and occurring at intervals of 10-11 minutes. The water level rose up to 2 m (7 feet), but there were no casualties. In Honolulu the sea level rose and fell 13 times within a few hours.

It is possible that the tsunami was also recorded on the island of Mangareva (Rooke, 1839; Jarves, 1843; Wilkes, 1844; Mallet, 1854; Perrey, 1854 c; Milne, 1912 b; Willis, 1929; Jagger, 1931; Sieberg, 1932; Bobillier, 1933, 1934; Heck, 1934, 1947; Gutenberg, Richter, 1949, 1954;

Shepard et al., 1950; Anon., 1961; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967; Lomnitz, 1970; Silgado, 1974).

1822, November 19 (after 22:30). There was a destructive earthquake in Valparaiso and surrounding districts (Fig. 21). The quake was preceded by foreshocks which occurred daily from the 14th through the 17th. The earthquake itself continued from 2 1/2 to 3 minutes and within that time the strongest vibrations lasted 40 seconds. It is reckoned that the macroseismic epicentre was located 25-30 km (15 miles) to the north or northeast of Valparaiso.

In Concon, at approximately 22:30, three shocks were felt within a period of 5 minutes. The second shock was the strongest and lasted 2 minutes. It was accompanied by a frightening rumbling sound which seemed to originate below ground. Strange atmospheric glows may have been recorded as well. The building in which an eyewitness lived sustained broken windows and damaged roof tiles. Other houses and a mill were damaged more severely. The canal connecting the mill with the River Aconcagua was filled with material from collapsed river banks, and the ground became littered with cracks of different dimensions.

In Quintero, the vibrations shook the palms strongly enough so as /42
to cause them to lean permanently. Huge cracks appeared along the lakeshore, and almost all the houses sustained damage to the point where they became uninhabitable. There were fires and casualties. In Casablanca, not a single house nor even a wall remained standing. In Quillota, many houses were destroyed and the remainder were damaged to a greater or lesser extent. Only 20 houses and one church remained standing. Vina del Mar had suffered almost complete destruction. The whole plain appeared to be strewn with cones of small sand volcanoes of a height of 0.3-1.2 m. Damage was also recorded in Limache and in La Ligua. Close to 200 casualties were recorded in the above areas. In Valparaiso, most of the public buildings and about 700 private houses were destroyed. All bell towers and turrets collapsed, including a well-constructed 20 m high bell tower. Buildings located on rocky ground suffered less than those on soft ground. The port area of Almendral, situated on alluvial soil, sustained particularly severe damage. All houses built of mud bricks disintegrated. Seventy-two persons (over 300, according to other sources) perished and over 110 were injured, mostly in brick buildings. Wooden houses were not damaged, but the old fortifications with thick stone walls sustained some damage as well. The stream discharge in Valparaiso increased, and new streams appeared but they soon dried up.

The shore at Valparaiso rose approximately 1 m (3 feet). [This is disputed by Cunningham, Belcher, Montessus de Ballore (1924) and others.] This left a whole colony of mollusks exposed on shore, including scallops, whose existence had hitherto been unknown. Many dead fish and seaweeds were left stranded. Cracks appeared in coastal granite cliffs, and rockslides took place.

At Concon, the sea coast apparently rose some 0.3-1.2 m (from 1 to 4 feet). The maximum rise probably averaged 1 1/2-2 m (5-7 feet), and

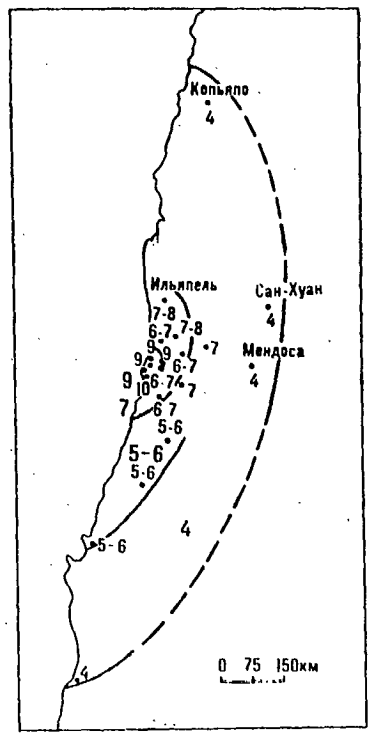


Fig. 21

The force of tremors and isoseists of the earthquake of 19.X.1822. Compiled by S.L. Soloviev from information in the literature.
The small figures designate the force of the tremors at various points. The large figures - the average force of the tremors between isoseists.

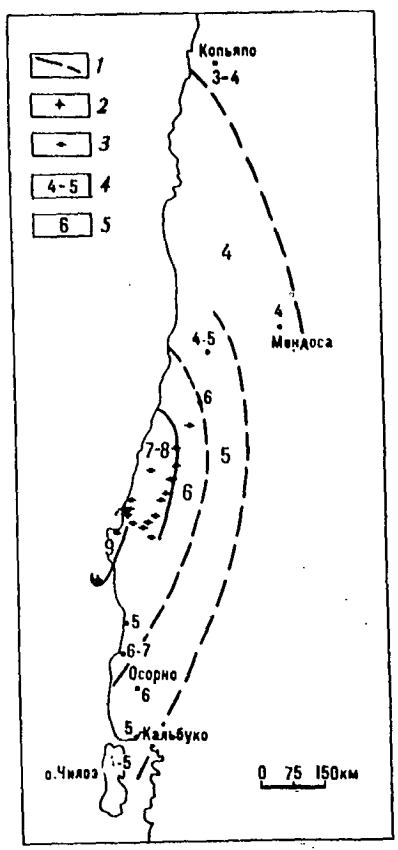


Fig. 22

The force of tremors and isoseists of the earthquake of 20.II.1835. Compiled by S.L. Soloviev from information in the literature.

1 - isoseists;
2 - tremors with a force of 9 points;
3 - tremors with a force of 7 - 8 points;
4 - tremors with a force of 6 points and less at individual places;
5 - the average force of tremors between isoseists.

it probably occurred 3-5 km from shore.

As a result of the lifting of the ocean floor, numerous rocks appeared above the water level in areas off Valparaiso, Concon and Quintero. A sunken vessel could now be reached on foot at half-tide, whereas previously, the only access had been by boat, even at low tide.

In time the shore slowly subsided again, returning to its pre-earthquake level.

At the time of the earthquake, the miners in the gold mines of El Bronse in Petorgue worked at a depth of 170 m (100 fathoms). The earthquake caused cave-ins in the shafts and some of the miners were trapped in the lateral drifts and perished. In Illapel, all the churches were damaged; and severe damage was caused in San Felipe as well.

In Santiago, no one was killed, but about 30 public buildings were damaged. The earthquake caused about the same amount of damage in the province of Aconcagua, approximately 90 km (50 miles) north-northwest of Santiago.

The earthquake appeared somewhat weaker in Melipilla, although some buildings were damaged as well. Vibrations were also felt in San Jose de Maipo, San Fernando, Talka, Rancaqua and Concepcion, but no damage was recorded. To the south, the quake was recorded as far as Valdivia; to the east, as far as Mendosa, Cordoba (see Fig. 28) and San Juan. In the north the earthquake was felt right up to Copiapo. According to some data, a seaquake [T-phase] was recorded on vessels anchored in Callao.

Repeated tremors in the epicentral zone of the earthquake were recorded at least until October 1822.

At the time of the most severe shocks, the ocean receded in the epicentral zone, only to rise and advance upon the shore again and again.

In Cintero, fishermen living near the shore fled to higher ground. Between Cintero and Concon the dunes were washed away by the tides, which resulted in a higher water level in the lagoon.

In Valparaiso, at the time of a full ebb, the sea suddenly rose and just as suddenly receded. A launch from the admiral's ship, which was on its way to render assistance to people on shore, was thrown up to /43
the gates of the customs house, located 3 1/2 m (12 feet) higher than the ordinary high tide mark. Suddenly, the sea began to recede very rapidly, stranding small vessels and boats. All this occurred within 15 minutes. Several minutes later, a second wave of reduced intensity appeared. In all, three large floods and ebbs of a height of 3.6 m (12 feet) were recorded. On the morning of the 20th, the sea level fluctuations were normal again (Graham, 1824; Parish, 1836, 1838; Cuming, 1840; Mallet, 1853; Perrey, 1854 c; Lyell, 1868; Anon., 1877, 1961; Suess, 1897; Goll, 1903; Krummel, 1911; Montessus de Ballore, 1911 b, 1912, 1924; Milne,

1912 b; Sieberg, 1932; Heck, 1934, 1947; Davison, 1936; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967; Lomnitz, 1970).

1828, March 20 or 30 (07:30). Lima experienced the strongest earthquake since 1746. In this quake, the walls of all buildings cracked within a few seconds and many roofs collapsed. Walls of a thickness of 2 m developed cracks from top to bottom. About 30 people died. The strongest shocks lasted for half a minute (70 seconds, according to other sources).

In Callao, the earthquake occurred somewhat later than in Lima, since the cloud of dust could be seen rising over the ruins of Lima before the shocks were felt. Almost all houses in the town were damaged. Chorillos and Chancay were also seriously damaged.

Apparently, the earthquake was felt throughout Peru. Several villages were destroyed along the coast north of Lima. In the area of Huarochiri, an entire village slid down the side of a hill in a landslide. Rockfalls had occurred in many sections of the road from San Mateo to Lima. In Surras, subterranean water forced its way to the surface. Trujillo and Huanuco experienced strong shocks but there was no damage. In Arequipa, the shocks were weak, and in Arica, the earthquake was not felt at all. Weak secondary tremors were felt in Lima for a week after the earthquake.

A strong sea quake was felt on vessels lying at anchor in Callao. These disturbances were accompanied by rumbling sounds resembling distant thunder. The water began to churn, bubbles of hydrogen sulphide rose from the bottom and many dead fish surfaced. The surface of the ocean, which previous to the earthquake was like glass, became agitated and the water became muddy. The vessel "Volant" rocked 35 cm [degrees?] to either side from its position of equilibrium.

In Trujillo, the earthquake was followed by pouring rain. In Lambayeque and Chiclajo, the rainfall was even heavier and continued for four days without a break. These towns were reduced to a heap of ruins, particularly the first of them, where the river overflowed and razed the whole town to the ground, with the exception of three streets. Farms were laid waste and crops damaged. Piura was destroyed in a similar manner. In the Sechura Desert - an area that never gets a drop of water - the heavy rain brought a stream into being (Mallet, 1853; Perrey, 1854 b; Polo, 1899 a; Silgado, 1968). Sieberg (Sieberg, 1929, 1932) mistakenly assumed that the coastal cities to the north of Lima were destroyed by tsunami waves.

1829, September 26 (14:00). Valparaiso experienced a severe earthquake (6-7 degrees). Four adventurers travelled through the coastal area of Allmendral, announcing that the ocean was rising at San Juan de Dios. This frightened the inhabitants to the point where they abandoned their homes and shops, leaving their possessions to be plundered by the thieves (Montessus de Ballore, 1916).

1835, February 20 (approximately 11:30). There was a destructive earthquake and tsunami in the central part of Chile with its source near Concepcion (Fig. 22).

It is possible that there were foreshock warnings, for on the 14th of February, Santiago experienced a weak shock which lasted 20 seconds.

The earthquake began in Concepcion with weak tremors which quickly became stronger. For the first half minute no one seemed alarmed but then all the inhabitants fled from their houses. It became impossible, not only to move from one place to another, but even to stand without some /44
kind of support. Even when lying on the ground, one had to hold onto something in order not to roll about. Some horsemen were thrown from their saddles; others fell, together with their horses, but none of them could remain mounted. There were many instances of seasickness. Then a severe shock which lasted 5-10 seconds, toppled over and destroyed almost all the buildings. In many places cracks opened up in the ground with a deafening crash. A thick cloud of suffocating dust rose into the air from the wrecked buildings and from the ground. All this took about two minutes from the start of the earthquake.

The city of Concepcion is situated on a low terrace of the river Bio-Bio on alluvial soils. On the east and north the valley is bounded by hills formed of tertiary shale rock. Apparently, the sedimentary cover settled, owing to the effect of the earthquake. Severe fragmentation occurr at the foot of the hills and the whole valley was dotted with cracks 2-30 cm in width.

Washerwomen repeated, that at the start of the earthquake, the water at the river bank suddenly rose approximately half a metre. A similar occurrence was observed in the mouth of the river at Lirquen.

As a result of the earthquake, more than 50 persons were killed, 10 were seriously injured, 30 were missing and more than 500 suffered concussion or injuries, out of a total population of over 5,000 (700-800, by other accounts). The casualties would have been greater if it had not been summer daytime and the quakes had not increased gradually. There were many cases of persons going out of their mind. Almost all mud brick houses were levelled to the ground. Houses of kiln dried brick suffered less, although they became unfit for habitation; in two-storey houses the upper stories collapsed and the lower were damaged. A single, two-storey building with supporting columns survived - the construction of its roof had just been completed. With the collapse of fireplaces and the falling of thatched roofs, quite a number of fires occurred, but they were all quickly extinguished.

In a technical report, compiled half a year after the earthquake, the percentages of completely collapsed houses, and houses that were damaged but still standing, were estimated as follows according to type: brick, 33 and 67%; mud brick, 71 and 29%; stone construction 95 and 5%.

In Talcahuano, the earthquake lasted three minutes and was just as severe as in Concepcion. There were only three houses, standing on rocky ground, that more or less survived; the remainder of the houses were situated on sandy, mobile soil between the shore and the hills, and they were completely destroyed (according to other sources, the destruction was less than in Concepcion). There were large rockfalls along the shores of the bay and at the mouth of the river.

On the island of Quiriquina, the tremors began suddenly. A rider /45
was thrown from his mount, and both horse and rider were rolled over from side to side by the effects of the shocks. Some cows, which had pastured near the shore, were hurled into the water. In many places, deep cracks appeared on the surface of the island, possibly as a result of the relative slipping of the strata. Near the cliffs, these cracks were as wide as 1 m. In some places, the upper rock layer of the substructure was shattered into small pieces. Huge rockfalls covered the beaches. A rock of 25,000 tons weight fell into the main approach to the bay.

The destruction was confined to an area between 35° and 38° S. The provinces of Concepcion, Marile, and vicinity were severely damaged. The towns of Penco and Toma were destroyed.

In Florida, only houses with thatched roofs were undamaged; in many areas the ground opened wide. In Coelemu, eight buildings were destroyed; the remainder survived but became unfit for further use. In Arauco, the church and all buildings, except a barracks, suffered to a greater or lesser degree. Extensive surface damage occurred in the interior of the island of Santo Maria. In Los Angeles, the earthquake lasted 3-4 minutes, and almost all buildings were completely destroyed; fires broke out, but were quickly extinguished. Apparently there were no casualties. In Curico, the church towers were destroyed; five houses collapsed. In some other house, the roofs and plaster were damaged. Chillan was almost completely destroyed. Close to the city a large crack appeared in the ground from which muddy, stinking water poured out. In Cauquenes, seven bodies were pulled from ruins. The temperature of the water from thermal springs dropped. In Talca, the earthquake lasted less than three minutes, during which the majority of buildings were destroyed, and those that had survived became unfit for use. There were about ten casualties.

Also damaged, to a greater or lesser degree, were the towns and settlements of Haulca, Rera, Yumbel, Polquera, Pemuco, Colyumo, San Carlos, Linares, Perales, Aredan*, Barras*, Vailoga*, Congas*, Parral*, Pera, Puchaquai, Ranquil, Erras*, and others. Constitucion was almost completely destroyed, but there were only two casualties since the inhabitants had sufficient time to flee from their homes. The total number of casualties amounted to 400-500.

In the province of Colchagua (located approximately between San Fernando and Curico), public buildings and churches suffered damage. Roofs were seriously damaged and some houses cracked, but there were no casualties. In San Fernando, for example, the most severe shock damaged

only the roofs. In Rancagna, an asylum and the church towers collapsed, and on some buildings the roofs were damaged. In Santiago, the inhabitants felt strong oscillations, not unlike those experienced on a swing.

On the island of Mocha, the earthquake was so severe that it was impossible to stand upright. A strong seaquake was felt on the whaler "Nile," whose position at the time of the quake was 39° 15' S., and on the vessel "Glenmalia" at 170 km from the mouth of the river Maule.

In Valdivia, the earthquake, at first weak, became stronger in the course of two minutes, was severe for the next minute, and then gradually calmed. Buildings were cracked but did not collapse.

This quake damaged buildings as far south as Osorno, and as far north as San Fernando. In Coquimbo, Huasco and Copiapo, the quake was felt only slightly; it was also felt in Mendosa and San Luiz; moderate but prolonged tremors were experienced in Calbuquo, Puerto-Montt, and Castro; and on the island of Chiloe, there were slow horizontal movements lasting six to eight minutes. Trees shook so strongly that their tops actually touched the ground. A seaquake was extremely noticeable on the vessel "Loper," whose position was 1100 km (600 miles) from the shore. A weak seaquake was felt near the island of Lemus.

At the same time, the seaquake was not felt on a French whaling ship which was anchored in calm water in the harbour of Queilen at the south of the island of Chiloe. Nor was the earthquake felt in the Cordilleras posite the island of Chiloe.

Thus, the area in which the earthquake was felt, extended from Copiapo in the north, to the island of Chiloe in the south, and from the island of Juan Fernandez in the west (see Fig. 77), where the earthquake /46
was fairly strong, to Mendosa in the east (see Fig. 22).

In Concepcion, the ground shook almost continuously for a period of three days. The many aftershocks were preceded by sounds resembling a distant artillery cannonade. Sometimes, there was a single crash without tremors. More than 300 tremors were counted between February 20 and March 4.

When the earthquake began, the whole surface of the water in Concepcion (Talcahuano) Bay churned. The water darkened and gave off the very unpleasant odor of hydrogen sulphide.

At approximately one half hour after the earthquake, the water in the bay receded to the point where all rocks and reefs were laid bare. Then it flooded once more and again receded so that vessels anchored in the bay appeared to be on dry land. Then a huge wave, from the island of Quiriquina, passed along the west shore of the bay, shearing off houses, uprooting trees, sweeping and carrying away everything that was movable. To be more exact, this was not a wave, but a huge step on the surface of the ocean moving forward in the form of a wall of water with a frightening roar. The wave had a height of up to 9 m (30 feet) above the highest

tide mark. The water almost completely flooded the whole of the town of Talcahauno, and receding in the form of a tempestuous current, carried off all light objects from the piled-up wreckage left by the earthquake.

After several minutes a second huge wave appeared, approaching with an even more terrifying noise and violence than the first. Despite the enormity of the wave, its passage was less destructive since there was little left to destroy.

Moreover, the main blow of the wave appeared to be not on Talcahauno but on the southeast area of the bay, on the island of Rey*. The island and neighbouring plain were completely flooded, resulting in considerable losses of livestock. Subsequently, the ocean level again receded and the water carried off with it the carcasses and the lighter parts of buildings.

After several minutes of tense expectancy, the inhabitants, who had taken refuge on higher ground, saw a third wave rolling between the island of Quiriquina and the mainland. This wave appeared even larger than the two previous ones (by other accounts, it was somewhat smaller); it roared, dashing against obstacles and carrying along everything in its path. Then suddenly, as if repulsed by foothills, the water receded, carrying away such a huge quantity of articles snatched from houses (partitions, furniture, etc.), that after the ebb, the whole ocean appeared to be covered with this wreckage. This disaster prompted the inhabitants to begin noticing approaching waves when they were still 5-7 km away from shore.

In the bay, seven vessels lay anchored in 7-13 m of water (4-7 fathoms): three whaling ships, one launch, two brigs and a schooner - each secured by a single anchor which rested on clay bottom. Before the earthquake, a fresh southerly breeze had been blowing which had turned the sterns of the ships seaward.

On the first occasion one of the whaling ships found itself grounded in just that position. The first large tidal wave lifted the stern and then the entire ship but without causing any damage. As the water level declined, the anchor chain slackened, stirring up the silt. The receding water rocked the ship a number of times and in the end left it grounded in approximately the same spot where it had been anchored before the wave moved in. The depth varied for 3 1/2 m (2 fathoms) when the ship became grounded, to 18 m (10 fathoms) during the height of the third wave.

None of these ships suffered much damage, although the anchors of some of them were dragged for several metres (fathoms). A number of ships turned on their anchors, as in a whirlpool, and there were some collisions.

A small schooner snapped its anchor chain at ebb tide, and was carried out to open sea. Here the schooner encountered a tidal wave, which raised it, but the water passed under the ship.

A Chilean naval schooner, standing under sail at the eastern mouth of the bay, passed through a wave in just the same way, without any damage.

Many ships moved out from shore before the water receded. Some met the tidal wave before it had begun to collapse and passed through it safely. Others, half inundated, ran aground on underwater rocks. /47

A small ship with displacement of 30 tons (according to other sources, 80 tons), prepared for launching from the building slips, was tossed 200-300 m from the dock over a half demolished wall.

As determined from a mark left on the wall of the home of the port captain, the main mass of water in Talcahuano rose 7-7.5 m (23-25 feet) above the usual high tide mark. The water penetrated the rooms in the first storeys, and seaweed was left on the floors and the remaining walls. However, where the water rolling up along the slope met no real obstacles, the height of the rising tide was greater: according to residents, 5-6 m (16-20 feet) higher than the rest of the water surface. Where the wave encountered large obstacles within 500 m (1/4 mile) from shore, the rollers broke up and the flow encroached a kilometer (half mile) inland. According to other sources, on open shore, the water encroached 4-6 km (1-1 1/2 leagues) inland.

The inhabitants who had climbed onto the elevated Tumbes peninsula could observe events on both sides of the peninsula at once. They reported th the sea swept over Talcahuano and San Vicente simultaneously, so that at one time it appeared that the peninsula on which they were standing was turning into an island.

One woman took to a boat with her son, but since she was not able to row, the waves tossed the boat onto a breakwater, where it struck an old anchor; the boat split and the woman drowned, but a few hours later they found the child unharmed amidst the debris on shore.

For many hours after the earthquake the ocean rose and fell two or three times an hour at Talcahuano and other places on the coast. For the next three days, flood tides and ebb tides were irregular, alternating very frequently.

For four days, the water surface in Concepcion Bay and out to open sea was covered with debris. The residents of Talcahuano gathered the remains of their belongings along the shore of Quiriquina[+] Island for several weeks. The shores of the bay were strewn with dead fish and shellfish after the earthquake.

In the narrow channel, separating Quiriquina Island from the Tumbes Peninsula [width about 2 km (1 mile)], depth 17 m (10 fathoms), the tsunami rose 9 m (30 feet) above the high tide mark or 10-12 m (40

[+] Transliterated - Transl.

feet) above mean sea level. Houses in the flood zone were heavily damaged and cattle were washed away. To the east of Quiriquina Island, the wave was less fearsome and destructive, possibly because the bay is wider and deeper here.

Tidal waves fell hard on the coast at Tome, though less furiously than at Talcahuano. The mean wave height was 4 m (14 feet), but the rise of water reached 12 m in places. Tome and Penco were inundated three times.

The waves travelled along the coast at Lirgnen without breaking.

On entering Talcahuano Bay, the tsunami appeared to break around Quiriquina Island into two streams: one passed along the eastern shore of the Tumbes Peninsula and fell on Talcahuano, the other crossed the entrance to the bay and fell on Tome.

In the small Coliumo+ Bay, situated north of Concepcion Bay and opening to the north, waves rolling onshore reached a height of 4 m (14 feet). The waves did not reach Dichato+ village, situated higher and farther from the sea than Talcahuano.

The lowlands were flooded between Cape Rumena* and the mouth of the Itata River; some damage was done.

At Coelemu+, the sea rose six times, flooding coastal fields and rising to a height of 24 m (28 vara)[?].

At Constitucion, approximately 1 1/2 hours after the earthquake, /48
the sea rose above its usual level and the rise supposedly also lasted 1 1/2 hours, after which the sea retreated. Fifty minutes later, the sea became agitated and rushed onshore in gigantic waves.

The water rose 3 1/2 m (12 feet) above its usual level in the Maule+ River. During the second flood, two schooners riding at anchor in the port were lifted up with their anchors and chains and carried inland to a thicket 140 m (150 yards) from shore. A third flood occurred after a half hour. This time the water rose more than 2 1/2-3 m (9 feet). Gradually diminishing flood tides were then observed for another two days. A sand bar at the mouth of the river was partially washed out and the fairway was somewhat deepened, by 1/2 m (2 feet).

At Valparaiso, a rapid, but calm and noiseless advance and retreat of the sea by approximately 1/2 m (2 feet) was observed.

The waves approached Santa Maria Island from the west, surrounded it on both sides, flooding the low terraces, and merged on passing the island. The crop was destroyed and a ranch was demolished.

At the mouth of the Tubul River*, east of Arauco, the waves appeared approximately an hour after the earthquake (according to other sources, at 1:00); they were not as strong as on Santa Maria Island, but

they were more numerous; six - seven large waves were counted.

At the southern tip of Mocha Island, the water rose above the rocks and attained a height not reached by splashes even in the strongest gales. One of the boats was set down on a rock.

The water came up to the walls of Arauco.

At Valdivia, the river swelled up and rapidly subsided to its usual level. In the port, the sea flooded the shore to the tide mark in a sudden movement, although it was low water time, and then just as quickly retreated. During the day, the sea and the river experienced alternating rises and falls in level. The river did not fall below its usual level, and the ocean did not recede further than the low tide mark. Flood tides recurred once or twice an hour.

Near Niebla+ Port, a man and a woman drowned, apparently while collecting shellfish. They were the only victims in the Valdivia region.

Slight oscillations in sea level were observed on Chiloe Island. One resident prepared to put out from shore in a boat, in the region of Sandy Point* at Ankud (San Carlos), but found that the boat had run aground. He went away, but was summoned by his son, who called out that the boat was floating again.

The anchor chains were snapped in two ships, standing at anchor at Lemus Is l, by a strong flood tide at noon.

At approximately 11:30, the breakwater and pier in Cumberland+ Bay, on Más a Tierra Island (Juan Fernandez Island) were almost completely flooded; the boats at the moorage floated up, although it was ebb tide time. Then the sea rapidly retreated almost 200 m (2 cuadro), drying up a large part of the bay. Old lost anchors could be seen on the bottom.

The soldiers and convicts (a camp has just been established on the island; there were 500 people, including 200 convicts, in the city), barely had time to save the boats and other property, when literally the whole city was covered with water, which rose 4 1/2 m (15 feet) above the mean level (according to other sources, the water rose 2 vara, that is, 1 1/2-2 m). Receding, it destroyed all homes, except for a store, the prison and a church. Cattle, debris of homes, supplies, boats and trees were carried off. The first story was flooded in the house of the governor and the barracks, just built on a high place, but they were not washed away. The sea encroached inland in this way, right up to the foot of the fortress, four times. Sand was carried into the city. When the waves had abated somewhat, a woman and a soldier were taken from debris rolling in the harbor; there were no victims.

[Old sources (Sapper, 1927; and others) gave undue attention to a waterspout observed near the island during the tsunami. It was thought that it was caused by a submarine volcanic eruption. Bruggen (1943), in his survey, even considers this hypothetical eruption to be the main /49

cause of the tsunami of 1835 on the Juan Fernandez Islands and attempts to reconstruct the origin of other major Chilean tsunamis on the same lines.]

The tsunami did moderate damage on Kauai Island (Hawaiian Islands).

A segment of the Chilean coast, situated in the focal zone of the earthquake, was elevated. Thus the bay at Talcahuano became shallower while the shore of the bay was lifted approximately 1 m (3-4 feet). The coast at San Vicente rose 1/2 m (1 1/2 feet).

Santa Maria Island rose 2 1/2-3 m (9 feet) in the middle, 3 m (10 feet) in the north, 2 1/2 m (8 feet) in the south. A waterfall was formed at the mouth of the hitherto navigable Tubul River; mollusc colonies dried up, etc.

Mocha Island rose 1/2 m (2 feet). There was no rise at Valdivia and at the mouth of the Maule River; on the contrary, according to some sources, the region of the mouth of the Maule River subsided.

Then began a slow subsidence of the elevated block, so that after two months the rise of the shores at Talcahuano was reduced to 1/2 m. This subsidence apparently came to a full stop simultaneously with the cessation of the aftershocks.

After the earthquake and tsunami, it is possible that fish catches and whale kills decreased off the shores of central Chile (Caldgleugh, 1836; King et al., 1836; Parish, 1836, 1838; Alison, 1838; Petit-Thouars, 1840; Dumont d'Urville, 1842; Wilkes, 1844; Mallet, 1853; Perrey, 1854 c; Lyell, 1868; Anon., 1877, 1961; Goll, 1903; Krümmel, 1911; Montessus de Ballore, 1911 b, 1912, 1916; Milne, 1912 b, 1913; Vallaux, 1925; Sieberg, 1932; Bobillier, 1933; Heck, 1934, 1947; Gutenberg, Richter, 1949, 1954; Shepard et al., 1950; Darvin, 1955; Hewitt, 1957; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967; Lomnitz, 1970; Silgado, 1974).

1836. July (or June) 3, at midnight. At Cobija (northern Chile) a strong surge was felt on a ship, riding at anchor. The sea beat powerfully on the rocks in the bay. The surge gradually increased; by 7:00 it had grown many times over and broke on the beach with great force, although the breeze had not become stronger. These flood tide phenomena were attributed by the residents to an earthquake, the shock of which was felt on land with a certain intensity at about 8:30. The earthquake was not noticed on board the ship, or even on a small peninsula to the south of the bay, connected to shore by a sand bar (Perrey, 1858; Montessus de Ballore, 1911 b).

In other compendia (Montessus de Ballore, 1911 a; Milne, 1912 b; Berninghausen, 1962; Iida et al., 1967), it is more definitely stated that an earthquake was felt at Antofagasta and Cobija and was accompanied by a tsunami.

1837, November 7, 8:05. A strong earthquake at Valdivia, Castro and Ancud (San Carlos). At Valdivia, this was the strongest earthquake since the founding of the city. It lasted about 10 minutes. It was difficult to remain standing. The city was completely destroyed, though no one died. Weaker shocks were felt all day.

On Chiloe Island and the Chonos Archipelago (at San Xavier*, Ancud), at Osorno and other points, the ground shook for 40 days with slight interruptions. During the main shock, those who were trying to keep standing by holding onto trees were thrown to the ground. The destruction was very thorough. The bulk of the houses, which were constructed without cross beams, but only on piles dug into the ground, were destroyed. At the mill, the mill stones began to move. The upturned sod in the potato field fell back in place. The trees were broken or uprooted. Everywhere, the ground was covered with cracks.

Avalanches took place in the southern part of the country.

The earthquake was rather strong at Talcahuano and Concepcion, where it lasted about 8 minutes. A strong subterranean rumble was heard, and the bells rang by themselves. The earthquake was not felt in the region of Los Andes.

As a result of a seaquake, the sparring shook loose in a whaler, /50
within sight of shore at 43° 38' S. On December 11, this whaler cast anchor at Lemus Island (Chonos Archipelago). It was found that the bay had become shallower by 2 1/2 m (8 feet). Mollusc colonies on shore dried up because of this elevation. It is possible that the shore also shifted at other places: it rose at Tecaume* and subsided at Tac Island (Chonos Archipelago). The shore was strewn with decomposing fish and tree branches, apparently as a result of strong tsunami waves.

At Ancud, in the Pudeto* River and in the strait separating Chiloe Island from the mainland (De Calbuco)+, unusual flood and ebb tides occurred, which were so strong that enormous amounts of seaweed and molluscs were thrown on shore, including some usually attached to rocks. The water penetrated 900 m (1000 yards) inland on low-lying shores.

There is a report that the sea at Valdivia after rushing back, again rushed onshore, rising to an appreciable height.

On Mangareva Island (see Fig. 77), the sea level rose substantially higher than any previously observed flood tides. A large basalt block, partially overgrown with coral polyps, was left on the beach 30-40 m from the water line, 2 m above the mean sea level. On Tara Vai+ Island (Gambie Islands)+ the sea rose rapidly between 12:00 and 13:00. This rising movement was brief, and in 3 minutes the sea began to subside, reaching the lowest low tide (equinoctial ebb tide) mark, and then rose again in four hours. Then strong flood tides and as many strong ebb tides were observed.

It was not possible to gather information about the tsunami on

the Marquesas Islands and Mariana Islands and Tahiti Island.

Oscillations of sea level began on the Samoan Islands, at Apia, on the 8th at 14:00. Observations ceased after 3 hours, but the oscillations still continued.

On Pago Pago, according to Wilkes, at 14:20, the sea suddenly rose 60 cm (2 feet) above the level of the highest spring tides. At 14:30, the level fell to the lowest low tide mark. At 14:35, the level rose as high as the first time. At 14:40 it fell back again to the spring low tide mark, and then rose quickly with great force 90 cm (3 feet) in 2 minutes. The water receded with equal force and at 14:52 it fell considerably below the low tide mark. At 14:55, it rose again as high as before, then fell by 45 cm (18 inches) and suddenly rose again to the same height as the third time.

Subsequently, flood and ebb tides alternated as follows: at 15:03, a flood tide; at 15:06:30, an ebb tide, stronger than all preceding ones. At 15:12, flood tide, the same as at 15:03, immediately falling 30 cm (1 foot); at 15:17:30, flood tide, almost the same as the third in succession; at 15:20 a drop in level to the low spring ebb tide mark; at 15:35, a rise to the spring high tide mark, a drop to half flood tide and at 15:36 a flood tide, the same as the first and second, accompanied by a drop in level by 60 cm (2 feet); at 15:42 a flood tide, almost the same as the third, followed by the strongest ebb. At 15:50, the level was still several feet below the low tide mark. At 15:54, the water rose 60 cm (2 feet) higher than the third time, and then fell approximately the same distance with the same speed as it had risen. At 16:00, the level was approaching that of large flood tides. At 16:15 it rose again, but by half as much as the preceding time and at 16:20 it dropped to the low water mark. At 16:32, a rise of the same magnitude as at 16:15, at 16:40, an ebb tide; at 16:55 a flood tide, the same as the first; at 17:03 an ebb tide. At 17:08, the water was 30 cm (1 foot) higher than that of large flood tides and it gradually fell to the low tide mark.

The flood and ebb tides continued with diminished frequency, not passing the regular flood and ebb tide marks throughout the evening. On the following day, flood and ebb tides were irregular both as to time of onset and as to height. Sometimes the water dropped somewhat below the low tide mark or rose above the flood tide mark, and sometimes the oscillations reached the levels of neap tides. This continued until 16:00 when the water rose to the same height as the first time, on the 8th, then fell to half flood tide and for a short time was almost motionless. At 16:24, the water rose to the same height as at 16:00, then fell back somewhat below the flood tide mark and continued in this movement all evening of this day and in the morning. /51

On the 8th, unusual oscillations of sea level were observed on the Vava'u Group (Tonga Islands). Flood and ebb tide recurred every 10 minutes, and this continued for more than 36 hours.

Detailed reports are available on the occurrence of the tsunami on the Hawaiian Islands.

At Hilo, according to the accounts of Coan and others, at approximately 19:00 (according to other sources, 18:30), it was noticed that the water retreated far beyond the regular low tide mark. In a few moments, it returned as a gigantic wave 6 m (20 feet) higher than the flood tide mark, rushing onshore with the speed of a racehorse. The movements of the water were eddy-like, accompanied by a thunderous noise like a mountain slide. All the lowlands near the coast were instantly flooded. The water rose especially high along river valleys. Crops and fish ponds were laid waste. Many homes, domestic utensils, food, fuel and canoes were washed away. The water also overwhelmed hundreds of residents, who were conducting a meeting in Hilo at that time and were not expecting the catastrophe. The flood lasted 15 minutes. Then the water retreated beyond the low tide mark and after a short pause returned again, but with less force. The movements of the water then continued for a short time, abating with each oscillation, until the usual level was restored.

After the abatement of the water, the shore of the bay was left strewn with debris of homes, tree branches, etc. Twelve Hawaiians, who had been washed away, were saved by the crew of the English whaler "Admiral Cockborn," which was riding at anchor in the bay.

According to the captain of the ship, the current velocity was 8-10 knots, ıe anchorage depth varied from 9 to 6 m (from 5 to 3 1/2 fathoms) and the greater part of the bay dried up at ebb tides. A mark left on a boatshed indicated that the peak rise of water at Hilo was 3.3-6.0 m (11-20 feet) above the usual flood tide mark.

In Kanokapa* and Kaahelu* 66 homes were destroyed as a result of the tsunami, and four men, two women, and five children died. A woman and a child drowned at Waiolama* and Hauna*. One woman died at Kauwale*.

In the Kau district, 108 homes were destroyed and 46 people died.

The sea retreated 36 m (120 feet) on the coast of the island of Maui, at Kahului. The inhabitants rushed to the drained area to collect fish. The sea suddenly rose in the form of a steep wall and rushed onshore, inundated the crowd, overflowed the beach slopes and carried the whole village, consisting of 26 grass huts, 240 m (800 feet) inland.

One of the residents, caught at home by the tsunami, swept a child into his arms and ran so fast that he was able to climb a small sand dune. Looking around, he saw that the village with all its residents and property was moving to the interior of the island. Some of the residents had climbed onto the roofs of their homes, others swam alongside. After this, the most severe and destructive wave, two more ran onshore. Then the sea calmed down and did not flood the land.

The destroyed homes of this village, men, women, and children,

broken canoes, poultry and cattle, were tossed for the most part into a small lake located just behind the village having a diameter of 5.5 km (3 miles). No one had expected this rapid and sudden deluge, save for the old men who knew that the ebb tide must be followed by a flood tide, and who took to the hills. However, all the inhabitants, having been swimmers since childhood, made it safely to solid ground. Only two old women died.

At Lahaina, on the south side of the island, the water rose 2 1/2 m (8 feet). /52

At Honolulu, according to Rooke, on the 7th at 18:00, an alarm arose, since the water had receded. The first ebb was the greatest, a little more than 2 1/2 m (8 feet). However, since no one had been trained to make observations, its exact magnitude was not measured. The reefs surrounding the harbor dried up. Most of the fish left on the dried bottom were dead. Several ships ran aground. The water quickly returned and in 28 minutes reached the height of the regular high flood tides. Barely halting, the water again retreated and fell by 2 m (6 feet). All this was repeated at intervals of 28 minutes. The third rise was 10 cm (4 inches) above the normal high tide mark, and the recession was 190 cm (6 feet, 4 inches). After the fourth flood tide, the duration of rises and falls varied, and their magnitude decreased gradually, but irregularly. At 23:00 the ebb tide lasted 26 minutes, and the flood tide 10 minutes. At 23:30, the combined duration of the flood ebb tide was the same, but their magnitude had diminished. The oscillations continued on the morning of the 8th.

The rate of recession of water varied in different parts of the bay. On the eastern shore, the peak rate noted was 15 cm (6 inches) per minute. However, on the northern coast at one time during the third ebb it was 90 cm (12 inches) in 30 seconds. Not once did the flood tide rise above the regular spring flood tide mark but the ebb tide fell 2 m (6 feet) below the ebb tide mark. There was no earthquake.

A tsunami with an intensity i = 0 was observed on the northeast of Honshu Island, in Iwate and Miyagi prefectures, in Kesen+ and Motoyoshi+ districts and on the Djika+ Peninsula (Rooke, 1839; Dumoulin, 1840; Dumont d'Urville, 1842; Jarves, 1843; Petit-Thouars, 1844; Wilkes, 1844; Mallet, 1853; Perrey, 1854 c; Lyell, 1868; Anon., 1877, 1961; Goll, 1903; Krümmel, 1911; Montessus de Ballore, 1916; Jagger, 1931; Sieberg, 1932; Navarrete, 1933; Heck, 1934, 1947; Davison, 1936; Imamura, 1949; Sammons, 1950; Shepard et al., 1950; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967; Lomnitz, 1970).

1838, May 7, afternoon. At Fort Galvez (see Fig. 17), there were two rather strong shocks. They were also felt at Talcahuano and Concepcion. The sea at the fort quietly rose 0.8 m in 40 minutes (Perrey, 1854 c).

1839, February 12, 9:10. Between Valparaiso and the Juan Fernandez Islands, there was said to be an underwater eruption and a

"maremoto"; a new islet was formed with coordinates: 33° 34' - 33° 40' S., 76° 49' - 76° 50' W. (Montessus de Ballore, 1911 b).

1840, January 28, 3:00. There was a strong earthquake at Lima, also felt at Chorillos. It was accompanied by a hurricane wind, blowing from the southwest, and a downpour. The sea was so agitated at Chorillos, and the air temperature fell so greatly, that bathing stopped on the beach and the people sought shelter (Polo, 1899 a).

1841 (no date), about 2:00. At Callao, the sea withdrew from shore more strongly than during the greatest ebbs, and ships ran aground, something which had not happened for a long time. Then the sea returned with still greater force "spreading terror everywhere." Nothing could withstand its fury. Meanwhile, not even slight underground shocks were felt and not the slightest change in temperature was apparent (Perrey, 1858; Sieberg, 1929). [One hypothesis is that this was the Kamchatka tsunami of May 18, 1841. However, the times of the earthquake and the oscillations in sea level at Callao correlate poorly.]

1847, May 23, 3:00. A strong seaquake was felt by the American frigate "Akushet" 110 km (60 miles) westsouthwest of San Lorenzo Island. On the same day, strong and unusual movement of water was observed at Callao, where this happens rarely. Three Peruvian ships supposedly sank, despite the prompt and energetic help from English and French sailors. The movement of water continued for many hours (Perrey, 1852, 1858; Iida et al., 1967).

1847, October 19. On the 8th at 11:10, there was a strong and /53
prolonged (2 minute) earthquake at Coquimbo. It was felt as far as Valparaiso, Santiago and Mendosa.

In Coquimbo there were many recurrent shocks, including the shock of October 19, causing a heavy surf. The population was frightened (Montessus de Ballore, 1911 b, 1916). [It is possible that the date is not exact and that the description refers to the events of November 17, 1849.]

1849, November (December, mistakenly June) 17 or 18, 16:10. At Coquimbo and La Serena there was a brief "terrible" rumble followed by an extremely strong earthquake lasting 85 seconds. There was no damage. The earthquake was also felt at Santiago (rather strongly) and Valparaiso.

From 8:00 to 21:00, another 19 subterranean shocks were registered.

At Coquimbo, half an hour after the earthquake (according to other sources, 10 minutes after), the sea quickly swirled backwards for some distance, so that two ships almost capsized. Then the water returned with "furious force and speed," destroying two wooden moorages at the copper foundry and flooding eight furnaces, five of which exploded with a terrible roar. The home of the owner of the foundry, the canal supplying

the foundry with water, and two customhouses were also partly or completely destroyed. A public moorage was damaged and one private moorage was half swept away. The water passed 300 m (3 cuadro) beyond the highest flood tide mark and rose 5 m (16 feet) above that mark. There were no victims (Perrey, 1860; Goll, 1903; Montessus de Ballore, 1911b; Milne, 1912 b; Willis, 1929; Heck, 1934, 1947; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967; Lomnitz, 1970).

1851, April 2, 6:48. A destructive earthquake occurred in central Chile (Valparaiso, Casablanca, Santiago and other cities). Many homes were destroyed. There were victims. Many aftershocks took place.

Rudolph's compendium (1887) mentioned that after the earthquake, "the water left the harbor." Apparently, this reference is incorrect (Iida et al., 1967). Only a seaquake was felt, 70 km (40 miles) from Valparaiso. As for the sea level, more accurate sources (Perrey, 1854 a, 1860; Goll, 1903; Montessus de Ballore, 1912) mentioned that "this time the ocean did not undergo the convulsive movements so often accompanying very severe earthquakes at Valparaiso. No special waves were observed, like those enormous waves which at other times have devastated the coast. Nor was any residual elevation of the land observed."

1851 (erroneously 1852), May 26, approximately 13:15. Copiapo, Huasco, Freirina and other inhabited points suffered greatly from an earthquake. Many buildings were toppled, or at least heavily damaged. In one place, a yawning crevice 40 m long and 0.2 m wide appeared in the ground. All the buildings were damaged and many were destroyed at Vallenar. No less substantial damage was done in the southeast and northwest of the Chanaral mines region. The tremors were accompanied by a rumbling which lasted almost 2 minutes. An earthquake of such magnitude had not been observed in the Freirina region for 50 years.

The tremors were somewhat less severe at Caldera and Tres-Puentes. The earthquake at Coquimbo, so it seemed, had come from the north. The frightened residents ran from their homes, however the buildings suffered no damage. The earthquake was very moderate at Santiago, and took the form of extremely long-period and consequently slow oscillations. All clocks in the city stopped. The earthquake was almost the same or weaker at Valparaiso.

The earthquake was accompanied by numerous after shocks. More than a hundred were counted at Copiapo before midnight. A week later, several shocks a day were felt. Individual shocks were noticed throughout June.

Some time after the earthquake, unusual oscillations of sea level began at Caldera. These were renewed at 7 to 10 minute intervals throughout the day, right up until nightfall, when observations ceased. /54

At Huasco a short time after the earthquake, the water left the bay with unbelievable speed and the bottom was drained to about 100 m from shore. Then a wave more than 3 m (10 feet) higher than the highest

flood tide mark suddenly rolled onto the beach and washed away everything in its path. This phenomenon was repeated every half hour throughout the day (Perrey, 1854 a, 1856, 1860; Goll, 1903; Montessus de Ballore, 1911 b; Milne, 1912 b; Sieberg, 1932; Heck, 1934, 1947; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967; Lomnitz, 1970).

[Sieberg's data, reproduced in Iida's compendium (Iida et al., 1967), indicating that a stronger tsunami was observed at La Serena and Coquimbo than at Caldera and Huasco, are doubtful.]

1852, November 27, 7:00. There was an earthquake at Lima, which was also felt at sea (Perrey, 1855, 1856). [Apparently, this only refers to a seaquake.]

1855, August 11, 5:15. At Valparaiso there was an earthquake, the strongest since the shock of April 2, 1851. The sea churned and anchor chains shook.

At Rancagua, there were two shocks lasting a total of 2-3 seconds, a rumble lasting about 10 seconds. At Santiago, two gradually fading tremors lasting a total of 18 seconds at 1 second intervals accompanied by a subterranean rumble. The earthquake was accompanied by a foreshock and aftershocks (Perrey, 1860; Goll, 1903; Montessus de Ballore, 1911 b). [Apparently, this concerns only a seaquake.]

1858, April 24, morning. At 7:15, there was an earthquake at La Serena last ~ 80 seconds, not causing any damage; there were tremors from time to time in the evening. At 7:45, there was an earthquake at Santiago. On the "Himalaya," situated approximately at 28° 54' S., 75° 59' W., the captain, the entire crew, and passengers were surprised in the morning at breakfast, to feel a strong earthquake lasting 25± seconds; the ship shook as if the water barrels were bouncing inside it. On the "Janette Bertha," crossing from Chanaral to Caldera in the period April 20 to 26, a shock was felt at 27° 03' S., 71° 21' W., as if the ship had struck bottom. At Coquimbo, the sea rose and rushed on shore, but did not do any appreciable damage to the blast furnaces. The water rose highest at the breakwater, as a result of which a strong current arose up the river (Montessus de Ballore, 1911 b, 1912).

1859 (possibly, 1860), April 22, about 14:00. There was a strong earthquake at Callao. Many buildings were destroyed, while those surviving were cracked. All the churches in Callao and Lima were damaged.

A resident of Callao Reads, who was engaged in the observation of phenomenal occurrences who and kept a homemade seismometer at home, noted that during the morning of the same [perhaps the following?] day "the sea began to rise" (Perrey, 1870 a).

[Most likely, the report refers to the earthquake of April 22 and 23, 1860; see below.]

1859, October 5, 8:00. At Copiapo, after a terrifying rumble,

there was a severe earthquake, lasting about 4 minutes. Weaker shocks, with a dull rumbling, continued through the day, almost without interruption. Aftershocks were felt at least until October 19.

The earthquake caused considerable destruction: 115 homes collapsed and 224 homes were rendered unfit to live in. The total damage was estimated at $930,000. The embankment of the Copiapo - Caldera railway crumbled on a 25 km (6 leagues) stretch. Cracks appeared in the ground at many places.

At Tierra-Amarilla, the buildings rocked like pendulums and many were damaged. A cave-in occurred at the "Carmen-Alto" mine, and 8 or 10 men were buried. At La Serena an underground rumbling was heard, which was followed by very long period oscillations.

The earthquake was felt for 1 1/2 ± minutes at Caldera; it caused great damage. A blast furnace collapsed. The sea withdrew from shore several times. The level fell by 6 m (19 feet) and the bottom was laid bare for a distance of 150 m from the low tide mark. All ships in the port suffered some damage (Perrey 1864 b, 1867; Goll, 1903; Milne, 1912 b; Willis, 1929; Heck, 1934, 1947; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967; Lomnitz, 1970). /55

1859, October 11. There was an earthquake in Copiapo in which two hundred homes collapsed. In the port of Caldera, the ocean was agitated again and ships riding at anchor experienced entirely the same effect as the shocks produced on land (Perrey, 1862 a).

[Apparently, the date is mistaken, and this report concerns the earthquake of October 5, 1859, since other more accurate catalogues (Perrey, 1867; Montessus de Ballore, 1911 b) note that on October 11 only two very brief shocks, not doing any damage, were felt at Copiapo.]

1860, April 23. On the 21st, about 2:00 in Peru (Lima, Callao and other points) the first of a large series of shocks took place. A severe earthquake occurred on the 22nd at 13:50. It caused great destruction at Callao, but the sea apparently remained calm [the only report possibly contradicting this is that of April 22, 1859.]

On the 23rd, in the morning, about 7:00, at Lima and Callao, there was a prolonged and severe earthquake of approximately the same strength as the shock of the 22nd. All the homes were cracked to some extent at Lima, and the church steeples collapsed. At Callao, walls which had withstood the first shock crumbled.

At Manta*, trees were uprooted, one of the hills collapsed, and stinking water flowed out of a crack about 300 m long and one meter (a few feet) wide. This was the strongest earthquake here since the catastrophe of 1746.

On San Lorenzo Island, the earthquake was so severe that it caused large rock slides. A shock occurred at Chorillos, but it did no damage.

At Callao, after 11:00, the sea withdrew a little from shore, then, changing direction, it barely flooded the shore. These oscillations in level caused general panic in the city.

Oscillations in sea level were not observed during the numerous subsequent shocks at Callao (Perrey, 1862 b, 1865; Krümmel, 1911).

1861, March 10, 20:45. Mendosa was destroyed by an earthquake.

Fourteen thousand dead were reported. There was considerable damage at San Luiz. The damage was not so great south of Mendosa. Several homes were damaged at San Vicente and Lujan-de-Cuiga+. Most of San Martin survived, but some homes were damaged. The rural environs of Mendosa suffered little damage. There were no signs of the earthquake at all at many farms, but everything was overturned at others. No subterranean rumble was heard during the earthquake (Perrey, 1864 b).

The earthquake affected part of Chile and was felt at Santiago and Valparaiso as strong undulating oscillations lasting 50 seconds (Goll, 1903).

"There was talk of a flood, which supposedly accompanied this earthquake, but I could discover absolutely no details, not even the date" (Perrey, 1864 b).

1865, January 8 and 9. There were two earthquakes at Callao. The sea was ·ry agitated and did great damage. A bathhouse was washed away, killing five people. The crest of the breakwater collapsed. Other structures were destroyed. In the port, off shore, and as far as the horizon the sea looked like a cauldron of boiling water (Perrey, 1867; Fuchs, 1885 b).

1865, March 1, at 6:30 in Callao Bay, extraordinarily heavy sea, described by the secretary of the American Embassy in Peru, T.G. Pope, who was on board the "Lancashire." According to Pope, the water surface around the ship, as far as the eye could see, was in such a "ferment" that the wind drove crests 30-40 cm (12-15 inches) into the air. The /56
hydrogen sulfide smell was unbearable; the white sails of the ship turned black.

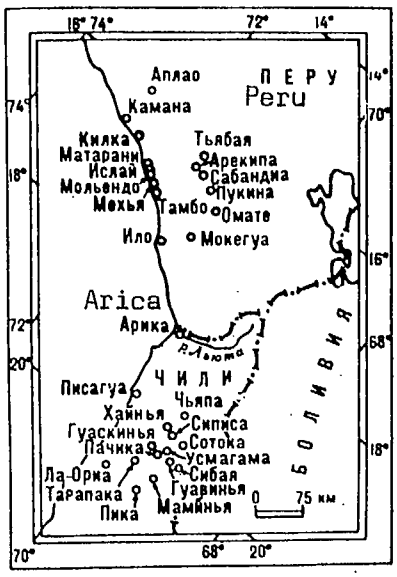
A similar phenomenon had recently been observed in the bay [obviously January 8/9, 1865], when an enormous wave fell on Callao, the bathhouse was washed away and several people died. But at that time there were many subterranean shocks, while Pope felt no earthquake on March 1 (Perrey, 1867; Fuchs, 1885 b; Bruggen, 1943).

1865, November. On the 28th an earthquake was felt in Lima and vicinity. The sea raged from the 25th to the 27th at Callao; some damage was done (Polo, 1899 a).

1868, August 13, 16:45. A destructive earthquake and catastrophic tsunami with source near the coastal cities of Southern Peru (see

Fig. 23

A general map of the border areas of Peru, Chile and Bolivia.



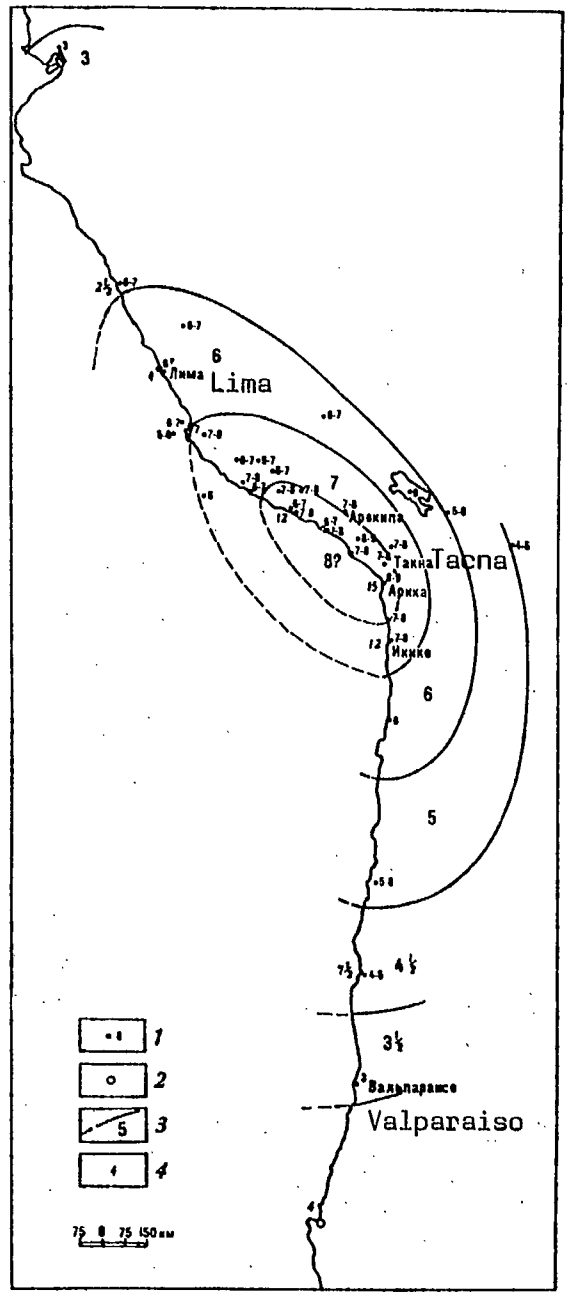


Fig. 24

The force of tremors and isoseists of the earthquake of 13.VIII.1868. Compiled by S.L. Soloviev from information in the literature.

1 - points where the earthquake was felt, and force in points;

2 - points where the earthquake was not felt;

3 - isoseists;

4 - rise of water in m during the tsunami.

Fig. 18, 23). The tsunami is known in the literature as the Arica Tsunami.

Hochstetter located the macroseismic epicenter between Tacna and Arecipa, while Silgado located it near Arica. Apparently, the pleistoseismic region stretched far along the coast (Fig. 24). Possible foreshocks of the earthquake were felt: on August 1 and from August 9-12 at Lima and on August 11 and 12 at Tacna.

A dull underground roar was heard in the pleistoseismic region before the earthquake. Then followed weak oscillations, which in 1/2 minute became such strong tremors, that it was very difficult to stand. In the Andes, numerous avalanches occurred on the mountain sides. In many places, cracks formed up to 5-8 cm wide from which issued flows of mud and water or dust and asphyxiating gases.

Such dense dust arose at Arica after the shock that it was difficult to breathe or see. For some time, the air was so "charged" with electricity that the hair sparked when a hand was run through it. The entire city, numbering 5000 residents, was turned into ruins, except for a few two-storey homes [8-9 degrees].

At Tacna, located in a valley on alluvial soils, 40 homes built of adobe and having heavy earthen roofs, completely collapsed. Three residents were killed and many were injured. Recently built frame homes with light roofs did not suffer. One could see waves passing over the surface of earth [7-8]. At 20:00-21:00, an unusual luminescence was observed in the sky over the Andes (a moving ball of light).

The cities of Sama and Locumba, situated near Tacna, were almost flattened, and the valley of the Liuta+ River was completely devastated [9]. In "splendidly built" Moquegua, not a single home remained standing and 150 people died [8-9]. At Arecipa, built up mainly with solid stone homes, "everything" collapsed, only the steeple of one church was left standing. Ten persons died of the 3,000-5,000 population of the city [7-8].

The cities of Quilca, Oconya+, Caravelli, Acari, Chuquibamba suffered very serious damage from the earthquake [7-8]. Tambo and Islai+ suffered slight damage [6-7]. At Chala, many buildings were damaged, but none collapsed; there were no victims [6-7 degrees].

The earthquake lasted about 8 minutes at Cusco. Solid buildings were almost totally destroyed. Steeples swayed like masts [6-7]. Lake Titicaca was stormy, as never before; one ship broke up on a rock; several rafts sank [6]. Cases of sea sickness were recorded at La Paz. Five severe shocks were felt at Corocoro during the eight days following the 13th. At Cochabamba, three shocks were felt on the 13th from 17:00 to 19:00, one on the 14th, and two on the 15th.

At Chonos* the home of an eyewitness cracked and a rumbling was heard [5-6]. Some damage was done at Naska, Kanara*, Charpa*, Guicachi*,

Cabacara*, Pucyo, Champa* [6-7 degrees]. Ica was almost totally destroyed by the earthquake; fire broke out; 12 people died [7-8]. More than 30 homes were destroyed at Pisco. Ships at 15° 45' S., 75° 44' W., and 55 km from Pisco felt a seaquake.

On the Chincha Islands, people were flung to the ground. The /57
roofs vibrated as if they were made of pliable material, and one could see parts of homes usually hidden by the cornices. The stones with which the yards were paved started to move and bounce.

The earthquake was very strong and lasted 3 minutes at Callao and Lima. Homes and churches rocked in every direction and seemed likely to collapse, but there was no destuction [6]. According to accounts Serro-de-Pasco, a mining center, supposedly turned into a pile of ruins [6-7?]. The earthquake was felt severely at Santa Cruz de la Sierra*, and it frightened the population; there was no destruction [5-6]. The earthquake was felt as strongly or more strongly on the Andes Plateau. Casma suffered damage [6-7 degrees]. The earthquake was felt at Guayaquil but /58
was not felt at Quito.

South of Arica, Pisagua and Iquique were destroyed [7-8]. The rich nitre mines at Molle* near Iquique were destroyed, as was the settlement of Molle* itself. The earthquake was comparatively slight at Cobija [6]. At Copiapo very long-period oscillations grew so strong that it was difficult to stand [5-6]. The earthquake was still rather strong at Coquimbo [4-5] and very weak at Valparaiso [3]. It was not felt at Talcahuano or on the Juan Fernandez Islands. The earthquake was accompanied by an enormous number of recurrent shocks.

The tsunami which followed the earthquake affected the coast of Peru and Chile, at least from Trujillo+ (where there was damage) to Chiloe Island. The belt most affected by the tsunami extended approximately from Chala and Islai to Iquique; it is possible that the mean rise of water exceeded 10 m here. The oscillations in level apparently began with the flood tide, but at most places, especially those remote from the source, the subsequent stronger ebb was noticed first. The tsunami did the greatest material damage at Arica.

At Arica, after the earthquake, the sea rose, according to various estimates, 2 to 5 m (6-16 feet) above the flood tide line, flooded the land 450 m (500 yards) beyond this line, and swept 200 residents from the breakwater where they had taken refuge from the earthquake. Twenty minutes after the earthquake, the sea suddenly retreated about 2 km (1 mile) from shore. The bay dried up, and all vessels were carried out to open sea with shocking speed. Several minutes later, the sea swept onshore in a terrible wave 15-18 m high (50-60 feet), carrying the vessels on its crest. It flooded a large area of land and tossed the ships on the beach like chips. The second tidal wave 15 minutes later was about as strong as the first. There were reports that the harbor at Arica shallowed after the earthquake.

According to Silgado's catalogue, the first big tidal wave 12 m

high occurred at 17:37. The ebb began at 18:17, and the water withdrew 90 m from shore. At 18:30, the sea rose 14 m. The water retreated at 18:56.

The Peruvian naval vessels "America," two ships of the American naval fleet (the "Watery" and Fredonia"), several sailboats and a flotilla of small merchant ships were on the roadstead at Arica. The vessels rode 200-300 m (yards) apart at a depth of 15-18 m (50-60 feet). The fate of the "Watery" steamship and the other ships is described in Billings' memoirs (1915).

During the earthquake, it felt as if the vessel was being shaken vigorously by a giant. Waves could be seen running along the surface of the ground onshore. A dense cloud of dust rose above the city and soon spread to the vessels. When the dust had settled, the city was seen to be a pile of ruins. Mummies spilled out of their graves at an ancient Indian cemetery on the side of the Andes.

A whaleboat with a crew of 13 men was let down from the ship to shore to help the residents. All this time the sea was quiet. Suddenly a crackling rustle was heard, and from the ship, the pier together with a crowd of residents was seen to disappear under water. The whaleboat and its officer was entrained by a strong current and broke on the coastal rocks. Then a terrible noise was heard on shore, and the ocean retreated so far that the bottom was exposed as far as the eye could see. Fish and various marine animals flopped on the dry bottom. All the vessels ran aground, and many keel ships capsized.

When the sea returned again in an enormous flood, some of the vessels were overturned or smashed, and some, such as the flat-bottomed "Watery," resurfaced. From this moment on, the sea was in continuous movement. Contrary currents swept the ships here and there. The "America" got up steam and tried to reach open sea, but at ebb tide its stern hit bottom, the engines were smashed, and the ship moved out of control backward and forward with the currents. The "Fredonia" was smashed on the bottom and sank. A small naval military fort, situated on /59
a cliff 2 1/2 m (8 feet) above the water, was completely washed away together with all structures, cannons and the garrison. A motor launch, let down from the "Watery" immediately after the beginning of the tsunami, in spite of its working motor, was swept this way and that, and in the end was smashed against the side of the "America."

After nightfall, at approximately about 20:30, an enormous "wall" of phosphorescing and foaming water mixed with sand moved in from sea with a thunderous noise. The solidly anchored "Watery" was sunk, but resurfaced. The ship was caught in the general movement of water, and then ran aground. At dawn, the crew found that the ship had been tossed by a wave clear across the city and left on a sandy plain 60 m from the rocky spurs of the Andes, 3 1/2 km from the shore line and 9 km from the ship's anchorage. From marks left on the rock sides, the amount of rising water was estimated at 14 m (47 feet), not counting some higher splashes. The "America" and the English "Chanaselia" were also tossed

onshore. In place of Arica stretched a smooth sandy valley with no trace of buildings. Only here and there on the mountain sides did there remain scattered little homes. An enormous band of debris extended at a height of 6-9 m (20-30 feet).

At Ilo, what remained after the earthquake was destroyed by the tsunami. No trace of buildings remained. Two vessels first sat on dry bottom, and then were tossed onshore. Twenty people died. Everything, including goods at the warehouses, was washed away at Mollendo.

Islai, built on a 30 m terrace, suffered comparatively little. Soon after the beginning of the shocks the sea withdrew very quickly from shore, and then inundated the coast five times. In an hour and a half after the earthquake, the water rose 12 m (40 feet) above its usual level. The city itself hardly suffered any damage, but all the vessels and boats riding in the harbor were either smashed or sunk.

Tambo was washed away and apparently more than 500 people perished. Such was also the fate of Tiabaya+, Vitar* and Mejia+.

The anchor chains snapped on the vessels situated in Chala harbor at ebb tide; fortunately, the ships escaped serious damage. Then the sea returned in a wave approximately 15 m high (50 feet), covering the rocks in the harbor and flooding the city to 300 m (1000 feet) from the beach. The flood tide recurred three times. The stone breakwater and houses belonging to the steamship-line were completely washed away. Thirty people died.

At Pisco, at 22:00 the sea withdrew 350 m (400 yards) and returned with shocking speed, destroying everything in its path. In particular, the stone breakwater was utterly flattened.

On one of the Chincha Islands, at 21:45, people living at the breakwater saw the water recede. At about 22:00 it was 60 m (70 yards) from shore, although at regular ebb tides the depth of the bay is 25-35 m (15-20 fathoms). Soon the water rose and broke onshore in a colossal flood tide. The island was hidden in the foaming waves. The water washed away houses and everything else in its path. Both breakwaters were destroyed and many steamships and boats were smashed. Many people died.

When the sea had calmed down a bit, one of the residents retrieved a boat and set out to have a look at the other two islands of the group. On reaching the end of the channel, he heard a terrible noise. The sea rose and fell with a speed of 3 m (10 feet) in 3-4 minutes and he had to go back.

At Canete, the sea retreated from shore just as at the other cities in Peru. At about 22:00, the city was completely flooded.

At Callao at 21:00, the water left the harbor, and then (22:30?) returned in a monstrous wave. However, it broke up on San Lorenzo

Island, lost energy and as a result it did only slight damage, having a height of 4 m (14 feet) onshore. The ships raced for deep water and collided with each other. Several ships were damaged, but none sank. /60
At 0:00 or 1:00 on the 14th, another such flood tide arrived. The water flowed over the dike, travelled 15 m (50 feet) and flooded the first storeys of the homes in the lower part of the city.

South of Arica at Pisagua, boats were tossed 270 m (900 feet) inland from shore. Three ships were smashed.

A small harbor 36 km (20 miles) north of Iquique [Caleta-Buena*?] was completely washed away. The flood and ebb tides recurred every 15 minutes.

At Iquique, immediately after the earthquake, it was observed that the sea level had risen extraordinarily high - approximately 1-1 1/2 m (4 feet) above the regular flood tide line. Suddenly, with ever increasing speed, the water rushed back, and the bay dried up as far as the 7 m (4 fathoms) mark, so that the bottom of the strait between the shore and the island screening the harbor was completely laid bare. While the water was still receding, a large wave approached from the southeast. It was described as a mass of blue water 12 m (40 feet) high without crest or foam, rolling forward with a speed of 14 knots. Part of it passed between the island and land. The other part skirted the island, covering it and the city with foaming waves. Eyewitnesses had the impression, not that a wave had rolled on land, but that the land had sunk under ter. The tsunami completed the destruction of the city begun by the earthquake. The city was completely submerged. When the water had receded, the entire lower part of the city, with buildings, steam locomotives, iron posts and other objects, was completely washed away; not a trace was left of any structure. About 150 people died. Of those carried off by the water only a woman and a child could be saved.

The sea rose to a considerable height at Cobija. Flood and ebb tides occurred irregularly.

At Mejillones harbor, situated beside a village with 200 residents, the flood and ebb tide recurred at 15 minute intervals. First, a tsunami of average size was observed, then a large one. During the two strongest ebb tides, the sea retreated 150 m from shore. Almost everything was washed away. The oscillations in sea level lasted more than a day. Twenty to thirty people were injured, but they were saved.

At Ferrocarril* [railway station of Mejillones], at about 19:19, the sea retreated about 200 m (2 cuadro) from shore and after a half hour, it surged onshore, rising 6 m (20 feet) and threatening to flood the city.

At Cobra* and Taltal, the flood and ebb tides were not strong and did no damage, but the tsunami did cause destruction at Chanaral.

At Caldera at 20:30 (or 20:45), the sea began to foam, then

slowly receded from shore. Flood and ebb tides followed. At 22:30, the water retreated 180 m (200 yards). The reefs behind the breakwater dried up. In a few moments, a large wave rushed in with a dull noise like that of a turbulent stream and it did considerable damage. The water flooded the breakwater and tossed onto it eight ships loaded with coal. A crane was overturned, and the port captain's hut was damaged. An English freighter, moored to the breakwater and unloading coal, was completely disabled and tossed onshore north of the breakwater. There were no victims.

At Carrizal Bajo, soon after the earthquake, the sea began to "swell" and foamy waves appeared. At about 20:00, seven ships, holding to their anchors, found themselves on dry bottom. The anchor chains of the other ships broke and the ships were carried out to sea in different directions, where they collided with each other, causing damage. The breakwaters at first dried up completely, and then were flooded more than 50 times with raging waves. The sea encroached on land to about 100 m. The residents fled their homes and ran to the hills.

At Coquimbo, at about 20:00, a strong ebb tide was noted. It was followed by a flood tide unusual for this month. The oscillations reached their greatest height, 7 1/2 m (25 feet), at 2:30 on the 14th. Damage was done. Ships were carried away with their anchors, and close ships collided. Two of the boats launched by Chilean naval vessel to help the other ships sank. Onshore, one of the breakwaters and a slaughterhouse /61
were destroyed; all the cattle kept there perished. A small area was flooded at the breakwater. The water penetrated into several houses, crossed the lagoon to Nigarez de Norte* and flooded the shore on this side to more than a kilometer (10 cuadro). The station suffered slight damage. Strong oscillations were observed until 7:00 on the 14th.

At Concon Bay, the sea retreated from shore so quickly and so far that many previously unknown shoals dried up. Oscillations in level continued until at least 3:00. Three fishing boats were carried off; one was later picked up.

At Valparaiso, strong flood and ebb tides recurred 3-4 times an hour; there was no damage.

At Constitucion, at about 21:00, during a rather large ebb tide, sea waves burst into the river with such force that the steamship "Independela" snapped all its anchor chains and the steamship itself was dragged for 400 m (4 cuadro) and set down on an island. The anchor chains also snapped on all the other ships riding in the harbor except for two, and the ships collided with each other. Almost all the boats in the harbor, including those laden with cargo, were torn from shore. At ebb tide most of them were tossed onto a bar, where they later sank. The amount of rise of the water was estimated at 1 1/2 m (4 feet) above the strongest flood tide mark. Strong flood and ebb tides continued until 3:00.

At Tome at 21:30 (or 21:45), the sea retreated approximately 200-

250 m (2-2 1/2 cuadro) beyond the lowest low tide marks. The frightened residents took to the hills. At about 22:00 the sea began to rise, flooded the beach, and then rising more than 2 1/2 m (8 feet) above the usual flood tide mark, it flooded the warehouses and destroyed the custom house. Several boats and sloops were completely disabled and tossed onshore. Strong oscillations in level continued until 3:00.

The water rose up the Collen* River and destroyed the abutment of a bridge under construction. It also rose upriver at Bellavista and washed away a railway bridge on the Tome to Concepcion line. The telephone link between these points was also broken.

A ship ran aground on Quiriquina Island. The crew abandoned ship and it sank.

At Talcahuano at 20:05, the water retreated 80-120 m (100-150 vara) from shore. At 20:30, the sea rose, not suddenly but gradually, and crossing the highest flood tide line it flooded most of Talcahuano and Penco. At 21:00, the waterline was 200 m further from shore than the lowest low tide mark.

According to the captain of the French "Margarita," which rode on 13 m (7 fathoms) of water before the tsunami, at 21:15 the depth of the water decreased to 4 1/2 m (2 1/2 fathoms), that is, by 8 m (27 feet). At about 22:00, it was noticed that the water had retreated 200 m (2 cuadro). Not long before 23:00, the water rose 3 1/2-4 m above its initial lev ! rushed onshore with a terrible roar and advanced 160 m beyond the highest flood tide mark, and flooded the city almost as far as the square. Since most of the residents had already taken to the hills, only four people drowned. A public moorage with cranes and boats, and two private moorings were destroyed. The customhouse was damaged. The vessels riding in the bay were not damaged. Flood tides continued every 20 minutes until 4:30 but got progressively weaker.

At San Vicente, the rise of water was slight, although the Bio-Bio River left its banks.

The sea rose at Coronel and Lota but did not do any damage. At Carampangue+, three schooners snapped their anchor chains and ran aground. At Arauko, the sea encroached inland but did not reach the city. At Lebu, a vessel almost ran aground, but in the end made it safely out to sea.

At Corral, around 22:00, with a full calm in the bay, an unusual roar was heard; whirlpools and small waves running in different directions, as from a herd of seals chasing fish, appeared on the surface. Several moments later, such a strong ebb tide arose that the bay resembled a colossal flood following a terrific downpour. Although ebb and flood tides recurred at short intervals, the current velocity stayed constant at 10-11 knots. The advance of flood tides along the coast was accompanied by the same roar mentioned above. The heavy sea lasted until 3:00, when it began to abate, although the water did not return to normal /62

until the 16th. The sea level dropped 4 m at ebb tide, so that all shoals off the river bar were completely laid bare, a thing almost unheard of even at the strongest ebb tides.

At Ancud, 46 flood and ebb tides were counted from August 13 to 16.

On the Juan Fernandez Islands, with still and fair weather, the sea rose 2 m above its usual level. Strong currents arose in the harbor and a roar was heard as if huge stones were being dragged along the bottom. The flood tides did considerable damage. All boats were wrecked on Mas Afuera Island.

In South America, 25,000 people died from the earthquake and tsunami.

The Arica tsunami affected practically the entire Pacific rim and lasted at least 2-3 days. It was registered by six tide gauges: at Sydney, on Kodiak Island, at Astoria, San Francisco, Los Angeles and San Diego (see Fig. 25). However, one cannot confidently pin-point the onset of the tsunami even on the tide gauge records, and for this reason, the published data on the travel time of the tsunami are unreliable.

Enormous waves ran up on the Marquesas Islands not long before midnight on the 13th. Some of the islands of this group completely disappeared under the crests of the huge waves.

At Opara*, a coaling stop for steamships nine waves coursing between Panama and New Zealand appeared in succession at 20 minute intervals. The largest wave flooded the coal warehouses.

At 23:30 on August 13, the huts were unexpectedly flooded on Rapa Island. The flooding lasted only a minute, but even so the boats and all light objects were washed away. About midnight, a loud roar was heard from the movement of a wave in the distance, followed shortly by a rumble from the entrance to the bay. Almost instantly, a second flood tide appeared, which, though somewhat weaker than the first, still flooded the beach and the street.

On the morning of August 15 between 1:00 and 2:00, three waves with an apparent period of about 10 minutes reached the Chatham Islands which screen New Zealand on the east. The settlement of Tupunga* on the north coast suffered most: a Maori village and two or three homes of European settlers were washed away. One resident drowned. Only sand and seaweed remained where the village had been. The strength of the wave was such that a 7-8 centner millstone was dragged over a considerable distance. Houses were also washed away at other places on the coast, in particular at Waitangi (main settlement on the archipelago, on the western coast of the main island, close to its narrowest part), and the residents narrowly escaped.

Passing the Chatham Islands, the tsunami rolled onto the eastern

coast of New Zealand, where the maximal wave height, usually observed at the innermost parts of the bays, fluctuated from 0.5 to 5 m. The shallow zone, extending latitudinally from the Chatham Islands to the Banks Peninsula (see Fig. 6) on Southern Island, apparently served as a wave guide, accumulating the energy of the tsunami. The tsunami was thus more intensive in the ria valleys on the Banks Peninsula than anywhere else in New Zealand.

At Lyttelton between 3:00 and 4:00, a wave retreated from shore with a speed of 12 knots, and the harbor dried up completely from the pier to "Officer's Cape"; ships fell on their sides. The water level at /63
mean high tide fell by 5 1/2 m (18 feet) and was 4 1/2 m (15 feet) below the low tide mark. The amplitude of oscillations in regular tides in the harbor is 2.1 m (7 feet). At approximately 4:30, the water entered the harbor with a terrific roar in a 2 1/2 m (8 feet) foaming roller or bore, raising the ships up high and snapping the anchor chains of most of them. The water rose 0.7 m (2-3 feet) above the highest spring flood tide mark; thus, the amplitude was 7.5 m (25 feet) in 20 minutes. Cables 20 cm thick snapped in ships tied to the pier and the ships were carried away from the moorage and damaged. A buoy with a heavy anchor and chain at the breakwater was carried a kilometer (half mile) into the bay. At 5:00 and 6:00, a strong ebb tide was observed; at 7:15, a flood tide in the form of a ground swell, rising 5.4 m (16 feet) in all. At 9:30, the level dropped 3.6 m (12 feet) below the undisturbed level, after which the water rose strongly and reached the spring flood tide mark. The fourth rise of water was registered at 10:30. At 11:00, the amplitude was 4.8 m (' feet). There were no strong oscillations after this, but weak ones continued for another three days and stopped only on the 19th. All this time, the water was very turbid and muddy.

On board the steamship "Taranaki," approaching Lyttelton on the morning of the 15th, it was noted that at 55 km from shore the water had become turbid and logs and building debris were floating in it.

Another steamship, the "Stormbird," left Lyttelton early in the morning for Timaru. Near Lyttelton, two or three waves fell on it, although the sea was calm. Then followed a current so strong, that it was impossible to move against it. The steamship was carried 18 km to the north.

In Pigeon Bay, at about 4:00 on the 15th, a roar was heard from the sea. At 7:00, it was found that objects left in the evening up to a height of 1.2 m (4 feet) above the high tide mark had been washed away, while the water level was considerably below the usual low tide mark. Then a strong surge occurred, and after 10 minutes it was 0.3 m (1 foot) above the usual high tide mark. Fishes of all species were tossed onshore. The water continued to rise and fall by 1.5 m (5 feet) at half hour intervals. At 9:15, the rise was especially strong and passed the highest high tide mark by 1.2 m (4 feet). At 10:20, a similar strong ebb began; it reached its lowest mark at 10:35. At 11:15, the water rushed onshore with enormous speed, and a small pier and part of a fence situated 1.2 m (4 feet) above the high tide mark were washed away. At

11:50, ebb tide began again. The next flood tide was stronger than all the preceding ones; a boatshed, another part of the fence and a stack of wood, lying 1.5 m (5 feet) above the highest high tide mark were washed away. At 12:05, the water retreated again, and at 12:40 it rose 2 m (7 feet) above the highest high tide mark, washing away another pier and a 30-ton launch, which was washed ashore again with the debris of the pier at 13:30. After this, the oscillations in level abated.

In Ocain+ Bay, waves were observed at about 3:00 - 4:00. The fourth was apparently the greatest; the period was approximately 15 minutes. At about 8:00, a fifth wave was noted, and smaller waves with a period of 15-30 minutes were observed between 10:00 and 12:00. At about 14:00, an awesome wave suddenly appeared. It rose 1.8 m (4 feet) above the highest high tide mark. Subsequently, waves gradually diminished, and regular flood tides resumed on the 18th.

In Le Bon Bay, on the eastern coast of the Banks Peninsula, the strength of the surge was so great that a wooden bridge on solid piles 3 km from shore was completely destroyed and even the piles were torn up and tossed about.

In Akaroa Bay, the peak rise of water was noted at 12:00; there was no damage.

The following reports came from points to the south of the Banks Peninsula.

At Timaru, at about 4:45 on the 15th, a sudden tidal wave whose height was estimated at 2-2 1/2 m (6-8 feet), rolled onshore with enormous speed and flooded it to 3 m (10 feet) above the highest high tide mark. In 5 minutes, the flood tide was followed by an ebb the likes of /64
which had never been seen here. Another flood tide occurred at 5:00 or 4:00. For four hours, the sea rose and fell rapidly with strong currents, whose direction changed simultaneously with the oscillations in level. Whirlpools at the entrance to the bay endangered the ships.

At Omaru at 11:50, unusual changes in sea level were noted, lasting all day. The level rose and fell 4 1/2 m (15 feet) vertically in 15 minutes, falling 2 1/2 m (8-9 feet) below the tide mark.

At Otago Bay, the observed movements of the sea were slight. The water rose only 0.3 m (1 foot) above the high tide line. For a long time, the sea level oscillated 0.3 m (1 foot) up and down.

At Port Chalmers at 10:00 on the 15th, the water rose 3.3 m (11 feet) and fell again quickly. Large vessels in the harbor twisted on their anchors. After the regular flood tide at 13:40 the water rose and fell continuously with a speed of 5 cm (2 inches) per minute.

At Bluff, on the night of August 14-15, the flood tide was stronger than ever before. Between 8:00 and 9:00 on the 15th, a terrible inrush and rise of water took place, although flood tide was expected only at 16:27. At 11:00, the level fell 48 cm (19 inches) in 20 minutes.

The following occurred on the coast of Southern Island north of the Banks Peninsula.

At Kaiapoi at 3:00, that is, 2 hours after the ebb tide, a colossal wave 1.2 m (4 feet) high burst into the river and turned the ships at the pier. It was followed by two others at intervals of about 15 minutes. Subsequent waves were smaller, but continued all day. The southern bank of the river suffered most.

No anomalies in flood and ebb tides were noted at Picton. By contrast, at Nelson Port, the tsunami was appreciable. The regular flood tide, arriving at 6:30, was succeeded by the regular ebb tide, but at 7:55, the water suddenly returned, and rising right up until 8:00, it flooded Boulder Bank more than regular flood tides. The height of the wave was estimated at 1.2 m (4-5 feet). About noon, another considerable rise and fall of water occurred. The same was repeated at 17:10, with a rapid drop in level by about 0.6 m (2 feet). The oscillations lasted two days.

In White's Bay, at 10:00 and 10:20, the sea unexpectedly retreated 35 m (40 yards) from the regular high tide mark. The ebb tides were followed by abrupt rises in level with a heavy swell and breakers. The oscillations lasted all morning.

On the western coast of Southern Island, at Westport on the 15th several bor[illegible] of extraordinary height passed up river from the sea with incredible [illegible]ed. The highest bore, 1.2-1.5 m (4-5 feet) high was observed between 17:00 and 18:00; it tore a ship from its moorings.

At Hokitika, to the south, there were no unusual flood tides.

At Wellington, at dawn, it was noted that the water in the harbor was rising and falling very quickly. At about 10:00, it rose 75 cm (30 inches) in 10 minutes and dropped 90 cm (3 feet) with the same speed. Observations on the oscillations in level were continued for 24 hours.

The following data have been collected on the effects of the tsunami on the eastern shore of Northern Island.

At Napier at 10:00 the water rose higher, and then in 10 minutes fell lower, than ever before. The oscillations continued hourly, with an amplitude of 1 to 2 m (3-6 feet).

At Cape Runaway, there was an enormous wave between 4:00 and 5:00, which did great damage. Traces left onshore indicate that its height was close to 3 m (10 feet).

At Opotiki at 8:30, during an ebb tide, a wave about 2 m (6 feet) high burst into the river [Opotiki] with a speed of 6-7 knots. The water rose to the high high tide line, remained there for several minutes, rushed back, and in 15 minutes ebb tide resumed. Then followed several smaller waves. Slight oscillations continued even on the following day. /65

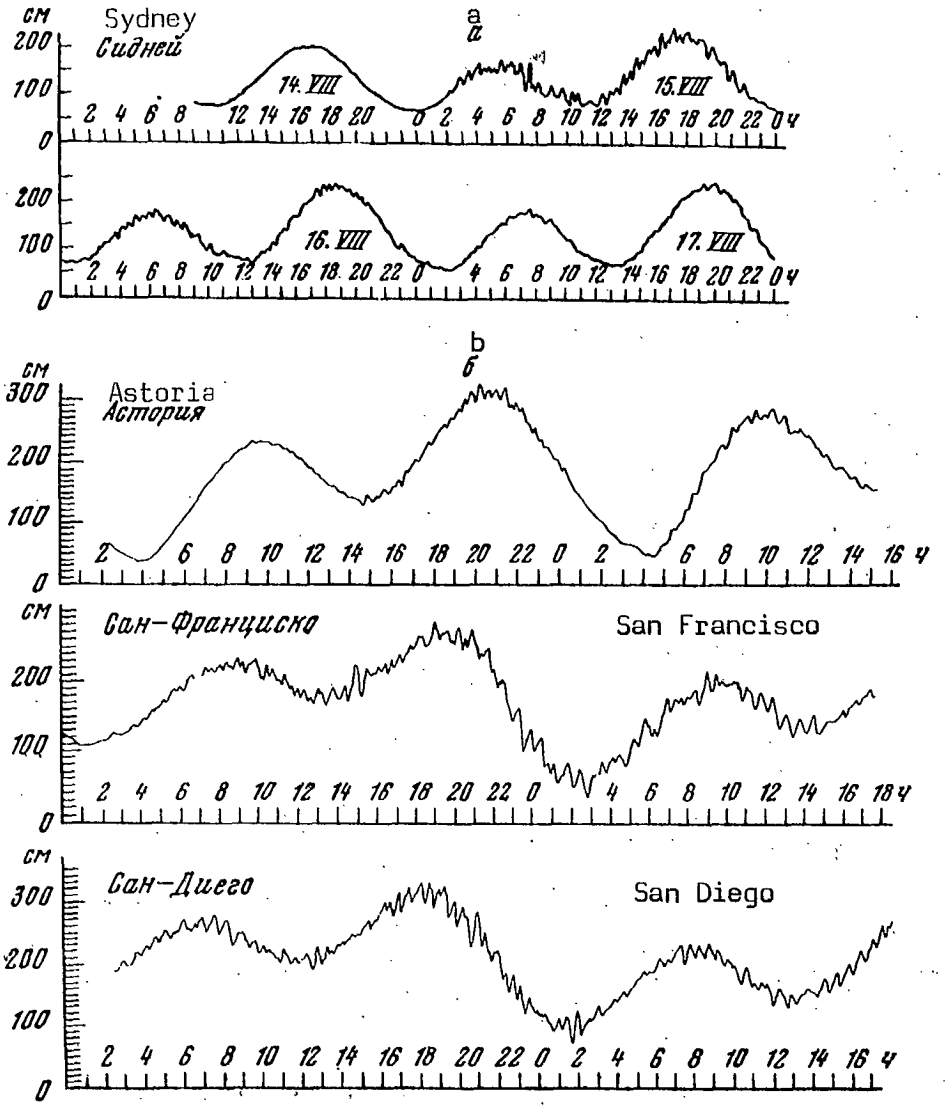


Fig. 25

Records of the tsunami of 13.VIII.1868 by tide gauges in Australia (Hochstetter, 1869c) (a) and by tide gauges in USA (Honda et al, 1908a, b) (b).

Similar phenomena were observed at Opani.

At Port Charles and Orewa, the water reached unprecedented height, rising and falling 1.8 m (6 feet) several times. Nothing out of the ordinary occurred at Auckland.

At Mangonui, disturbances such as flood tides were registered, lasting until the 17th. Between 9:00 and 14:00, the water rose and fell 1.2-1.5 m (4-5 feet) many times.

The tsunami approached Australia from the southeast (see Fig. 77).

A tidal wave, flooding a large plain never previously covered with water, was observed at Newton in Tasmania early on the morning of the 15th. This phenomenon recurred throughout the day.

A tide gauge in Jackson Port in Sydney (Fort Denison on Pinchgut Island) noted the first slight flood tide oscillation (Fig. 25 a) at 2:00 on the 14th. The strongest oscillations with an amplitude of about 30 cm /66
(1 foot) were registered after 7:00. From the 14th to the 15th of August, the tide gauge registered no less than 170 oscillations with a mean period of 28-29 minutes. According to visual observations, the water in Sydney Harbor rose and fell 1.2 m (4 feet) several times.

At Newcastle on the Hunter River at about 6:30 on the 15th, very unusual flood and ebb tides were noted. The water level fell suddenly 0.3-0.6 m (feet) and rose just as quickly. The flow of water seaward was very strong, reaching 12 knots at times. The phenomenon continued with varying intensity all day. The greatest flood and ebb tides occurred at about 11:30; the fall in level was 1.2-1.5 m (4-5 feet). Vessels were tossed here and there, but did not suffer any substantial damage.

At Sandgate+ in Moreton Bay* on the 15th, the residents noted five unusual flood and ebb tides.

The tsunami was not observed in the Melbourne region, which is screened from the ocean by Tasmania, but it did occur to the west in the Adelaide region. Thus in Port Fairy on the 15th, at about 13:00, an unusual rise of water in the river was observed. Ships preparing to put out to sea encountered a strong current and were forced to drop anchor. A reverse current of water set in unexpectedly, and the ships almost ran aground. Soon afterwards, a bore 1 m (3-4 feet) high rose up the river; one of the ships ran aground on the reefs in the southwest passage. The water in the river, usually transparent, became turbid.

The tsunami also showed up strongly to the north of New Zealand. On the 15th, the sea rose very high at the mouth of the Reva River [that is, at Suva] on the southeastern shore of Viti-Levu Island (Fiji Islands, see Fig. 4), but did not cause any damage.

At Apia, on the north shore of Upolu Island (see Fig. 1), at 2:30

on the 15th, with good weather and a calm sea, the sea left the beach and flooded the land to 1.2 m (4 feet) above the highest high tide, which is about 1.3 m (4 1/2 feet) here. In 10 minutes it retreated far, although 3:00 was the high water time. The reefs were laid bare, and the water among them dropped so low that the bay was like a basin, fenced in by a steep coral wall. The roar of the ebb tide had just ceased when the sea began to roar again, rolled back, and in 5 minutes the water rose 1.3 m (4-4 1/2 feet) above the highest high tide mark. When the water appeared to have reached its highest level, suddenly and with enormous force it again rushed forward and rose another 1.5 m (5 feet); most of the homes were washed away; a church and a bridge were wrecked and their debris was tossed inland. After this, the harbor dried up again for 10 minutes. In another 5 minutes, the water rose 1.8 m (6 feet) above the highest high tide mark. Then the flood tides abated; the next two rose only 0.9 m (3 feet) above this mark, the next barely 0.6 m (2 feet), with the same period of oscillations approximately 15 minutes.

On the morning of the 15th at 9:00 it could be made out (visibility was limited by night) that the ebb was 1.5 m (5 feet) lower than usually expected at that time. The oscillations in sea level surpassed the high tide marks by 0.5 m (1 1/2-2 feet) on the evening of the 15th, and 0.4 m (1-1 1/2 feet) on the evening of the 16th. On the 17th, the oscillations were within these marks, but recurred every 15 minutes.

The flood and ebb tides were stronger on the eastern shore of the island, and the damage was even greater than at Apia.

On the Hawaiian Islands (see Fig. 73) at Hilo, from 2:00 on the 14th until the 16th of August, the sea was in constant movement (the first waves were possibly not noticed). The period was 10 minutes. Judging by a mark, left on a coconut tree and other data, the rise of water was 1.5 m (4-6 feet) higher than regular flood tides, but according to Hitchcock it was 4.5 m (15 feet) above sea level. Along the Waiohi* River at Waiakea, the water apparently rose higher, since a bridge was washed out here.

At Kahului (Maui Island), the first oscillations in sea level were noted at dawn on the 14th. They lasted all day; the reefs and rocks in the harbor dried up. The water level rose and fell approximately 3.6 m (12 feet); the greatest oscillations were observed at 7:00 and 11:00. /67

On Molokai Island on the 14th, about 10:00, it was noted that the flood tide exceeded the usual tide mark by about 1.2 m (4 feet). In 4 hours of observations, the sea rose and fell 12 times. The water rose so high that two homes in Kanaio* were flooded, and the inhabitants collected fish in the dry places at ebb tide. The oscillations in level lasted two more days with a gradually increasing period.

At Honolulu, the local residents in the southern part of the city, at "Fisherman's Spit," noticed that the sea rose above its usual tide mark at about 21:00 on the 13th. The water did not flood any homes, but it reached the thresholds. At about midnight, the residents were

awakened by a terrible roar, which, as it turned out, was produced by the retreating ocean passing over the reefs. After this the sea rose and fell continuously. About 7:00 on the 14th, a strong ebb tide was observed, in which the level fell 1.1 m (3 feet, 10 inches) from its highest position. Fifteen minutes later a flood tide was observed. An ebb tide began at 8:20, lasting 15 minutes, after which in 8 minutes, the sea rose 70 cm (28 inches). Then the ocean fell and rose every 20 minutes. The greatest rise, 1.6 m (5 feet, 4 inches) above the highest high tide mark, was noted at 14:35. The water flowed into the harbor through the channel entrance with great velocity, and rapids formed at the embankment in the northern part of the harbor.

In Waimea Bay on the southwest coast of Kauai Island, on the 14th between 10:00 and 16:00, the sea rose and fell about 1.8 m (6 feet).

On the south of Hokkaido Island, at Hakodate, according to Captain Blakiston, marked oscillations in sea level with an amplitude of up to 3 m and a half-period of 10 minutes began at 10:30 on the 15th and continued until 15:00; the water rose and fell rapidly beyond the high and low tide marks. The tsunami was registered on the northeast of Honshu Island, in Motoyoshi district. The harbor was flooded at Yokohama. Oscillations with a 35-minute period were observed at Simoda. At Naka, on the Ryukyu Islands, oscillations in level were observed (or noticed) 16-17 times on August 15 between 8:00 and 21:00.

The tsunami was observed on the Philippine Islands.

The tsunami showed up on the coast of California (USA). At San Pedro, the ocean flooded the coast approximately 20 m (63 feet) further than usual, and then retreated almost as far back. The flood tide was succeeded by an ebb tide every half hour, and this continued for several hours. The tide gauge at San Pedro registered a rise of water by 0.3 m; the wave period was 16 minutes.

The range of oscillations, according to tide gauges at San Diego, San Francisco and Astoria (Fig. 25 b) was 60, 50, and 22 cm respectively; the predominating periods of oscillations were estimated by a group of Japanese investigators (Honda et al.) at 31.0 minutes, 35.1 minutes, 46.8 minutes, 19.2 minutes, 36.4 minutes, 41.2 minutes, 24.0 minutes, 26.6 minutes, and 36.3 minutes.

The tide gauge on Kodiak Island, according to Hilgard, began to register waves at 10:00 on the 14th (local time).

There are also indirect data on the manifestation of the tsunami in the Antarctic. The frigate "Nereida," situated midway from Tahiti Island to Cape Horn on about August 15, experienced a terrible swell during stable atmospheric pressure. From August 27 until September 10, at 51° S. and farther south, the ship met icebergs, a few at first, then more and more. One of them rose about 100 m out of the water. The clear-cut, strange, pointed shapes indicated that the icebergs had been formed very recently, and their unexpected, premature (they are usually

formed in October to January and are found at higher latitudes) appearance could be an indication that the tsunami was strong enough off the coast of the Antarctic to break up the ice floe.

Table 4 shows the main data on the Arica tsunami (Hochstetter, 1868, 1869 a-c; Domeyko, 1869; Hector, 1869; Haast, 1869; Gibson, 1869; Fuchs, 1869, 1885 b; Coan, 1869, 1870; Perrey, 1872 a,b, 1873, 1875 a; Hilgard, 1873; Anon., 1877, 1961; Guillemin, 1886; Goll, 1903; Dutton, 1904; Honda et al., 1908 a,b; Hitchcock, 1909; Montessus de Ballore, 1911 a; Milne, 1912 b, 1913; Vallaux, 1925; Jagger, 1931; Sieberg, 1929, 1932; Bobillier, 1933; Heck, 1947; Gutenberg, Richter, 1949, 1954; Laing, 1954; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967; Silgado, 1968, 1974; Shuleikin, 1968; Lomnitz, 1970). /71

1868, September 14, 19:00. There was a mild earthquake at Santiago; at night (?) at Talcahuano, a flood tide swept over the coast with great force, and the water supposedly was hot (Perrey, 1872 a; Goll, 1903; Bruggen, 1943).

1868, October 2, 5:00. A rather strong earthquake occurred at Lima. Arequipa, Arica and other coastal settlements suffered damage. The sea level rapidly rose and fell at Talcahuano (Perrey, 1872 a).

1868, October 16, 3:00. There was a rather strong, brief earthquake at Santiago; there was no rumble. Oscillations in sea level like the August ones were observed at Valparaiso. The water rose to the same height. These oscillations, it is thought, also spread to the nearest small ports (Perrey, 1872 a; Fuchs, 1885 b; Goll, 1903; Montessus de Ballore, 1911 b).

1869, January 27, 0:20. A subterranean shock occurred at Santiago. A rather strong, brief earthquake at Valparaiso. The sea retreated from shore at Tome, and then swept back (Montessus de Ballore, 1911 b).

1869, February 6. There was a mild earthquake at Valdivia. A strong earthquake occurred lasting 3-4 seconds at the lighthouse at Corral. The sea churned (Montessus de Ballore, 1911 b).

1869, April 22, 14:00. There was an earthquake at Lima; it lasted about a minute; great damage was done to buildings; accidents were recorded. Miraflores and Chorillos suffered less. The earthquake was preceded by a strong shock and was followed by numerous aftershocks.

There was a rumor that the sea had retreated far at Corral* [Callao?] port and that many families had left the port and gone to Lima (Polo, 1899 a).

1869, June 25, 5:00. An earthquake occurred at Iquique (Chile) and a strong earthquake at Pisagua. It was accompanied by a loud rumble. People and animals were frightened. A strong shock was felt on board a ship, rocked by long waves (Montessus de Ballore, 1911 b).

Table 4

Basic data on the tsunami of 13.VIII.1868.

Compiled by S.L. Soloviev.

Observation point	Time between earthquake and beginning of noticeable oscillations in level, hours.	Peak rise of water, m.	Effect of tsunami
SOUTH AMERICA			
Trujillo+	–	–	Damage done
Casma	–	2 1/2	–
Callao	4	4	Water reaches nearby houses
Canete	–	–	City flooded
Chincha Islands	–	–	Two breakwaters and homes destroyed
Pisco	–	–	A breakwater destroyed
Chala	–	15?	A breakwater and houses washed away
Islay	–	12	Two ships suffered damage
Mollendo	–	–	Everything washed away
Tambo	–	–	City washed away
Ilo	–	–	A level surface remained in place of the city
Arica	0.15	15	The same; T^1=15 min
Pisagua	–	–	Three ships smashed
Iquique	0.5?	12	–
Tocopilla	–	–	Considerable damage
Cobija	–	–	Water rose to considerable height
Mejillones	–	–	Almost everything washed away. T = 15 min
Ferrocarril'*	2.5	6	–
Taltal	–	–	Slight oscillations in level. No damage
Chanaral	–	–	Some destruction
Caldera	3.7	–	Breakwater flooded; ships ran aground
Carrizal Bajo	–	–	Shore flooded to 100 m
Coquimbo	3.2	7 1/2	Breakwater, slaughterhouse, ships destroyed

[1] T is the wave period.

Concon	–	–	Boats carried away
Valparaiso	–	–	Strong flood and ebb tides; T = 15–20 min
Constitucion	4	3±	–
Tome	4.5	4±	–
Talcahuano	3.5	4±	–
San Vincente	–	–	Slight rise of water
Coronel	–	–	Rise of water; no damage
Lota	–	–	The same
Arauco	–	–	Sea encroached inland
Lebu	–	–	Vessel almost ran aground
Corral	5	4±	–
Ancud	–	–	Marked oscillations in level
Juan Fernandez Islands	–	2	Some damage
OCEANIA			
Marquesas Islands	–	–	Some islands flooded
Rapa Island	11	–	Huts flooded, boats carried off
Samoa Islands, Apia	16	3	Most homes washed away T = 15 min
Fiji Islands	–	–	High rise of water; no damage
NEW ZEALAND			
Mangonui	–	3/4	–
Orewa	–	1	–
Auckland	–	–	Tsunami not observed
Opotiki	–	2	T = 15 min
Runaway Cape	18.5	3	–
Napier	–	1	T = 10 min
Wellington	–	3/4	–
Hokitika	–	–	Tsunami not observed
Westport	–	1 1/2	–
Nelson	–	1 1/4	–
Picton	–	–	Tsunami not observed
Chatham Islands	15	–	Village washed away; T = 10 min
Kaiapoi	17	1 1/4	T = 15 min
Lyttelton	17.5	4	Ships damaged
Pigeon Bay	18	2 1/2	Launch, stack of wood, pier, boatshed washed away
Ocain Bay+	17.5	2 1/2	T = 15 min
Le Bon Bay	–	–	Bridge washed out
Akaroa	–	–	Large rise of water; no damage

Timaru	18.7	3 1/2	–
Omaru	–	2 1/4	T = 15 min
Otago Bay	–	1/2	–
Port Chalmers	–	3 1/4	–
Bluff	–	1±	Large rise of water
AUSTRALIA			
Newcastle	–	1±	–
Sydney, tide gauge	23.7	0.3	–
visually	–	1 1/4	–
Melbourne	–	–	Tsunami not noticed
Port Fairy	–	1±	
Tasmania Island	–	–	Plain flooded
HAWAIIAN ISLANDS			
Hilo	14.2	4 1/2	T = 10 min
Maui Island, Kahului	–	3.6	–
Molokai Island	–	1 1/2	T = 20 min
Honolulu	14.6	0.8	The same
Kauai Island, Waimea	–	1.8	–
JAPAN			
Hakodate	25?	2	T = 20 min
Motoyoshi district	–	–	Tsunami noticed
Yokohama	–	–	Pier flooded
Shimoda+	–	–	Tsunami waves observed; T = 35 min
Ryukyu, Naha Islands	27?	–	Tsunami noticed
NORTH AMERICA			
Kodiak	22.0	–	Registered by tide gauge
Astoria, tide gauge	18.9	0.11	–
San Francisco, tide gauge	12	0.25	–
Los Angeles, San Pedro tide gauge	–	0.30	–
San Diego, tide gauge	11.9	0.30	–

1869, August 9, 4:30 and 14:00. At Coquimbo there were strong but brief earthquakes; sea level rose 3 m more than usual (Perrey, 1872 b; Goll, 1903).

1869, August 19, "dead of night". A terrible earthquake occurred at Arequipa. It shook the whole city and lasted 70-80 seconds. Shocks had not been felt in the city in the two preceding weeks. Immediately after this earthquake, and at least until September 8 (letter dated September 10), shocks were frequent; eight were noted in one night. At Arica there were more than 40 more or less strong shocks in a day. They were also felt at Tacna. Strong shocks were recorded at Ica on the same day.

Fearing a tsunami, the inhabitants of Arica went to Tacna (Perrey, 1872 b, 1875 a; Montessus de Ballore, 1911 b).

In other reports (Montessus de Ballore, 1911 a; Milne, 1912 b; Heck, 1947; Berninghausen, 1962; Ponyavin, 1965), apparently due to misinterpretation of the text cited, it is incorrectly asserted that the earthquake was accompanied by a tsunami.

1869, August 21, 12:40. At Iquique there was another strong shock, followed by milder shocks until 16:30. The sea remained calm, but was somewhat agitated on the following days. The earthquake possibly was felt at Arequipa and Copiapo (Montessus de Ballore, 1911 b).

1869, August 24, about 13:15. A strong earthquake occurred in the region stretching about 550 km (300 miles) north of Iquique. There was a very strong earthquake lasting a minute at Tacna. Visible ground /72
waves travelled from north to south. One could hardly stay on one's feet. All the pendulums of clocks stopped. This was the strongest shock since the earthquake of August 13, 1868. Numerous recurrent shocks were felt; foreshocks had been felt since at least August 20.

At Arequipa, the earthquake was the strongest in recent months; the shocks continued for about a week. A strong earthquake was felt at Maipo*. Material damage was done at Pica.

The steamship "La Paita" with a 2070 ton gross weight steaming to the south, felt a strong seaquake lasting about 50 seconds at 19° 17' S., 70° 21' W., 5 1/2 km (3 miles) from the coast and 90 km (49 miles) south of Arica, at a depth of 135 m (75 fathoms). General panic ensued on board, since the passengers had never before experienced the like. In two hours, about another 20 shocks were felt; the last was noted at 15:40. For the first 7-8 minutes tremors occurred almost continuously at intervals of only a few seconds.

It was hard to remain standing during the seaquake; one person fell overboard; heavy objects lashed to the deck jumped a decimeter (several inches); the compass and rigging were put out of commission and the thermometers were smashed, but there was no damage to the engine. As far as the eye could see, the sea seethed around the ship; streams 40-60

cm high (from 1 1/2 to 2 feet) leapt up with a sound like that of heavy rain at sea. A dull subterranean roar was heard at the same time.

The coast, visible in the distance with steep bluffs 600-800 m high, seemed to shake from top to bottom. Enormous rock chunks broke off the slopes and slid into the sea. Clouds of spray and dust rose up in the air, hiding the coast to the north as far as the horizon.

According to a report from Lima, published by a French and some South American newspapers, the earthquake was followed on the coast of Peru by tsunami waves, almost as destructive as those of August 13, 1868. At Iquique and Arica, the sea receded rapidly from shore, entraining ships and boats. Then it returned in an enormous wave up to 2 m (6 feet) higher than the usual level. The wave retreated five times and then rolled onshore without much force. Normal life was totally disrupted. Homes were abandoned at Arica. The situation was almost the same at Iquique and Pisagua.

At Pisagua, the sea level dropped 5 m (16 feet), and then rose 2 m (6 feet) above its usual level. All ships, fearing that the anchors would not hold, made ready to put out to sea.

The above-mentioned steamship, "La Paita" arrived at Iquique on the night of August 24-25. The crew and passengers discovered that there had been strong shocks in the city, weaker than those felt on the ship, and that all the inhabitants had taken refuge in the hills surrounding the city. The panic had still not died down when the ship arrived. According to the inhabitants of Cobija where the steam ship arrived on the following night, the earthquake was not felt at all (Fuchs, 1870; Perrey, 1872 b, 1875 a; Montessus de Ballore, 1911 a; Milne, 1912 b; Heck, 1934, 1947; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967; Lomnitz, 1970).

1871, February, from the 5th to 7th or even until the 9th. On the Chincha Islands (Guano), there were strong oscillations in sea level with calm weather. The waves and resulting whirlpools almost damaged the ships. According to Diffenbach+, this phenomenon was accompanied by an earthquake (Fuchs, 1872, 1885 b; Perrey, 1875 b).

1871, March 25, about 11:00. At Santiago and in a large part of Chile, there was an earthquake, the strongest in the last 20 years. It was preceded by a very weak shock, lasting 2-3 seconds. The total duration of the earthquake was 60-70 seconds.

The earthquake was strongest at Curepto. Here four homes collapsed, many sank to one side, and all the rest were cracked. Rather deep cracks opened up in the valley of the Mataquito River. The river stopped flowing for a few seconds. Then eddies with funnels and crests /73
up to 1 m (1 vara) high appeared in it.

At Talca, several homes tilted or cracked, but none collapsed. The stucco collapsed in places. Several walls cracked at Curico. At Linares and Chillan, buildings toppled over.

At Rancagua, all the inhabitants ran from their homes. The crockery was broken. At Santiago, cracks formed in some buildings. The Mapocho* River stopped flowing for a few moments. There was panic and a barely audible rumble at San Felipe, but the buildings were not damaged. There were also strong shocks but no damage at Loilai*, Limache and other settlements. The earthquake was felt as far south as Los Anjeles.

At Valparaiso, several dilapidated homes collapsed and 15 buildings suffered heavy damage. Two children were injured. There was much light damage at other buildings. The railway was damaged. A strong seaquake was felt on a ship in the harbor. The sea became very agitated. The ships in the harbor felt strong tremors. Some of them ran aground.

The earthquake was accompanied by numerous recurrent shocks (Perrey, 1875 b; Montessus de Ballore, 1911 b, 1912; Greve, 1964).

1871, August 20 (21). At Valparaiso (and also at Santiago), there was an earthquake accompanied by such large sea waves that ships making ready to enter the port were obliged to go back out to sea (Perrey, 1875 b; Goll, 1903). [Perrey thought that these might also be waves from the Peruvian earthquake of August 21, 1871.]

1871, August 21, 20:32. At Callao, a very strong earthquake lasted 15 seconds. It was also felt at Cerro Azul and Pisco. About the same time, the "Colon" felt a strong seaquake to the west of Chala Cape, and waves appeared immediately on the surface of the sea.

At Callao, the sea, which had been unusually calm, suddenly became heavy; a strong south wind came up. The sea remained very agitated for two days at Cerro Azul (Perrey, 1875 b; Fuchs, 1872, 1885 b; Milne, 1912 b; Heck, 1934, 1947; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967).

1871, October 5, 0:50. At Iquique a terrible earthquake lasting 2 minutes. The railway was damaged. Many homes collapsed in the province. The cities of Pica and Mamina were largely destroyed. Usmagama, Guasquina, and Pachica+ suffered greatly. A church and more than a hundred houses collapsed at Tarapaca.

Strong shocks were recorded at Arequipa and Tacna. The earthquake was felt at Pisco, Sabay, Jion*, Limasina* and Purca*.

Slight tremors reached Lima and Callao. A "maremoto" was also recorded at Callao. Seaquakes were felt at 20° 14' S., 71° 31' W., and 20° 35' S., 71° 07' W. However the water did not flood the shore, as is usual in such cases (Perrey, 1875 b; Goll, 1903; Montessus de Ballore, 1911 b; Lomnitz, 1970).

Sieberg's monograph (1932), on the basis of these data, and apparently data on the earthquake of August 21, mistakenly mentions a weak tsunami at Callao.

1871, December 28, immediately after midnight. There was an earthquake at Puerto-Montt. A tent frame fell; apparently, the hillsides had collapsed. The sea was very agitated (Montessus de Ballore, 1911 b).

1872, January 10, 7:17. There was a terrible earthquake at Arequipa, beginning with an abrupt shock and a deafening rumble and lasting about a half minute. Recurrent shocks of lesser strength were felt for an hour. The earthquake coincided with the strongest flood tides of the year (Polo, 1899 b; Montessus de Ballore, 1911 b).

1873. On Kyuyo Island (Ryukyu Islands), there were unusual flood tides and oscillations in the water level in wells; date and month not indicated (Anon., 1961). The effects described in this catalogue are explained by the Chilean earthquake on July 7, 1873 at 2:30 and the accompanying tsunami. The catalogue of Iida et al. (1967) considers this explanation unlikely. In fact, the older catalogues (Fuchs, 1874; Goll, 1903; Montessus de Ballore, 1912) give the following account. /74

The earthquake of July 7 completely destroyed La Ligua, more or less destroyed Quillota, and did great damage to Limache and Petorca. There were victims. The earthquake lasted little more than a minute at the epicenter, and was accompanied by a thunderous rumble and was stronger than all preceding earthquakes in the 19th century. The homes rocked like ships in a storm at sea. The earthquake was felt at least from Mendosa and San Juan (Argentina) where it took the form of strong shocks, to 350 km (200 miles) from the coast out to sea and from Copiapo to Concepcion. he earthquake was accompanied by numerous recurrent shocks.

The surface of the sea was calm for many days before and after the earthquake, as well as during these events.

1873, November 19, 18:30. Three large rollers hit Antofagasta. They were considerably larger than in 1868 and advanced farther onshore. The sea was completely calm both before and after. On the 18th at 12:55, a strong earthquake and an extremely loud rumble were recorded at Antofagasta and the inhabitants were frightened (Goll, 1903; Montessus de Ballore, 1911 b).

1877, May 9, 20:00. There was a destructive earthquake and catastrophic tsunami with source off the northern coast of Chile (Fig. 26). This is sometimes mentioned in the literature as the Iquique tsunami.

At Iquique at 20:20, a slight booming rumble was heard, accompanied by slow oscillations of the ground, which soon became terrible tremors lasting about 4 minutes. It was impossible to stand without holding on to something. A cloud of dust arose in the air. A fire was started by overturned lamps in the southern part of the city. However, it was soon extinguished. This earthquake was considered stronger than any previously felt in the city [7 degrees].

There was a similar earthquake at San Pedro, accompanied by a terrible rumble. Buildings were partially destroyed, and many

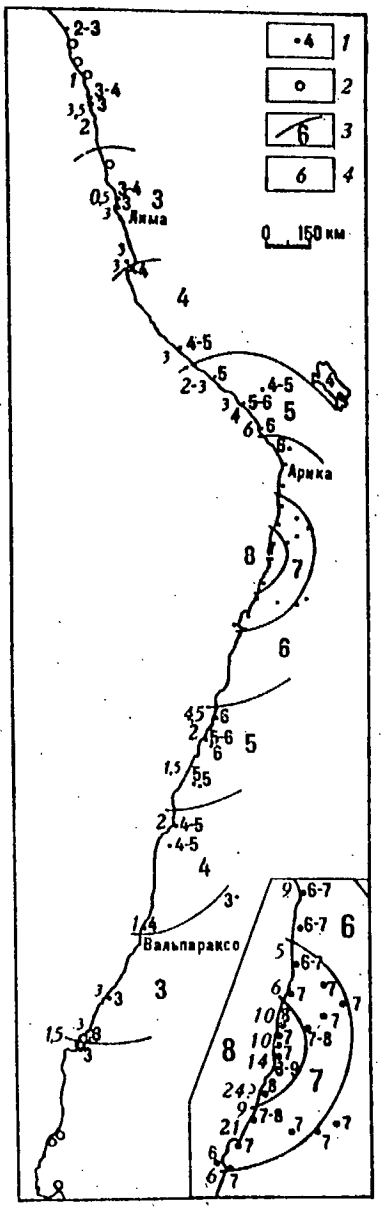


Fig. 26

Force of tremors and isoseists of the earthquake of 9.V.1877. Compiled by S.L. Soloviev.

1 - points where the earthquake was felt;

2 - points where the earthquake was not felt;

3 - isoseists;

4 - height of the tsunami (in m).

inhabitants were confused, but no one died, since people had time to run from their homes [7-8 degrees].

Tarapaca, Mamina+, Pica, La Horia, La Tarama*, Conchones*, and Punta Lobos were more or less destroyed [7].

At Caleta Pabellon de Pica, the earthquake lasted 5 minutes with increasing force. More than 10 fires were started by overturned lamps. The fires were extinguished by the flood. Thirty-three workers died in a landslide [7].

At Chanabaya, of 400 homes, supposedly only two remained standing. /75
Furniture and lamps were overturned; fires broke out. Colossal chunks of rock fell from the mountain sides; cracks up to 15 m deep in places opened up in the ground. According to reports, 30 workers were buried in a guano pit [8]. A slight shock was felt here three or four days before the earthquake.

The guano grooves caved in at Huanillos. All homes were destroyed [8-9].

Tocopilla was destroyed. Forty miners (according to later reports, only three or four) died when a shaft collapsed 8 km south of the city. At Cobija, almost all adobe houses were damaged or destroyed. People were thrown to the ground [7-8]. The earthquake lasted 3-8 minutes; all the furnaces collapsed at Caracoles [7].

At Mejillones, a very severe earthquake lasted 7 minutes; people were thrown to the ground [8].

At Antofagasta, tremors lasting 3-5 minutes were so strong that it was difficult to remain standing. The wooden homes of which the city was constructed suffered no damage. There was no rumble [6-7]. A strong seaquake was recorded at 23° 43' S., 70° 47' W.; the surface of the sea was absolutely calm.

At Chañaral, the tremors lasted 2 minutes; several cornices and flimsy brickwork collapsed [6]. The earthquake was barely felt 300 m down in the Fortunata mine at Chanaral although it was strong on the surface.

At Caldera, the earthquake was moderately strong and lasted about 3 minutes [5-6]. It was stronger at Copiapo, but it did no damage even there [6].

The earthquake was rather strong at Vallenar, but was not accompanied by a rumble and lasted 2 minutes [5]. At Freirina, tremors lasted 3-4 minutes [5]. At Coquimbo the earthquake lasted 4-5 minutes; lamps rocked violently [4-5]. At La Serena, mild oscillations lasted 2 minutes [4-5]. A strong and prolonged earthquake was felt at Ovalle [5]. At Valparaiso, a prolonged but mild earthquake occurred [4]. At Constitucion, Concepcion and San Juan there was a prolonged but very mild

earthquake [3-4], and at Coronel, a barely noticeable shock [3]. The earthquake was not felt at Tome, Talcahuano, Lota, Valdivia, Corral or Puerto Montt.

North of Iquique at Mejillones del Peru*, heavy rockfalls occurred [7-8]. At Punta Gorda, Pisagua and Arica, there was a strong earthquake without substantial destruction; luminous phenomena may have been observed [6-7]. The earthquake lasted 2 minutes at Tacna; the pendulums stopped in many clocks [6]. There was an earthquake at Ilo, Mollendo, Islay, Chala, Pisco, Santa. At Arequipa, mild oscillations lasted 3 1/2 minutes [4-5]. The earthquake was mild at Tambo de Moro*, Callao, and Chimbote [4]. It is possible that it was felt in Puerto Etén. The zone of mild tremors [4] extended to Lake Titicaca on the east. The earthquake was not felt on the Chincha Islands, or in Supe, Salaverry, Huanchaca or Pacasmayo.

The earthquake was accompanied by many recurrent shocks, some rather strong. After the earthquake, it is possible that the Isluga volcano ejected a cloud of smoke.

The surface seismic waves were so strong that they were noted at the Pulkovo astronomical observatory in observations through a meridian telescope. The coast off Iquique dropped 1/2 m (2 feet) at a number of places; in particular, many rocks were covered with water in the harbor at flood tide. Displacements of the shore were also reported at Pisugua.

Tsunami waves occurred on a large stretch of the South American coast. At the source of the earthquake and the tsunami, the mean rise of water was 10 m. The oscillations in level apparently began here with a small ebb tide.

At Iquique, the first rise of water was noted 20-30 minutes after /76
the earthquake, during the diurnal half tide. It took place quietly, while the ebb was considerably quicker. It is possible that a small drop in level occurred before the first flood tide, but because of the darkness reports about this are not quite reliable. A second rise of water, stronger than the first, occurred at 21:00. Afterwards, until 1:00 on the 10th, another three to five large floods were recorded, the last being the most severe in consequences. The rise of water was estimated at 4.8 m (16 feet) (according to other sources, 6 m (20 feet)). Still another source indicates that the water rose 2-3 m (6-10 feet) at the walls of the customhouse. The workers' district of the city, lying lower than the others, was flooded, destroyed and washed out. The custom house, all warehouses, and nitre stocks were also washed out. A refrigerator was destroyed. One or two ships were sunk and many others damaged; all the boats were smashed. One schooner and the steamship "Grimioza" ran aground on an island. A small breakwater in the southern part of the harbor was completely destroyed. According to official accounts, 30 people in the town died. The ocean was still so agitated on the 13th and 14th that communication with ships was impossible.

At Caleta Pabellon de Pica, the sea fell upon the shore about 25

minutes after the earthquake. The flood was apparently stronger at the point on the coast. Six strong flood tides were recorded. The city, constructed of wooden houses, was completely destroyed to the 10 m mark; five ships were sunk, while another 27 were put out of commission. Two hundred people died (40 according to other reports).

At Chanabaya, a retreat of the water was noted immediately after the earthquake. A flood tide set in 20 minutes after the start of the underground jolts. There were three waves at intervals of 8-10 minutes. The second wave was the greatest and rose to a height of up to 10 m (35 feet). The city was completely flooded. Forty to fifty people died in a landslide caused by the flood, and many drowned; more than 3500 residents were left homeless. From 20:25 to 22:10, five waves fell on the city. Seven ships sank, while others were badly damaged in collisions. All the long boats were destroyed.

At Punta Lobos, the sea retreated from shore immediately after the earthquake and returned about 10 minutes later in a tidal wave 6 m (20 feet) high. A second wave rushed in 30 minutes later, washing away everything to a height of 10 m (35 feet). Two ships were lost and 14 were seriously damaged. However, it appears there were no victims.

At Huanillos, 15 minutes after the first shocks, the ocean gradually retreated from shore, then returned, rising slightly above its usual level. Then the oscillations intensified, and there were three especially strong flood tides at 30 minute intervals. The height of the largest among them, the first tide, was 9 m (30 feet) above the usual sea level; the subsequent rises were smaller. According to other sources, the height of the strongest wave was 18 m (60 feet); all homes were washed away, except for 20 situated higher than the others; the vessels "Avonmore," "Geneva," "Conway Castle" and "Conference" were sunk and another 13 were damaged; there were many victims.

At Tocopilla, the sea rose 15 minutes (according to other sources 30 minutes) after the earthquake. The height of rise was estimated at 24 m (80 feet). Homes were completely destroyed and washed away; the streets leading to the mines were hit especially hard. Ships were not damaged. All the nitrate quarries between Tocopilla and Cobija were washed out.

At Cobija, according to reports, the sea rose 9 m (30 feet) 8 minutes after the earthquake and flooded approximately three quarters of the city, completing the destruction begun by the earthquake and washing away the majority of buildings. All the boats were smashed.

At Caleta*, the sea rose 18 m (60 feet) 20 minutes after the earthquake.

At Mejillones, a flood tide began half an hour after the earthquake. Its vertical height was about 10 m (35 feet). Then the sea retreated approximately 200 m (2 cuadro) from shore. A quarter of an hour after the first flood tide, a second occurred, surging with dizzying /77

speed; it reached a height of 21 m (70 feet) or more and did great damage. After another quarter of an hour, a third flood tide occurred. The speed of currents was estimated at 6-7 knots. Two thirds of the city was destroyed. The guano deposits in the region of the city were washed out.

At Antofagasta, the sea was completely calm during the earthquake, but it encroached on land 10 minutes after the earthquake. It invaded the residential districts three times, reaching about as far as the central square of the city; some homes were destroyed, others were shifted, some to another quarter; the shops suffered great damage. The height of the flood, according to some estimates, was 6 m, while according to others it was 2 1/2 m above the mean sea level or 2 m above the flood tide level. The destruction would have been greater if the city had not been screened from the sea by a spit. The oscillations in level continued on the 11th and 12th with a period of up to 40-80 minutes.

At Caldera at about 21:00 the sea began to retreat from shore, and the first flood tide set in about 21:30. The oscillations in level gradually intensified. Flood and ebb tide alternated regularly: first at 5, then 10, 15 and 20 minute intervals. The oscillations were especially frequent at the beginning of the tsunami, and also on the following day. At about 23:00, the sea suddenly and quietly retreated 60 m (200 feet) from shore, after which it flooded the shore to 1.5 m (5 feet) above the tide mark just as quietly, gradually, and without any surf. According to other sources, the rise of water reached its greatest height, 2 m (7 feet) above the mean sea level or 1.2 m (4 feet) above the tide mark roughly in the third wave, at 1:05. The full range of oscillations was 4.2 m (14 feet) as against 1.8 m (6 feet) in regular tides. The flood tides at 7:00 and 16:00 of the 11th reached almost the same height, although on this occasion, the water rose more slowly and the waves were weaker. The water continued to eddy for another three days.

At Carrizal Bajo, about 20:00-22:30, it was noted that the sea was slowly retreating from shore. Ten minutes later it returned and rose 1.2 m (4 feet) above the highest high tide mark. The rises and falls in sea level continued for 3 hours. Many ships were damaged.

At Chañaral at 21:15, the sea encroached inland with a roar, apparently advancing 50 m. Then it retreated from shore and again returned to its previous level. The surges begun in this way continued on the following day. About 22:30-23:30, the water quietly retreated at least 200 m from shore, then surged back again with a terrifying roar, advanced 50-100 m inland and flooded all the buildings as far as the station.

At Coquimbo, at about 22:30, the sea retreated far from shore, then returned and flooded the shore to the middle of the port square. A stronger flood occurred at 23:00. The oscillations in level, during which the sea rose, then fell 1 1/2-2 m, lasted till 13:00 on the 10th.

At Valparaiso, unusual movement of water was noted at 23:00. In the next two days, flood and ebb tides lasting 15 minutes each occurred

in the harbor. The amplitude was about 2.2 m.

At Constitucion, unusual flood and ebb tides began at 21:30 or 22:00, and lasted until the 12th. The height of the flood tide was 2 1/2-3 m.

At Tome, the oscillations in level began at 0:00 on the 10th with a 70 cm rise of water (the observations were done 500 m from the mouth of the Collen River). A rise of water by about 75 cm was observed at 2:00. A rise of water by 60 cm was observed at 3:00 and 6:00. The oscillations lasted several days; tides alternated at intervals of 30 to 90 minutes. The tides were quiet and like slow breathing. At Concepcion Bay at 23:00-24:00, the water began to slowly recede from Talcahuano, and by 0:30, it had retreated 150 m, to near Rocuan* Island. The sea level /78
dropped 1.2 m below the regular low tide mark, so that some vessels lying at anchor found themselves on dry bottom. Then the water began to advance slowly, and at about 1:00 on the 10th it rose about 1 m above the highest high tide mark (or 2 m higher above the regular high tide mark) at Talcahuano and Concepcion. At Penco, situated below the other inhabited points, the water advanced 125 m (1 1/4 cuadro) inland, and one home was flooded. This phenomenon then recurred with a period of about 1/2 hour.

At about 2:30, the water rose at Talcahuano 3 m above the usual level (2 m above the high tide level). The roadbed of the railway was damaged and washed out. The rise in level was followed by a drop of the same magnit :. Rises and falls then continued, but less noticeably. According to other sources, the interval between tides was 12-15 minutes; the ebbs were stronger than the floods.

At Coronel, oscillations in level were observed from 2:00 until 9:00. In about 50 minutes, four rises and falls of level occurred with an amplitude of 3 m (10 feet). The rise of water surpassed the usual high tide mark by about 1.2 m (4 feet). One of the captains went to go ashore at 2:00, but the water level had dropped so low, that he had difficulty catching the ladder and climbing onto the pier. When he returned to the pier an hour later, the boat had risen so much that he got on board without any difficulty.

At the time of the tsunami, a small coasting steamship was situated between Santa Maria Island and Cape Lavapie. Currents carried the steamship from Arauco Bay out to sea, then back to the bay, until in the end it was able to rest behind the cape at Llico.

At Llico on May 10, unusual rises and drops in level of the same amplitude as the diurnal tides were observed. They continued with lesser intensity, as also at Coronel, Lota and Arauco, on the 11th and 12th.

At Lota, at 0:30, the ocean advanced a little and then retreated far from shore. This phenomenon recurred with the same period, but with lesser amplitude, and then once again with still smaller amplitude before 6:00. There were no marked oscillations in level after this, but at

10:00 the sea slowly rose 1 1/2 m (5 feet) above the high tide mark, after which it dropped just as slowly, returning to normal by 11:30. Strong eddies developed during the oscillations and snapped the anchor chain in one ship. According to other sources, at 2:15 the sea rose to the watchhouse, after which it retreated so far that all the piles of the embankment dried up.

At Arauco, a tidal wave travelled 4 km (1 league) up the Carampangue River from its mouth.

In Corral Bay at Ensenada* settlement, oscillations in level were noted at 4:00 on the 10th. The rise of water by 0.3-0.6 m (1-2 feet) exceeded the height of spring high tides and storm waves. The tsunami was noted in Corral port only at 6:50; the water rose to the usual high tide mark, but never reached the level of winter storms. The rise and fall of the water level in Corral Bay on the 10th had a 10-minute period. The period was 20 minutes on the next day, and even 30-40 minutes by evening. There was an absolute calm during the tsunami.

The tsunami was barely noticed at Valdivia.

At Ancud between 23:00 on the 9th and 3:00 on the 10th, ships riding in the harbor felt an unusual surge of water, causing the bows to rock back and forth from north to south, with a period of about 1 hour. The water level rose and fell three times on the 10th from 11:00 to 12:00 at the embankment.

Very slight movements of the sea were observed at Puerto Montt.

The tsunami was observed on the Juan Fernandez Islands, but was weak.

The following reports came from the coast north of Iquique.

At Mejillones del Peru*, the sea rose at about 21:10. Before this, it retreated 5-6 m (18-20 feet) from shore. Four oscillations with a period of 4-8 minutes were recorded. The fourth wave was the strongest. /79
The rise of water was about 3 m (10 feet). The city was flooded; many inhabitants died and considerable damage was done.

At Pisagua, the sea level dropped at about 23:00. Strong flood tides were recorded 2, 3, and 10 hours later. In the second, highest oscillation, the water rose 4.2-4.8 m (12-16 feet). The station and all structures at the same level were destroyed; the railway was greatly damaged.

At Arica, oscillations in level began at 21:00 with a withdrawal of the water to about 450 m (1/4 nautical mile) from shore. The first rise of water occurred in phase with the diurnal flood tide; the sea reached the level of the embankment. Flood tides recurred with a period of 30 minutes. In Arica Bay the floods generated eddies; these mainly moved from south to north. There were eight large waves. The highest

wave occurred at 4:00-4:30 on the 10th, reaching a height of 8-9 m (other sources: 25 m (75 feet); 7-8 m (20-25 feet) at the island which screened the harbor from the north and 5 m (15 feet) in the city itself. The water reached the cathedral and the central streets of the city, tossing a loaded railway car there. The "Watery" which had run aground in the tsunami of 1868, was shifted.

Around 22:30, the underwater telegraph cable between Arica and Mollendo was broken. Although a rather strong shock was felt around this time at Mollendo and Lima, the cable was apparently broken by the tsunami waves. The damaged section, as was later discovered, was situated near Arica. The cable was dragged a considerable distance by the water, twisted and buried under tons of bent iron and other remains of the port structures.

At Ilo, the sea withdrew from shore about 15 minutes after the earthquake; then came a large roller. In all, three large waves were observed with a period of 30 minutes. The third wave was the highest. The sea fell 6 m (20 feet) below its usual level, and then rose just as high above it (according to other sources, the height of the flood was 4 m). Considerable damage was done. Strong oscillations continued until 5:00.

At Tambo, the largest wave, 3 m (10 feet) higher than the highest high tide mark was recorded at 1:40. Subsequent rises occurred at 2:35 and 3:15, the last coinciding with the diurnal flood tide. Strong oscillations in level with a period of 10-20 minutes continued until 3:50.

The sea began to rise at Mollendo at 23:30, and surpassed the highest high tide mark by 2 m (7 feet). A drop in level was recorded at 23:45. The first three oscillations occurred at 10-15 minute intervals with a mean height of 2 1/2-3 m; the second wave was the highest. The waves came more from the south-south-east than from the south. The sea was not especially agitated on the 10th, but it was very heavy on the 11th, 12th, and 13th. According to some reports, in the port, a 100 m stretch of the railway was washed out, being covered with 1.8 m (6 feet) of water.

At Islay, after the earthquake, three waves were observed 2.4 m (18 feet) or 1.5 m (5 feet) above the usual high tide mark; the embankment was destroyed. At 20:40, the sea retreated 20 m from shore, and ten minutes later rolled onshore in a large wave, advancing 300 m inland. Oscillations continued until the 13th.

At Chala there were no floods on the 9th and 10th, but early on the morning of the 14th it was noted that the sea was agitated. From 10:00 on the 14th, and until the 16th, the flooding of the shore was menacing; the flood tide passed its usual mark by 1.8 m (6 feet).

Unusual movements of the sea were noted at Pisco after 20:00. They began with the ebb tide. The wave at 1:45 was the strongest. The second strong wave occurred at 3:00 in phase with the diurnal flood tide.

Weaker oscillations with a 10-15 minute period followed and continued until the 11th. The maximum rise of water was 3 m. Damage from the flood was slight.

On the Chincha Islands, a tidal wave was noted first. The highest /80
rise in level occurred at 1:00 and surpassed the highest diurnal flood tides, equal here to 3 m (10 feet), by 10-20 cm (1/2 foot).

At Callao, at 23:00, the sea in the harbor was strange and restless. The state of the sea was still unusual even at dawn and there was a strange roar. The harbor became full of eddies, which twisted the ships on the anchors. Moreover, the usual heaving or surging was absent, and the surface remained calm. Essentially, a rise in level of the sea on the whole had occurred. At 4:00 or 5:30 on the 10th, the water rose especially high, by about 3 m (10 feet), and spilled over the walls of the port. Although nothing was washed away, there were hundreds of victims and losses were heavy. Eddies continued in the harbor with greater or lesser force for three days.

At Ancon, the tsunami was observed from 2:00 until 6:00 on the 10th; a tidal wave was noted first; a flood and ebb tide lasted about 5 minutes each; the first of these waves was the largest, reaching a height of 1.2-1.5 m (4-5 feet) and flooding the shore. At Huacho one could not get to the beach.

At Supe, oscillations in sea level occurred for 24 hours with a period of 10 minutes. The first flood tide advanced 30 m (100 feet) up the beach. The second tide, the highest, advanced 6 m (20 feet) further and rose 1 m (3 feet) higher than the first one.

At Casma at 0:30, not long before the onset of the maximal diurnal flood tide, a wave passing 25 m (75 feet) inland was noted. The second wave was larger and flooded the wares and vessels lying onshore. The greatest, the third wave, completely flooded the pier and almost reached homes situated 550 m (1800 feet) from the shore at 2 m (6 feet) above sea level. Then the sea retreated, but a flood tide equal to the first recurred at 2 hour intervals. The oscillations continued until the 11th.

At Samanco, on the night of the 9th-10th, the low-lying part of the city was flooded. Waves rose 3.5 m (12 feet) above the mean sea level. Even on the 10th, the sea continued to advance and retreat at least 30 m (100 feet).

At Chimbote, the sea dropped 6 m (21 feet) and rose 2 m (6 feet) at 9:50 on the 10th.

At Santa, the sea rose about 3 m (10 feet) above the usual level around 1:00, 3:00, and 7:00 on the 10th. The last of these waves was the highest.

At Salaverry at 23:00, the sea receded; the ebb and flood tide

lasted 15 minutes. The oscillations in level continued until 2:00 on the 10th. The water rose 75 cm above the mean high tide mark. The first wave was the highest.

At Huanchaco, between 2:30 and 3:00 on the 10th, an ebb tide receded 30 m more than usual. Subsequently, three exceptional flood tides were observed. The water advanced 20 m inland. The ebb tides were even more unusual and ships riding in 20-25 m of water ran aground.

An ebb tide occurred at Pacasmayo at 7:45. The sea returned to its usual level in 2 minutes. The water level was unusually high at Pimentel.

At Tumbes, tidal currents moved from north to south. The greatest wave was noted at 11:00 on the 10th; a second wave followed in 20 minutes. At Salinas, the sea rose 4.5-6.0 m (15-20 feet) at night.

The tsunami apparently was not noted at Panama, Costa Rica and Guatemala.

The tsunami hit the coast of Guerrero State in Mexico. According to a ship's officer, unusual and rapid rises of water took place at 10:00 on the 10th in the harbor at Acapulco. The water flooded the streets and rose to the main square. Four flood tides with a period of 15 minutes were noted; each time the water rose and fell by 1 m (3 feet). Weaker oscillations with a 20 minute period occurred from 12:00 to 16:00. A rapid rise - fall of level was noted on the 11th between 11:15 and 11:40 and a second rise was noted at 11:50. From 12:00 to 16:00 on the same day, five tidal waves were noted, at irregular 25-35 minute intervals.

At Gaviota+ (USA) at 7:10 on the 10th, the sea rose 3-4 m (12 feet), then fell, then rose and fell three times in 20 minutes. /81

At San Francisco, the tide gauge registered a tsunami from 6:11 on the 10th until 12:00 on the 15th (Fig. 27 a), although the final oscillations were very irregular in form and time of onset. The agitation began with the flood tide; in 1 hour and 20 minutes, six large waves each 15 cm (6 inches) high occurred. A group of Japanese investigators (Honda et al.) established the following predominant periods of oscillations: 17.3 minutes; 27.8 minutes; 34.3 minutes; 47.4 minutes.

The tsunami was observed at all the islands of the Hawaiian archipelago. The peak rise of water, depending on the contour of the coast, varied from 1 to 12 m above the lowest low tide mark. Nevertheless, no great damage was done.

At Hilo, according to the local sheriff (Hitchcock, 1909), from about 4:00 on the 10th, unusual rises and falls of water in the bay were noted. At about 5:00, the water rushed onshore in a mighty wave, which flooded almost all near-shore stores and washed away a great deal of lumber and all the stone barriers of the moorage. According to later /82

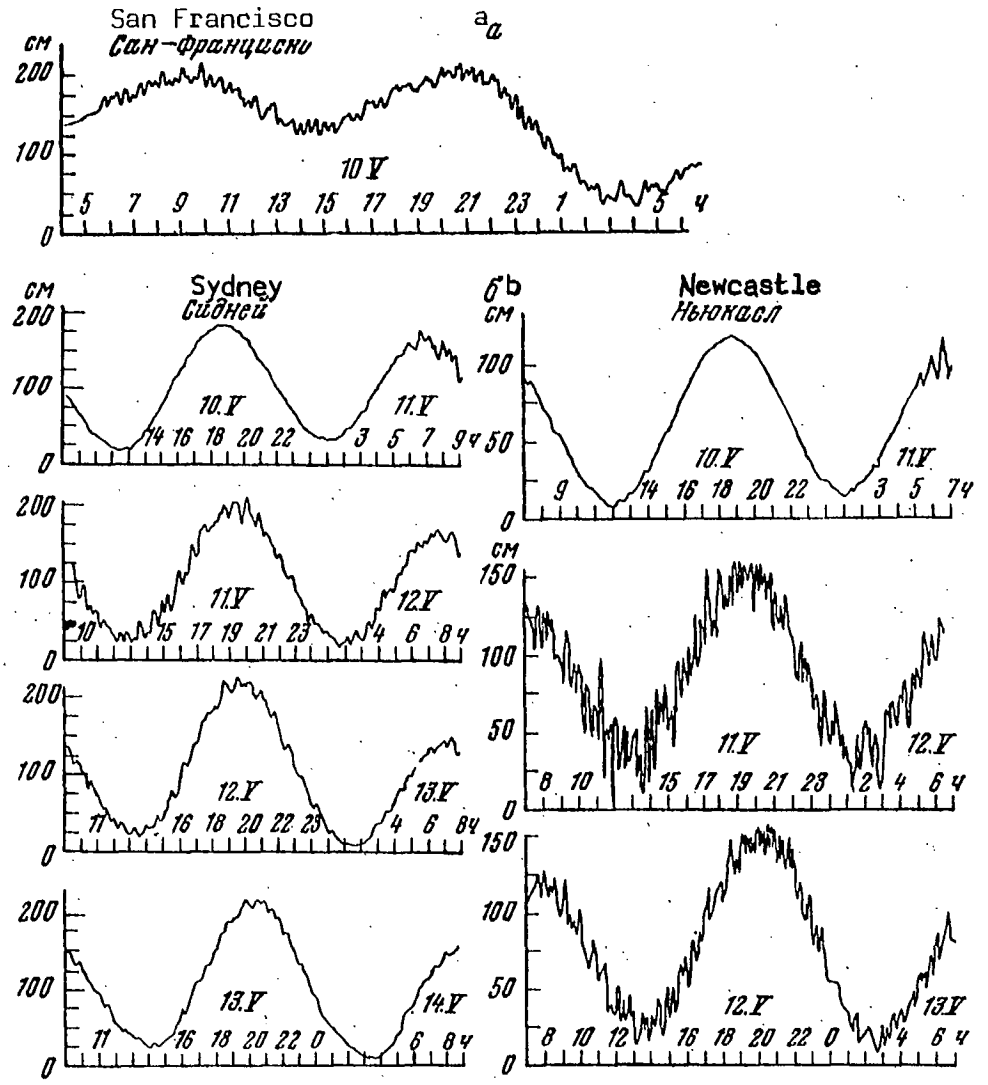


Fig. 27.

Records of the tsunami of 9.V.1877 by a tide gauge in USA (a) (Honda et al, 1908a, b) (a) and by tide gauges in Australia (Geinitz, 1878) (b).

measurements at the pier lamp post, the water had risen 3.7 m (12 feet 3 inches) here above the regular low tide mark [sic! - Transl.].

The destruction was terrible in the Waiakea River area. In an instant, all structures were washed away for a distance of hundreds of meters (yards) from the water line, including the steamship pier, a warehouse, the bridge across the river and homes. Their debris was tossed inland. Thirty-seven homes were completely destroyed and 17 were very heavily damaged. Five people died and seven were seriously injured; 163 residents were left without homes or belongings. The height of the wave in this region must have been 4.8 m (16 feet).

At Waiakea, waves washed away most of the settlement, that is, the 57 homes situated within 100 m (yards) from shore, tossing their debris inland. Five people drowned, seven were injured and 113 were left homeless. Seventeen horses and mules also drowned.

Cocoanut Island was almost completely flooded (see Soloviev, Go, 1974, Fig. 6), and the hospital there was washed away. An American whaler riding at anchor in the bay at a depth of 7 m (4 fathoms) touched bottom. Boats were lowered from the whaler and six residents were pulled from the water.

The rises and falls of sea level lasted all day. According to measurements of one of the oscillations done by the sheriff at about 7:00, about 4 minutes elapsed from the minimal to the maximal water level, and the water rose 4.2 m (14 feet) in this time. In the second half of the day, the water rose and fell three times per hour. As measured visually at 15:00, in 10 minutes, the water rose 1.8 m (6 feet) above the high tide mark; 10 minutes later, the level fell to 0.6 m below the low tide mark; then the water rose in 8 minutes to 2.4 m above its mean level and fell in 12 minutes to the low tide mark. After this, it rose in 15 minutes to 1 m (3 feet) above the high tide mark.

The range of oscillations was 1.5 m (5 feet) at Kawaihae, on the western shore of Hawaii Island, and 9 m (30 feet) in Kealakekua Bay.

At Kahului, on the northern coast of Maui Island, the water retreated at about 4:45 and the bay dried up completely. Then the water began to flow into the bay through the mouth in a rapid tidal wave and rose 1.2-1.5 m (4-5 feet) above the regular flood tide mark. The second wave was not as large, the third was still smaller, but the fourth was almost the same size as the first. Flood and ebb tides were still greater than usual on the 12th, but the sea had calmed down.

At Lahaina, on the southern coast of the island, the water rose 3.6 m (12 feet).

At Honolulu at 5:20 on May 10th it was noted on the pier that the water was leaving the bay with great speed. According to estimates, the level fell 52 cm (21 inches) in 5 minutes. The water returned at 6:00, and the level rose 85 cm (34 inches) in 10 minutes. Such flood and ebb

tides continued all day and night, gradually abating. The greatest height, observed before dinner, was 145 cm (58 inches).

The water rose 1 m (3 feet) in Nawiliwili Bay, on the south-eastern shore of Kauai Island.

The tsunami occurred on the Samoan Islands at Apia on the 11th at 4:30, during ebb tide. The greatest oscillations were recorded at 6:00; their range was 1.8 m (6 feet) or a little more. The phenomenon was repeated at 10 minute intervals throughout the day. At 20:00 the rise and fall of water was still estimated at ~1.5-1.8 m (5-6 feet). There were no accidents.

The tsunami was noticed on the Fiji Islands. According to Cooper, who was travelling in the archipelago at this time, the wave swept away thousands [?] of inhabitants of the atolls.

The tsunami occurred on the night of May 10-11 in the Chatham Islands. It was weaker than that of 1868, but all the same, one bridge was washed out, one home was flooded and half of Old James* village was washed away.

On the whole, in New Zealand, the tsunami of 1877 was also /83
weaker than that of 1868, although it was noticable along the entire eastern coast of the country. The maximal amplitude at different points fluctuated from 1 to 2 m (3-8 feet). The waves rose highest in the northern part of the coast.

On the Banks Peninsula, in Lyttelton Bay, early in the morning on the 11th the residents were frightened by the fact that the water rose above its mean level at ebb tide. At 7:00, the sea surged into the bay with remarkable speed, rising 45 cm (18 inches) per minute; the water was very dirty. At about 9:00, the sea receded; it fell 1 m (3 feet) every 5 minutes, later 1 m (3 feet) every 9 minutes. By noon, when the flood tide was due, the agitation in the bay abated somewhat, although the water remained silty. Unusual movements of water, although weaker, continued until night.

Agitation was considerable in Pigeon Bay. A flood, at least 2 m (7 feet) higher than the mean sea level, did some damage.

An unusually high flood tide was noted about 7:00 in Le Bon Bay. Long heavy waves were observed and were immediately followed by rapid recessions. In some cases, the water retreated so far that one could walk along the bottom from the shore to the end of the breakwater. At about 12:00, such a strong wave fell that two bridges were destroyed, and their debris was carried far inland. Strong flood tides after dinner caused fresh destruction. The oscillations in level continued on the following day.

At Akaroa, tidal waves peaked at 15:00; the water rose at least 3 m (10 feet) above the high tide line; all coastal homes were flooded.

The oscillations began to abate at 17:00.

At Timaru, waves appeared at about 7:00, and the sea continued to rise and fall rapidly until evening.

At Omaru, the water retreated far, and 15 minutes later it flooded the coast. At about 12:00, the sea began to tear into the bay with terrific force and destroyed the solidly built pier. A few minutes later, the sea rushed out of the bay in a vortex flow. The currents and eddies had ceased by 12:30.

At Port Chalmers, oscillations in sea level were noticed at dawn, when the surface of the water fell about 0.3 m (1 foot). Sudden rises and falls in level, estimated at 2 to 6 m (7-20 feet) occurred after dinner. They lasted many hours.

Further south, the tsunami was noticed at Bluff.

At Kaiapoi, the first wave apparently arrived at about 6:00. Three more waves arrived before 8:00. After dinner, two large waves entered the Waimakariri* River, and reached a suspension bridge 5 1/2 km from the mouth of the river, where the water rose 0.6-0.9 m (2-3 feet). The current in the river was disturbed many times before evening, although the surface was calm.

At Wellington, not long before 7:00, during an ebb tide which was 3/4 of a full ebb, unusual flood movements occurred. High water entered the harbor and rocked the ships. Fifteen minutes later the water rose above the flood tide mark. Then the water retreated with the same speed and in 15 minutes reached the low tide mark. The oscillations in level lasted all day with a half-period of 10-15 minutes. Their amplitude was 1.5 m (5 feet) at 8:00, 0.6 m (2 feet) at 10:00.

Information on the tsunami from the west coast came only from the mouth of the Buller River (from Westport).

On the east coast of North Island, the tsunami was observed at Napier and further north. The first wave approached Gisborne almost unnoticed between 0:00 and 2:00 on the 11th. Another wave arrived at approximately 4:00 and reached a height of about 1/2 m (2 feet). Since this was the time for flood tide, the wave's approach seemed like a swelling of the flood tide or a surf from a remote storm at sea. However, at 7:00, when the flood tide receded considerably, a very heavy wave burst in with terrible force, and in 7-8 minutes, the level rose 2-2 1/2 m (7-8 feet) vertically and then fell just as quickly. Retreating, the water washed away 50 m of a sand bar. The wave appeared without a preliminary roar or any other warning. Similar waves appeared at 9:00, 11:00, 12:40, /84
14:30, but the rise was only 1/2-1 m (2-3 feet). Oscillations in level continued at irregular intervals until the morning of the 14th.

At Tauranga, at 8:00, it was noticed that the water rose 1 m (3 feet) above the highest spring high tide mark. Short-period oscillations

in sea level lasted all day. The sea rose 2.7 m (9 feet) at Auckland on the morning of the 11th. In Manawaora Bay, at 5:00 on the 11th, the sea rose 1.8 m (6 feet) above the highest spring high tides, flooding several lowlands at the top of the bay and alarming the population.

At about the same time, a strong wave was observed at the mouth of the river at Waitangi. Several large launches, tacking along the river, were forced to cast anchor to avoid running aground. At Russell, at least seven flood and ebb tides occurred at irregular intervals during the day. Opposite Russell, at Wairoa*, at 4:00, a wave fell onshore with great force, flooding it to at least 10 m (yards) above the high tide line. A whaleboat ran aground. The wave retreated rapidly, but then surged back, reaching its previous mark, and remained there for more than 10 minutes. There was just enough time to load the boat, when the water rushed back and the boat was left on dry bottom, out of reach of ordinary high tides. After this, flood tides alternated with ebb tides but did not reach the same height.

In Australia, at Sydney, the water level rapidly fell 1/2 m (2 feet) on the morning of the 11th, and then returned to its previous level. At Newcastle, the level also fell 1/2 m (2 feet) in 5 minutes (see Fig. 27 b).

The tsunami was noticed on the entire eastern coast of Japan, from Hakodate to Shikoku Island. At Hakodate, on May 11, at 10:30 (according to other sources, 11:30), the water rapidly receded from shore, and 10 minutes later again rose 2 m (7 feet). Then the sea rose and fell with diminishing force every 20 minutes. The greatest rise - 2.4 m - occurred between 14:30 and 14:35; part of the city was flooded. The sea calmed down by sunset.

There was such a rapid, high rise of water in Kamaishi Bay between 9:00 and 10:00, that according to some sources, the villages on both shores of the bay were rapidly hidden under water, and their residents took to the hills. The oscillations in level soon abated, but they recurred at 12:00 and again at 14:00. The maximal rise of water was 3 m, or, according to other sources, 1.7 m (5 1/2 feet) above the usual flood tide level. The flood tides recurred with a 15 minute period (according to other sources 5 minutes). Between 17:00 and 18:00, the sea again rose and fell 3 m (10 feet), every 15 minutes. All was quiet by midnight. The surface of the sea was calm during these phenomena, the weather was good.

On the Boso Peninsula, many residents drowned or were injured. At noon, large waves flooded the open coast at Kazusa (Chiba prefecture), but the sea soon quietened. At 16:00, still larger waves devastated the same coast, causing numerous casualties.

In Tokyo Bay, the water rose 70 cm. On the south of Shikoku Island, at Tosashimizu, unusual tidal phenomena were recorded. The main data on the tsunami are given in Table 5 (Geinitz, 1877, 1878; Crisp, 1878; Macfarlane, 1878; Fuchs, 1878, 1885 b; Milne, 1880, 1912 b, 1913;

/85

Table 5

Basic data on the tsunami of 9.V.1877.

Compiled by S. L. Soloviev.

Observation point	Time between earthquake and beginning of noticeable oscillations in level, hr.	Peak rise of water, m	Effects of the tsunami
1	2	3	4
SOUTH AMERICA			
Salinas	–	–	Shore flooded
Tumbes	–	–	Oscillations in level and current noted
Pimentel	–	–	High level noted
Pacasmayo	–	–	Ebb tide noted
Huanchaco	–	–	Shore flooded to 20 m
Salaverry	3	1	–
Santa	–	3	–
Chimbote	–	2	–
Samanco	–	3.5	–
Casma	5	2	–
Supe	–	–	Shore flooded to 40 m
Huacho	–	–	Shore flooded
Ancon	–	1.5	–
Callao	3.5	3	Great damage
Chilca	1.3	–	Shore flooded to 300 m
Chincha Islands	–	3	–
Pisco	1	3	Slight damage
Chala	–	3	–
Islay	–	2-3	Embankment destroyed
Mollendo	3	3	Section of railway washed out
Tambo	–	4	–
Ilo	0.3	6	Extensive damage
Arica	0.7	8-9	Lower part of city washed out
Pisagua	2.5	5	Station and other structures destroyed

Iquique	0.3	6	The lower quarter of the city, the customhouse and warehouses washed out; ships and boats run aground or were damaged; 30 people died.
Chanabaya	0.1	10	City completely flooded; casualties; ships sunk.
Caleta Pabellon de Pica	0.4	10	Lower part of city destroyed; 5 ships sunk and 27 damaged
Punta Lobos	0.1	10	2 ships sunk and 14 damaged
Huanillos+	0.25	9-18	All homes washed away except for 20; 4 ships sunk and 13 damaged; casualties.
Tocopilla	0.1	24?	Homes destroyed and washed away. /86
Cobija	0.1	9	3/4 of city flooded; 14 people died
Mejillones	0.5	21	2/3 of city destroyed; 33 people died; T^1 = 15 min
Antofagasta	0.1	6	Homes destroyed
Chañaral	0.9	4-5	City partially flooded
Caldera	0.7	2	-
Carrizal Bajo	2	1.5	Ships damaged
Coquimbo	2	2	-
Valparaiso	2.5	1.1	T = 15 minutes
Constitucion	1.5	5	-
Tome	3.5	0.7	-
Talcahuano	3	3	-
Coronel	-	1.5	-
Lota	4	1.5	-
Arauco	-	-	The flood tide passed 4 km upriver
Llico	-	-	Rises and falls in level within usual amplitude of flood and ebb tides
Corral	7.5	-	The same
Valdivia	-	-	Tsunami was barely noticed

+ Spelling approximate - Transl.
[1] T - wave period.

Ancud	2.5	–	Surge of water; rises and falls in level
Puerto Montt	–	–	Slight movements of the sea
Juan Fernandez Islands	–	–	Weak tsunami
OCEANIA			
Samoa Islands, Apia	15	0.9	–
Fiji Islands	–	–	Tsunami noticed
NEW ZEALAND			
Waitangi	–	–	Strong wave; currents
Russell	–	–	Flood and ebb tides
Auckland	–	2.7?	–
Tauranga	–	1	–
Gisborne	–	1.2	–
Napier	–	–	Tsunami noticed
Wellington	13.5	0.8	–
Westport	–	–	Tsunami noticed
Chatham Islands	–	–	Bridge and homes washed out
Kaiapoi	–	1	–
Lyttelton	–	1	–
Pigeon Bay	–	2	–
Le Bon Bay	–	–	Two bridges destroyed
Akaroa	–	3	Coastal homes flooded
Timaru	–	–	Rises and falls of water /87
Omaru	–	–	Pier destroyed
Port Chalmers	–	2-6?	–
Bluff	–	–	Tsunami observed
AUSTRALIA			
Newcastle	–	0.6	–
Sydney	–	0.6	–
HAWAIIAN ISLANDS			
Hilo	14.0	4-5	Homes washed away; 5 people drowned; T = 20 min.
Kawaihai	–	0.8	–
Kealakekua	–	4.5	–
Kahului	–	1.5	–
Lahaina	–	3.5	–
Honolulu	14.4	0.7	T = 20 min.
Nawiliwili	–	0.9	–

JAPAN			
Hakodate	25	2.4	Part of city flooded; T = 20 min.
Kamaishi	23	3	T = 15 minutes
Boso Peninsula	-	-	Coast flooded, casualties?
Tokyo Bay	-	0.7	-
Tosashimidzu	-	-	Unusual flood tides
NORTH AMERICA			
San Francisco	13.5	0.3	-
Gaviota+	-	3-4?	-
San Pedro	-	2	-
Wilmington	-	2	-
Acapulco	-	1	-

+ Spelling approximate - Transl.

Holden, 1898; Goll, 1903; Dutton, 1904; Honda et al., 1908 a,b; Krümmel, 1911; Montessus de Ballore, 1911 a, 1916; Westervelt, 1916; Vallaux, 1925; Davis, 1928; Jagger, 1931; Sieberg, 1932; Bobillier, 1933, 1934; Bruggen, 1943; Heck, 1947; Gutenberg, Richter, 1949, 1954; Laing, 1954; Anon., 1961; Ponyavin, 1965; Iida et al., 1967; Silgado, 1968, 1974; Shuleikin, 1968; Lomnitz, 1970).

1877, May 14, 19:10 and 21:00. There were strong shocks at Callao; the sea rose very high at Ancon (Geinitz, 1878).

1877, May 15, 2:00. One of the recurrent shocks of the Iquique earthquake was felt at Huanillos; according to observations, the sea was restless (Geinitz, 1878).

1877, June 15 (?). An enormous column of water arose at Pisagua not far from shore and strong eddies formed. It was reported that at the same time prolonged tremors, accompanied by a rumble, were felt at Caleta Pabellon de Pica and Chañaral (Fuchs, 1878; Goll, 1903; Bruggen, 1943).

1877, August 23, 16:55. A strong short tremor occurred like a shock at Iquique; three large sea waves fell on the coast 10 minutes later and reached the esplanade (Goll, 1903; Montessus de Ballore, 1911 b).

1877, September 2, 14:00. At Valparaiso, with good, completely calm weather, there was a high swell which is usually observed only with a very strc · north wind. At the same time there was a strong thunderstorm /88
at Santiago (Goll, 1903).

1877, October 9, 2:00. There was a rather strong earthquake at Lima, accompanied by a rumbling, and an earthquake at Pisco on the 9th. The sea was very agitated off the coast at Antofagasta and Chañaral (Polo, 1899 b).

1878, January 23, 19:55. A strong earthquake occurred in the north of Chile in the province of Tarapaca. The earthquake lasted 1 1/2 minutes at Iquique; 40 mild shocks were registered at night. The earthquake spread to Arica and was very strong even at La Horia, where many homes were destroyed, and at Poso-Almonte and Pisagua. Sibay, Usmagama, Limariña*, Guaviñya, Guaskiñya, Sipisa, Sotoka, Chyapa and Jaiña were also destroyed.

After the earthquake a wave fell onshore. It destroyed Pica, Tarapaca, Mamiña and many other settlements. Pisagua and Arica were flooded (Fuchs, 1879, 1885 b; Milne, 1912 b; Sieberg, 1932; Heck, 1934, 1947; Anon., 1961; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967).

In contrast to other authors, Goll and Montessus de Ballore (Goll, 1903; Montessus de Ballore, 1911 b) mention that at Arica and Iquique the sea was calm, unlike the earthquake of May 9, 1877, and emphasize that Pica, Tarapaca and Mamiña, situated 60-70 km from shore,

could not have been destroyed by the tsunami waves.

1878, January 27. The sea rushed onshore at Callao. Boats and small ships ran aground. A recurring flood tide passed 100 m inland from the breakwater of the inner harbor, carrying with it everything on the beach. Five people drowned. Enormous chunks of stone were tossed around like toys. There was no earthquake that day (Fuchs, 1879).

1878, January 28-30. At Valparaiso, with still and splendid weather there was such a strong surf, that a new road was washed out; nobody drowned. It was also reported that the sea raged for three days and encroached inland at Caldera, Chañaral, Iquique, and Pisagua; some damage was done here and there. In particular, on the 28th, from 5:00 to 8:00 at the lighthouse at Caldera, there was an unusual disturbance of the sea, which rose 25 m [along the horizontal?] beyond the highest flood tides (Fuchs, 1879; Goll, 1903; Montessus de Ballore, 1911 b).

[It is possible that this and the next two events are connected.]

1878, February 3. At Iquique and Pisagua, there were storm waves at sea continuously throughout the day (Goll, 1903). At 11:40, at La Serena regular tremors; a faint rumbling. At 22:40, a subterranean shock at the lighthouse at Coquimbo (Montessus de Ballore, 1911 b).

1878, February 4, 23:45. There was a mild earthquake at Callao; the sea raged on the 4th (Polo, 1899 b).

1878, February 14. At 4:00, the steamship "Chile" experienced a "terrible" shock in Concepcion Bay (Talcahuano). The ship almost sank in the three enormous waves which accompanied this shock (Goll, 1903; Montessus de Ballore, 1911 b).

1878, March 12. At Iquique, there was an earthquake and agitation at sea (Polo, 1899; Montessus de Ballore, 1911 b).

1878, April 12, 20:00. At Iquique, there was a mild but prolonged earthquake with underground rumbling. On the 13th, at 3:45, an enormous wave suddenly fell onshore at Buchupureo and penetrated 60 m inland (Goll, 1903, Montessus de Ballore, 1911 b).

1878, June 12 or 16, 3:00. At Antofagasta, a very strong earthquake occurred lasting about half a minute; this was followed by strong "movement of the sea," which seemed likely to encroach inland (Goll, 1903; Montessus de Ballore, 1911 b, 1916).

1878, last days of June. In Southern Peru (Chilean) harbors, there were unusual "movements of the sea" so strong that the steamship "Riman" could not unload (Goll, 1903).

1878, last days of September. The sea was restless at Iquique and and Chañaral as during a very strong storm (Goll, 1903) /89

1878, November 23-25. There was a very strong disturbance of the sea at Valparaiso and a strong flood tide (Goll, 1903).

1879, August 8, morning. At Valparaiso, the sea suddenly receded far from shore; then three large waves fell, tossing three loaded long-boats onto the railway roadbed (Goll, 1903; Montessus de Ballore, 1911 b).

1880, August 15, 8:48. A strong earthquake occurred with source north of Santiago.

At Illapel, a loud rumbling was heard from the north. It rapidly intensified for 10 seconds, after which what seemed like an explosion was heard and the ground shook violently for a minute. Two of these shocks were especially strong. All the public buildings, homes, blast furnaces and stone quarries were almost completely destroyed. Six hundred families were left homeless with no means of subsistence. Since it was a holiday, all the people were in the streets, as a result of which there were only two casualties. Ground waves were observed. The regime of subterranean waters and springs changed (VIII degrees, on the M. scale). Aftershocks continued at least until the first days of October.

Several walls collapsed at Ovalle; a number of buildings were severely damaged (VIII). Extensive physical damage was done at Salamanca (VIII). At Petorca there were strong tremors lasting 1 minute, preceded by a loud rumble. Public buildings were heavily damaged. The majority of homes were rendered unfit for habitation, and some of them collapsed completely (II).

There was slight damage at San Felipe (VI-VII?). A cathedral was destroyed at Quillota (VII-VIII). One church tower collapsed, and another sank to one side at Viña del Mar (VI-VII). The roof of one home collapsed at Limache (VII-VIII). At Valparaiso, cornices collapsed and walls cracked here and there. At Santiago, there were strong prolonged tremors, causing slight damage: cornices collapsed here and there, walls cracked, statues tumbled (VI-VII). The bells rang at Rancagua (VI-VII). There were strong tremors at Talca. Several dilapidated walls crumbled at Concepcion, and underground rumbling was heard from the north (VI).

The earthquake was stronger at La Serena (VI) than at Los Vilos (VI); one or two ranch houses sank to one side. There were strong, prolonged tremors at Copiapo. The earthquake was noted at Mendosa, La Rioja and San Juan.

There were strong tremors at Coquimbo. Large columns of water arose at sea, as a result of which the anchor chain snapped in one ship. The underwater cable across the mouth of the Limari River* was broken at a depth of 1.8 km (Montessus de Ballore, 1912).

1881, July 14, 8:00. There was a terrible earthquake at Iquique, as a result of which the sea became so agitated that here and there it encroached inland, reaching the office of the foundry situated near Molino* Bay (Montessus de Ballore, 1916).

1881, October 27-29. At Pisagua, there were rather strong earthquakes. Apparently the sea was so agitated because of these shocks that it was difficult to unload the ships at the moorage (Montessus de Ballore, 1916).

1882, February 23, 20:30. At San Antonio (center of Chile), a faint rumbling was heard and oscillations began which grew into a catastrophic earthquake. The rumbling grew deafening and lasted several minutes. The inhabitants rushed into the streets. The sea calmed down as soon as the rumbling ceased (Montessus de Ballore, 1916).

1882, September 14, 14:15. There was a strong earthquake at Pisagua, lasting about a minute. After this, the sea was so agitated that rigging became impossible in the port (Montessus de Ballore, 1916).

1885, November 12, 2:40. At Iquique, there were strong and prolonged oscillations of the ground coming from the north. At 3:40, another earthquake, just as strong as the first. At 4:15, still another earthquake, less strong than the first two. /90

On the same day, the harbor alternately and temporarily dried up, then waves broke on the beaches, islands, and reefs of this port (Polo, 1899 b; Montessus de Ballore, 1911 b).

1886, August 29. Two shocks were felt at Iquique panicking the population, which feared a tsunami. Many families rushed inland. Others pitched tents on the hillsides. There was also fierce panic at Arica. Goods were evacuated from the customhouse in expectation of flooding (Montessus de Ballore, 1916).

1896, March 13, 20:30. There was an earthquake, felt from Copiapo to Mendosa and Concepcion. At Limache, the earthquake was VIII degrees (on the M. scale) and fore and aftershocks were recorded. The residents of Valparaiso was terrified and those most fearful sought shelter in the hills around the city, since an ominous rumor was circulating that the sea would encroach inland. However, the earthquake had negligible effects in the city: walls collapsed in a number of buildings, and several dilapidated homes crumbled in the Almendral region. The cornices collapsed on many public buildings. Crypts at the cemetery were split open (Montessus de Ballore, 1911 b, 1912).

1898, July 23, 22:30. An earthquake with source in the Concepcion region was preceded by a foreshock and a subterranean rumble.

At Concepcion, the residents took to the streets in panic. About 50 homes suffered some damage. The destruction was not so serious, as extensive: walls cracked and warped, partitions collapsed and cornices fell. There were injuries (VIII degrees, on M. scale).

At Talcahuano there was similar but less serious destruction; one home sank so far to one side that it had to be pulled down (VIII). At Tome, all buildings suffered some damage, although none collapsed (VIII).

At Florida, the walls cracked and warped in some homes and the roofs fell in (VIII). Several buildings collapsed at Quillon (VIII). Three homes were completely destroyed at Rere+ and many others became uninhabitable. There were six casualties (VIII). All the buildings cracked at Yumbel (VIII). All buildings suffered some damage at Santa Juana (VIII).

The following points fell within the VI degree isoseismal, according to Montessus de Ballore: Cauquenes, where cracks appeared in old walls; Chillan, where the school walls cracked and warped; Bulnes, where there was terrible panic and dishes were broken; Yungay, where stucco fell off; Mulchen, where the tremors were preceded by a rumble, lasted 1 minute, and caused some walls to crack; Angol, where strong tremors lasted 1/2 minute and damaged two or three partitions, broke dishes and caused panic.

At Coronel, Arauco, Linares and Talca, strong tremors caused panic. At Lebu there were strong and prolonged tremors. The earthquake was felt in Valparaiso and Santiago.

A lot of aftershocks were felt.

The report of the Mayor of Concepcion mentions no special phenomena in the sea in the surrounding ports (Montessus de Ballore, 1912).

In contrast, Milne (1900 a) reports that in the region of Concepcion and Talcahuano, the sea retreated and the inhabitants were terrified, fearing a tidal wave.

1903, September 26. Sea waves of seismic origin were observed at Iquique (Montessus de Ballore, 1904).

1903, December 7, 10:09. There was an earthquake in Chile, felt at least from Santiago in the south to Taltal in the north and La Rioja and Mendoza (Argentina) in the east, and particularly at La Serena (strongly), Caldera, and at the lighthouse on Tortuga* Cape. It was felt at San Fernando. Aftershocks were registered.

At Vallenar, the earthquake was very strong, accompanied by a rumbling and lasted more than a minute. Not a single home was left untouched. The residents panicked; the railway was damaged. The earthquake was also strong at Freirina where some buildings were damaged. /91

Several walls collapsed at Huasco. The sea was very agitated (Rudolph, 1905; Montessus de Ballore, 1911 b)

1906, May 7. There were strong shocks lasting about 35 seconds at Tacna and Arica and the sea was agitated (Montessus de Ballore, 1906 b).

1906, August 16, 20:40. There was an extremely strong earthquake /92

+ Spelling approximate - Transl.

in the center of Chile, with source near Valparaiso (Fig. 28). According to the director of the meteorological observatory at Santiago, the earthquake began suddenly without any preliminary rumble and with marked oscillations. Their amplitude gradually increased; strong oscillations lasted 1 1/2 minutes. According to other sources, the earthquake lasted 4-5 minutes in the focal zone.

The earthquake was felt as far as Tacna (Peru), Buenos Aires, Chiloe Island and the Juan Fernandez Islands. The seaquake was felt at Deseado* Cape (Atlantic coast of Argentina). According to the Central International Seisomological Bureau at Strasbourg (Scheu, 1911) and a number of investigators who collected press reports (Steffen, 1907; Sieberg, 1932) the intensity of tremors at individual points is estimated as shown in Table 6.

The strongest seaquake took place at the port of Valparaiso. On the steamship "Thuringia," two vertical shocks were felt against the hull; a leak apparently developed. The railings of the gangway were broken in the engine room. Pipes and flanges were broken in the engine on the steamship "Varda"; the captain ordered the boats to be readied in case the steamship broke up. The steamship "Airon"+, which left port half an hour before the earthquake, felt a very strong quake at sea but suffered no damage.

The Valparaiso-La Serena underwater cable broke about 3 1/2 km (2 miles) from Valparaiso.

The axis of the pleistoseismic zone of the earthquake may have been directed along the 20° azimuth. Weak structures on loose soil were almost the only ones destroyed. The territorial distribution of damage in such large cities as Valparaiso and Santiago is especially significant in this respect (Montessus de Ballore, 1924). At Valparaiso, damage was mainly done not by the earthquake itself, but by the subsequent fire. Limache was almost completely destroyed; 116 of 3000 residents died. The northern part of San Antonio was buried under a large mud flow. Many water and mud gryphons were formed on the plain near Curepto.

The residents of many coastal settlements observed luminous phenomena at the time of the earthquake (lightning, diffuse luminescence, falling stars, phosphorescent air near the ground, sparking of wires etc.).

The shore at some places in the focal area was elevated 0.7-0.8 m (Fig. 28), and then slowly returned to its previous position. Apparently, due to the latter fact, the authenticity of the elevation was questioned by many specialists, including Montessus de Ballore, who soon after headed the seismological service in Chile (Montessus de Ballore, 1924).

A high level of seismic activity in the focal area continued for 18 months.

+ Transliterated - Transl.

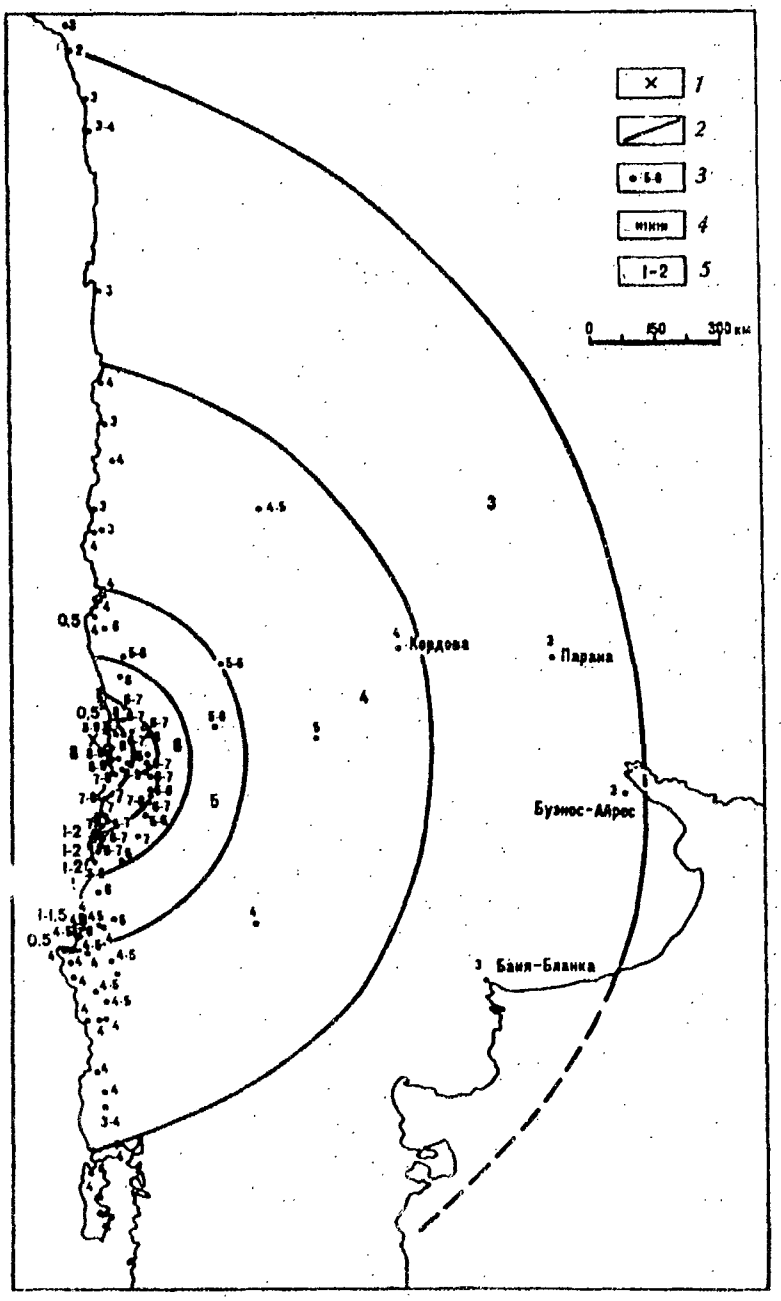


Fig. 28

Force and isoseists for the earthquake of 16.VIII.1906.
Compiled by S.L. Soloviev from information in the literature.

1 - epicentre;

2 - smoothed isoseists;

3 - places of observation and force in points;

4 - parts of the shoreline which rose;

5 - height of rise of water (in m).

Table 6 /93

Force of earthquake of 16.VII.1906.

Observation point	Degree
Zapallar	8-9
Nogales	8-9
Viña del Mar	8-9
Valparaiso	8-9 (IX-X, R.F.)
Tunquen	8-9
Casablanca	8-9 (IX-X)
Limache	8-9 (IX-X)
Quillota	8 (IX-X)
San Antonio	8
Melipilla	8 (IX)
Quilpue	7-8
Lampa	7-8
Curacavi	7-8
Matanzas	7-8 (VIII)
Graneros	7
Requinoa+	7
Pichilemu	7 (VIII)
Llico	7 (VIII)
Curico	7 (VIII)
Petorca	6-7
Cabildo	6-7
San Felipe	6-7 (VII)
Catemu+	6-7
La Calera	6-7
Tiltil	6-7
Santiago	6-7 (VII)
San Bernardo	6-7 (VII)
Talagante	6-7 (VII)
33° 51' S., 72° 16' W.	6-7 (VI-VIII)
Rengo	6-7 (VII)
Paredones	6-7
Vichuquen	6-7
Licanten	6-7
Curepto	6-7 (VII)
Ovalle	6 (VI-VII)
Illapel	6 (VII)
Los Andes	6 (VI-VII)
Rancagua	6 (VI)
San Fernando	6 (VI)

+ Transliterated - Transl.

Observation Point	Degree
Putu	6
Talca	6 (VI-VII)
Cauquenes	6 (VII)
Chillan	6 (VII)
Concepcion	6 (VII)
Combarbala	5-6 (VI)
Constitucion	5-6 (VI)
San Juan	5 (VI)
Mendoza	5 (VI)
Colina	5 (V-VI)
San Luis	5
Quillon	5
La Rioja	4-5 (VI)
Lota	4-5 (V)
Los Angeles	4-5 (V)
Los Sauces	4-5 (V)
Mulchen	4-5 (V)
Traiguen	4-5 (V)
Taltal	4
Copiapo	4
La Serena	4
Freirina	4
Coquimbo	4
Tongoy	4
Cordova	4
Ranquil+	4
Bulnes	4
Tome	4
Penco	4
Punta Lavapie	4
Santa Juana	4
Coronel	4
Arauco	4
Curanilahue	4
Cañete	4
Carahue+	4
Temuco	4
Nueva Imperial	4
Valdivia	4
La Union	4
Puerto Montt	4
Ancud	4
Juan Fernandez Islands	4
Iquique	3-4

+ Transliterated - Transl.

Observation point	Degree
Isorno	3-4
Tecna	3
Pisagua	3
Antofagasta	3
Chañaral	3
Carrizal Bajo	3
Huasco	3
Parana	3
Buenos Aires	3
Bahia Blanca	3
Cabo Deseado*	3
Arica	2

The following is known about the oscillations in sea level which accompanied the earthquake:

According to all observers, no unusual movements of the sea took place south of Arauco, as the stormy weather at that time made it difficult to follow the level of the ocean.

At Coronel, immediately after the shocks, extremely strong surges were noticed in the northern part of the bay, though there was not the slightest wind.

At Penco and Tome, the surface of the sea during the earthquake was completely calm. A short time after (according to different estimates, from 15 minutes to 1 hour later), the water retreated 50-60 m, after which followed a quiet rise. The rise was apparently 1-1 1/2 m, since the water encroached on land, past the railway embankment and through the drains. Oscillations in level recurred in the same way three or four times, causing panic among the residents, especially at Penco.

On the coast of the provinces of Maule, Talca and Curico, unusual /94
tidal phenomena were observed soon after the earthquake. The sea rose an estimated 1 m above the level of the highest known high tides. In the mouth of the Maule River (at Constitucion), a wave coming from the sea caused a head in the river, [already] swollen from the recent heavy downpours. The small coastal settlements of this region, such as Buchupureo+, Putu, Llico and others reported that during the earthquake the sea began to seethe or boil, which disturbed the regular wave generation process. In the next several days, sounds were heard at sea like peals of thunder or shots, as far as Curepto, that is, 18 km from shore.

Very few places on the stretch of coast in the pleistoseismic zone of the earthquake reported agitation at sea. Thus it was reported from San Antonio and from the lighthouse on Curaumilla Cape, that some time after the earthquake, a heavy swell began which did not appear to be in any connection with meteorological conditions. The sea apparently remained calm at other points after the earthquake.

The situation was the same in the northern provinces of Chile. Although a "surge" was observed at Coquimbo, Caldera, Taltal and Iquique after the earthquake, this phenomenon was not considered to be unusual.

There is indirect evidence that the tsunami did some damage on the Juan Fernandez Islands (Anon., 1906 a), but Montessus de Ballore categorically denies this.

At the same time, the tsunami generated during the earthquake reached a considerable height on the Hawaiian and some other islands, and was registered in the USA and Japan (Fig. 29).

On Nuku Hiva Island (Marquesas Islands) the tsunami damaged the church at Haetaeoo* on the south coast of Haatuatua*+ Bay.

On the Hawaiian Islands at Hilo, the rise of water was 1 1/2 m (5 feet). A coaster lying at anchor off the northeast coast of Hawaii Island in calm weather, was dragged by a sudden ebb current so strong that it bro[illegible] the anchor chain. Apparently, the tsunami was focused at Hawaii Isla[illegible], and on the south coast of Maui Island, the water rose 3 1/2 m (12 feet), destroying the pier and Maalaea and MacGregor*. The road along the beach was flooded at Kahului, and some damage was done.

At Honolulu, tide gauge data show (see Fig. 29) that a mild tsunami began at 15^h45^m (5:15) and lasted 20 hours. The period of oscillations was 25-35 minutes, the height (or range) was 7-10 cm. The oscillations continued, though weakened, until the 19th, with a height (or range) of 5 cm.

At San Diego, according to the tide gauge record, the oscillations began at 14^h30^m (6:30) and lasted about 12 hours; the height (or range) was 15 cm, the period was 22 minutes.

On the tide gauge record at San Francisco (in Presidio), oscillations were traced from 15^h42^m (7:42) for 15 hours. At first the height was 9 cm, with predominating periods of 20 and 60 minutes; then the height diminished to 8 cm with predominating periods of 25 to 40 minutes.

In Japan, the greatest height of the tsunami was registered by the tide gauge at Kushimoto, of Wakayama prefecture (see Fig. 29). On the tide gauge record, the tsunami began at 0^h27^m (9:27) on the 18th, with a crest $3 \pm$ cm high. Two slight oscillations occurred during the first 40 minutes; the subsequent eight oscillations had a mean period of 21 minutes; their height gradually increased, and the peak seventh

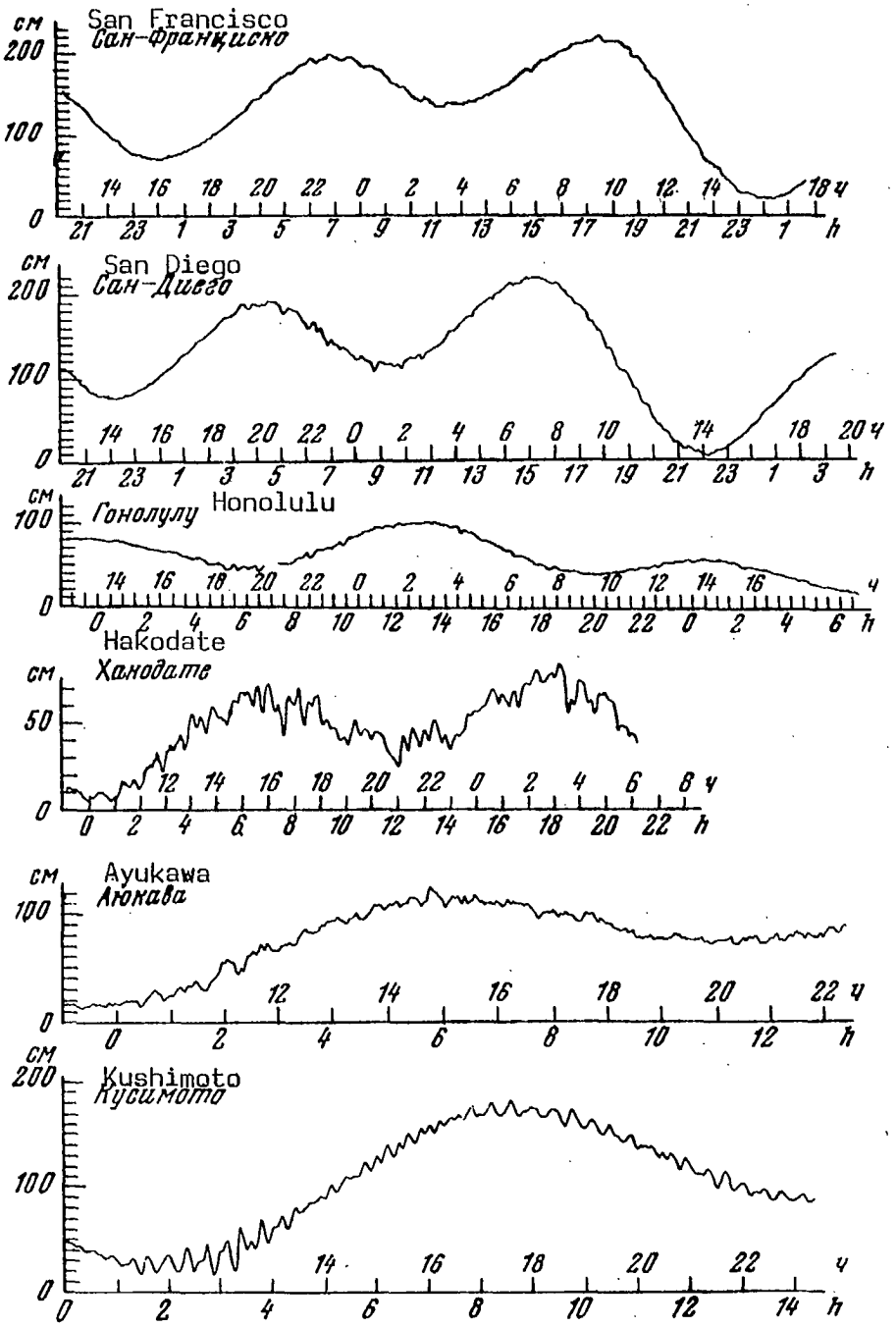


Fig. 29

Records of the tsunami of 16.VIII.1906 by tide gauges in USA and Japan (Honda et al, 1908a, b).

oscillation had a height of 44 cm. In the next 4 1/2 hours, the height of oscillations decreased to 10 cm, and then again increased to 16.5 cm.

According to Omori, the arrival of the tsunami was registered on the tide gauges at Misaki of the Kanagawa prefecture at 23^h23^m (8:23) on the 17th, at Ayukaura+, Miyagi+ prefecture, at 0^h30^m (9:30), and at Hakodate at 1^h02^m (10:02) and was also recorded very faintly by the tide gauge at Aburatsubo, Kanagawa prefecture. The peak amplitude at the last three points was 20, 30, and 8 cm respectively (Anon., 1906 a-c, 1961; Omori, 1907; Steffen, 1907; Honda et al., 1908 a,b; Kawasaki, 1930; Sieberg, 1932; Navarrete, 1933; Heck, 1934, 1947; Davison, 1936; Shepard et al., 1950; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967; Hatori, 1968; Lomnitz, 1970; Adams, 1971; Silgado, 1974). /95

Gutenberg, Richter (1954): 17.VIII; 00^h40^m; 33° S., 72° W.; M=8.4.

[Although the onset of the tsunami is uncertain on the records of remote tide gauges, they create the impression that the tsunami everywhere began here with the flood tide.

The agreement of calculated and observed travel times of the tsunami confirms that the oscillations in level recorded by remote tide gauges were really generated by the Valparaiso earthquake, and not by the almost simultaneous strong Aleutian one, as is sometimes supposed (Lomnitz, 1970).] /96

1909, June 8. In the Chañaral-Copiago region, there was a moderate earthquake. It was felt on steamships off the coast as a very strong seaquake; the hulls of the ships shook. The sea was not agitated (Montessus de Ballore, 1910). Navarrete (1933) mistakenly mentions that the earthquake was accompanied by tidal waves.

Gutenberg, Richter (1954): 8.VI; $05^h46.5^m$; 26 1/2° S., 70 1/2° W.; M=7.6.

1913, July 28, 12:40. There was a 6 degree earthquake at Arequipa. Everyone sleeping was awakened, and felt strong tremors which lasted 70 seconds. The second shock was felt 1 1/2 minutes later. At 12:46 when they entered the seismic pavillion, the needle of the instrument appeared to be still moving. The ground shook for a long time but not very strongly. The pendulums of some clocks stopped. There was universal panic in the city. The cable companies reported serious damage to cable lines off the coast of Peru, probably due more to the seaquake than to the earthquake (Campbell, 1914).

A strong earthquake occurred at Tacna; there was a "maremoto" at Mollendo; a cable was broken (Montessus de Ballore, 1915).

It was felt between Chala and Mollendo. The cable broke at 17° S., 78.3° W., at a depth of 4209 m (Silgado, 1968).

Gutenberg, Richter (1954): 28.VII; $05^h39.3^m$; 17° S., 74° W.; M=7.

[Apparently only a seaquake, without generation of a tsunami.]

1914, January 12, 1:45. At Callao, there was an earthquake lasting 55 seconds. There were no casualties. It was reported that immediately after the earthquake, a tidal wave flooded the foundations of the naval academy and several hotels at La Punta. [The western tip of the spit on which Callao is situated.] (SN, 1914, vol. 4, N 1; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967).

[There are apparently no instrumental data on the earthquake.]

1914, February 26. At Arequipa, the strongest earthquake of the year occurred, reaching 6-7 degrees. There was considerable panic. The earthquake was even stronger west and south of Arequipa and extended to northern Chile. The loud roar of breakers was heard at a distance of 55 km (30 miles) inland from the coast at Mollendo immediately following the tremors. To the north and east the earthquake was in general hardly noticed (Campbell, 1915).

Gutenberg, Richter (1954): 26.II; $04^h48.2^m$; 18° S., 67° W.; 130 km; M=7.2.

1918, December 4, 7:44. Weak oscillations rapidly gaining strength began at Copiapo. The tremors lasted 3-6 minutes. There was no rumbling. Damage to the city was heavy; 21% of the homes were completely destroyed, and 21% were seriously damaged. The remaining 944 homes suffered comparatively little, but not one home in the city remained undamaged. The destruction was increased by the fact that the residential district of the city, situated on the alluvial loams of the Copiapo River, was built up mainly with old, dilapidated homes of the pisé or wood cottages type with heavy flat roofs (25%), adobe homes with very flimsy mortar (25%), covered frame houses (25%), and reed panel homes (25%). It was mainly homes of the first and to some extent, of the second type, especially those situated on the weakest soils, which suffered. Numerous cracks up to 100 m long formed in the ground [8 degrees].

Near Copiapo, at Potrero-Seco, moderate damage was done to flimsy houses [6-7]. A collapse occurred near Punta Colorado, blocking the railway [7]. At Pugios*, not a single home escaped some damage (it was mainly pisé houses which were damaged); small cracks formed in the ground [7]. At San Antonio and Loroz+, some homes were destroyed and many were damaged; several irrigation canals were completely destroyed [7-8]. At Tres-Puentes, numerous avalanches blocked the highway [8]. At Vallenar, walls cracked in some buildings [6-7]. A strong earthquake was felt at Pueblo Undido+ and Tierra Amarilla. /97

The earthquake was preceded by two foreshocks and was followed by aftershocks.

At Caldera, the earthquake also lasted about 6 minutes. It was difficult to walk. The railway pier suffered damage. The cross was knocked off the church and shop windows were broken. Small cracks opened up in the ground near the beach. There was no other damage to the city, which was built up mainly with wooden homes [6-7].

After the earthquake, the sea slowly retreated from shore and the passenger quay dried up completely. Then, just as slowly, the sea flooded the beach. The usual high tide passed 11 m beyond the mean water line, but this time the water encroached 48 m, at another place, 141 m. The passenger quay was almost completely flooded. The rise of water along the vertical was 4.5-5 m above the level of regular flood tides. The ebbs and floods recurred 4-5 times. The vessels lying at anchor in the harbor were tossed about; the anchor chains were stretched to the limit (Willis, 1929; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967; Lomnitz, 1970).

Gutenberg, Richter (1954): 4.XII; $11^h47.8^m$; 26° S., 71° W.; M=7 3/4.

1920, August 20, 11:30. There was an earthquake on the coast of Chile which was felt from the mouth of the Mataquito River to Reloncavi Fiord. At Angol, several public buildings, including the school, were seriously damaged, and a number of homes were virtually demolished. On Mocha Island, two lighthouses cracked to the foundation and became unserviceable, and the tower of the eastern lighthouse was in danger of falling. A. the structures damaged had been in an extremely dilapidated condition. The earthquake was not felt at Santiago. On Mocha Island, 21 aftershocks were noted on the same day, more than at any other point on the coast.

In the harbor at Talcahuano, the movements of the water, which followed the earthquake, tossed about the vessels riding at anchor (SN, 1921, vol. 2, N 1; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967).

[20.VIII; $16^h15^m38^s$; 38° S., 73 1/2° W.; M=6.9.]

1922, November 10, 23:53. There was a very strong earthquake in the southern part of Atacama province, with a zone of destruction approximately from Copiapo to Coquimbo (Fig. 30). It was felt from Iquique to Concepcion (according to other sources, from Antofagasta to Valdivia) and from Buenos-Aires to San Felix Island (where volcanic activity may have intensified). The underwater cables broke near shore at depths of 100 and 2200 m. The instrumental and macroseismic epicenters were fixed at sea in the region of Vallenar - Huasco.

Like many others, this tsunami generating earthquake began with relatively weak, but comparatively rapidly intensifying oscillations, lasting from 1/2 to 8 minutes according to different estimates. The chief of the seimic station of Copiapo described the earthquake as follows:

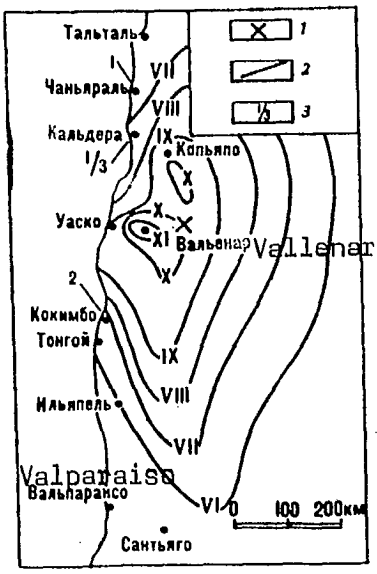


Fig. 30

Isoseists of the earthquake of 10.XI.1922.

1 - epicentre of the earthquake

2 - isoseists

3 - passage time of the tsunami (hrs)

4 - force of the tremors on the Mercallo-Kankani-Sieberg scale (Sieberg, 1932).

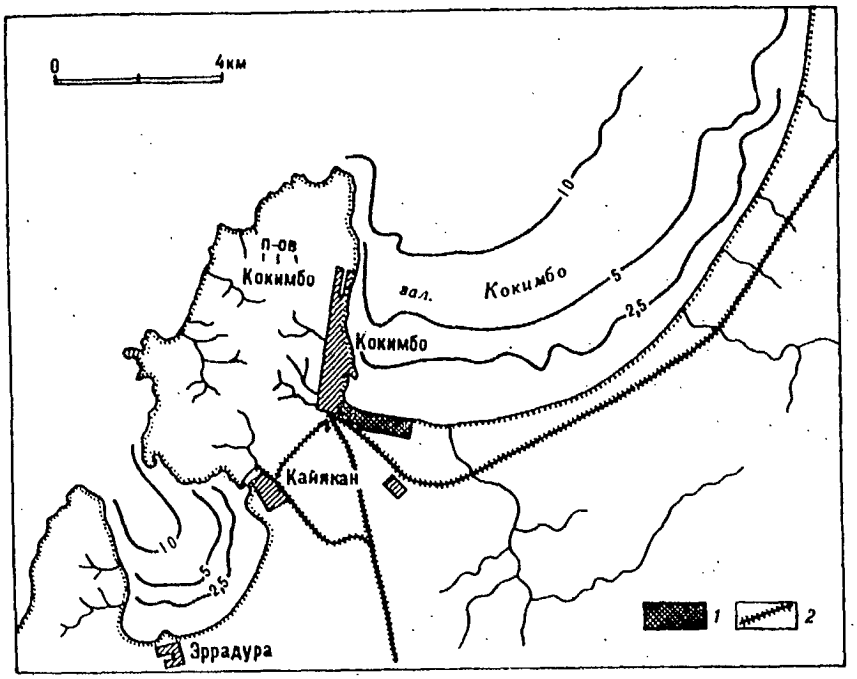


Fig. 31

Sketch of Coquimbo Bay (Willis, 1929).

1 - flooded part of Coquimbo town;

2 - railroad

A terrible roar was heard, like loud peals of thunder, which awakened all those who were asleep. At the same time, ground oscillations began with an intensity of 4-5 degrees (V according to R.F.), intensifying in 20 seconds to 7 degrees (VIII). The tremors then reached their maximal intensity and continued, without abating, for another 3 minutes, then gradually began to die down. According to other sources, the earthquake began with abrupt vertical shocks; essentially, it consisted of two independent tremors. /98

At Copiapo and other places, it was mainly flimsy structures (pise homes) on loose soils which suffered damage. More than 500 people died. Luminous discharges in the atmosphere were observed at many places. It is possible that a slight elevation of the coast took place in the Chañaral region. The surface effect and the geological preconditions of the earthquake have been described in detail by Willis (1929).

The earthquake was preceded by strong foreshocks, felt on the 3rd and 7th of November. Seismic activity in the focal zone of the earthquake was high for two months.

The following data were published on the tsunami on the coast of Chile and Peru.

At Chañaral, the tsunami began an hour after the earthquake and lasted about 4 hours. The sea surged onshore three times. It rose 9 m above the high tide mark, destroyed 14 homes, and carried four homes inland (there was no destruction resulting directly from the earthquake here). The tides were calm, but prolonged.

At Caldera the sea at first remained completely calm after the earthquake, but then it rose: 15 minutes, 30 minutes, or 45 minutes after the earthquake, according to different estimates. The most reliable in this respect, is the report of a witness, who at the time of the earthquake was on a ship riding in the harbor, and who set off for the port in a boat immediately after the strong shocks had ceased. When the boat arrived at shore 15 minutes later, the water had risen about 5 m above the high tide level and almost splashed over the moorage.

The several subsequent flood tides were larger than the first, but they all occurred slowly and were not accompanied by waves, breakers, or special noise. The greatest rise, 7 m above the mean sea level (according to other sources, 6 m above the maximum flood tide line) was reached at 3:30 on the 11th; damage was extensive. The water encroached 600 m inland at Ramadas* Cape. The water encroached 50 m in the upper part of the port. The customhouse, station, and other buildings were destroyed or shifted. Many flood tides, each lasting about 20 minutes, were counted until 9:00.

At Coquimbo, the sea was absolutely quiet before the earthquake. About 2 hours after the earthquake, a tsunami appeared. The waves spread from the northeast to the southwest along the axis of the bay (Fig. 31), passed along the western and eastern shores, but did not cause any damage. On the south shore, the water rose to a considerable height. Three

large tidal waves were observed, the third being the most destructive. The water penetrated 2 km at the most low-lying places, and the rise was 5 m above the maximum high tide line or 6 m above the mean sea level. It reached 7 m above mean sea level at the railway quay. The water rose and fell slowly; the ebb was smaller than the flood; the surface of the water was calm. As a result, the part of the city situated at the southern apex of the Bay was totally destroyed, not alone by the water, but also by boats and other objects which it carried.

Several hundred people drowned in the waves.

The tsunami was noticed at Huasco and Antofagasta. The water rose 2.4 m at Callao.

As a result of the earthquake and tsunami off San Felix and San Ambrosio Islands, the lobsters, which had been numerous here, almost all died. Only a few young seagulls survived these events in the islands.

The tsunami arrived at the tide gauge at San Diego 13.0 hours after /99
the earthquake and at the tide gauge at San Francisco 13.8 hours after the earthquake and was registered with a height of 20 cm and a period of 15 minutes (Fig. 32 a).

The tsunami arrived at Hilo (Hawaiian Islands) in 14.5 hours. The period of oscillations was 20 minutes, the height of the tsunami was 2.1 m; many boats were washed away and some damage was done. The wave reached Honolulu in 15.0 hours. The period of oscillations was 23 minutes, the height 0.3 m.

The tsunami arrived at Apia (Samoa Islands) in 14.1 hours. At Pago Pago on Tutuila Island, the period of oscillations was 20 minutes,

/101

Table 7

Tide gauge data on the tsunami of 10.XI.1922.

Observation point	Time of arrival h	m	Maximal oscillation of level time of onset h	m	range cm	Duration, hours.
Hanasaki+	2	22	4	57	60	48
Ayukawa	2	46	5	46	65	48
Aburatsubo	3	18	4	48	5	11.7
Kushimoto	4	18	5	48	70	47
Hosojima	4	24	16	04	39	33
Keelung	5	48	6	18	6	15
Takao	6	20	8	30	6	20,7

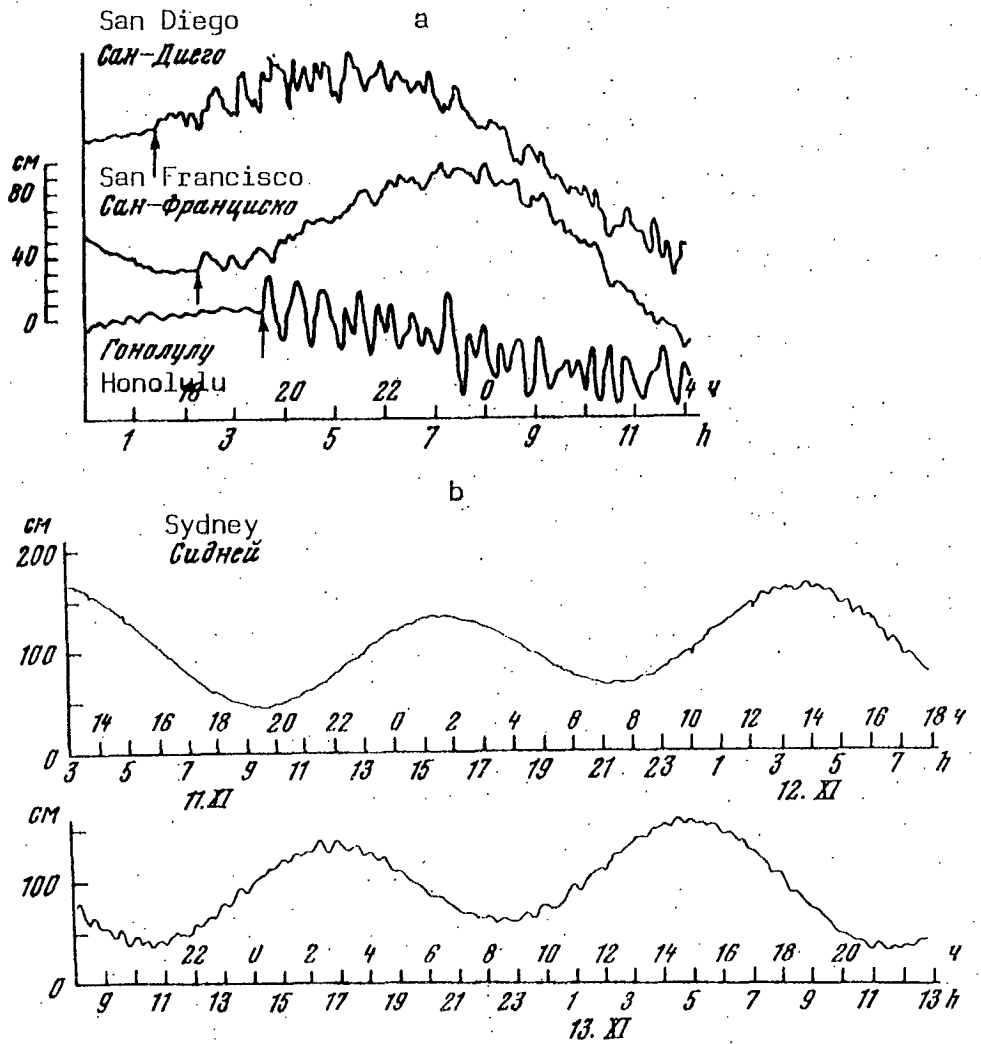


Fig. 32

Records of the tsunami of 10.XI.1922 in (a) USA (California and Hawaiian Islands), and (b) Australia (Hart,1931).

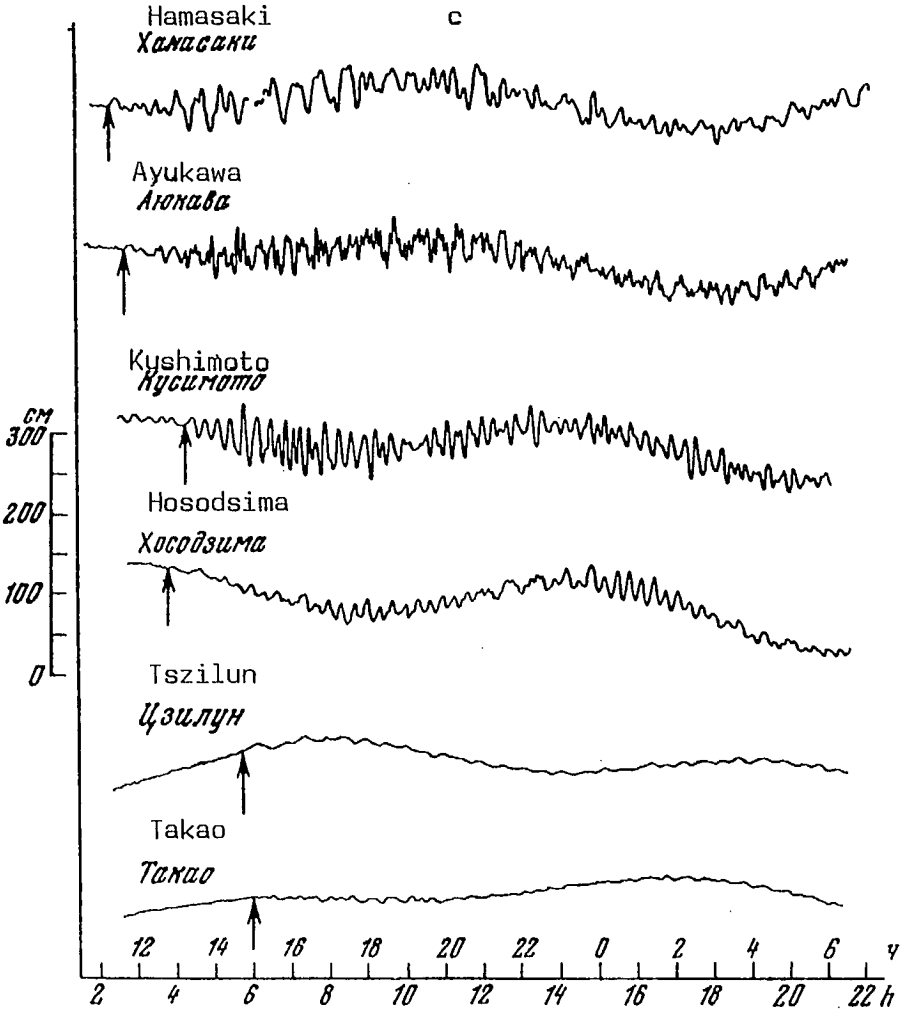


Fig. 32 (continued)

Record of the tsunami of 10.XI.1922 in (c) Japan and the island of Taiwan (Imamura, Moriya, 1939).

the height of waves was 1.8 m; some damage was done.

In New Zealand, at Port Chalmers slight oscillations in water level up to 18 cm (7 inches) in height were noted on the 12th and 13th. A similar phenomenon was noted at Timaru.

At Sydney (Australia, Fig. 32 a,b), the oscillations reached a height of 15 cm and had a mean period of 30 minutes.

In Japan at Ofunato (Iwate prefecture) at about 17:00 on the 12th, 30 homes were washed away. The paper by Imamura and Moriya (1939) gives the parameters of the tsunami based on data of seven tide gauges in Japan and on Taiwan Island (Fig. 32 c, Table 7).

A typical feature of the records is the presence of long waves with a period of about 1 hour. The tsunami was also registered by the stations of Choshi, Kobe, Osaka, Nagasaki (Japan) and Tansui (Taiwan Island). The tsunami was apparently not registered at Shanghai.

By studying the records of the tide gauge at Zamboanga (Philippines), it was established that the tsunami arrived here on the 12th at 6^h40^m. Five peaks are shown on the record, with an average wave period of 103 minutes and a height of 10 cm. The tsunami was also registered at Isabela (Basilan Island) (ISS, 1922; Selga, 1923; Finch, 1924; Willis, 1929; Hart, 1931; Sieberg, 1932; Orrego, 1933; Bobillier, 1933, 1934; Heck, 1934, 1947; Gutenberg, 1939; Imamura, Moriya, 1939; Bruggen, 1' , Imamura, 1949; Gutenberg, Richter, 1949, 1954; Laing, 1954; Iida, 1956; Anon., 1961; Berninghausen, 1962, 1969; Ponyavin, 1965; /100
Iida et al., 1967; Hatori, 1968; Lomnitz, 1970; Silgado, 1974).

Gutenberg, Richter (1954): 11.XI; $04^h32.6^m$; 28 1/2° S., 70° W.; M=8.3.

1923, February 17, about 5 or 6:00. At Constitucion on the Maule River (Fig. 33), strange phenomena were observed; the water level rose gradually, reaching the highest high tide mark, then fell, reaching the lowest low tide mark; the period of oscillations was 20 minutes. The amplitude of oscillations was about 2 m and continued to grow right up to 18:00, reaching a value of 3 m at that time, and then began to diminish more rapidly. The usual amplitude of high tides at Constitucion is 1 m 50 cm, and the amplitude of the highest high tides is no more than 2 m. The discharge of the Maule River in the summer is 700 m^3/sec, and as a result sea water does not enter the river at high tide. The oscillations in level during the unusual phenomenon were thus on a scale greater even than the highest high tides, and since the period of these oscillations, was 20 minutes instead of 12 hours 25 minutes, they were accompanied by strong currents, whose rate at the pier, where there was usually no current at all, was 1 m/sec (Orrego, 1933).

[It is possible that the date is mistaken and the description /102
applies to the Kamchatka tsunami of 4.II.1923.]

1923, March 4. According to a Reuter report the captain of the steamship "Marta" related that, returning to Coquimbo after catching lobsters and fish off the uninhabited San Ambrosio and San Felix Islands, while off the latter island, his ship encountered a tidal wave 35 m high, which arose on a calm sea surface. Arriving at San Felix Island, the captain noted that the island had shrunk. When they cast anchor, they noted that the water was warm, and the bottom had become sandy instead of rocky. The air was saturated with a strong sulfur smell, and the beach was strewn with dead fish. The sea birds had died in their nests (ISS; Malladra, 1925; Brugger, 1943). [The changes on San Felix Island may have been caused by the strong tsunami of 10.XI.1922.]

1923, May 4, 17:47:40. Apparently, this was the strongest aftershock of the earthquake of 10.XI.1922. It was felt from Antofagasta to Santiago, and reached an intensity of 8 degrees.

At Vallenar, many walls and several structures collapsed; there were no casualties. At Copiapo, the earthquake began with oscillations with an intensity of 5 degrees, later reaching 7 degrees; the earthquake lasted 3 1/2 minutes. Many walls in poor condition requiring repairs collapsed; partitions cracked; the populace was in a panic. There was a very strong earthquake at La Serena and Coquimbo, a strong one at Chañaral and a moderate or mild one at Illapel, Petorca, Quillota, Taltal and Antofagasta (SN, 1923, vol. 13, N 2; Bobillier, 1927). A Japanese catalogue (Anon., 1961) indicates that after the earthquake, a tsunami fell on the coast of Chile. The source of information, as also noted in Iida's catalogue (Iida et al., 1967) is unknown.

Gutenberg, Richter (1954): 4.V; $22^h26^m45^s$; 28 3/4° S., 71 3/4° W.; 60 km; M=7.

1923, August 12 7:11. A strong earthquake occurred at Arica; the sea rocked (Bobillier, 1927).

1926, December 9, 17:58. There was a rather strong earthquake in the central regions of Chile. There were very strong tremors at Vallenar; the populace was frightened. There was a strong earthquake at Copiapo; the populace was frightened; 6 degrees. It was felt from Taltal to Ovalle.

At Huasco, Potrerillos, Caldera, there was a strong earthquake; at Carrizal Bajo and the valley of the Huasco River, 5 degrees. There were mild tremors at La Serena, Coquimbo, the valley of the Copiapo River and Chañaral. There was a mild earthquake at Taltal and Ovalle. Recurrent shocks were noticed.

The sea became agitated at Huasco, Caldera and Chañaral (Bobillier, 1928). /103

[The earthquake was registered by the station at Santiago. According to a bulletin, the parameters of the earthquake could be estimated as follows: 22^h42^m; 28° S. ±1 1/2°, 71° W. ±1°; M=6 ±1.]

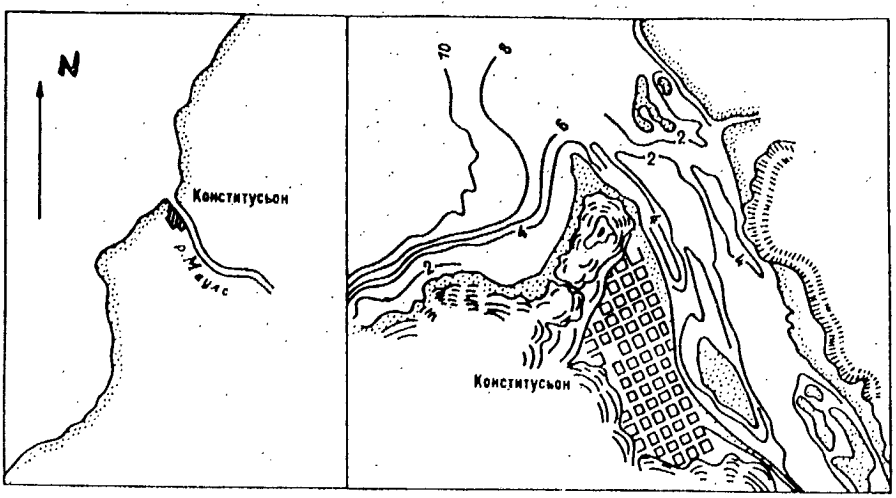


Fig. 33

Sketch of the Port of Constitucion (Orrego, 1933).

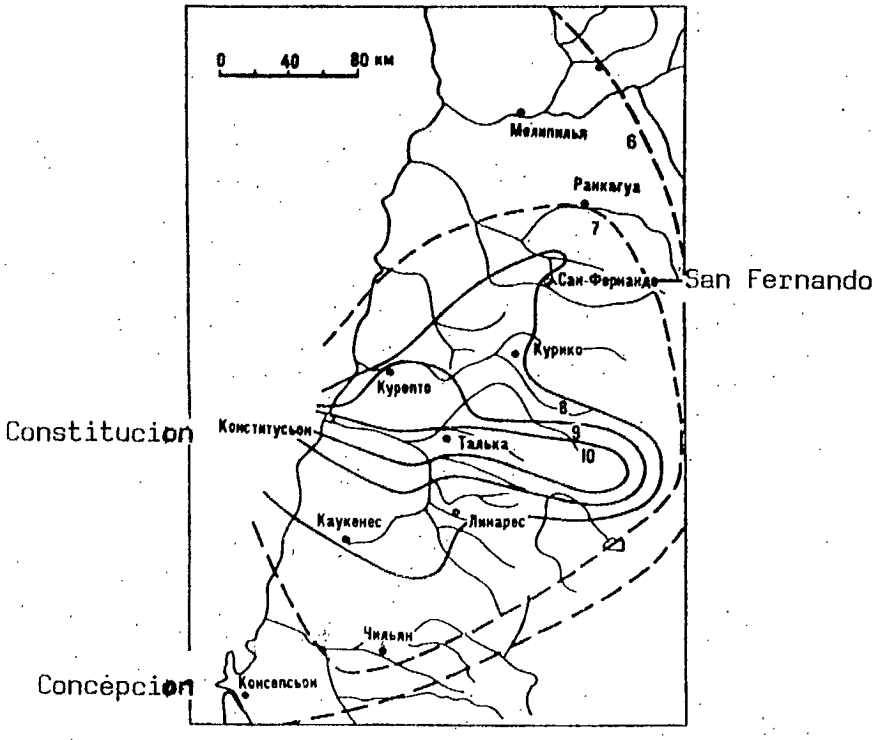


Fig. 34

Isoseists of the earthquake 1.XII.1928 on the 12 point scale (Robillier, 1930).

1927, November 21. There are reports about waves along the coast on a 45 km (25 miles) stretch in the region of Puerto Aysen. The water advanced 100 m (325 feet) inland. A boat with its crew was transported to a tree top. (SN, 1927, vol. 17, N 4; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967).

Gutenberg, Richter (1954): 21.XI; $23^h12^m25^s$; 44 1/2° S., 73° W.; M=7.1.

1928, March 31. At Antofagasta, enormous waves poured over the parapet of the embankment at Molito* Port (Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967). [There are no instrumental or macroseismic data on the earthquake.]

1928, April 9, 12:30. There was a destructive earthquake in south-east Peru with a source under the eastern slopes of the Andes. Structures at Makusani+, Ollachea+, Aiapata+ and other places were destroyed and damaged. The strongest recurrent shock was on April 27 at 15:34 (Silgado, 1968).

In some papers (SN, 1928, vol. 18, N 2; Berninghausen, 1962; Ponyavin, 1965), it is apparently mistakenly indicated that in the region of Arequipa "considerable damage was done on the coast by the frequent tidal waves which followed this series of destructive shocks."

Gutenberg, Richter (1954): 9.IV; $17^h34^m15^s$; 13° S., 69 1/2° W.; M=6.9. 27.IV; $20^h34^m58^s$; 13° S., 69 1/2° W.; M=6 3/4.

1928, December 1, 0:07. There was an earthquake which destroyed Talca and Constitucion. At Talca, strong vertical shocks lasted 1 minute 45 seconds; a fire broke out after the earthquake; the city was almost totally destroyed; 108 people died; railway, telegraph and telephone links with the city were broken. At Constitucion, the breakwater sank to one side. Sixty-seven people died; about another 50 people died at other settlements in the epicenter zone. Shortly after the earthquake, the rock dump at the Baraona# copper mine in the upper part of the Cachapoal*+ valley collapsed; 54 miners died. At Putu settlement, which was almost totally destroyed by the earthquake, the shore was lifted up and the water line receded more than 200 m.

A strong seaquake was felt on the "Santa Elisa" and "Poseidon" steamships situated 11-13 km (6-7 miles) off shore at Constitucion, in the direction of Valparaiso. The crew of the "Santa Elisa" reported that the vessel experienced "a strong trembling; it first appeared that some force was raising it above the water, and then tossing it down to the depths." Waves of unusual size moved in every direction on the surface of the sea; a clear moonlit night made it possible to observe the waves for a considerable distance. This phenomenon lasted no more than 1/2 minute. The steamship "Magdala" also felt a seaquake at 35° 33.5' S., 72° 54' W.

Possibly Baranoa - Transl.

The zone of damage by the earthquake stretched from Valparaiso to Concepcion. The intensity of tremors varied greatly even at adjacent points, depending on soils and other peculiarities of geological structure (Fig. 34). The earthquake was felt at Antofagasta, Buenos Aires and Puerto Montt.

After the earthquake, high seismic activity was observed in the focal zone. It gradually abated in the first months of 1929.

During the entire morning of December 1, irregular flood and ebb tides of unusual height were observed off the coast of Central Chile. At Constitucion, the water rose an estimated 1.5 m above the diurnal high tide line (SN, 1928, vol. 18, N 4; Bobillier, 1920; Navarrete, 1933; Lomnitz, 1970).

Gutenberg, Richter (1954): 1.XII; $04^h06.2^m$; 35° S., 72° W.; M=8.0.

1929, August 9. At Antofagasta at night, large waves were observed in the harbor, although there was nothing unusual about them. In places, the waves poured over the parapet of the breakwater, situated /104
at a level 7 m 50 cm above the highest high tide mark. By 22:00, an unusual drop in sea level was recorded. It rapidly reached a mark 1 m 30 cm below the lowest low tide mark, which could be clearly fixed from the dried up joints between the individual blocks of the embankment, already erected in section G of the port (Fig. 35). This caused great alarm among the population, since a rapid and unusual rise of water was to be expected whose consequences would be hard to predict. In fact, several minutes later, three waves fell on the breakwater at 4 minute intervals and poured over the parapet along its entire length at once, forming a stream from 3 m 50 cm to 4 m deep. These waves made the first breach BC in the structure. Less than 2 hours later, about midnight, a rapid fall in level was again recorded, accompanied by another rise in level and the formation of unusual waves, which made the second breach DE near the outer end of the breakwater. Somewhat later, more waves of the same kind breached the remaining sections AB and CD. Until 11:00 of the following morning, one could see unusual waves, flooding the upright piece of the breakwater DE, which held, since it was considerably thicker than all the rest of the structure (Orrego, 1933; Ponyavin, 1965).

[There are no instrumental or macroseismic data indicating an earthquake. Apparently, this was a storm tsunami.]

1930, December 29, 3:26:24. At Copiapo, there was strong oscillations reaching an intensity of 5 degrees, not accompanied by a rumble; the population was alarmed. There were strong underground shocks at Freirina and Vallenar. The earthquake was felt at Coquimbo and La Serena. It was preceded by a shock at 23:55 on the 28th, which was felt mildly at Caldera and was accompanied by aftershocks, which were recorded until the 30th.

In the Coquimbo region and on a 550 km (300 miles) stretch to the

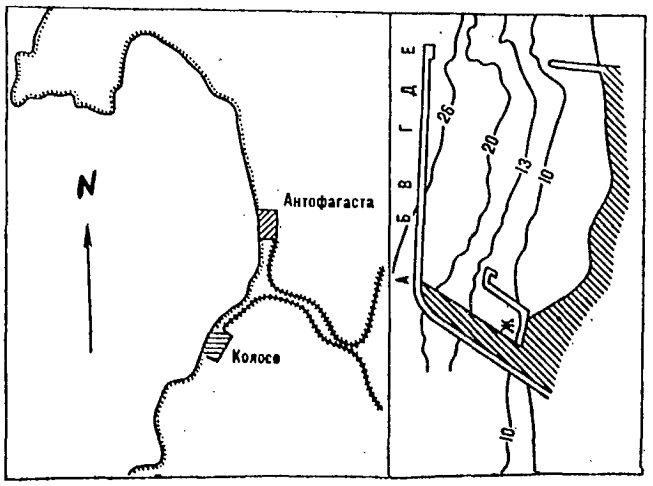


Fig. 35

Sketch of the Port of Antofagasta (Orrego, 1933).

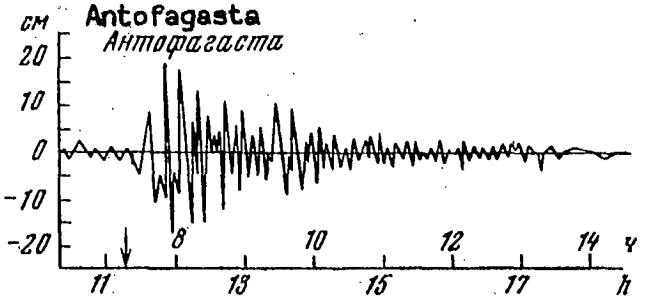


Fig. 36

Record of the tsunami of 13.VII.1936. The usual flood tide oscillations of sea level are eliminated.

north, unusually large flood tides and a very heavy sea were observed during the day following the first earthquake. The gigantic waves were of a deep green color, the water had an unpleasant smell and was saturated with plankton (SN, 1931. vol. 21, N 1; Bois, 1931 a; Bobillier, 1932; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967).

[The earthquake was registered by the Santiago station. According to a bulletin of the station, the parameters of the earthquake were as follows: 28 1/2° S., ± 1 1/2°, 71° W. ± 1°; M=6 ±1/2.]

1933, February, (mistakenly January) 23. There was a "maremoto" at Iquique (Anon., 1937).

[23.II; $8^h09^m12^s$; 20° S., 71° W.; 40 km; M=7.6.]

1933, October 2, 10:31. As reported by the Chief Geologist of Ecuador, G. Shepard, a strong earthquake took place on the Santa Elena Peninsula. The submarine cable was broken 25 km (14 miles) south of Salinas.

Ground oscillations were visible in Ancon and the water flowed /105
over the northeastern edge of a large reservoir. Among the subsequent shocks, the shock which occurred on October 3 at 5:36 was only slightly weaker than the main earthquake.

At [illegible]a Libertad, the sea retreated from shore immediately after the earthqu[illegible], rose to the high tide mark at 11:30 (the ebb tide was due at approximately 10:00), fell to the ebb tide level at noon and again rose to its previous mark at 14:00 (SN, 1933, vol. 23, N 4; Anon., 1933; Anon., 1934).

Gutenberg, Richter (1954): 2.X; $15^h29^m21^s$; 2° S., 81° W.; M=6.9.

1934, December 4, 12:45. There was a strong earthquake in the border regions of Peru and Chile. Many homes collapsed in the rural locality of Iquique and Pisagua and there were injuries. Several old walls also cracked and partially crumbled at Iquique, Pisagua and Arica; there were injuries (7 degrees); Antofagasta, six degrees. The earthquake was felt strongly at Taltal and was noted at Copiapo. Twelve perceptible recurrent shocks were recorded in the focal zone. There were signs of agitation of the sea at Arica (Bobillier, s.a.; SN, 1935, vol. 25, N 1; Silgado, 1968).

Gutenberg, Richter (1954): 4.XII; $17^h24^m38^s$; 19 1/2° S., 69 1/2° W.; 130 km; M=6.9.

1936, July 13th, 7:15. There was a strong earthquake with source north of Taltal. At Taltal, the tremors lasted 3 minutes. Many buildings were destroyed, including two schools and the British Consulate. One child died and 40 people were injured. The zone of greatest destruction also included the saltpetre placers to the northeast and east of

Taltal. The railway was damaged at many places, including a case of track rupture.

Chañaral hardly suffered. The destruction was negligible at Copiapo: several walls and partitions cracked and partially crumbled; various wares were smashed. At Antofagasta, the tremors were moderate; there was no damage. The earthquake was felt at Vallenar and La Serena.

Oscillations in sea level began at Taltal 3 hours before the earthquake. They intensified half an hour after the earthquake and reached a maximum another hour later. The maximal amplitude of oscillations was most likely 1 1/2 m. The tsunami was registered by the tide gauges at Antofagasta (Fig. 36) and Talcahuano. At Antofagasta, the maximal period was 40 minutes, that is, it was equal to the period of those oscillations in level which began 3 hours before the earthquake. At Talcahuano, the tsunami was very weak and was observed from 10:00 to 14:00 (SN, 1936, vol. 26, N 4; Donoso, 1939; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967).

Gutenberg, Richter (1954): 13.VII; $11^h12^m15^s$; 24.5° S., 70° W.; M=7.3.

1940, May 24, 11:35. There was a very strong earthquake with source in the central regions of Peru; 179 were killed, and 3500 injured. The material damage has been estimated at 3.6 million sols. It was felt all over Peru and beyond to Guayaquil+ in the north and Arica in the south (Fig. 37). /106

The tremors were strongest in the littoral zone to the north of Lima. There were many slides of loose material and rock falls on the western slopes of the Cordilleras. The settlements situated on alluvial soils on the terraces of the Chancay River (Canchapille*+ was laid waste) and the Huaura River (Huascoy* and Jumbilka*+ were almost completely destroyed), suffered most of all. Many buildings in Chancay (in particular, two churches collapsed), Huacho, Barranca, Lima, Callao, Chorrillos and Lurin were destroyed. It was mainly flimsy and dilapidated buildings which suffered. According to estimates, 38% of reed panel homes, 23% of adobe homes, 20% of brick homes, 9% of reinforced concrete buildings and 10% of buildings made of other materials were destroyed in the pleistoseismic zone. The intensity of tremors at Lima, according to Silgado, was 7-8 degrees.

The following was reported from other places. The earthquake was weaker at Chosica than at Lima [7 degrees]. Homes sank to one side at Cajatambo [7]. At Huarmey, Cañete, Chincha and Pisco, there was moderate destruction, and there were strong tremors at Paramonga [6-7]. There was some damage at Yauyos and Huaitara, [6-7]; the earthquake was milder at Huancavelika, Pampas and Lircay [6]. There was a strong earthquake at Huancayo [5-6]. The earthquake was noticed at Satipo and Ojapampa+ [5?]. It was not strong at Santo Tomas and was accompanied by rumbling [4-5]. It was strong at Chachapoyas, Cajamarca, Chota and Mollendo [4-5]. At Cotahuasi, Cuzco and Puno it was felt with some intensity

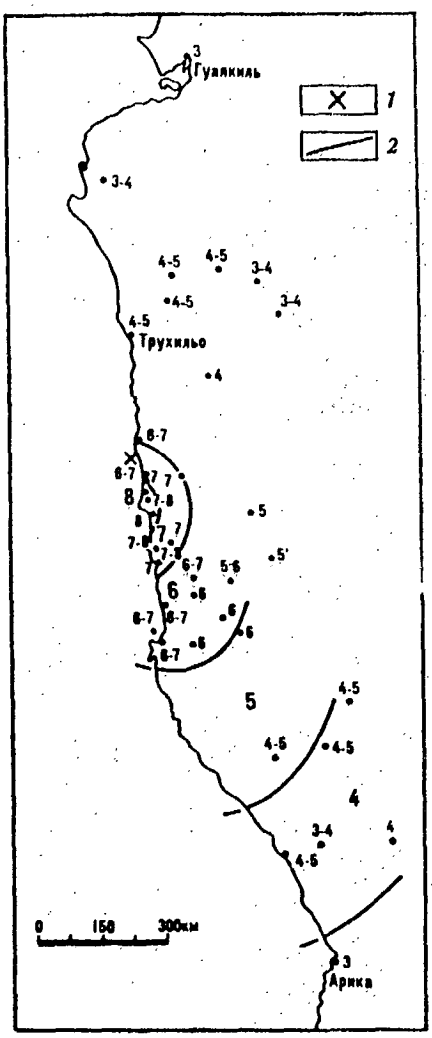


Fig. 37

Force of the shocks and isoseists of the earthquake of 24.V.1940. Compiled by S.L. Soloviev from information in the literature.
1 - epicentre of the earthquake;
2 - isoseists.

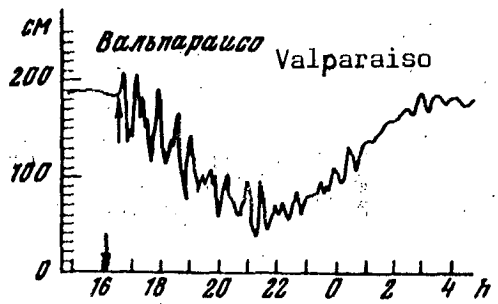


Fig. 38

The record of the tsunami of 6.IV.1943 (Bodle, 1945).

[4-5]. It was light at Tayabamba [4]. It was also light at Moyobamba and Tarapoto [3-4]; not everyone noticed it at Arequipa [3-4]; there were long period oscillations at Guayaquil [3]. Silgado gave the following direct estimates for some points: Trujillo, 4-5 degrees, Paita and Piura, 3-4 degrees. /107

Apparently, oscillations in the sea level developed. According to the Chief of the Hydrographic Service in Peru, E. Zimich, they were stronger [in the Huaura-Chankay region?] than those of 17.X.1966.

The source of the earthquake was located under the earth's crust. There were no aftershocks, or in any case, no strong ones (Lomnitz, Cabre, 1968; Silgado, 1968).

Gutenberg, Richter (1954): 24.V; $16^h33^m57^s$; 10.5° S., 77° W.; 60 km; M=8.

1942, August 24, 17:51. There was an earthquake with a pleistoseismic area of 18,000 km^2 between 14° and 16° S., in the boundary regions of the departments of Ica and Arequipa. The maximum intensity was estimated at 9 degrees; 30 people died and 25 were injured. It was felt with a force of 3-4 degrees or more on an area of 400,000 km^2, which included Huaras in the north, Serro de Pasco+ and Ojapampa in the northeast, Cuzco in the east and Mocegua in the south. It lasted more than a minute (according to other sources, up to 2 minutes).

At Nasca+, a third of the buildings collapsed completely. The settlements of Acari and Jaqui were left in ruins. Only modern buildings remained standing at Caravelli. Buildings suffered damage at Ica, Pisco, Chincha, Coracora, Huancapi, Chala and Arequipa. At Chala, some residents could not remain standing.

A number of avalanches occurred, which blocked the roads leading to the interior, especially near Puquio and in other places on the western slopes of the Andes, and also northwest of Cangallo settlement on the eastern slope. The rocky slopes of Calpa* Mountain in the Caravelli district cracked. A section of coast in San Juan Bay rose, as a result of which, a cutwater dried up to 1 m.

Many recurrent shocks were felt for 24 hours at Nasca+ and Lomas.

At Lomas, the sea retreated 200 m and then flooded the settlement, destroying moorages and customs warehouses. Several people were injured.

The tsunami was registered by the tide gauges at Matarani and Callao. At Matarani, the record began about 39 minutes after, and at Callao, 1 hour and 39 minutes after the earthquake. At Callao, the amplitude of oscillations was 1.6 m, the period 30 minutes; at Matarani, 0.5 m, and 21 minutes.

It was supposed that the tsunami was due to an underwater slide or avalanche, triggered by the earthquake (Bodle, 1944; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967; Silgado, 1968; Kelleher, 1972).

Gutenberg, Richter (1954): 24.VIII; $22^h50^m27^s$; 15° S., 76° W.; 60 km; M=8.1.

1943, April 6, 12:07. There was a strong earthquake with source 200 km to the north of Santiago. Combarbala, Ovalle, Illapel and Salamanca were largely destroyed. Heavy landslides occurred to the northwest of Illapel, blocking roads, in particular, the coastal highway and the highway from Illapel to the sea. A rock dump collapsed at the Kosinera mine near Ovalle. Five miners were killed. In all, 11 people died as a result of the earthquake. A building of the Ministry of Defense was damaged at Santiago. The earthquake was strong at La Serena. It was felt as far as Iquique, Valdivia and Buenos Aires, where crockery was broken in some high buildings and the ink spilled from inkwells. There were many aftershocks, some strong.

There was a small tsunami which damaged fishing boats at Los Vilos.

The tsunami arrived at the tide gauge at Valparaiso at 16:30, that is 22.3 minutes after the earthquake. The initial height of oscilla- tions was 80 cm, the average period about 40 minutes, and the duration of oscillations about 36 hours (Fig. 38).

The tsunami was registered in the Hawaiian Islands, California and Japan. At Honolulu, the amplitude of oscillations was 1 cm, the period 20 minutes. The amplitude of oscillations was 10 cm at Hanasaki+ (Hokkaido Island) and Shimosato (Wakayama Prefecture), 25 cm at Kushimoto /108
(Wakayama Prefecture) 30 cm at Nagasaki. The travel time to Kushimoto was 23 hours 25 minutes (SN, 1943, vol. 33, N 3; Bodle, 1945; Heck, 1947; Shepard et al., 1950; Anon., 1961; Berninghausen, 1962; Iida 1963 a; Greve, 1964; Ponyavin, 1965; Iida et al., 1967; Hatori, 1968; Lomnitz, 1970).

Gutenberg, Richter (1954): 6.IV; $16^h07^m15^s$; 30.75° S., 72° W.; M=7.9.

1948, December 26. There was an earthquake felt along the coast of Chile between 22° and 23°; it had an intensity of 7 degrees. At Antofagasta, the intensity was 5-6 degrees, at Copiapo 4 degrees. The earthquake was felt in a radius of 450 km. There was a tsunami at Tocopilla (ISS; SN, 1949, vol. 39, N 2).

[26.XII; $7^h12^m21^s$; 22.5° S., 69° W.; 100 km; M=7.]

1949, December 17, 11:06. There was a strong earthquake at Tierra del Fuego (Fig. 39). It was preceded by a shock at 2:50. At Punta Arenas the intensity was 7 degrees . The main damage was the collapse of the fire walls between wooden homes; there were no casualties.

Fig. 39

General map of Terra del Fuego.

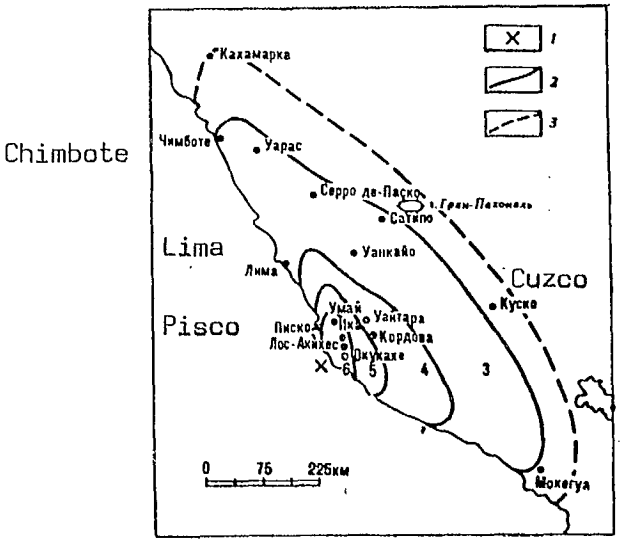


Fig. 40

Isoseists of the earthquake of 9.XII.1950 (Silgado, 1952).

1 - epicentre of the earthquake;

2 - isoseists;

3 - boundary of the area in which the earthquake was felt.

There were no reports of damage from the oil fields of Tierra del Fuego. About 30 recurrent shocks were felt on the first day.

Landslides and collapses occurred along the western coast of Tierra del Fuego, especially along the shores of Fagnano lake and the Belverde River*+ and at San Nicolas* in Admiralty Bay, 50 km south of Punta Arenas. At San Nicolas three men died in a saw mill destroyed in a long landslide. There were also jets of salt water from the ground here.

Tsunami waves of a local nature and unusually strong tidal currents were observed at Porvenir (Admiralty Bay), in the Zig Zag Strait near Gabriel Channel and at other places (SN, 1950, vol. 40, N 1; Rothé, 1953; Lomnitz, 1970). /109

Gutenberg, Richter (1954): 17.XII; $15^h07^m55^s$; 54° S., 71° W.; M=7.75.

[The description applies to closed basins. Apparently, it would be more correct to speak of strong seiches than of a tsunami.]

1950, December 9, 21:55.50. There was a strong earthquake felt on an area of 490,000 km^2, including Chimbote, Huaras and Cajamarca in the north, Serro de Pasco+, Satipo, the Gran Pajonal Mountains in the northeast, Cuzco in the east and Mocegua+ in the south. The strongest, approximately 6-degree tremors encompassed 900 km^2 (Fig. 40).

At ıdo La Vela* small cracks appeared in ploughed land, from which water issued for several hours after the earthquake. Landslides of loose material occurred here and there on mountainsides. One of them crossed the Ica-Cordova highway. The road was buried under a landslide coming down from the Cuya-Huasi Mountain on a 30 mile stretch near Huaytara Village. Similarly, near the Muchique district in Huaytara, an avalanche diverted the river channel.

Ica suffered most of all from the earthquake. Four residents died and 12 were injured. In the poor districts of this city, many adobe homes, especially those in poor condition, were destroyed by seismic oscillations. At the same time, at the center of the city, the overwhelming majority of adobe structures remained undamaged, and damage here amounted to the opening up of joints and the collapse of cornices and stucco. Reinforced concrete structures were completely unharmed. In a block building, built on filled land, the stairway block settled 1 1/2 cm. The walls of the cemetery partially collapsed.

At Achirana*+ and Los Aquijes, homes suffered light damage. On the farms situated along the road at Ocucaja, homes with reed walls withstood the earthquake well.

At the same time, on the Ocucaja estate, recently built brick homes suffered damage. In the wine cellar of the estate, a row of casts, oriented at 15° along the azimuth, shifted 10 cm here and there. The majority of adobe homes were seriously damaged at Huaytara. At Humay

many old homes, already damaged by the previous eathquakes, cracked. Slight collapses of the upper parts of buildings occurred at Pacarapa*+.

According to reports, the sea encroached 5 m inland at Pisco port. /110

In the 24 hours after the earthquake, nine new shocks were felt at Ica, including one strong one, and then for some time, including January 1951, several weak recurrent shocks were felt or registered at the Huancayo station (Silgado, 1952).

[10.XII; $2^h50^m39^s$; 14.6° S., 76.3° W.; 80 km; M=6.9.]

1953, February 15, 4:33. At Lima, a strong earthquake was felt lasting a little more than 15 seconds. The intensity of tremors (more than 5 degrees) and the accompanying rumble caused many residents to leave their homes. On the basis of the records of the accelerograph in Lima, the horizontal acceleration of the earth's surface was estimated at 25-30 cm/sec^2, vertical acceleration at 13 cm/sec^2, with periods of 0.07-0.10 seconds.

The force of tremors at other points was as follows: San Isidro 5 +; Matucana, Pachacamac, Mala, Limatambo 5; Chorillos, Chancay 4+; Ancon, Pucusana+, Santa Eulalia, Yauyos, Lachaci+ 4; Chincha Alta, Supe 3-4; Cañete 3; Chimbote 2. The earthquake was felt on an area of about 60,000 km^2.

At Chancay, according to a report by one of the seismic correspondents, the sea receded (Silgado, 1957 a).

(BCIS): $9^h32^m25^s$; 12° S., 77.5° W.

1953, December 12, 12:31. There was a destructive earthquake in the northwest regions of Peru and the southern regions of Ecuador. It was felt on an area of about 700,000 km^2 (Fig. 41).

The zone of major destruction occupied an area of 5000 km^2. Here cracks up to 50 m long appeared in the swampy grounds. Mud and water fountains gushed up in different places. Small landslides came down. Modern reinforced concrete buildings were damaged; some brick and many adobe homes were destroyed. The superhighway cracked. The earthquake lasted 30-40 seconds. Six people died at Tumbes and Corrales and 20 were injured. It was difficult to remain on one's feet (7-8 degrees). The earthquake caused dizziness far from the epicenter (Silgado, 1957 a, b; ISS).

A tsunami developed with an amplitude of 1 m (3 feet) at Talara and 0.2 m (0.7 feet) at La Libertad (Ecuador) (Murphy, Cloud, 1955; Iida et al., 1967).

[$17^h31^m25^s$; 3.4° S., 80.6° W.; M=7.3.]

1955, April 19. There was an earthquake in central Chile with

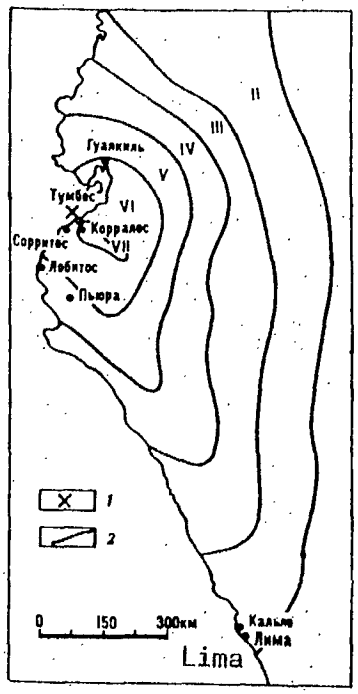


Fig. 41

Isoseists of the earthquake of 12.XII.1953 on the 12 point scale (Silgado, 1957b).
1 - epicentre of the earthquake
2 - isoseists

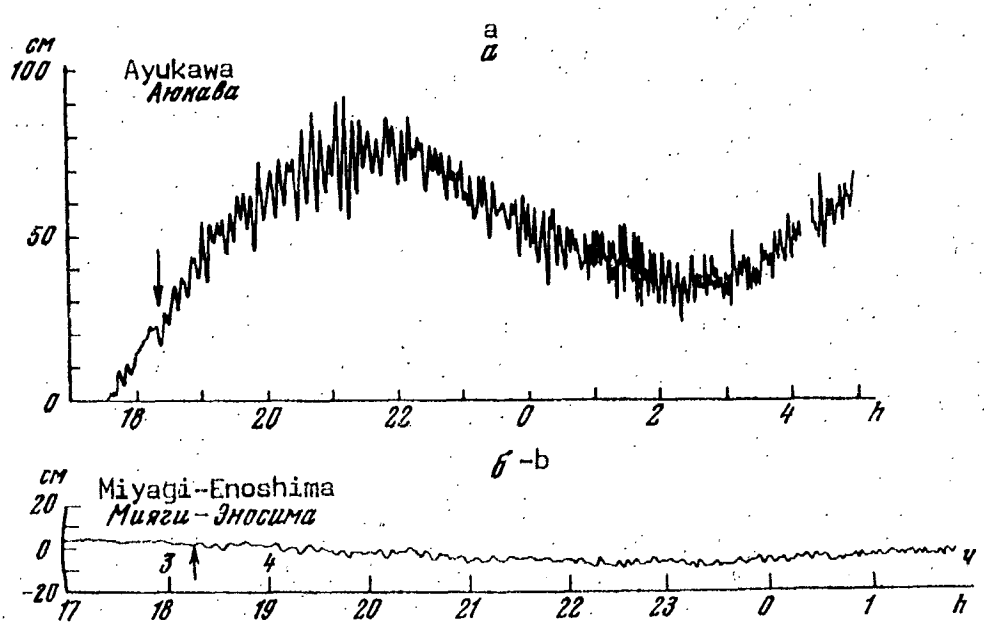


Fig. 42

Records of the tsunami of 20.XI.1960 by a tide gauge of the usual type (Hatori, 1968), (a) and by a tide gauge of the Van Dorn System (Hatori, 1968), (b).

aftershocks. It was felt as far as Buenos Aires. On the coast between 26° and 32°, its intensity was 5-6 degrees.

A tsunami occurred. At Coquimbo, the lower districts of the city were flooded. The water advanced 100 m at Tongoi, and 170 m at La Serena. The rise of water reached 1 m (3 feet) adove the usual flood tide level at Coquimbo, La Serena and Tongoi. At the latter two points, there was some damage; one person died; the crop was damaged at La Serena. It is possible that the tsunami was observed in the Arica Region with an amplitude of 0.5 m (SN, 1955, vol. 45, N 3; Murphy, Cloud, 1957; Rothé, 1956; Berninghausen, 1962; Greve, 1964; Ponyavin, 1965; Hamamatsu, 1966; Iida et al., 1967).

[19.IV; $20^h24^m05^s$; 29.9° S., 71.6° W.; M=7.0.]

1958, April 9. The earthquake caused a tidal wave which fell on /111
the coast of Peru. Some of the residential districts of Callao were flooded with water to a depth of almost 1/2 m (2 feet) (SN, 1958, vol. 48, N 3).

In "Seismological notes" (SN, 1958, vol. 48, N 4) it is explained that the above report was published in the newspapers in Lima on April 9. Later, the Peruvian seismologist, E. Silgado reported that in fact, it was not a tsunami which took place on April 9 in Callao, but a high sea, which coincided with the onset of high tide, as a result of which some of the residential districts of the city were flooded. By coincidence on the same day at 9:33:15, the station at Huancayo registered a shock with an epicenter 230 km from the station, which was felt in Lima with a force of 3 degrees.

1959, February 7, 4:38. There was a strong earthquake on the northwest coast of Peru, between Tumbes amd Chiclayo. At Talara, light damage to several concrete homes (6 degrees). Underground rumbling and strong tremors frightened the residents at Tumbes, Paita, Piura, Talara, Sulyan+, Chulucanas and Chiclayo. Some families abandoned their homes, despite the early hour. It was felt very strongly at Guayaquil (SN, 1959, vol. 49, N 3; Silgado, 1968).

Traces of the tsunami were found on the tide gauge record at Talara (Eppley, Cloud, 1961; Berninghausen, 1962).

Iida's catalogue (Iida et al., 1967) notes that oscillations in level at Talara with a period of 22 minutes and an amplitude of 20 cm began an hour before the earthquake, and expresses doubt as to the actuality of the tsunami.

[7.II; $9^h36^m51^s$; 4° S., 81 1/2° W.; M=7.1.]

1960, January 13, 10:40. There was a destructive earthquake in the Arequipa Department. Of the 63 people killed and 200 injured, 30 died at Chuquibamba, which was almost totally destroyed. Caravelli, Cotahuasi, Omate, Puquina, Mocegua+, Arequipa, Tyabaya+, Tingo-

Maria*, Sabandia+ and Aplayo also suffered. The mines in the Acari region were destroyed. Many roads were blocked by avalanches. There was slight damage at Mollendo. There were strong tremors at Cuzco. The earthquake was felt in a radius of 750 km. At Lima 3 degrees, at La Paz 3-4 degrees, near Antofagasta 2 degrees. It lasted up to 50 seconds (Silgado, 1968).

A tidal wave fell on the Pacific resort of Ancon. The spray almost reached the top of the ten-story homes, standing on the embankment (SN, 1960, vol. 50, N 2; Rothé, 1962).

[13.1; $15^h40^m34^s$; 15.75° S., 72.75° W.; 130-200 km; M=7.8.]

[That the wave was connected with the earthquake is doubtful.]

1960, May 22, 15:12. There was a catastrophic earthquake and tsunami with source in the southern part of Central Chile. The maximal rise of water was 25(?) m in Chile, 10 1/2 m on the Hawaiian Islands, 6-9 m in Oceania, 6 1/2 m in Japan and the USSR, 3 1/2 m in the USA, 3(?) m in the Aleutian Islands, 2 m in New Zealand, and 1-1 1/2 at other places in the Pacific. About 1000 people died in Chile, 60 people on the Hawaiian Islands, and 200 in Japan. A strong preliminary earthquake occurred on May 21 at 6:00; it was accompanied by a mild tsunami. No detailed description of these events is given here. One can find brief notes on the tsunami in Iida et al.'s catalogue (Iida et al., 1967).

196., November 20, 17:02. There was an earthquake in northwest Peru, felt by a large number of residents.

Several hours later, a tsunami fell on the coast of Lambayeque Department. The first wave about 9 m high did material damage at Puerto Eten and Pimentel ports and in Santa Rosa and San Jose Bays; three persons died. The Lobos de Afuera Islands were completely devastated. The first wave was followed by two others of smaller size (Silgado, 1968).

According to other sources, the Guañape+ Islands also suffered; 13 people died, 50 disappeared, 2 were seriously injured, and more than 800 were left homeless. The losses were estimated at more than 550,000 dollars (SN, 1961, vol. 51, N 2; Lotze, 1961; Rothé, 1962; Talley, Cloud, 1962; Hamamatsu, 1966).

The tsunami was registered at the following tide gauge stations: /112
Talara with an amplitude of 10 cm, Chimbote - 70 cm, Callao - 50 cm, Matarani - 10 cm, Hilo - 10 cm, with a 14-minute period.

According to Hatori, it was registered by some tide gauges in Japan (Fig. 42 a,b; Table 8). (SN, 1961; vol. 51, N 2; Talley, Cloud, 1962; Iida et al., 1967; Hatori, 1968).

[20.XI; $22^h02^m01^s$; 6.9° S., 80.8° W.; M=6.7.]

1966, October 17, 16:42. There was an earthquake in Peru,

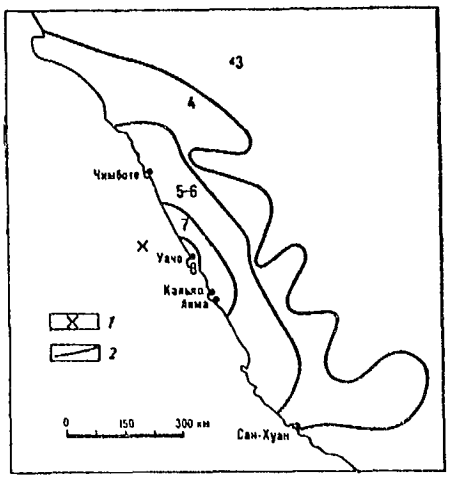


Fig. 43

Isoseists of the earthquake of 17.X.1966 (Lomnitz, Cabre, 1968)
1 - epicentre of the earthquake
2 - isoseists

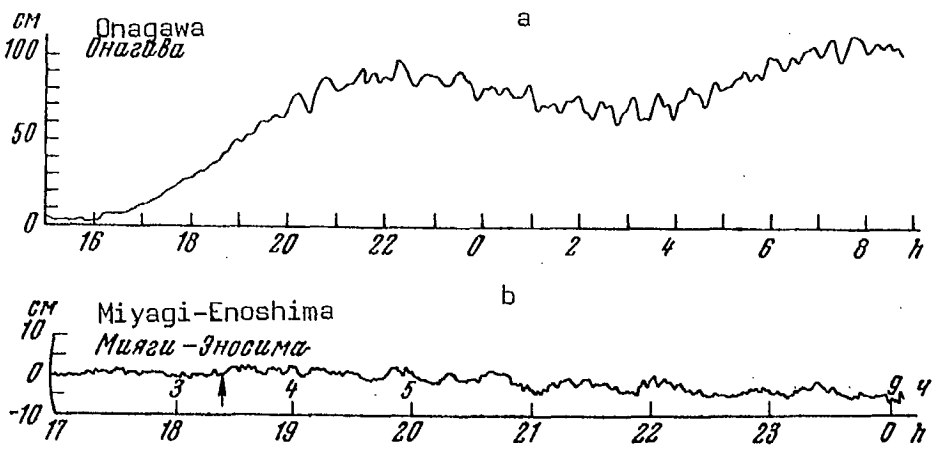


Fig. 44

Records of the tsunami of 17.X.1966 by a tide gauge of the usual type (Hatori, 1968), (a) and by a tide gauge of the Van Dorn System (Hatori, 1968), (b).

causing destruction in the coastal zone approximately between 10° and 13° S. (Fig. 43). One hundred and ten people died and 3000 were injured; damage amounted to 35 million dollars. The area of damage had a length of about 400 km and a width of less than 50 km. The port city of Huacho, the nearby villages of Huaura and San Nicolas (3 km south of Supe) and also the village of Puente Piedra+, situated in a swamp (a filled in lake) in the vicinity of Lima, suffered especially. Here all homes were destroyed or damaged; the ground cracked.

The accelerograph at Lima registered a peak horizontal acceleration of 0.4 g in unusually high-frequency oscillations of 5-10 Hz. The destruction along the coast and at Lima was "spotty," being mainly confined /113
to places with alluvial soils. Besides flimsy structures (adobe structures and those damaged by the preceding shocks), some brick and concrete structures including a two-storey school not designed for short-period effects also suffered. Flexible structures withstood the shocks well.

The collapses of sand dunes near Pasamayo+ put the Panamerican superhighway out of service. A quartz deformograph at Naña+ registered a permanent shift in the earth's surface.

A strong seaquake was felt on the ships at sea. The earthquake was accompanied by a series of aftershocks, which arose rapidly one after another (SN, 1967, vol. 57, N 2; Lemke et al., 1968).

A t ami occurred. A slow rise in level began at Callao (at La Punta) at 1[illegible]32. The oscillations in level had a period of 15 minutes. The greatest, the seventh wave, with a height of 3.5 m (the difference in the level between the crest and the trough) arrived at 19:40. The water was estimated to have risen 2.1 m. At approximately the same time, a wave up to 3 m high partially flooded Chiquito*+, Huara, the Buenos Aires* resort at Trujillo, and possibly Ancon and Huacho.

Among the settlements which suffered most were: Tortuga+, where the range of oscillations surpassed 6 m, and where the majority of structures in the area of the square were washed away; Puerto-Chimu*+, Culebras+ and Casma, where many fish canning factories were seriously damaged and the pier was broken in pieces. Ninety percent of the homes were damaged in the Huarmey region. It must be noted that Tortuga Bay and Casma Bay have a funnel-like shape, which tended to intensify the tsunami. In addition, Casma is situated in lowlands and is easily flooded when the sea level rises. The damage was estimated at 2 million dollars (40 million sols) at Casma.

At all points on the Peruvian coast, the tsunami began with a crest. Within Peru, it was registered distinctly by the tide gauges at Chimbote and San Juan. According to the data of the Hydrographic Service of the country, the parameters of the tsunami were as follows (Table 9).

Outside Peru, the tsunami was registered by many tide gauges, especially in the eastern and central parts of the Pacific Ocean (Table 10). There were only slight traces of the tsunami on the records of the /116

Table 8

Tide gauge data on the tsunami of 20.XI.1960.

Point of observation	Travel time hr	Travel time min	Maximum range of oscillations in level, cm
Kushiro	19	52	16
Hakodate	20	21	15
Hachinohe	20	14	25
Ayukawa+	20	21	34
Onahama	20	29	18

Table 9

Data of Peruvian tide gauges on the tsunami of 17.X.1966.

Observation Point	Time of arrival hr	Time of arrival min	Maximum range of oscillations in level, m	Maximum height of rise of water above mean sea level, m
La Punta (Callao)	22	32	3.5	2.0
Chimbote	22	48	2.2	1.0
San Juan	22	58	-	-

Table 10

Tide gauge data on the tsunami of 17.X.1966.

Observation point	time of arrival day	h	m	period (from first to second crest) min	First wave Initial rise (crest), cm
Avila	–			–	–
San Francisco	–			–	–
Crescent City	18	09	45	15	6
Alaska					
Sitka	–			–	–
Snug Harbor	18	18	30	–	–
Kodiak	–			–	–
Aleutian Islands					
Adak Island	–			–	–
Attu Island	–			–	–
Hawaiian Islands					
Hilo	18	10	00	16	6
Kahului	18	10	19	21	12
Honolulu	18	10	30	36	3
Nawiliwili	–			–	–
Wake Island	–			–	–
Guam Island	–			–	–
Samoa Islands, Pago Pago	–			–	–
Chile					
Lebu	18	01	53	12	15
Talcahuano	18	02	46	9	18
Valparaiso	18	01	17	8	12
Caldera	18	00	37	18	18
Antofagasta	18	00	04	18	6
Peru					
Matarani	–			–	–
San Juan	17	22	54	19	27
Callao	17	22	33	15	58
Chimbote	17	22	50	8	67
Talara	–			–	–
Galapagos Islands	–			–	–
USA					
San Diego	18	07	49	33	3
Newport Bay	–			–	–
Long Beach	–			–	–
Los Angeles, pier 60	–			–	–
Rincon Island*	–			–	–

Subsequent fall (trough), cm	time of beginning day	h	m	maximal rise or fall in level rise or fall	duration min	height cm
–	18	17	34	fall	10	12
–		–		–	–	3
6	18	19	36	fall	7	27
–		–		–	–	12
–		–		–	–	12
–		–		–	–	12
–	19	05	16	fall	10	12
–		–		–	–	12
18	18	18	21	rise	7	27
24	18	17	37	rise	10	39
3	18	23	24	fall	7	9
–	18	16	24	fall	7	12
–		–		–	–	6
–		–		–	–	3
–	18	16	32	fall	11	21
30	18	02	09	rise	6	33
36	18	04	35	fall	7	58
15	18	03	39	rise	3	39
30	18	01	14	fall	7	45
6	18	04	10	rise	8	18
–	17	02	45	rise	3	39
48	18	03	41	fall	8	70
106	18	01	21	fall	8	230+
82	18	03	56	rise	8	102
–		–		–	–	9
–	18	06	13	fall	4	30
3	18	18	41	fall	15	9
–		–		–	–	3
–		–		–	–	15
–		–		–	–	6
–		–		–	–	9

instruments at Arica, La Libertad (Ecuador), and Avila. In Japan, according to Hatori, the tsunami was registered by some tide gauges as shown in Table 11 and on Fig. 44 a,b, (Berkman, Carrier, 1967; Esteva et al., 1967; Iida et al., 1967; Hatori, 1968; Lomnitz, Cabre, 1968; Pararas-Carayannis, 1968; Anon., 1970 a; Tokunaga, Katsumata, 1971; Kelleher, 1972).

[17.X; $21^h41^m56^s$; 10.7° S., 78.8° W.; 40 km; M=8.1.]

Table 11

Data of Japanese tide gauges on the tsunami of 17.X.1966.

Observation point	Travel Time hr	min	Maximum range of oscillations in level, cm.
Kushiro	20	18	16
Urakawa	20	30	14
Hakodate	20	38	18
Hachinohe	20	20	38
Onagawa+	20	48	18
Onahama+	20	58	18
Mera+	20	48	13
Owase	21	08	18
Kushimoto	21	18	14
Tosashimizu	21	28	20
Aburatsu	21	30	10
Ofunato	-	-	24
Shionomisaki	-	-	16

1966, December 28, 4:18. There was an earthquake in the north of Chile, which did substantial material damage in the Taltal region; three people died and at least six were injured. A tsunami arose. At Caldera the oscillations in sea level had a range of 84 cm; at Antofagasta, 45 cm; at Arica, 30 cm; at Matarani, Chimbote, on the Easter and Wake Islands, 10 cm; at San Juan (Peru) and on the Galapagos Islands, 20 cm; at Kahului and Hilo, 30 cm (SN, 1967, vol. 57, N 3; Iida et al., 1967; Lemke et al., 1968; Anon., 1970 a).

[28.XII; $08^h18^m07^s$; 25.5° S., 70.6° W.; 47 km; M=8.0.]

1967, September 3. There was an earthquake in Peru, felt at

Lima. The tsunami was registered at La Punta at 22:00 with a height of 30 cm and at Chimbote (Iida et al., 1967; Anon., 1970 b).

(USCGS): $21^h07^m31^s$; 10.6° S., 79.8° W.; 38 km; M=6.9.

1967, December 4, 18:40. There was an underwater eruption in Telephone Bay on Decepcion Island (Antarctic), during which the water in Pendulum Cove* began to boil and churn. The oscillations in level had a period of 2-3 minutes and an amplitude of 1/2-1 m (Smithsonian Institution, Center for Short-lived Phenomena, Event Information Reports No. 222-225, November 12, 1968).

[4.XII; $19^h00^m23^s$; 63.0° S., 60.5° W.; 33 km; M=4.7.]

1967, December 20, 22:25. There was an earthquake in Northern Chile. Tocopilla was 20% destroyed. Later, vessels in port collided three times due to the unusually strong waves (NL, 1969, Vol. II, No. 1).

[21.XII; $02^h25^m23^s$; 21.7° S., 69.5° W.; 33 km; M=7.5.]

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NORTHERN ECUADOR, COLOMBIA, PANAMA

1827, November 16. In his account of the destructive earthquake in Colombia, Sieberg (1932) mentions a flood at Magdalena and the valley of the Cauca River. According to other sources (Mallet, 1853; Ramirez, 1969), these floods were only due to overflows of the Magdalena and Cauca Rivers, and were not caused by a tsunami (see Fig. 18, 48).

1868, August 16. Some Japanese sources (for example, Takahasi, 1951) mention that on this day a small tsunami was noticed on all the Ryukyu Islands, and surmise that it was caused by the earthquake in Ecuador, or by one of the aftershocks of the Arica earthquake of 13.VIII.1868.

A catastrophic earthquake in Ecuador and southwestern Colombia occurred on the 16th at 1:15. The cities of Otavalo, Catocachi, Ibarra, Atuntaqui [situated 10 km west of Ibarra] and San Pablo* were destroyed. An estimated 40,000 people died in Ecuador and 30,000 in Colombia. The source of the earthquake was apparently situated 100 km (60 miles) east of Quito, in the region of the western spurs of the Andes, that is, quite far from the coast (Fuchs, 1869, 1885 b; Milne, 1912 b; Ramirez, 1969).

[There are no data at all on the occurrence of the tsunami off the coast of Ecuador, Colombia or Peru or in the central part of the Pacific. ;t likely it was a reflection of the Arica tsunami.]

1877, October 11, 9:00. The steamship "Paita" in Esmeraldas Port was torn from its anchors by a sudden storm and was almost lost. Simultaneously, a similar phenomenon was observed at Buenaventura Port, where it was accompanied by an earthquake (Goll, 1903).

1882, September 7, about 3:00. There was an earthquake at Panama, stronger than any previously known. Undulating oscillations lasted 40-45 seconds; their intensity gradually increased, and then just as gradually decreased. All homes in the capital were more or less destroyed. Thick walls cracked, and some collapsed. Heavy tiles fell down from roofs and the streets were full of rubble. The cathedral was heavily damaged; a crack appeared from top to bottom in the facade; the bell towers collapsed; one of the naves was completely destroyed; the roof sagged dangerously. At the town hall, the facade collapsed and people were killed. The Panama-Colon Railway was damaged. The underwater cable to Jamaica was broken. A loud underground rumbling was heard at Gamboa. Barbacoas Port* on the Chagres River†, Gatun, Chagres†, Cruses[1] and other settlements in the interior as far as Colon, suffered damage. At Colon (Aspinwall), the railway depot was destroyed; cracks appeared in the ground; there were dead and injured.

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1 [Vicinity of the modern city of Gamboa.]

In Venezuela, at Riosucio in the valley of the Atrato River, sand and mud volcanoes appeared. A thermal spring appeared on one of the streets at Turbo and almost flooded the city. The populace of these cities fled their homes in panic. The earthquake extended to San Juan del Norte (Nicaragua), Guayaquil (Ecuador), Maracaibo and Caracas (Venezuela), that is, it was felt along the entire northwestern coast of South America.

It was accompanied by numerous aftershocks (Fuchs, 1883 b, 1885 b; /119
Montessus de Ballore, 1888; Milne, 1912 b; Ramirez, 1933, 1969).

Fuchs adds that the earthquake was felt strongly on the islands in the Gulf of Panama. According to Montessus de Ballore and Ramirez, the "Honduras", situated in a road 3 1/2 km (2 miles) from Panama, felt a seaquake, preceded by a rumbling. Although no visible waves appeared on the surface, the sea began to move rapidly. The vessel began to move, as if at full speed, and ran aground on a pebble bed.

Sieberg (1932), in giving the basic data on the earthquake, reports that it was accompanied by tsunami waves which were observed from Panama to Guayaquil [source of information unknown].

Iida (Iida et al., 1967) surmises, without much evidence, that two earthquakes occurred: one in Panama and Nicaragua, the other in Colombia.

1884, November, on the night of the 5th-6th. There was a destructive earthquake on the Panama Isthmus. It was felt at a number of cities in Colombia, in particular, a church was damaged at Cali. In Panama, Acada* [Acandi?] and Paconia* suffered especially. There, a seismic wave [it is not clear whether this was an earthquake or a tsunami] destroyed churches, state buildings and private homes (Fuchs, 1885 b, 1887 a; Milne, 1912 b; Sieberg, 1932; Ramirez, 1933; Iida et al., 1967).

1904, January 20, 9:17. There was an earthquake with an intensity of up to 4 degrees (V on R.F. scale) at Panama and Costa Rica. It was felt all over in both countries, but there was no damage. On the 21st, the ship "City of Panama" at 20° N., 110° W., encountered floating trees and animal corpses - possibly the result of the seismic catastrophe on the 20th (Oddone, 1907).

Gutenberg, Richter (1954): 20.I; $14^h52.1^m$; 7° N., 79° W.; M=7.75.

1906, January 31, 10:30. There was a catastrophic earthquake and strong tsunami with source off the coast of Ecuador and Colombia.

The earthquake was preceded by several less severe shocks. At Guapi, two shocks were recorded: at approximately 7:00 and 9:00 on the 31st. The second was stronger and was felt as far as Guayaquil and Quito, although this shock was not noticed at Manta. The low-sensitivity Omori-Bosch seismograph at Quito registered the onset of seismic waves at

9:02, 9:08, 9:25 and 9:40; the second onset was so strong that the pen of the seismograph jumped from the drum. The shock at 9:00 damaged some structures at Esmeraldas and vicinity; all unsecured objects were overturned or shifted.

The following eyewitness accounts give a picture of the main earthquake and the tsunami. At the time of the earthquake, a resident of Tumaco was standing outside his home on the street talking to a neighbour. Suddenly, very strong oscillations began and everybody fell to the ground (according to other sources, the intensity of the oscillations gradually increased). The entire island on which the city is situated appeared to move, and houses rose and fell like ships on an furious sea. It was impossible to move. The witness tried to make for home several times, but was not able to take a single step. His wife was in a room on the second floor. She was thrown to the floor by the first oscillations. After many unsuccessful attempts, she was able to make it to the stairs and get outside. Five minutes later, the oscillations, which had been accompanied by a deafening rumble, died down. Everything was topsy curvy inside the home, the plaster had fallen off, but the house remained standing. The same occurred in all the other homes in the city. Only four wooden homes and several bamboo huts collapsed. Had the city not been built up exclusively of wooden homes, it evidently would have been left entirely in ruins.

Another eyewitness was on Pindo* Island, south of Tumaco. When he got ready to sail back, the earthquake began. The huts of the fishermen and the coco palms swayed in every direction; nuts fell; cracks opened /120
and closed on the sandy beach. The oscillations ceased in 3-4 minutes. The witness made it to his boat and returned to the city, where panic already reigned.

Half an hour after the earthquake, a tidal wave fell on the city. It was 2 1/2 m high (according to other sources, 5 m). It would have been larger had the city not been screened from the sea by two small islands which softened the force of the wave, but one of the islands was half washed away. The wave submerged part of the city and washed away several moorages and homes in the port. There were no casualties. Had it not been ebb tide, the destruction would have been much worse. A second tidal wave followed in 20 minutes, and then a third. Large waves were observed for 4 hours at Tumaco, and flood and ebb tides were supposedly irregular for two weeks.

The earthquake was felt with approximately the same intensity as at Tumaco from Esmeraldas to Micay (Fig. 45). Thirty homes collapsed at Esmeraldas; heavy damage occurred at Limones+, where two people died and many were injured. Homes collapsed at Rioverde. The ground cracked on Cape Manglares, and water gushed forth. At Guapi, some of the homes collapsed and the ruins caught fire.

The earthquake was felt with somewhat lesser intensity in the zone /121
from Otavalo to Buenaventura (see Fig. 45, 8-degree zone). Here only large stone structures like churches were damaged. About 200 km from

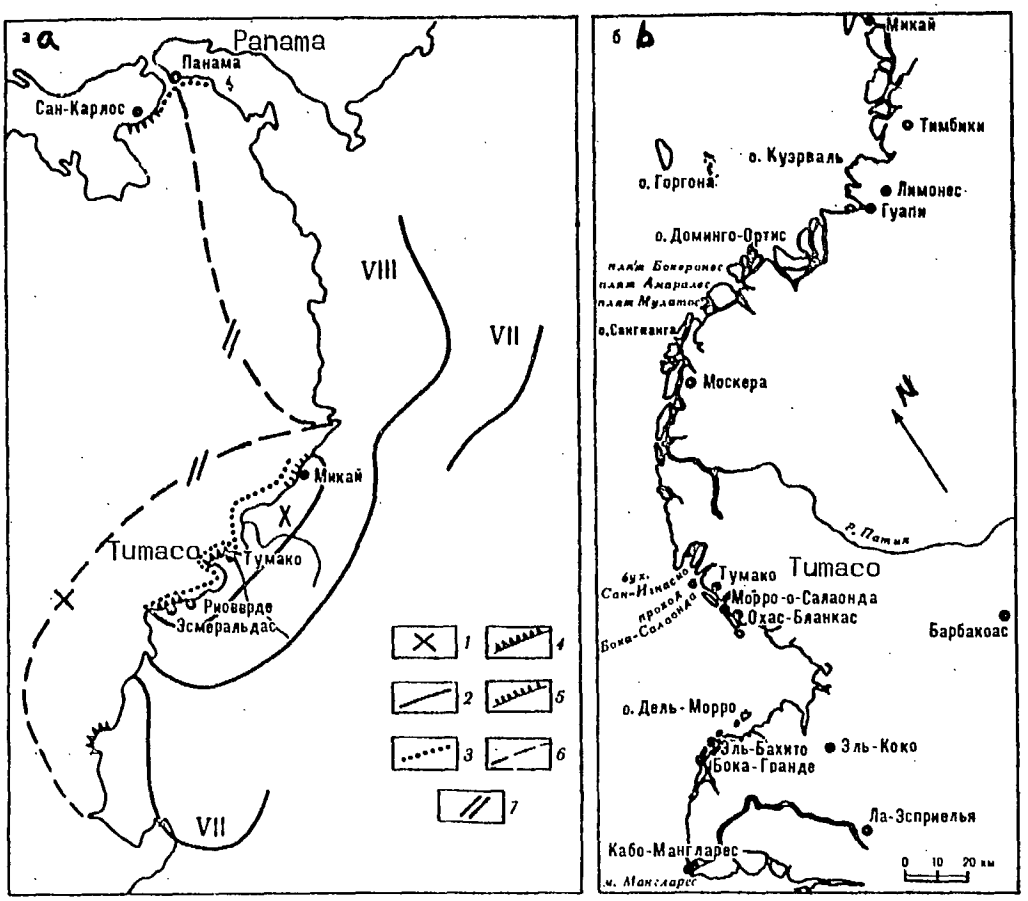

Fig. 45

A sketch of the earthquake and tsunami of 31.I.1906 according to Sieberg (Sieberg, 1932), (a) and a map of populated points, (b).

1 - instrumental epicentre;
2 - isoseists (the force of the shocks are shown on the Rossi-Forell scale);
3 - places where the tsunami appeared;
4 - sections of the coast which lifted;
5 - sections of the coast which sank;
6 - undersea cables;
7 - places where cables were broken.

Buenaventura, two underwater cables were broken at 18 places. In the 7-degree zone, shown in Fig. 45, the earthquake was strong, but did not cause any destruction or damage. Beyond the 7-degree zone, it occurred as mild long-period oscillations. Recurrent shocks were felt at least until the end of March. The aftershock of February 2 was especially strong.

The tsunami was most destructive on the low-lying coast from Rioverde to Micay. Here all homes on the coast or in the estuarine parts of rivers were washed away; by various estimates 500 to 1500 persons died.

Among the settlements which suffered most were Cabo Manglares, Trujillo, Boca Grande, El Bajito+, Domingo Ortiz, El Piñal*+, Chilbi*+, Salahonda and Morro-o-Salahonda (4)[1], Hojas Blancas (10), San Ignacio (22), San Juan* (149), Caballos*+ (8), Gulecama* (11), Timbiqui (53), Sangianga (12), Mulatos (64), Amarales (83), Boquerones (48), La Candelaria*, El Coco* and other settlements in the region of Micay (100), Cuerval+, Quiroga (32), Cansara*+ (2), Mosquera+ (2), and Varela (9).

The sea was calm before the earthquake at Manglares Cape. After the earthquake, a foaming roller fell onshore like a gigantic torpedo. Heavy flooding was observed in the valleys of the Mira and Patia Rivers. Along the Patia River and its tributary, the wave reached Barbacoas, where it destroyed 30 homes. Twenty-three homes were destroyed at the coastal village of La Tola.

At Guapi, situated on the banks of the river, 20 km from its mouth, a second wave reached the tops of the tallest trees and destroyed 49 homes. All vegetation was destroyed on the coast. The arrival of the tsunami (before 11:30) was accompanied by a loud rumbling. At Sangianga, of 400 homes situated on the coast, only three remained. A little more than an hour after six waves had rolled onshore with gradually diminishing amplitude, the sea level began to return to normal. Strong oscillations ceased by 22:00. Weak ones continued long after, and flood tides were irregular until February 4.

The second tidal wave damaged Buenaventura.

At Esmeraldas, the river left its banks after the earthquake and flooded the low-lying regions of the city. Another six tidal waves with gradually diminishing height were recorded during the day.

At Bahia de Caraques at 12:10, 2 hours before the onset of the usual ebb tide, the sea level rose 80-100 cm in 20 minutes, and with such a head that a vessel here was smashed on the cliffs at the throat of the bay. The flood and ebb tides recurred, slowly abating, three times before 21:00.

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[1] The figures in brackets indicate the number of residents killed.

No oscillations in the level were noted at Manta. A tidal wave appeared at noon at Guayaquil.

There are reports that after the earthquake and tsunami, some changes in coastal relief took place in the vicinity of the source. The roadsteads at Manta, Esmeraldas, Tumaco and Buenaventura shallowed by almost 2 m (1 fathom). In the Micay region, by contrast, the road deepened. Changes were observed in the channel of the Esmeraldas River. Some of these changes may have resulted from the redeposition of loose material by the tsunami waves, some from residual deformations of the earth's surface.

The tsunami was observed along the entire coast of Central America, in Mexico and California.

The wave reached Panama at 17:50. The amplitude of oscillations in level were twice those of regular tidal oscillations. At San Carlos the sea retreated, exposing a large beach. The tsunami was clearly registered by the tide gauge on Naos Island+, situated 5 km to the south of Panama (Fig. 46). The oscillations began with a distinct positive head wave with a period of about 1 hour and an amplitude of 70 cm. Subsequent oscillations were weaker. With the arrival of the tsunami, the water around the island became turbid. By 4:00 on February 1, the amplitude of oscillations in the sea level decreased to 2 cm. Slight oscillations were traced until 15:00. /122

A tsunami occurred on the Pacific coast of Costa Rica about 14:00. A beach 2 km long dried up in Potrero Bay; then the water rushed onshore, tossing up boats.

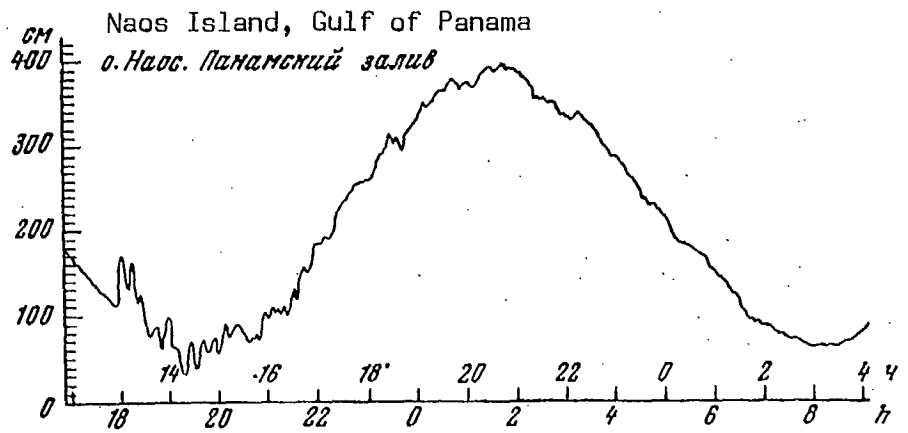

Fig. 46

Record of the tsunami of 31.I.1906 by a nearby tide gauge (Ammon, 1907).

The tsunami arrived at San Diego (USA) at ebb tide. The succession of the ebb current by a flood current occurred so suddenly that it was noticed immediately by sailors and fishermen on shore. All the ships and boats were turned around 180°. The tsunami had an amplitude of about 5 cm on the tide gauge register at San Diego (Fig. 47 a). The wave was recorded at San Francisco.

At Hilo (Hawaiian Islands), the tsunami arrived approximately 12.5 hours after the earthquake; the range of oscillations in water level was 3.6 m (12 feet), the period 30 minutes. The channels of the Wailuku and Wailoa+ Rivers alternatively dried up, then disappeared under the tidal wave.

At Kahului there were three waves, arriving at 20 minute intervals. The second wave was larger than the first, while the third was larger than the second. The water rose about 30 cm above the mean level mark. According to other sources, the water surface rose to the level of the old steamship pier and the road running along the coast.

The tide gauge at Honolulu began to register oscillations about 12 hours after the earthquake (see Fig. 47 a). The tsunami apparently began with a tidal wave; then the oscillations intensified, and the fourth wave, which was the greatest, had a height of 25 cm. The period of oscillations was 20-30 minutes. Three separate trains of oscillations were registered.

Ac ›rding to the accounts of witnesses, disturbances in level on Honolulu Bay began to be observed at 3:30 on the 1st. At 4:15, there was an extremely great ebb. All the steam and sailboats in the bay were turned around. Then a sudden flood tide reached a considerable height.

Nineteen and a half hours after the earthquake, the tsunami reached the coast of Japan, where it was registered by tide gauges at Hakodate, Ayukawa, Kushimoto, Hosojima, Nagasaki and Fukahori*+ (see Fig. 47 b). According to Hatori, the parameters of the tsunami were as follows (Table 12).

Strong seiches were generated on the northern (Atlantic) coast of Colombia (Anon., 1907; Honda et al., 1908 a,b; Scheu, 1911; Rudolph, Szirtes, 1911; Kawasaki, 1930; Sieberg, 1932; Heck, 1934, 1947; Gutenberg, Richter, 1949, 1954; Shepard et al., 1950; Anon., 1961; Berninghausen, 1962; Ponyavin, 1965; Iida et al., 1967; Hatori, 1968; Ramirez, 1969; Silgado, 1974).

Gutenberg, Richter (1954): 31.I; 15^h36^m0; 1° N., 81 1/2° W.; M=8.6.

1906, February 7. Oscillations in sea level resumed on the coast near the Colombia - Ecuador border as a result of the earthquake (Scheu, 1911).

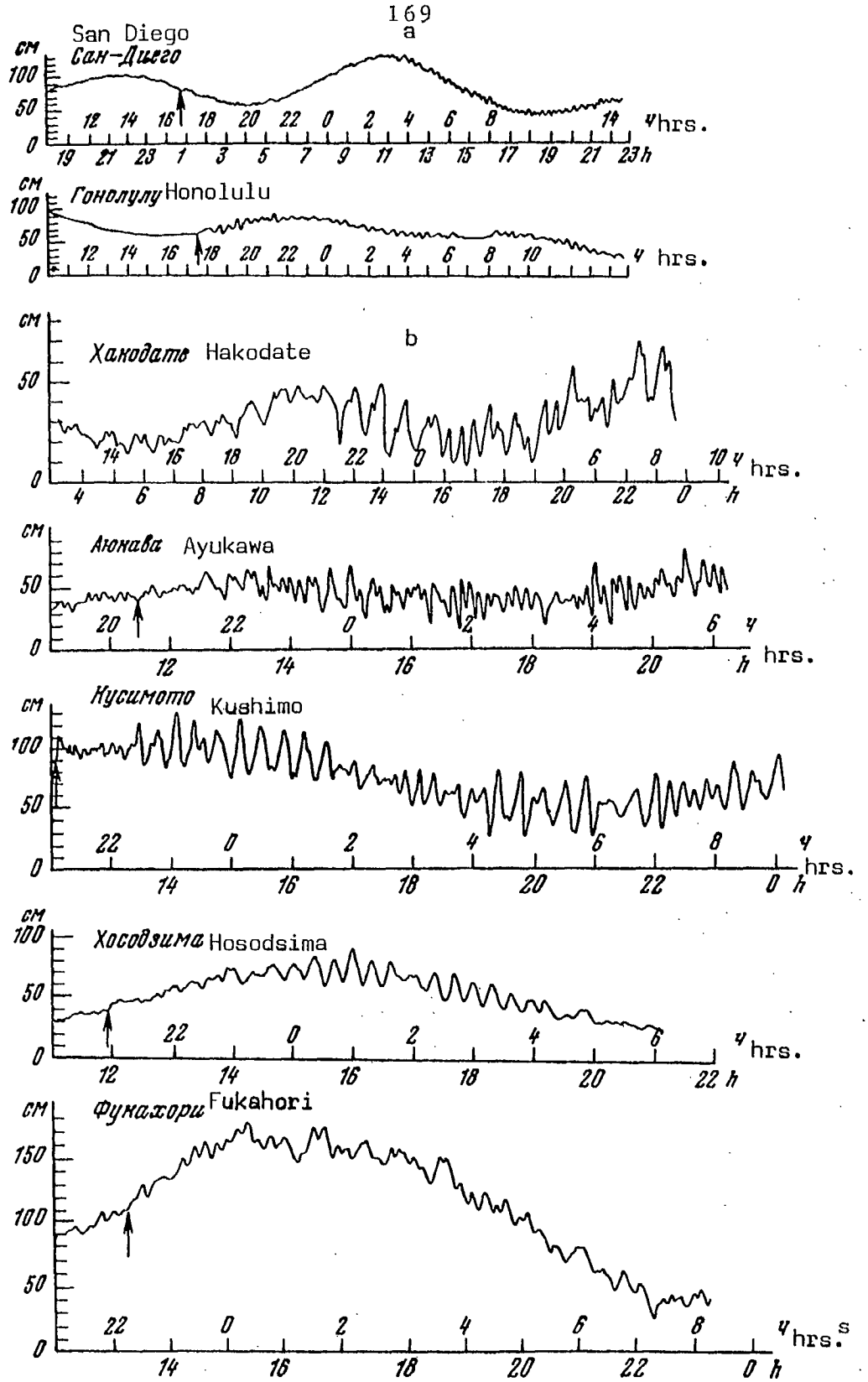

Fig. 47

Records of the tsunami of 31.I.1906, by tide gauges in USA (Honda et al, 1908a) (a) and by tide gauges in Japan (Honda et al, 1908a, b) (b).

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Table 12.

Tide gauge data on the tsunami of 31.I.1906.

Observation point	Travel time hr.	min.	Maximum range of oscillations in level, cm
Hakodate	19	24	34
Ayukawa+	19	48	36
Kushimoto	20	27	48
Hosojima	20	18	30
Nagasaki	21	33	28

1916, January 31. A tide gauge in the Panama Canal zone registered a strange change in level. One can surmise rather confidently that it was due to displacements on the bottom, very likely along a supposed fault running along the coast of the Pacific Ocean (Kirkpatrick, 1920).

1942, May 22. There was an earthquake felt in Colombia in the region of Buenaventura Gulf. According to press reports, soon after the earthquake, Gorgona Island in Buenaventura Gulf was flooded by an enormous wave. However, the record of the tide gauge set up in this bay shows no unusual oscillations in level in the time interval in question (SN, 1942, vol. 32, N 3; Bodle, 1944; Kelleher, 1972).

Gutenberg, Richter (1954): 22.V; $10^h30^m50^s$; 4 1/2° N.; 75° W.; 130 km; M=5 3/4.

1958, January 19, 9:09. There was a strong earthquake in the coastal regions of Ecuador and Colombia. Approximately 30% of Esmeraldas (Ecuador) was destroyed, including the children's department of the hospital, where three children died. In all, 11 persons died and 45 were injured as a result of the earthquake. Water mains were broken and power transmission lines were damaged. The Esmeraldas-Quito highway collapsed at many places. Many other roads of the country were made impassable by cracks and fallen trees. According to press reports, a landslide from the slopes of the Andes at Panado* village buried a hundred people. The earthquake was destructive in the cities on the northern coast of the country and was strong from Latacunga to Quito, Ibarra and Tulcan. It was felt at Guayaquil.

In Colombia, Tumaco suffered most of all. Several old residences and a wooden home for railway workers collapsed. The large brick ovens used for drying pulp collapsed at the sawmills. The brick wall of the new church cracked. The walls of a number of other buildings cracked. The rafters of the roof of the tide gauge box set up at the end of the breakwater (on Del Morro Island) came out of their grooves, the roof collapsed and carried the instrument and the box with it into the water. Pile wooden homes rocked so strongly in a north-south direction, that 8 cm gaps appeared in the ground at the foundations. The corrugated roof of the lower shed was bent in by the collision of two adjacent sheds. The embankments connecting Tumaco Island with adjacent islands crumbled and cracked. Bottles, vases, dishes, cameras, typewriters, etc. fell and broke. Water splashed out of tubs. The telegraph link between Tumaco and La Espriella was out of commission for twenty four hours because of fallen posts. A resident of the city was injured. Eyewitnesses between Tumaco and Esmeraldas found it difficult to remain standing. Water gushed /125
out of cracks in the ground on Manglares Cape, and trees fell.

The earthquake was strong at Pasto, Ipyales, Imuesa*+, Tuquerres and Sapuyas*+; it lasted about 40 minutes, but did not cause material damage. At Cali and Pereira, the population was frightened. At Bogota, the pendulums stopped on the clocks at the seismic station.

Many recurrent shocks were felt at the epicentral zone; the two

strongest occurred on January 19 at 9:45 and on February 1. According to geodesic data, the breakwater at Tumaco was shifted 1 cm along the vertical by the earthquake.

The earthquake gave rise to a tsunami. A launch almost sank at Esmeraldas; four customs officers died. The waves damaged Tumaco and Guayaquil (Ramirez, 1958, 1969; SN, 1958, vol. 48, N 3; Brazee, Cloud, 1960; Anon., 1961; Berninghausen, 1962; Ponyavin, 1965; Hamamatsu, 1966; Iida et al., 1967; Kelleher, 1972).

Iida's articles (Iida, 1963 a,b) erroneously indicate that the tsunami was registered in Japan (Iida et al., 1967).

[19.I; $14^h07^m27^s$; 1.5° N., 79.5° W.; 60 km; M=7.6.]

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CENTRAL AMERICA

(FROM COSTA RICA TO MEXICO)

1537. There was an earthquake in the Valley of Mexico (Fig. 48). It is possible that the source of the earthquake was in some adjacent state: Guerrero, Puebla or Veracruz (Milne, 1912 b: Montandon, 1962). According to a Japanese catalogue (Anon., 1961 b), the coast of Mexico was hit by a tsunami. Iida et al. (1967), quite justifiably, express doubt as to the reliability of these data.

1732, February 25. At Acapulco there was a very strong earthquake, which destroyed almost all buildings. It was accompanied by unusual flood and ebb tides at sea. The water rose 3 m, flooded the town square, and then, after a brief state of equilibrium, it retreated. Oscillations in level recurred several times (Petit-Thouars, 1841; Belcher, 1843; Perrey, 1847; Mallet, 1855; Milne, 1912 b; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967).

1754, September 1. On the 17th (or 24th) of August, earthquakes began at Acapulco. The strongest occurred on the night of August 30-September 1 at 2:00. It destroyed almost the entire city and was felt strongly at Mexico City. The source of the earthquake was apparently situated near Acapulco and San Marcos. Strong aftershocks were registered. The earthquake gave rise to a large tsunami. The sea at Acapulco suddenly retreated, dropping a vessel riding at anchor on the bottom of the bay. The flood tide was stronger than in 1732. The rise of water passed the maximal flood tide mark by 3-4 m. The tsunami damaged the citadel and the fortress walls and destroyed most of the homes in the city (Petit-Thouars, 1841; Perrey, 1847; Mallet, 1855; Orozco y Berra, 1888; Milne, 1912 b; Bose et al., 1908; Heck, 1934, 1947; Flores, 1934; Anon., 1961; Ponyavin, 1965; Iida et al., 1967).

1773, June 3. The capital of Guatemala, situated in the same place where Antigua is now located, experienced terrible earthquakes ten times between 1565 and 1773. The sea encroached inland on June 3, 1773.

Two volcanoes near the city appeared to boil. Flows of hot water issued from one and flows of burning hot lava issued from the other. Cracks and gaps formed everywhere on the surface. The ground was in continuous motion.

This terrible state lasted five days. Finally, on the 7th, a chasm opened up and almost the entire city disappeared together with 5000 families (Berghaus, 1844).

These data, including those about the flood, are doubtful. Essentially, as is directly stated in Mallet's catalogue (1854), the matter concerns the issue of water from a caldron lake. Putte's (1924) book about seismic events gives the following account. In 1773, the capital

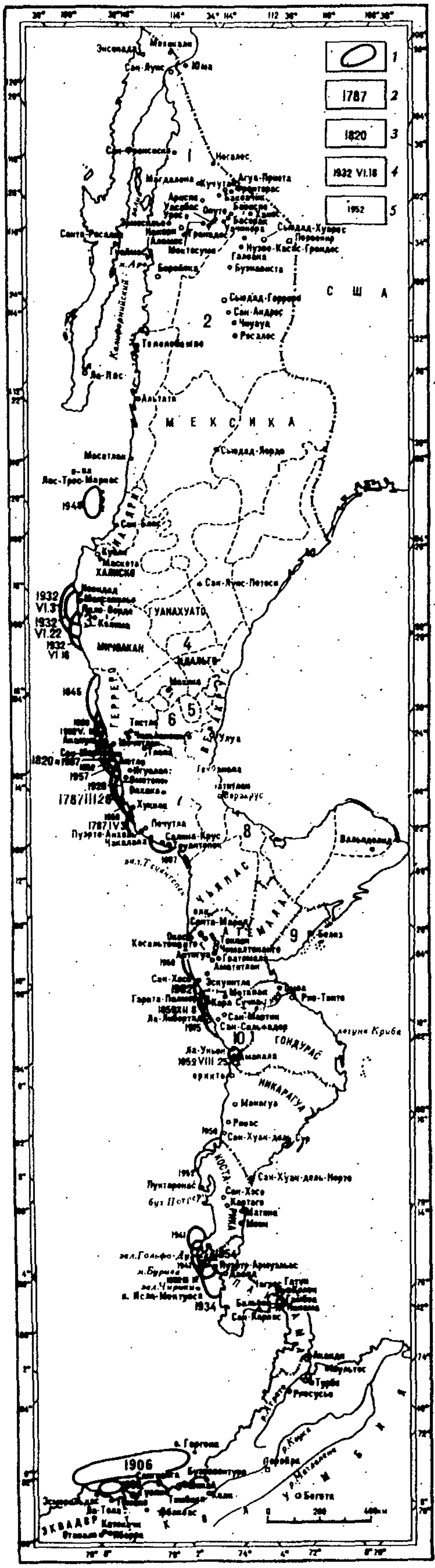

Fig. 48
Columbia, Central America, and Mexico

1 - centres of tsunamis (definite or likely)
2 to 5 - dates and intensities of tsunamis I;
2 - I=3; 3 - I=2; 4 - I=1;
5 - I≤0

Numerical designation: 1 to 8 - States of Mexico;

1 - Sonora
2 - Chihuahua
3 - Colima
4 - Querataro
5 - Tlaxcola
6 - Puebla
7 - Oaxaca
8 - Tabasco
9 - Belize
10 - Salvador

of Guatemala was completely destroyed by a series of earthquakes, the first of which occurred on June 10. On July 29, a "fatal" earthquake completed the destruction of the city. One hundred and twenty persons were killed and 300 injured, even though the population lived in tents because of the continual shocks. The shocks continued for several more months, since the church and the monastery, which remained standing, although greatly damaged on July 29, finally collapsed only on December 13. The pleistoseismic zone was apparently very limited, since the residents who fled from the capital settled at the settlements of San Lucas [14 km west of Guatemala], Micsco+ [8 km west of Guatemala], Amatitlan, Petapa+ [15 km south of Guatemala], Pinula+ [eastern suburb of Guatemala], Tecpan, Escuintla, Villa Nueva [13 km south west of Guatemala], and Chimaltenango [35 km west of Guatemala], which were very close to the former capital. /127

1787, March (mistakenly April) 28 (mistakenly 14 and 18), 11:30. There was a large earthquake with source near San Marcos, affecting the coast of the states of Oaxaca, Guerrero and Michoacan and causing much destruction (Fig. 48, 49). In Mexico City, an oscillatory movement lasting 6 minutes was felt; buildings were damaged. At Igualapa+, it was felt for 7 minutes. Three churches were almost totally ruined in Teuchitlan. Reports about the earthquake arrived from Morelia, Oaxaca, Chilapa, Chiautla, Tlapa, Ayutla, Cuautla+, Acapulco, Ometepec, Veracruz, and Tehuantepec. The earthquake was not so strong at Ulua and Tulancingo. It was felt at San Luis Potosi and Valladolid. Thirty-five recurrent shocks were counted until April 3.

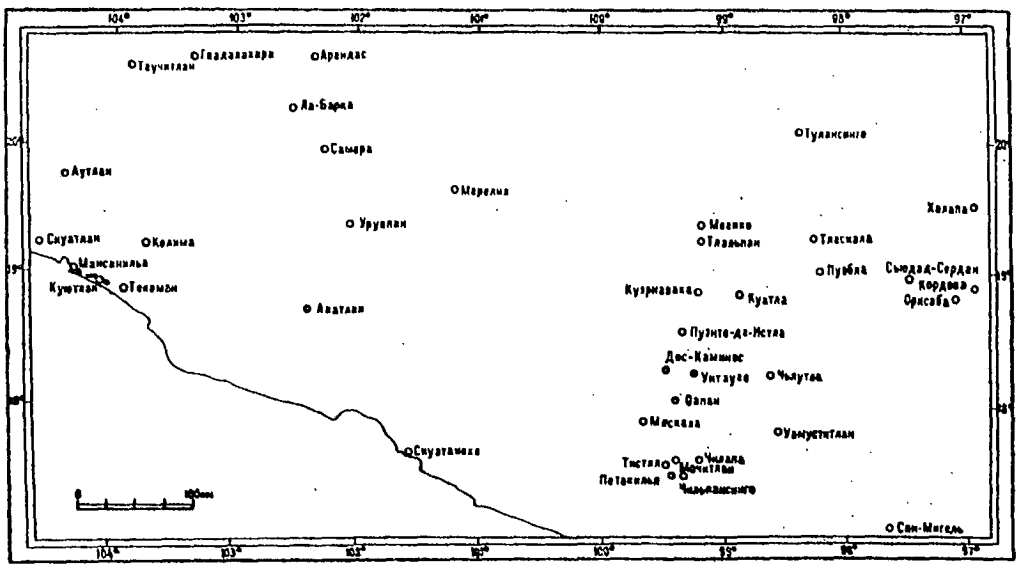

Fig. 49

General map of Central Mexico.

The master of Acapulco port, in a report to the Spanish government describes as follows, the phenomenon observed on the sea coast during the earthquake. "Approximately in the middle of the day, the sea suddenly began to retreat and advance in an unprecedented way, without waves and without any special agitation. The oscillations became more noticeable at 14:00; in 4 minutes, the water fell 3 m (10 feet) and rose in 6 minutes, and the amplitude of each oscillation was 80-85 m (100 vara) along the horizontal. This was repeated with ever increasing force; by 16:00 the water had already risen more than 3 1/2 m (12 feet), flooding the dam and penetrating near-by homes....Although the movements of the sea already began to abate at 17:00, this terrible spectacle continued until 24:00 when all died down. On open shore, where the sea met no obstacles such as mountains, as in Acapulco, it encroached inland drowning most of the herd grazing on the meadow. The butler on the estate of the city councillor of Oaxaca, saw the advancing water and climbed a big tree, thus saving his life; but then, to return home, he had to walk, since his horse had perished in the waves."

As related by the old mayor of Igualapa+, several fishermen were on shore making osier fish traps, and some, having caught their fish, were sitting on horseback. They watched in horror as the sea retreated more than 4 km (1 league), exposing the bottom consisting of areas of different color, including the rocks and plants. Then, with the same speed as it disappeared, the sea returned and again retreated leaving thousands of fish on land, picked up the fishermen, tore 11 men to pieces, and left them to hang between the beams of a rather high bridge, 6 km (1 1/2 leagues) from the sea. The few who were saved were injured and very frightened. /128

A galleon from the Philippine Islands was riding in the harbor of Acapulco at a depth of 18 m (60 feet). During the ebb tide, the water shallowed to 8 1/2 m (25 feet). The city was destroyed.

The wave was also observed in the region of Pochutla, Tehuantepec and other settlements in the state of Oaxaca (Hoff, 1840; Perrey, 1847; Mallet, 1853; Orozco y Berra, 1888; Bose et al., 1908; Milne, 1912 b; Sieberg, 1932; Flores, 1934; Heck, 1934, 1947; Gutenberg, Richter, 1949, 1954; Anon., 1961; Figueroa, 1963; Ponyavin, 1965; Iida et al., 1967).

1787, April 3, 9:30 - 10:00. Apparently, this was the strongest aftershock of the preceding earthquake. At Oaxaca, the destruction of the most solid buildings was completed; thus, at San Francisco church, one of the bell towers collapsed. The shock was felt rather strongly at Mexico City, and also at Tehuantepec. In some places on the coast, situated 18 km (4 leagues) from Tehuantepec, an unusual movement of the water and a menancing roar were observed simultaneously with the earthquake. Previously unknown fishes and enormous shellfish were tossed onshore. The same occurred on the coast at Pochutla and Juquila (Orozco y Berra, 1888).

1820, May 4 (mistakenly 10), 14:30. There was a large earthquake on the western coast of Mexico, in the states of Guerrero and Oaxaca, and

also in the states of Puebla and Veracruz. The source of the earthquake apparently lay off Acapulco and San Marcos.

Public buildings, the church and the jail were destroyed at Chilapa. Many buildings collapsed altogether, while the others were heavily damaged. At Mochitlan, the church and different homes were destroyed; a pit 17 m deep with a circumference of 170 m appeared in one place by the river on the road. Collapses took place from the hill sides.

At Chilpancingo, Petaquilla, Dos Caminos, Arendas+, San Miguel, and Oampampa*+, the most solid structures suffered serious damage. There was destruction at Acapulco and Tixtla+. There were several accidents at Mexico City; one church collapsed; buildings and aqueducts suffered considerable damage.

At Oaxaca and the settlements of the state, strong oscillations were observed which lasted 35 seconds and frightened the population. A loud underground rumble was mixed with the cracking of roofs, which threatened to collapse. Many buildings cracked.

At Puebla, Tlaxcala, Orizaba, Cordova, Veracruz and other points in this direction, the earthquake was the strongest in the 19th century.

A multitude of aftershocks were felt. They continued without interruption until the 10th.

A tsunami arose. At Acapulco, the sea retreated to the middle of the bay, exposing the reefs. Alternate quiet flood and ebb tides were observed with some pauses in the movement of water on reaching the highest and lowest levels. Two hours later, the flood tide was so large, that the water reached the doors of the church situated in the highest part of the city square. The square was flooded. The ocean advanced inland like a wall and with great speed, sweeping away everything in its path. Then, in a strong ebb tide, stronger than in 1787 [?], the greater part of the bottom of the bay was laid bare. After this, the sea level began gradually to return to its normal state. After the tsunami, the breakwater was totally covered with sand for 1 1/2-2 m (5-6 feet), while the beach had expanded by 17 m (20 vara).

There is also an account by the master of Acapulco port. "Yesterday at 14:00, a strong earthquake occurred in the port. It lasted 5 minutes; it recurred in the next quarter of an hour, and was followed by other shocks, not so prolonged. All this terrified and depressed the inhabitants....After the horrors of the earthquake, there began movements /129
of the sea in the form of an unusual flood and ebb tide, the first (along the horizontal) from 40 to 50 m (from 60 to 60 vara), and the second approximately from 15 to 20 m (from 20 to 25 vara). One of the two ships, which was taking on provisions in the harbor, was forced to retreat out to the bay for safety" (Petit-Thouars, 1841, 1844; Belcher, 1843; Perrey, 1847; Mallet, 1853; Orozco y Berra, 1888; Bose et al., 1908; Milne, 1912 b; Flores, 1934; Heck, 1934, 1947; Montandon, 1962; Figueroa, 1963; Ponyavin, 1965; Iida et al., 1967).

1833, March 10, about 22:00. There was a strong earthquake at Acapulco. Mild oscillations lasting about 1 1/2 minutes were felt at Mexico City. The sea retreated 12 m (40 feet) and quietly returned to its initial position (Belcher, 1843; Heck, 1947; Ponyavin, 1965; Iida et al., 1967).

1834, March 13/14. On March 11 about 22:30, at Acapulco, there was a strong vertical shock, followed by others, which were observed for several days. At Mexico City, there were undulating tremors lasting more than 2 minutes.

On the third day, the sea retreated about 33 m from the shore and then gradually returned to its usual level (Petit-Thouars, 1841; Belcher, 1843; Perrey, 1847; Mallet, 1853; Heck, 1947; Ponyavin, 1965; Iida et al., 1967).

[This and the preceding description have been taken from different sources; it is possible that they relate to the same event.]

1837. On August 9th at 16:30 at Acapulco, there was a strong earthquake which did much damage to buildings. It was not felt very strongly at Mexico City and Morelia. Recurrent shocks lasted a month almost without interruption: the strongest occurred approximately 30 hours after the earthquake.

On October 18, about 16:00, another strong earthquake occurred and lasted more than a minute. It was also rather strong at Mexico City. With a hundred tremors, which were accompanied by an underground rumbling, it lasted until 22:00 on the 19th, when there were two very strong shocks, also with rumbling. Two hours later, that is, at midnight, there was a new earthquake so strong that it almost destroyed the city. Strong tremors were felt at the same time in Mexico City. Strong shocks were felt at 2:00 on the 21st and 10:00 on the 22nd, after which the frequency and intensity of shocks began to diminish, but they lasted even until the first months of 1838.

None of these exceptional earthquakes caused any disturbances in the movement of the sea, if one ignores a few eddies and unusual currents. Flood and ebb tides were completely regular (Petit-Thouars, 1841; Belcher, 1843; Perrey, 1847).

Montessus de Ballore, (1906) writes more definitely about a tsunami at Acapulco in 1837.

1845, April 7, 15:30. At Acapulco, there was an earthquake and then a tsunami. The earthquake began with light oscillations, whose intensity gradually increased until they became very strong. In half an hour, an enormous wave appeared at sea. It penetrated approximately 40 m (50 vara) inland; then the water rapidly retreated, exposing the bottom for 35 m (42 vara), after which the oscillations in sea level abated little by little. This earthquake was observed at many places in the states of Guerrero, Michoacan, Puebla, Hidalgo, Guanajuato, Colima, Veracruz,

San Luis Potosi, Queretaro, Jalisco and Oaxaca, and also in Mexico City, where homes and arcades of the water main were damaged. The cupola of Saint Theresa Cathedral collapsed (Orozco y Berra, 1888; Milne, 1912 b; Flores, 1934; Montandon, 1962).

1852, November 29, about noon. A strong earthquake in the south of the state of California (USA) affected a vast area with a diameter apparently of about 550 km (300 miles)[1]. It was felt in the lower reaches of the Colorado River, at Yuma and San Luis, and at San Diego. /130
Long cracks appeared in the focal zone (in Lockwood* Valley). The earthquake lasted about 2 minutes at San Diego; the ground appeared to shift up and down by 10-15 cm (5-6 inches). About 15 recurrent shocks were felt on this and the following day.

The crew of a ship, riding at anchor on the Colorado River 55 km (30 miles) from the mouth, felt a shock which was preceded by a rumble. Suddenly the water receded, and the vessel, which had been lying in 4 m (14 feet) of water, ran aground in no more than 1 m (3 feet) of water. It floated up only during the subsequent flood tide. The banks of the river were greatly changed after the earthquake (Perrey, 1855, 1864 b, 1872a; Holden, 1898; Townley, Allen, 1939).

1852 (mistakenly 1854), December (or November) 4, 22:10. There was an "indescribable" earthquake, which struck and totally destroyed Acapulco. The earth shook with a terrible roar. Everybody was seized with terror. As far as one can judge, four or five shocks occurred in a second. Almost all the buildings collapsed, clouds of dust obscured the city, and the residents poured into the streets and squares of the city to avoid being buried in the ruins of their homes. Nothing remained of the city except heaps of ruins. Fortunately, it was not very late and almost no one had gone to bed. For this reason, only one person died, but many were slightly injured. Recurrent shocks at short intervals lasted all night.

The earthquake and aftershocks were felt at Ayutla, Uamustitlan+ and other places in the state of Guerrero. It lasted more than 40 seconds at Tlalpan, Cuernavaca, Cuautla+, Puente de Ixtla, Chilapa, Chilpancingo and Tixtla. The earthquake was strong at Mexico City, where it lasted 10 seconds. It was felt in the Valley of Mexico, and also at Puebla, San Andres Chalchicolisl*+, Orizaba, Cordova, Jalapa, and Veracruz.

At Acapulco, the sea retreated about 6 m (20 feet) from shore, and the residents were very much afraid that it would return with greater force and flood them all; however, the regular sea level was gradually restored (Perrey, 1854 b; Orozco y Berra, 1888; Milne, 1913; Leet, 1948;

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[1]The primary sources apparently mistakenly indicate, not that the diameter of the area on which the earthquake was felt was equal to 300 miles, but that the area was 300 square miles and that the earthquake was felt at San Luis Obispo instead of San Luis.

Iida et al., 1967).

1854, August 7. On the 4th, at 23:30, there was a very strong earthquake which affected all Costa Rica. It was felt at least from Colon (Aspinwall) in Panama to Pubaqui in Nicaragua. At San Jose and Cartago, tremors lasted 2 minutes with approximately the same intensity. Several more light shocks were felt until 5:00 on the following day. A long stretch of coast on the Pacific at Golfo Dulce sank underwater. On the Atlantic coast, the tremors were strong at Matina and Moni* [Moin].

Shocks were felt again on the 5th at Costa Rica and Nicaragua and on the night of the 6th-7th at Costa Rica. The village of Golfo Dulce* on the Pacific Coast was flooded by the sea and destroyed (Perrey, 1855, 1856; Montessus de Ballore, 1888).

1856, August 4, 16:47. Suddenly, an earthquake destroyed settlements on the Atlantic coast of Honduras, approximately from Omoa to Beliz. The port of Omoa was almost totally destroyed. Many cracks appeared in the walls of the ancient Spanish fortress. The ground cracked in a radius of 50 km (12 leagues) in the vicinity of the city and on the coast between the Rio Tinto and Ulua Rivers. The town of San Jose* was also destroyed, and Beliz suffered damage. Weak tremors lasting 30 seconds were felt at Guatemala. Underground shocks lasted all the night of the 4th-5th. Then for a week more than a hundred were counted, and they lasted at least until the 27th. The Indian tribes of Honduras long remembered this earthquake.

At Omoa, the sea fell and rose to a height of 5 m in still weather; it reached the foot of the fortress and added to the destruction begun by the earthquake. A similar phenomenon was observed on the shore of Criba lagoon (Perrey, 1872 a; Montessus de Ballore, 1888; Milne, 1912 b; Sieberg, 1932; Heck, 1947; Montandon, 1962; Ponyavin, 1965; Iida et al., 1967).

1859, August 25. A strong earthquake in El Salvador [and Honduras] caused some damage at La Union and Amapala ports, on Tigre Island, at San Diego* and La Brea* settlements. A roar was heard. The shocks continued almost without interruption on the 26th and 27th. The /131
shocks ceased on the 28th, but several more shocks were felt on September 1-3.

At La Union, the earthquake was accompanied by tsunami waves, which did some damage. In particular, two dug-out canoes and one brigantine were lost (Perrey, 1864 b; Montessus de Ballore, 1888; Milne, 1912 b; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967).

1859 (mistakenly 1869), December 8, after 20:00. There was a destructive earthquake in adjacent regions of Guatemala and El Salvador.

The earthquake lasted 2 1/2 minutes at Izalco. The parish church was destroyed, except for the nave and the altar; in particular, the bell tower collapsed. Approximately 40 of the "best" homes and a large number

of smaller homes were destroyed; fortunately no one died.

At Tepecoyo+, the church, the mayor's residence and many homes were destroyed. At Guatepéque*+, the church and mayor's residence were partly destroyed. Jahyaque suffered just as much: many homes were destroyed, and the church was damaged. The ground settled in the vicinity, up to 90 m (100 yards) in width in some places.

At Guaymango+, some of the homes were destroyed and the church was substantially damaged. At Panchimalco, homes were destroyed, and large gaping cracks appeared in the ground. The churches and town halls were partly destroyed at San Martin and Comasagua+. At Escuintla*+, many homes collapsed. The earthquake lasted about 2 minutes at Sonsonate. Almost all the buildings were damaged to some extent; in particular, roofs were damaged.

At Nahuizalco, the monastery was destroyed. Great destruction was also done in Sonsonate Department at Dolorez-Izalco, Masahuat, Nauilingo+, Juajua+, Santo Domingo [de Husman], San Antonio [del Monte], Caluco+, Cacalote*+ and Ishuatan. The ground cracked badly in the vicinity of Dolores Izalko*, and the width of cracks reached 4 m.

At Santa Ana, the earthquake lasted a minute and damaged many buildings. At Ahuachapan, Atiquizaya, Texistepek, there was much destruction but no one died. The earthquake was strong at Guatepéque*, [San Juan] Opico+, Apopa, Tepecoyo+ and other cities.

At the same time there were reports that there was no destruction at Masahuat, Santo Domingo [de Husman] and Atiquizaya, and that the earthquake was not felt at [San Juan] Opico+ and Apopa.

At San Salvador, there was a very strong earthquake, lasting 2 or 3 minutes. However, not a single building collapsed.

At Guatemala, the earthquake lasted 1 1/2 minutes, but did not do any damage. A pendulum about 3 m long with a mass of 550 gm completed an oscillation of amplitude 4 cm. The beams of houses cracked constantly. The earthquake was accompanied by a rumble.

At Nicaragua, the earthquake was apparently felt only at Managua, on the shore of the lake of the same name.

The earthquake was accompanied by a tsunami. According to a report of the governor of Sonsonate, the sea became very agitated at Acajutla port; the waves rose to an extraordinary height with a terrible noise; the sea retreated far from shore; the docks and river boat yards dried up almost to the breakwater; on shore, caves and grottos collapsed; the state warehouses were destroyed; the breakwater and customhouse were flooded; an enormous chain about 70 m (40 fathoms) long and an anchor disappeared, carried off by waves, and it was impossible to find them; holes of such size were formed in the sand that sailors sank in them up to the waist. Fish floundered on the beach and on the terraces and they

were collected in large numbers (Perrey, 1862a, 1864 b; Montessus de Ballore, 1888; Milne, 1912 b; Larde, 1916; Heck, 1934, 1947; Montandon, 1962; Ponyavin, 1965; Iida et al., 1967).

1860, March 17, about 9:00. A loud explosion, like a cannon shot, was heard at Acapulco. It was caused by a heavy eruption of one of the volcanoes situated in the direction of Mexico City. At the same time or a little earlier, Commodore Watkins, the captain of the "Golden Age", saw three enormous waves approaching the ship (the rest of the sea was altogether calm). The waves reached the ship and surrounded it in a semi- /132
circle, after which they disappeared, leaving the sea as calm as it had been before (Perrey, 1862 b).

1868, August 12 (or 11), 4:00. An earthquake was felt at Acapulco (although not by all residents). A weaker shock was noticed at 11:00. Apparently, the unusual flood and ebb tides of the sea, observed from morning until 20:00, should be ascribed to this earthquake. The water at first retreated 35 m (40 vara) beyond its usual mark, and then covered the shore also for 35 m (40 vara) beyond the usual line, flooding nearby homes (Orozco y Berra, 1888). [Probably effects of the Arica tsunami, see p. 74.]

1871, February 7. Two underground shocks occurred at Minatitlan [off the Atlantic coast of Mexico] followed by a sea wave 0.3 m (1 foot) high. An earthquake was felt at Mexico City on the same day (Fuchs, 1872, 1885 b; Perrey, 1875 b).

1875, February 23. There was a strong earthquake at Manzanillo and Colima with great movement of water (Fuchs, 1885b). Apparently, the report relates to the earthquake of 24.II.1875, about which the following is known. At 4:43, there was a strong earthquake at Manzanillo, accompanied by a deafening roar of the sea. It was felt weakly at Guadalajara. The night before, on February 23 at 20:18, a mild earthquake was felt at Guadalajara and a number of adjacent cities, and was accompanied by a series of aftershocks (Orozco y Berra, 1888).

1883, March 12. According to a report from Cuale (Mexico, Jalisco State), the sea left its usual bed on a very long stretch of coast on March 12. It retreated far from shore, so that elevations and depressions on its bottom dried up. In particular, one could see that the Las Tres Marias Islands are the tops of a large underwater mountain protruding over the water surface. Many different fishes, as well as corals, shellfish and other benthic animals were stranded on the irregularities of the sea floor. It is not known how long the ebb tide lasted, but some time later, the sea returned rather quickly and with considerable noise to its previous position.

Nothing about an earthquake was reported. On the following day, a hurricane and downpour broke on this locality (Orozco y Berra, 1888; Montessus de Ballore, 1906 a).

1887, May 3, 14:45. There was a strong earthquake in northwest

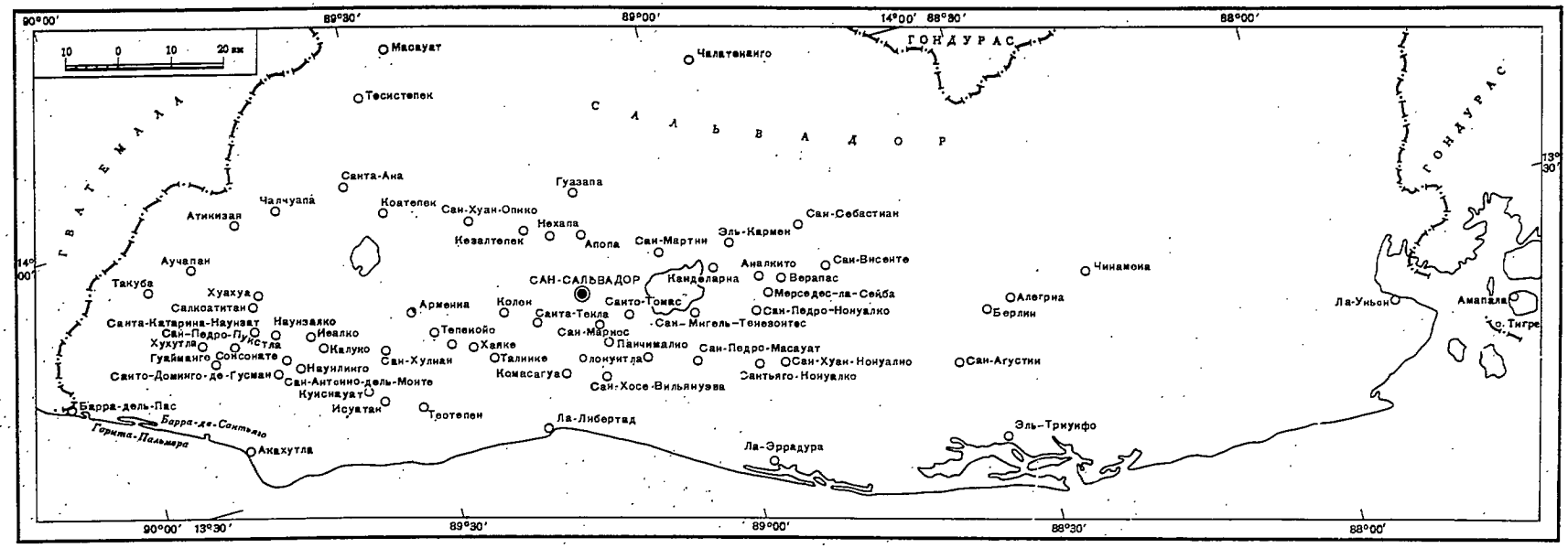


Fig. 50 A general map of Salvador

Mexico, in the states of Sonora and Chihuahua. Thirty-five persons died and 39 were seriously injured in the State of Sonora alone. Bavispe was totally devastated.

At Oputo, many buildings were completedly levelled, while the rest were heavily damaged and collapsed during the aftershocks; 9 residents died and many were injured; water gushed up along ditches and in the valley.

At Guásabas and Granados, most of the buildings were destroyed. Buildings were damaged at Opocura (29° 55' N., 109° 29' W.), the center of the Moctezuma district, at Concepcion Guerrero* and Ciudad Juarez (Paso del Norte). The earthquake occurred with similar force at San Miguelito [30 km southeast of Fronteras], Baserac+, Guachinera+, and Nacori (40 km southeast of Granados).

At Arizpe, several homes collapsed, while some other homes and the church were destroyed; fissures appeared in ploughland and in lowlands and water spouted from them; the ground subsided at several places; enormous blocks rolled down from the mountain tops, raising clouds of dust on the slopes.

All the buildings cracked at Bacoachica; deep funnels appeared in the ground, and large cracks, spouting water, appeared in the lowlands and on the banks of the river.

At Fronteras+, several homes were destroyed and still more were damaged; a mass of cracks appeared in the ground, from which water spouted in greater or lesser volume; the channel of the river dried up for an instant, but then water appeared again in abundance, and its discharge approximately doubled; clouds of dust arose from all the surrounding mountains.

The entire valley between Bocadehuachi+ (29° 44' N., 109° 30' W.) and Cuchuta+ was covered with cracks from which issued water; the ground subsided in places; the tops of adjacent mountains collapsed.

Cracks also appeared in many places in the valley between Porvenir and Agua Prieta. An abundance of water poured forth from these cracks, so that the ground became swampy and impassable. /133

At Janos, almost all homes were destroyed. Homes and the church suffered seriously at Galeana; the tremors lasted 20-25 seconds. The earthquake was strong at Nuevo Casas Grandes+. The earthquake was rather strong at Ures and Santa Rosalia.

The earthquake was felt, but did not do any serious damage, at Nogales, Magdalena, Baroyeca+, Buenavista, Alamos, and also, according to not quite reliable sources, at San Francisco and Masatlan+.

At Chihuahua and Rosales, the tremors lasted 5-10 seconds and frightened the residents. The earthquake was rather strong at San Andres

and damaged buildings; one of the nearby springs began to eject more water, mixed with colored clay; after a while, the color and discharge of water returned to normal. The tremors were mild at Guaymas.

Near the lighthouse on Haro Cape, following the earthquake the water retreated from shore a considerable distance, and then retreated again several times with the same force. An unstable part of the hill to the west of the lighthouse collapsed from the impact of the tidal waves (Orozco y Berra, 1888).

1891, July 30, 6:00. The region of Ciudad Lerdo (Mexico) was apparently the center of a very strong earthquake. It seems that it caused a tsunami of considerable height at the apex of Golfo de California. The locality affected by the earthquake was so sparsely settled that there was no destruction. Reports about this earthquake are vague and contradictory; not enough reliable information is available about this tremor, which covered a large area (Holden, 1898).

1897, June 20, 3:00. On June 5 at 19:22, a strong vertical shock occurred in Mexico with source near Tehuantepec and Salina Cruz (Fig. 51). Tehuantepec was reduced to ruins. The streets running from west to east suffered more than the streets running north to south. Most of the residents left the city. The shock was felt in an area extending to the states of Colima and Chiapas and to the latitude of Mexico. Nothing unusual happened on the Pacific, in Salina Cruz Bay.

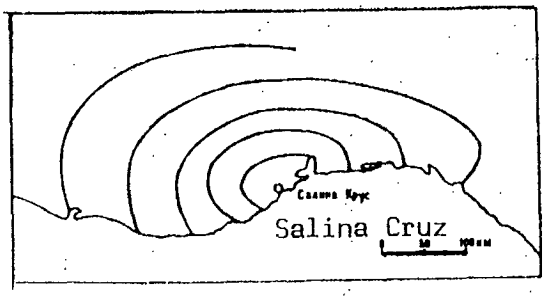
After the earthquake shocks continued all night, at 4-5 minute intervals, and on the following days. A loud rumbling preceded them by 3 seconds.

On June 14, the geologists Sanchez and Rangel went out from Mexico City to investigate the earthquake. On the night of the 19-20th, which they spent at Salina Cruz, there was a strong undulating earthquake in the north-south direction, which did not stop the agitation at sea and the oscillations in its level (Sanchez, Range, 1897).

1902 (mistakenly 1912), February 26 (mistakenly 2 and 21). On January 18, 1902 at 17:20, a very strong earthquake occurred, which affected the entire territory of Guatemala and lasted about 1/2 minute. Several homes collapsed at San Martin* village near Quesaltenango, while three sand ridges about 2 km long formed at Ocosa. The visible ground waves, according to accounts, were 25-30 m long and 25-30 cm high. Two 20-ton locomotives were shifted 1 1/2-2 m. Similar phenomena were observed on the coast of Mexico at San Benito*.

On February 26, the residents of the Pacific coast border regions of Guatemala and El Salvador heard a loud rumble, like cannon shots, which appeared to come from under the bottom of the sea. A strong earthquake then occurred. The residents were frightened. Soon they saw the water retreating, exposing the sea bottom for a considerable distance. After this, a black wall arose at sea: this was a large wave, whose might increased as it approached the shore. The wave surged onshore with

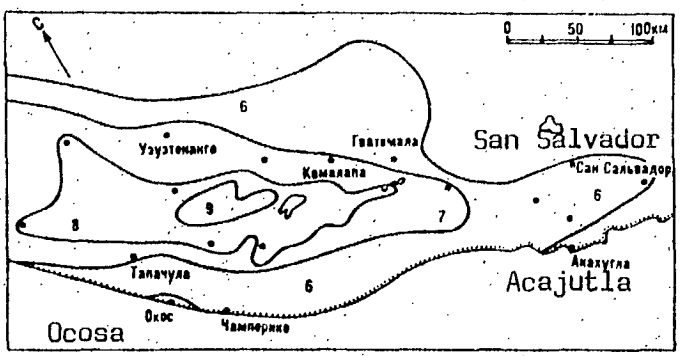
Fig. 51



The determination of the epicentre of the earthquake of 5.VI.1897 by means of the macroseismic times of the propagation of the shocks which were felt. The isochrons are constructed for apparent path times of 2; 5; 10; 15 and 60 min (?) (Sanchez, Rougel, 1897).

Fig. 52

Isoseists of the earthquake of 18.IV.1902 on the 12 point scale (Sieberg, 1932).



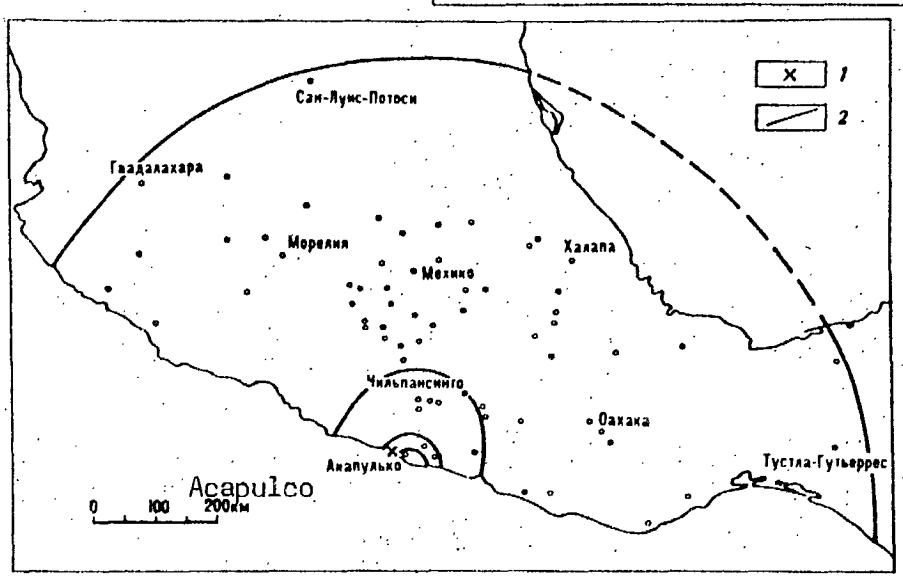


Fig. 53

Surface effect of the earthquake of 14.IV.1907 (Bose et al, 1908).

1 - instrumental epicentre

2 - boundary of the destruction zone and the zone of shocks of various intensities. The dots are places from which there were reports on the earthquake.

terrifying force. The residents did not have time to run to safety and they perished. The tsunami was observed on a 120 km stretch of coast which included Acajutla (see Fig. 50 & 52). One hundred people died and about the same number were injured at Barra de Santiago settlement. About 85 people died at the village of Barra del Pas. Homes and trees were /135
washed out to sea, and the clothes were ripped from people caught by the water. Three waves were reported, the first being the smallest.

Later, on April 18, a considerably stronger earthquake occurred than on January 18. It lasted about a minute and was felt as far as Mexico City. The greatest destruction occurred at Quesaltenango, San Pedro* and Solola*. In particular, a church built during the Spanish Conquest collapsed. The coast in the Ocosa region subsided 1 m (Fig. 52).

Then weak shocks occurred. On September 23, there was another strong earthquake, and on October 23/24, the Santa Maria volcano, which was thought to be dormant, exploded, forming an enormous new crater (Sapper, 1902, 1905: Montessus de Ballore, 1906 a, 1907; Anderson, 1908; Krummel, 1911; Larde, 1916; Sieberg, 1932; Schultz, 1963; Iida et al., 1967).

Richter (1963): 19.IV; 02^h23^m; 14° N., 91° W., M=8.3.

[There are apparently no instrumental data on the earthquake of February 26.]

1902, August. A tsunami, possibly of seismic orgin, supposedly fell on the coast of the Golfo de California in the region of Altata port (Montessus de Ballore, 1906 a).

1903, July 16. There were very strong shocks at Acapulco, Tulancingo, and Mescala. There was also a seaquake (Rudolph, 1905).

1905, early January. According to a report from one of the steamships, the islands of Revilla Gigedo (see Fig. 77) supposedly disappeared, due either to a volcanic eruption or to a terrible tsunami generated by a submarine earthquake (Montessus de Ballore, 1906 a). [The incident is doubtful. The nearest earthquake in time and location of focus was: 20.I; $14^h52.1^m$; 7° N., 79° W.; M=7 3/4 (Gutenberg, Richter, 1954).]

1906. A tsunami fell on the beach at Los Negros (Larde, 1961). [Apparently, this relates to the Colombian-Ecuador tsunami of January 31, 1906.]

1907, April 14, 23:31. There was a destructive earthquake with source near San Marcos, covering a large part of Mexico (Fig. 53). The earthquake began with comparatively weak oscillations, which then became strong tremors. The oscillations were so strong at Mexico, that sleepers awoke and ran to the street, the beams of buildings shook, and electrical and telegraph wires in the street became entangled. Several buildings and walls collapsed. The oscillations lasted about 2 minutes.

Several new huts, woven of branches, collapsed at San Marcos: mongooses were thrown from trees to the ground. The majority of stone homes were destroyed at Ayutla and eight persons were killed. At Acapulco, the buildings suffered only slight damage. The water left the Chacalapa*+ lagoon situated on the coast south of San Marcos; the cabins with baths here were buried in the sand to a depth of 1 1/2 m; large trees fell.

During April, numerous recurrent shocks were felt in the epicentral zone.

After the earthquake, the sea rushed onshore on the entire stretch of road from Acapulco to Tecuanapa+ road, which served as a port for the city of Ometepec. At Acapulco, the rise of water reached 185 cm; the water penetrated 150 m inland from the beach. During the ebb tide, several small rivers dried up. In the Tecuanapa+ roadstead, the water rose 50 cm, as determined from marks on the rocky shores, and flooded the customhouse, [already] severely damaged by the earthquake (Bose et al., 1908; Scheu, Lais, 1912; Sieberg, 1932; Gutenberg, Richter, 1949, 1954; Iida et al., 1967).

Gutenberg, Richter, (1954): 15.IV; $06^h08.1^m$; 17° N., 100° W.; M=8.1.

1909, July 30 (incorrectly 31), 4:16. There was an earthquake with source near Acapulco, where many homes were destroyed. The destruction occurred on a large area which included San Marcos and Chilpancingo. The earthquake was felt in a zone about 2500 km by 780 km (700 by 435 miles) [sic.]. At Acapulco, the sea receded from the shore; the flood tide reached 9 m (30 feet) [apparently along the horizontal] (Krummel, 1911; Milne, 1912 a; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967). /136

Gutenberg, Richter (1954): 30.VII; $10^h51.9^m$; 17° N., 100.5° W.; M=7.75.

1915, September 6, at night. There was a strong earthquake in El Salvador. The intensity of tremors on the 10-degree Mercalli scale was estimated by local seismologists as follows (see Fig. 50).

X degrees - Juajúa, Salcoatitan.

VIII-IX degrees - Nahuizalco+, Santa Catarina Nauizat+, Ataco*, Ahuachapan.

VIII degrees - Atiquizaya, Chalchuapa, Santa Ana, Coatepec, Izalco, Caluco, Armenia, Jayaque, Colon, Quetzaltepeque, Santa Tecla, San Marcos, Santo Tomas, San Miguel Tenezontes, Analquito+, Jiboa*+, Verapaz, San Pedro Nonualco, La Seiba*+, Chinameca, Tenezontes, Comasagua, San Julian, Naulingo, Sonsonante, Tacuba.

VII degrees - San Moreneo*, Texistepec, [San Juan] Opico, Nejapa,

Apopa, Tonaeatepec*, Candelaria, San Sabastian, San Visente, San Augustin, Izulutan*, San Juan Nonualco, La Erradura, Santiago Nonualco, San Pedro Masauat, Olocuitla, Panchimalco, San Jose Villanueva, Talnique, Teotepec, Isuatan+, Cuisnahuat+, San Pedro Pucstla+, Jujutla+.

VI degrees - Metapan, Tacachico*, Guazapa+, Chalantenango, Guayabel*+, El Carmen, Apletepec*, Berlin, Alegria, La Union, Zacatecomuzacar*, La Libertad, Guaymango.

There are unreliable reports about a disturbance at sea, arising after the earthquake. The master of Barra de Santiago port reported that during the earthquake an enormous wave appeared at sea. The residents of the city were seized with panic. However, if we are to believe another eyewitness, situated at the same place, a hurricane raged; the sea was very agitated, but the above-mentioned enormous wave did not occur.

The weather was bad at night at Acajutla, and the sea was stormy; no one noticed any unusual waves.

The master of La Libertad port categorically denied the occurrence of any unusual phenomena at sea either before or after the earthquake.

At El Triunfo Bay, according to a report of the port master, no greater disturbance was observed after the earthquake than that which was observed on the preceding three days, although flood tides were higher than usual all this time.

The master of La Union Port reported that, because of the rain and the hurricane, it could not be seen whether the earthquake affected the state of the sea. One of the observers kept track of the sea from 17:00 to the end of the earthquake. All this time, there were large waves. They reached enormous size not long before the seismic shock and began to diminish only some time after the earthquake (SN, 1915, vol. 5, N 3; Larde, 1916).

Gutenberg, Richter, (1954): 7.IX; $01^h20.8^m$; 14° N., 89° W.; 80 km; M=7 3/4.

1925, May 4, 11:25 and 11:35. The American vessel, "Hefron," at 14° 35' N., 106° 06' W., encountered a heavy surge, coming from the south and lasting 10 minutes. The first group consisted of three waves 4 1/2-6 m high (15-20 feet) (ISS for 1929).

1925, November 16. The port of Sihuatanejo (Guerrero State) was partially washed away by a wave, whose height was estimated at 10 m (35 feet) (Montandon, 1927 a,b; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967).

Gutenberg, Richter (1954): 16.XI; $11^h54^m54^s$; 18° N., 107° W.; M=7.

1927, September 6 (not exact). On the western coast of Mexico, a strong storm raged, causing destructive floods between Guayamas and Tehuantepec Bay. Many ports and cities suffered damage, and Guayamas and Salina Cruz were partly flooded. The total damage was quite considerable. In places where dikes were demolished and port structures were flooded, there were casualties (Montadon, 1931).

1928, June 16, 16:49. There was a very strong earthquake in the states of Oaxaca, Guerrero, Puebla, Tlaxcala, Mexico, Michoacan, Veracruz, Hidalgo and partly in the state of Tabasco. The destruction covered a vast area, including Oaxaca, which had just been rebuilt after the last earthquake. Four persons died. Many recurrent shocks were felt during June. /137

A tsunami arose. At Puerto Angel, the water advanced 55 m, destroying the warehouse on the embankment. At Chakahua, the water advanced 45 m inland.

The tsunami was registered by tide gauges in California: at La Jolla with an amplitude of 10 cm and at San Francisco with an amplitude of less than 10 cm.

After 8.4 hours (at 1:18 on the 17th), the tsunami reached Hilo (Hawaiian Islands), where it was registered by a tide gauge (Fig. 54). The water rose and fell 0.4 m (1.3 feet); the wave period was 12-22 minutes; the scillations lasted more than a day. At Honolulu, the tsunami appeared ... ours later and was barely noticeable, having an amplitude of 5 cm and a period of 16 cm on the record of the tide gauge.

The tsunami was registered by the tide gauge at Apia (Samoa Islands) 14.7 hours after the earthquake (SN, 1928, vol. 18, N 2; Wilson, 1928 b; Anon., 1930; Jones, 1931; Heck, 1934, 1947; Leet, 1948; Shepard et al., 1950; Anon., 1961; Ponyavin, 1965; Iida et al., 1967).

Gutenberg, Richter (1954): 17.VI; $03^h19^m27^s$; 16 1/4° N., 98° W.; M=7.8.

1932, June 3. There was a very strong earthquake on the coast of the States of Colima and Jalisco. It was preceded by weaker shocks. Apparently, more than 400 persons died in the epicentral zone, including more than 30 in Guatemala. Communications with Manzanillo were cut off.

At Colima, more than 200 homes suffered some damage. Several roofs collapsed. Twenty residents died and about 70 were injured. At Ayutlan, five people died and about 50 were injured. There were also casualties at Manzanillo, Sihuatlan+, Samora, Acatlan and other places.

The zone of very strong tremors extended to Guadalajara and La Barca in the northeast, Mascota in the northwest, and Uruapan in the southeast. In this zone, all the residents fled to the streets in panic; many buildings cracked, although only some of them collapsed; water mains and metal cables were broken; water splashed out of basins; bells rang by

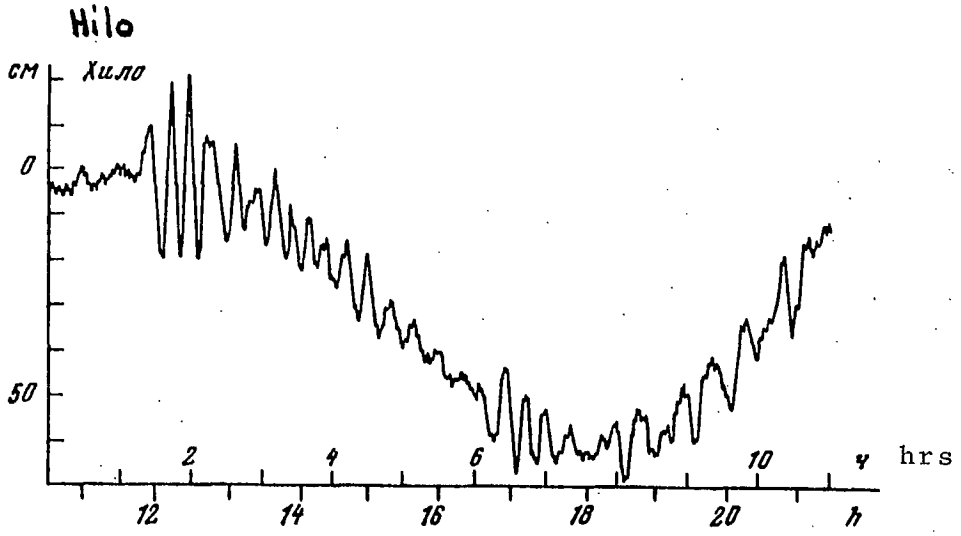


Fig. 54

Record of the tsunami of 16.VI.1928 (Wilson, 1928b).

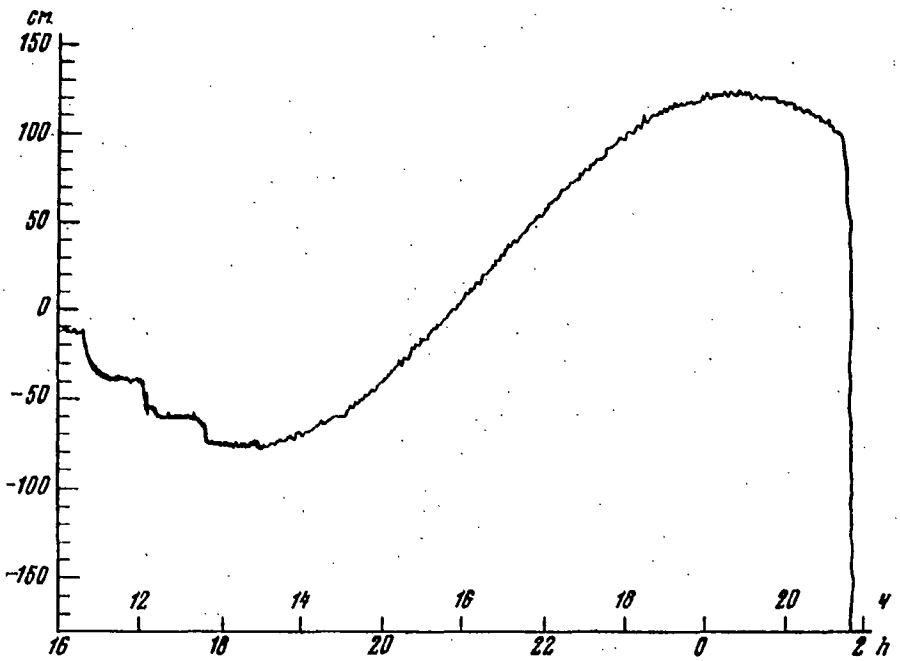


Fig. 55

Record of the tide gauge at Puerto Armuelles, 17.VII.1934 (Kellar, 1935).

themselves; clocks stopped.

At Cuyutlan and Navidad Village, wooden and wattle homes were not damaged, but the residents of Navidad related how waves could be seen running along the sandy beach; it was impossible to remain standing; all /138
the dishes broke in houses. The shore apparently rose in the Cuyutlan region.

At Mexico City, the earthquake took the form of mild oscillations, lasting about 2 minutes; slight damage to structures was recorded.

After the earthquake, the sea at Manzanillo port to the southeast became agitated, retreating and advancing unusual distances. A section of the railway between Cuyutlan and Manzanillo was washed out. The port of San Blas in the state of Nayarit was partially washed out.

Some time after the earthquake a large wave approached the rocky spit on which Navidad is situated, reaching the edge of the cliff. In Manzanillo Bay, the water, judging by traces left on the cliffs, rose 40-75 cm. The rise of water was small at Cuyutlan.

The tsunami approached Hilo 6.9 hours later. It had an amplitude of 40 cm and a period of 18 minutes. It approached Honolulu 7.7 hours later and had an amplitude of 8 cm and a period of 10 minutes. The tsunami was registered at San Diego and Apia (SN, 1932, vol. 22, N 3; Ordonez, 1933; Flores, 1934; Heck, 1934, 1947; Gutenberg, Richter, 1949, 1954; Shep[illegible] et al., 1950; Anon., 1961; Ponyavin, 1965; Iida et al., 1967).

Gutenberg, Richter (1954): 3.VI; $10^h36^m50^s$; 19 1/2° N.; 104 1/4° W.; M=8.1.

1932, June 18. There was an earthquake of almost the same intensity as that of June 3, affecting practically the same area and causing new destruction, thereby worsening the situation which developed after the first earthquake. Tecoman was completely destroyed, including the main building of the church; the residents left the city. Colima was among the most affected cities. At Guadalajara, several buildings, including the cathedral and the university, suffered serious cracking.

After the earthquake, small tidal waves were observed at Manzanillo. A tsunami was registered at Hilo with an amplitude of 10 cm (Anon., 1932; Ordonez, 1933; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967).

Gutenberg, Richter (1954): 18.VI; $10^h12^m10^s$; 19.5° N., 103.5° W.; M=7.8.

1932, June 22. There was a destructive earthquake at Colima, with numerous recurrent shocks. A tsunami arose. At the old summer resort of Cuyutlan at 7:05, the water suddenly receded from shore and then returned in a wave 6 m (20 feet) high. The wave flooded the shore

for 3 1/2 km (2 miles). It flooded across a low lying dune separating the beach from the resort, and washed away or destroyed all the main buildings of the resort: two wooden, rather large hotels, and also several small wooden cottages. The water penetrated 550 m (600 yards) inland and flooded the lower part of the settlement, built up mainly with flimsy wattle huts, to a depth of 1 m. The huts were completely destroyed, and more than a few residents died. The tsunami fell on land without much force. The wave was high in the east to Palo Verde where a broad swath of vegetation was destroyed, the residents of a rancho were drowned and the herd perished. Most of the debris carried off by the water accumulated at the railway embankment. After the water receded, Cuyutlan was strewn with a mixture of sand, dead fish, shrubs and even small trees.

The tsunami was recorded at Hilo with an amplitude of less than 10 cm (SN, 1932, vol. 22, N 3; Ordonez, 1933; Flores, 1934; Heck, 1934, 1947; Figueroa, 1963; Ponyavin, 1965; Iida et al., 1967).

Gutenberg, Richter (1954): 22.VI; $12^h59^m24^s$; 19° N., 104.5° W.; M=6.9.

1932, June 29. There was a tsunami at Cuyutlan (Heck, 1934, 1947). Iida's summary (Iida et al., 1967) casts doubt on the reliability of the data. Ordoñez (1933) notes that, as well as mild earthquakes, less strong incursions of the sea were observed many times in the south of Jalisco state and in Colima state after June 22.

1934, July 17, 21:30. A destructive earthquake with its source in /139
Chirika Bay (west of Panama) was felt on the coast with a force of about 7 degrees. The belts jumped off the conveyors for loading of bananas and the structures were bent at the moorages at Puerto Armuelles. The water main and the sewer system in the city were broken and several homes were destroyed, but solid buildings did not suffer serious damage; the population was frightened and many spent the night on the street. The base of a triangulation tower was shifted about 1 cm downhill 20 km south of the city. At David, the damage was estimated at 50,000 dollars: walls collapsed, iron and tile roofs sagged and almost all homes suffered some damage. Four persons were injured in the fall of adobe homes. A strong seaquake was felt on several American hydrographic ships, riding at anchor in the focal zone, particularly at Punta Burica and Montuosa Island. A crack 1/2-1 m wide and 6 m deep developed along the axis of Montuosa Island. Collapses took place on other islands in the focal zone. In homes in the Panama Canal zone, the stucco collapsed, mirrors and dishes fell and clocks stopped; several cables and water mains and sewers were broken; machines broke down; partitions cracked; a resident jumped from a third floor window in panic. The earthquake was followed by a large number of aftershocks.

Apparently, a tsunami developed during the earthquake. At Puerto Armuelles, two large anchored buoys were displaced 300 m from the moorage out to sea, in such a way that their relative position did not change. The water level several times passed the mark of the highest high tides,

although flood tides should have been small at this time of year. The main street of the Indian village was covered with water several times and a number of homes facing the sea were completely washed out.

The well of the temporary tide gauge, set up at Puerto Armuelles by the American hydrographic expedition, was also washed away. Ten minutes after the earthquake, this instrument apparently began to register a tsunami beginning with a strong ebb tide wave (Fig. 55). During all this, nothing unusual was observed on the surface of the water (Kellar, 1935; Neumann, 1936).

Gutenberg, Richter (1954): 18.VII; $01^h36^m24^s$; 8° N., 82.5° /140
W.; M=7.7.

1941, December 5. An earthquake at Panama and Costa Rica causing oscillations in sea level, was recorded by the tide gauge at Puntarenas (Costa Rica). The record of oscillations began at 15:45, on 90° West meridian time, and lasted 6 hours. The average amplitude of oscillations was 22 cm (3/4 feet), the period about 3/4 of an hour. The oscillations occurred during the flood tide (Neumann, 1943).

Gutenberg, Richter (1954): 5.XII; $20^h46^m58^s$; 81.5° N.; 83° W.; M=7.5.

1941, December 6. The tide gauge at Puntarenas registered oscillations in sea level. They began at 16:20, on 90° West meridian time and lasted abc t 8 hours. The mean amplitude of oscillations was less than 8 cm (1/4 ot), while the average period was between 10 and 15 minutes. The oscillations occurred during the flood tide (Neumann, 1943).

Gutenberg, Richter (1954): 6.XII; $21^h24^m40^s$; 8.5° N., 106.5° W.; M=6.9.

1948, December 3. The Las Tres Marias Islands, which serve as a place of exile, were hit by destructive earthquakes and a tsunami. At least four people died and several persons were injured. Considerable material damage was done on Maria Madre Island [the largest of the islands] (SN, 1949, vol. 39, N 1).

Gutenberg, Richter (1954): 4.XII; $00^h22^m48^s$; 22° N., 106 1/2° W.; M=6.9.

1950, October 5, 10:10. There was a strong earthquake at Costa Rica. At San Jose, the frightened residents ran into the streets; several people were injured in the crowd. Destruction was reported at Puntarenas. In addition, the tide gauge at Puerto Armuelles (Panama) was destroyed by the earthquake. The tide gauge at Puntarenas (Costa Rica) felt a tremor and soon after registered seiches, or possibly a tsunami, with an amplitude of 10 cm and a period of 30 minutes. In El Salvador, the tsunami was registered by the tide gauge at La Union with an amplitude of less than 10 cm and a period of 43 minutes and with a height of 8.9 cm by the tide gauge at La Libertad. A mild tsunami was registered

by the tide gauge at San Juan del Sur (Nicaragua) and also at Hilo (Hawaiian Islands) where the amplitude of oscillations was 10 cm, the period 18 minutes (SN, 1951, vol. 41, N 1; Murphy, Ulrich, 1952; Iida et al., 1967).

Gutenberg, Richter (1954): 5.X; $16^h09^m31^s$; 11° N., 85° W.; M=7.7.

1950, October 23, 10:13. There was an earthquake at Guatemala, causing heavy destruction at San Marcos. Only scattered buildings escaped damage in the city, and the majority of homes were destroyed. There were injuries. The earthquake was preceded by shocks at 13:38, 14:55 and 15:04, and was followed by many recurrent shocks.

In 2.2 hours after the earthquake, the tide gauge at San Jose (Guatemala) registered a wave with an amplitude of 20 cm and a period of 15 minutes. There were barely noticeable oscillations with an amplitude of less than 10 cm and a period of 30 minutes on the record of the tide gauge at La Union (El Salvador). The tsunami was not recorded by other tide gauges in Mexico and Central America, but was registered 9.3 hours later at Hilo, where it had a height of 10 cm and a period of 16 minutes (SN, 1951, vol. 41, N 1; Murphy, Ulrich, 1952; Iida et al., 1967).

Gutenberg, Richter (1954): 23.X; $16^h13^m20^s$; 14 1/2° N., 91 1/2° W.; M=7.1.

1950, December 14, 8:16. A heavy earthquake in the southeast and center of Mexico did considerable damage. It was felt in the capital with an intensity of about 5 degrees; the residents took to the streets in panic; stucco and tiles fell; a wall of a 13-story building crashed down; electrical circuits were broken.

The earthquake generated a series of waves, which were recorded /141
0.3 hours later by the tide gauge at Acapulco. The peak wave had an amplitude of 30 cm and a period of 23 minutes. Other tide gauges in Mexico and Central America did not register the waves. On the Hawaiian Islands at Port Allen, a tide gauge registered a tsunami with an amplitude of less than 10 cm and a period of 25 minutes (SN, 1951, vol. 41, N 1; Murphy, Ulrich, 1952; Iida et al., 1967; Pararas-Carayannis, 1969).

Gutenberg, Richter (1954): 14.XII; $14^h15^m51^s$; 17° N., 97 1/2° W.; M=7.3.

1952, May 13, 13:32. There was an earthquake at Costa Rica. The tide gauge at Puntarenas registered a single ebb tide wave with an amplitude of less than 10 cm, 12 minutes after the shock (Iida et al., 1967).

[19^h32^m; 10 1/2° N., 85° W.; M=6.7.]

1957, July 28, 2:40. There was a destructive earthquake with source near San Marcos. Table 13 gives an idea of the effects of the earthquake near the focal zone.

Table 13

Effects of the earthquake of 18.VII.1957.

Point	Number		Percentage of damaged buildings
	Dead	Injured	
San Marcos	-	11	95
Chilpansingo	7	-	90
Chilapa	-	7	70
Huamustitlan+	-	3	60
Ayutla	4	1	-
San Luis Acatlan	-	-	60
Uitzuco+	-	-	50
Tlapa	-	-	50

In Mexico City, at a distance of 350 km from the source of the earthquake there were 54 dead; only buildings on loose water-saturated soils were destroyed.

The earthquake was felt on an area of 350,000 km^2. Fig. 56 shows a map of the isoseismals.

The earthquake was followed by a tsunami, which was registered by the tide gauges at Acapulco, Salina Cruz and Manzanillo (Fig. 57). The tide gauge at Manzanillo, which registered the start of the wave, stopped due to a faulty mechanism. The tsunami was not registered by other tide gauge stations on the coast of Mexico. The main data about the tsunami are given in Table 14 (Merino y Coronado, 1957 a,b; SN, 1958, vol. 48, N 1; Brazee, Cloud, 1959; Rothé, 1959; Iida et al., 1967).

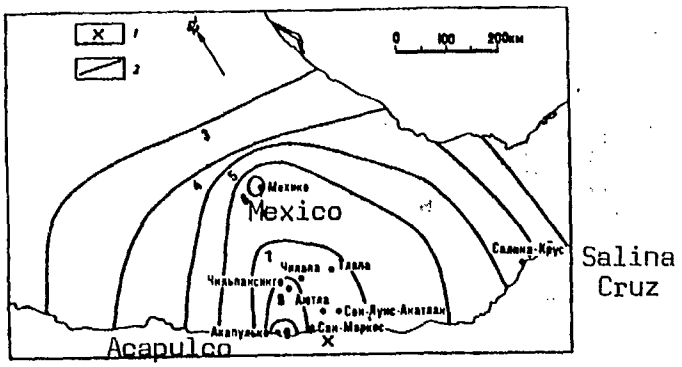


Fig. 56

Epicentre (1) and isoseists (2) of the earthquake of 28.VII.1957 on the 12 point scale (Figuero, 1957).

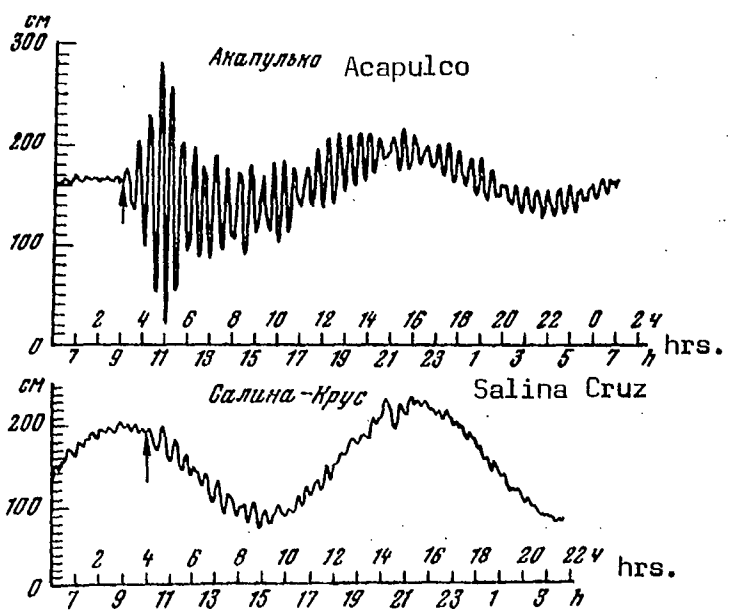


Fig. 57

Records of the tsunami of 28.VII.1957 (Merino y Coronado, 1957a).

/142

Table 14

Tide gauge data on the tsunami of 28.VII.1957.

Observation point	Travel Time hr	min	Maximum range of oscillations in level, m	Period of oscillations, min	Duration of oscillations hr	min
Acapulco	0	13	2.6	30	20	07
Salina Cruz	2	07	0.3	30	11	20

Figueroa (1957): 28.VII; $08^h40^m00^s$; 16° 21' N., 99° 13' W.; 25 km, M=7.5.

1962, March 12. There was an earthquake with source off the coast of Panama and Costa Rica. It did light damage at Puerto Armuelles and David. It was felt at Balboa with an intensity of 5 degrees (many people woke up) and at Panama. A small tsunami occurred and was registered 2.7 hours later by the tide gauge at San Cristobal (Galapagos Islands; see Fig. 77) with an amplitude of 10 cm and with approximately the same height by the tide gauge at Puerto Armuelles (Lander, Cloud, 1964; Iida et al., 1967).

[12.III; $11^h40^m12.2^s$; 8.1° N., 82.9° W.; M=6.8.]

1962, May 11, 8:12. There was an earthquake with an intensity of 8 degrees at Acapulco, where there was destruction, four dead and many injured. At Mexico City, the earthquake had an intensity of up to 7 degrees.

A tsunami with a height of 75 cm (2.8 feet) was registered at Acapulco (SN, 1962, vol. 52, N 4; Lander, Cloud, 1964; Rothé, 1964; Hamamatsu, 1966; Iida et al., 1967).

[11.V; $14^h11^m54.1^s$; 17.2° N., 99.7° W.; 40 km; M=7.2.]

1968, September 25. There was a strong earthquake at Salina Cruz (Mexico); 15 dead, 500 injured; great material damage was done. It is possible that a tsunami occurred with a height of 2 m (7 feet) (NL, 1969, vol. II, No. 1).

[25.IX; $10^h38^m38^s$; 15.6° N., 92.6° W.; 138 km; M=7.0.]

1812, December 21, 10:30. There was a strong earthquake in the south of California (Fig. 58), accompanied by an "enormous" tsunami in the Santa Barbara Strait (according to other sources, the tsunami was caused not by the first, but by a second, more powerful earthquake at 10:45).

The earthquake was preceded by a weaker shock on December 8, which was felt from San Diego as far as the Franciscan Mission of Purisima, situated approximately at the site of the present city of Lompoc[1]. At San Juan Capistrano, a church dome collapsed (largely due to the flimsiness of the structure); about 40 Indians, gathering for morning mass, were killed in the wreckage; other buildings at the mission were not damaged. At San Gabriel, the church cracked severely; the top of the building separated from the foundation; the icons fell from the altar and broke; most of the buildings at the mission were heavily damaged.

The following is known about the earthquake of the 21st. The church at San Fernando was seriously damaged. At Ventura, the church was so heavily damaged that the facade and dome had to be reset. At Santa Barbara, the buildings of the mission and the fort were damaged; recurrent shocks lasted several months; the residents left the settlement and lived in open air for two or three months. At Santa Inez, the roofs on all structures collapsed; the corner of the church building collapsed. At Purisima, the earthquake lasted 4 minutes and was so strong, that one could only remain standing with difficulty. Fifteen minutes to 30 minutes after the first shock, a second shock occurred. The church collapsed and all one hundred Indian homes and the public kitchen, made of adobe and covered with tiles, crumbled or cracked; several residents were injured. The mission was later rebuilt in another place. In the focal zone (possibly near Santa Barbara), the alluvial ground cracked; new mud volcanoes and asphalt springs appeared.

At Santa Barbara, the sea was restless. At Ventura, the population fearing a tsunami, moved 2-4 km (1-2 miles) from shore and lived there until April. A Spanish ship at Refugio was carried off by the waves to a canyon, and then returned to open sea (Bancroft, 1885, Holden, 1898; Sieberg, 1932; Heck, 1934, 1947; Townley, Allen, 1939; Gutenberg, Richter, 1949, 1954; Richter, 1958, 1963; Ponyavin, 1965; Iida et al., 1967; Joy, 1968).

1812. According to a report from a female resident of Spanish origin from San Francisco, related to another resident, in 1812 there was

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[1] The magnitude of the shock in the area in which it was felt can be estimated at 6 1/2 $\pm$ 1/2.

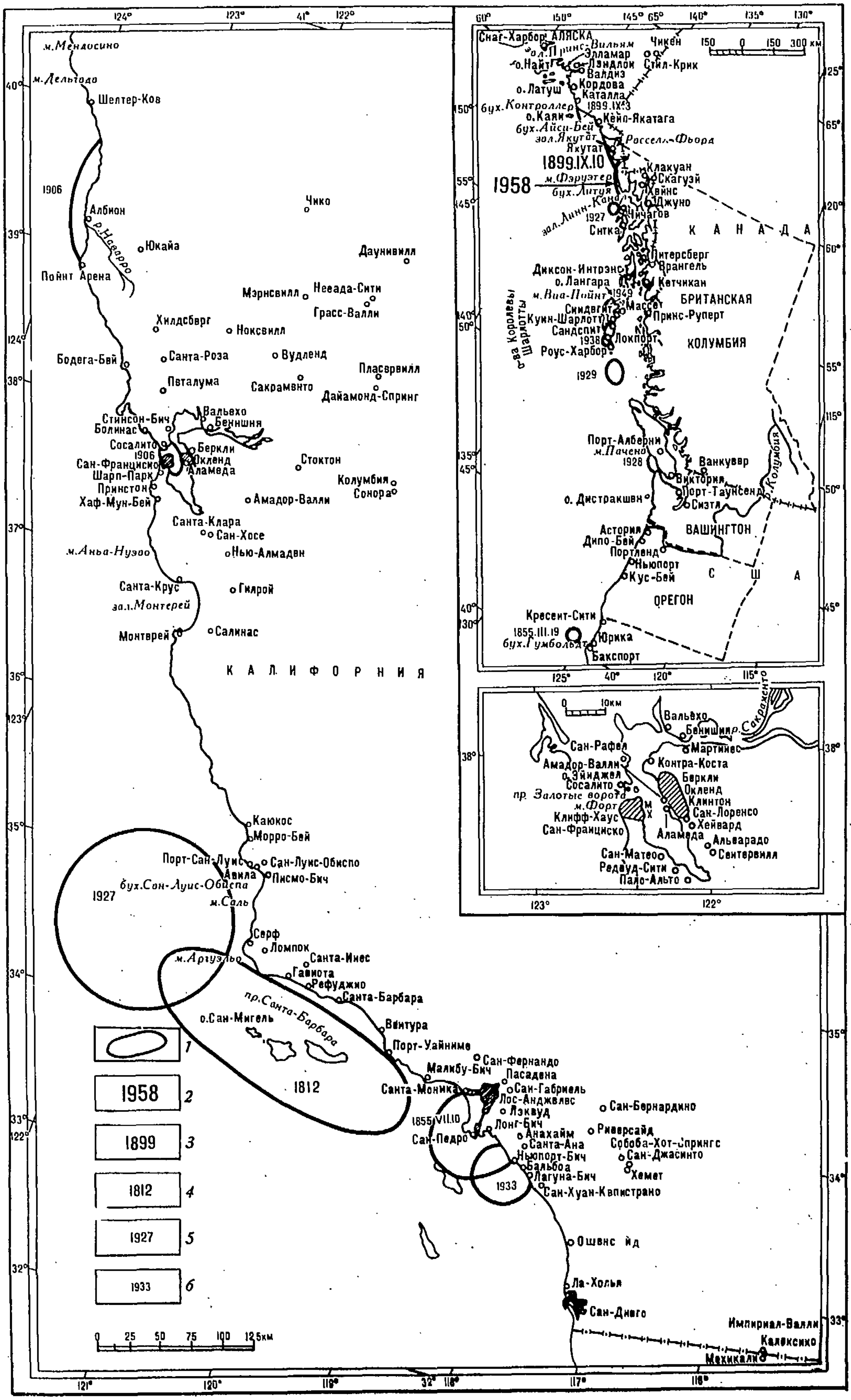


Fig. 58 The Pacific Ocean shoreline of USA and Canada

1 – the centres of tsunamis (definite or likely);
2 – the dates and intensities of the tsunamis I: 2 – I=4; 3 – I=3; 4 – I=2; 5 – I=1; 6 – I=0.

The letters on the inset indicate: M is Mission Bay; X is Cape Huntress.

an earthquake so strong that tidal waves arose, which flooded the place where the main street of the city is now located (Holden, 1898; Townley, Allen, 1939). Iida (Iida et al., 1967) assumes with justification that this report relates to the events of 21.XII.1812, and for this reason this description applies to the Santa Barbara region, and not to San Francisco.

1840, January 16-18. There is mistaken data in many catalogues (Holden, 1898; Heck, 1934, 1947; Townley, Allen, 1939; Iida et al., 1967) about an earthquake and tsunami at Santa Cruz. In fact, (Louderback, 1944) there were heavy waves at sea at Santa Cruz on January 16 and 17. /144
The water encroached inland approximately 170 m (200 vara) and washed away all the roofing material stocked up for the local community. On January 18, the bell tower collapsed at Santa Cruz due to prolonged heavy rain and weak ground.

1845. Yakutat Bay, there was the collapse of a glacier. It caused a wave. A hundred residents died (Miller, 1960 a; Cox, Pararas-Carayannis, 1969).

1851, March, April and then May 15, 17 and 28. At San Francisco and Salinas, there were mild shocks with marine flooding (Perrey, 1872 a). The tsunami is not mentioned in other sources. The American catalogues (Holden, 1898; Townley, Allen, 1939) give additional information only for the shock of May 15. They mention that it occurred at 8:10, lasted about 1/2 minute, had an intensity of 7 degrees at San Francisco and was felt on board ships in the harbor.

1851, November 13, 19:00. There was a shock at San Francisco; on board ship, "unusual movement of water" was felt (Perrey, 1854 a, 1856; Holden, 1898; Townley, Allen, 1939; Iida et al., 1967).

[It is possible that this was a seaquake.]

1853/1854. During studies in Lituya Bay, mainly in 1948 and in 1952-1953, clear traces of the past effects of a strong wave were found. Namely, along the northern and in places along the southern shore of the Bay, an age-old forest grew, beginning only at a certain well-marked boundary (Fig. 59). Below this boundary and as far as the zone of flood tides, there grew only a young forest. Judging by the number of rings on trunk sections, it was established that the wave arose between the middle of August 1853 and the beginning of May 1854.

The maximal known height of this boundary is 120 m (395 feet) above mean sea level; the maximal distance from the water line is 750 m (2500 feet); the known area of the zone of destruction of forest is 3 1/2 km^2. Judging from the remaining traces of erosion, the destructive force of the wave of 1853/1854 was little less than that of the waves of 1958.

According to an Indian legend, in the 60's of the XIX century, at the exit from Lituya Bay, eight canoes with people were lost in a sudden

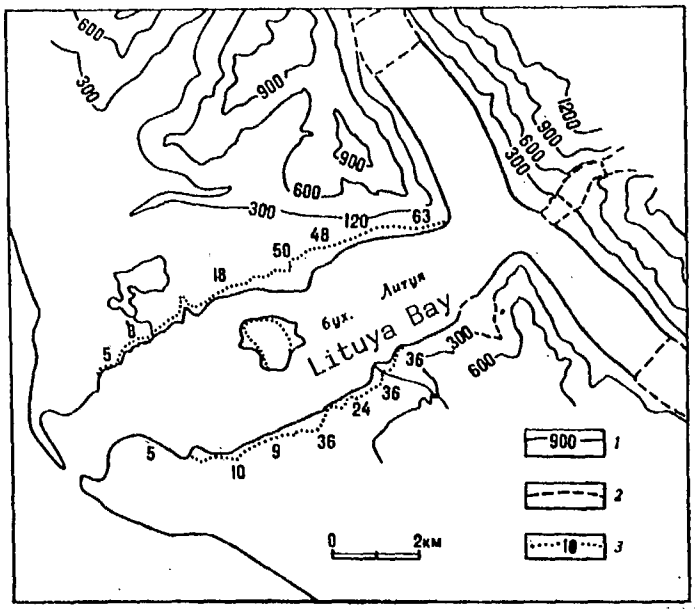


Fig. 59

The inundation in Lituya Bay in the years 1853/1854 (Miller, 1960a).

1 - contours (in metres)

2 - boundaries of the glaciers

3 - boundary of the flooding of the shore and height of the rise of water (in metres).

flood. The cause of the waves is unknown (Miller, 1954, 1960 a; Cox, Pararas-Carayannis, 1969).

1854, May 31, 4:50. There were three shocks at Santa Barbara. The first was accompanied by a muffled rumble and the second was preceded by a rustling like the approach of a strong wind. There was a pause of 4-5 seconds between the shocks. The people were frightened and fled their homes. The sea was very agitated, but did not do any damage (Perrey, 1859; Townley, Allen, 1939; Iida et al., 1967). In Joy's opinion (Joy, 1968), either these data are mistaken or these were seiches. /145

1854, October 26, about midnight. At San Francisco, there was a strong shock, felt also at Benicia. It was accompanied by sea waves. The ships riding off the embankment were shaken vigorously (Holden, 1898; Townley, Allen, 1939; Iida et al, 1967; Joy, 1968).

1854, November 1 or 10, or December 1? 10:00. On Angel Island (San Francisco region), in the absence of the slightest wind and with a calm surface of the sea, the water suddenly rose a metre (several feet) with enormous waves, lasting about a half hour. No one could remember the like here (Perrey, 1856; Holden, 1898; Townley, Allen, 1939; Iida et

al., 1967; Joy, 1968).

1855, March 19th, 16:30. An earthquake in the vicinity of Humboldt Bay was felt 55 km (30 miles) from Eureka. It was strongest at Backsport. Milk splashed from a saucepan. The discharge of water in the rivers changed. The water in Humboldt Bay was agitated for an hour (Perrey, 1857; Holden 1898; Townley, Allen, 1939).

1855, July 10, about 20:00. At Los Angeles, there was a strong earthquake which caused substantial damage. Cracks 2-5 cm wide formed in the ground at many places and remained for several days. Twenty-six buildings were damaged in the city, including the church. It was mainly walls, made of unpolished stone, which were destroyed. The bells were cast down from the bell tower at San Gabriel. The earthquake was felt 15 km east of San Bernardino and at Santa Barbara.

At San Juan Capistrano, immediately after the earthquake, movement of the water accompanied by a dull loud rumble was noted. Two unusually large waves surged on shore (Perrey, 1857, 1865; Holden, 1898; Heck, 1934, 1947; Townley, Allen, 1939; Ponyavin, 1965; Iida et al., 1967; Joy, 1968).

1855, October 21, 19:45. There was a strong earthquake at San Francisco. Homes situated on the shore felt peculiar tremors. Ships riding at anchor were dragged with their anchors by a current for several minutes before the shock; the surface of the sea was very agitated (Perrey, 1857; Holden, 1898; Townley, Allen, 1939).

1856, February 15, 5:20. At San Francisco, the strongest (since 1848) earthquake occurred lasting about 10 seconds (8 degrees). It was preceded by mild shocks and an underground rustling. It was accompanied by a rumble. It was 7 degrees at Oakland, 6 degrees at San Jose, 5 degrees at Monterey, 4 degrees at Bodega Bay. There was a shock at Santa Rosa (4 degrees?) but nowhere to the north. There was a mild shock at Stockton but nowhere to the east. It may have been felt at Knoxville. It was not felt at Sacramento, Marysville, Placerville, Downyville, Nevada City, Diamond Spring, Columbia, Sonora, Contra Costa, Alameda, Santa Clara, Alvarado, Clinton and other places.

The water in San Francisco Bay rose, kept a high level for five minutes, and then dropped 1/2 m (2 feet) below the usual level (Perrey, 1859; Holden, 1898; Townley, Allen, 1939; Iida et al., 1967).

1859, September 24, 3:00 (or October 18, 6:00). There was an earthquake at San Francisco and Half Moon Bay. The schooner "Black Warrior" was riding at anchor in Half Moon Bay. Suddenly the water retreated 4 1/2 m (15 feet) and the ship found itself on dry bottom, where it stayed for several seconds. Then the water returned so fast that it damaged the schooner (Perrey, 1862 a; Holden, 1898; Townley, Allen, 1939; Iida et al., 1967).

1861, May 5 (or 4). In the second half of the day, there was a

light underground shock in the vicinity of San Francisco. It was noticed that during this week the ebb tide dropped 30-45 cm (a foot or 18 inches) below the lowest mark, at which it had previously stopped. The shoals in the bay between Chévres Island and the Oakland River* dried up twice so that one could walk across them without getting one's feet wet (Perrey, 1864 a; Holden, 1898; Townley, Allen, 1939).

1865, October 4, 12:45. There was a destructive earthquake in California, possibly caused by a small shift along the San Andreas fault in the Santa Cruz region. All brick homes were damaged, and stoves collapsed. There were abundant rock falls in the mountains. The ground along the river cracked, and gryphons spurted. The water splashed out of small bodies of water, or they were covered with sand. The water level dropped in wells. At New Almaden, several homes collapsed and there were rock falls. Cracks opened and closed in the ground, ejecting clouds of dust. /146

At San Francisco, a strong shock lasted 5 seconds, and then after a very short pause, another, considerably stronger shock lasted 10 seconds or more. The stucco cracked in all buildings, and here and there it fell off in sheets. Several buildings collapsed, but no one died. The water main and the gas main broke on swampy sections. Cracks up to 2 cm were formed in the ground.

The effect of the earthquake on the water of Mission Bay and on Long Bridge* was terrifying [?].

At San Jose, one of the walls of the jail and the wall of the church collapsed; the bells rang by themselves. At Santa Clara, some of the stoves were destroyed and the stucco collapsed in all homes. At Sacramento, the earthquake was strong and caused dizziness, although it did no damage. The earthquake was strong at Petaluma and Stockton.

The area of tremors extended 190 km to the north and 190 km to the east of San Francisco. The earthquake was not felt at Eureka, Marysville, Placerville, Santa Barbara or south of Monterey Bay. The schooner "Fayaway," situated 45 km (25 miles) from Ano Nuevo Cape felt a very strong shock.

The earthquake was accompanied by aftershocks, which were felt at San Jose, Santa Clara and Santa Cruz.

According to the newspapers, at the moment of the earthquake, the flood tide rose very high and was then succeeded by a very strong ebb tide (Fuchs, 1866, 1885 b; Perrey, 1867; Holden, 1898; Lawson et al., 1908; Davison, 1936; Townley, Allen, 1939).

1868, October 21, about 8:00. In California there was an earthquake, more destructive than all known earthquakes since the foundation of the mission there in 1776. Apparently, it was caused by a shift along the Hayward Fault (Davison, 1936; Richter, 1963). Besides small horizontal movements, the southwestern flank probably subsided. The intensity

of tremors was greatest along the fault. At Hayward, almost all homes were tumbled from their foundations - X degrees [according to R.F. scale].

At San Francisco, the earthquake lasted about 2 minutes and caused great destruction to structures on filled grounds, as a result of which they settled slightly. Well-built homes on bedrock hardly suffered. Thirty people, out of the 150,000 population of the city, died in the wreckage of buildings - IX degrees.

Basically the following is known about the effects at sea. Two sailors in a small boat were rowing between Cape Fort and Mill House* towards San Francisco Bay. Suddenly the water trembled, and its surface rippled; at the same time, a booming rumble was heard from the depths. At the same time with complete still, three high waves appeared on the previously calm surface of the water to the northwest. They fell on the boat and broke on shore.

Other boats and ships, riding in the harbor, reported no marked disturbances of the water. The tide gauge at Cape Fort in no way registered the earthquake. However, a tide gauge on Government Island* registered an unusual rise of water. In addition it was reported that a small flood tide was observed off Cliff House. After the earthquake, a large wave surged onshore here, rising 4 1/2-6 m (15-20 feet) above the usual mark.

At Oakland, buildings and pipes were destroyed - IX degrees. The water in the bay was calm, and no waves caused by the earthquake were observed.

Off Sacramento, the water in the Sacramento River rushed back, leaving the "Globes" on dry bottom, and soon thereafter returned in a wave at least 1/2 m (2 feet) high. Ships riding at anchor were tossed about. /147

At Santa Cruz, 2-3 seconds after the first shocks, it was noticed that water was rushing up river, against the current, and only after some time did all quiet down.

At Martinez, Alameda, Alvarado, San Lorenzo, Hayward, and Redwood City, IX degree tremors were recorded, at Amador Valley and Vallejo, VIII degrees, and at Marysville VII degrees.

The earthquake was strong or very strong at Grass Valley, San Mateo, San Jose, Gilroy, Santa Cruz, Healdsberg, Woodland, Centerville, Stockton, San Rafael, Petaluma, Santa Rosa, Contra Costa and other points.

The earthquake was moderate at Sonora and other places. It was not felt north of Chico and south of Monterey (these points are 350 km apart). In particular, the earthquake was not felt at Los Angeles and San Diego (Fuchs, 1869, 1885 b; Griesbach, 1869; Perrey, 1872 a; Holden, 1898; Lawson et al., 1908).

1869, February 13, 4:30. There was a light shock at San Francisco. The tide gauge established at Fort Hornet* recorded several earthquakes at unknown points (Perrey, 1873).

1872, August 24. A tsunami of remote origin was observed at Astoria, San Francisco and San Diego. There are no details available. Almost at the same time, a weak tsunami was observed on the Hawaiian Islands (Joy, 1968).

1872, September 16/17. Oscillations in level of the tsunami type were recorded at Astoria, San Francisco and San Diego. There are no details available (Joy, 1968).

1874. At approximately this time, a wave may have arisen in Lituya Bay (Fig. 60). It washed away the forest on the northern shore, on a stretch of at least 7 1/2 km (4 miles), at a height of up to 25 m (80 feet) above the high tide line. The cause of the wave is unknown (Miller, 1960 a; Cox, Pararas-Carayannis, 1969).

1877, April 19, 6:00. A light earthquake was felt in San Luis Obispo Bay. According to dubious data, a tsunami 3.6 m (12 feet) high was observed at Cayucos and Anaheim Landing*. It is possible that this has been confused with the Chilean tsunami of 10.V.1877 (Joy, 1968).

1878, November 22. According to some sources, there was a wave 2 m (6 feet) high at Wilmington [southern suburb of Los Angeles]. Waves, which did some damage, were observed in San Luis Obispo Bay, Surf, Sal Cape, at Port Harford*, Pismo Beach, Avila, Morro Bay and Cayucos (Joy, 1968).

1879, August 10. There was a rather strong shock at San Fernando - IV-V degrees (according to other sources, 5-6 degrees). There was a very light shock at Los Angeles. There was a tsunami at Santa Monica (Holden, 1898; Townley, Allen, 1939; Iida et al., 1967; Joy, 1968). /148

1880, October 26, 13:30 (according to other sources, 20:45). At Sitka, there was a tornado, accompanied by an earthquake, which terrified the residents and did great damage. Half an hour later, a second shock was felt, and another seven or eight shocks occurred during the next two days. The first shock lasted about 30 seconds; then a large tidal wave appeared. The earthquake was strong at Honniak Village*+. Shocks were felt along the entire cost of Canada, but were not noticed on Kodiak Island. In the same year, a strong earthquake occurred on Chirikov Island (Aleutian Islands) with the formation or revival of a surface fault (Fuchs, 1881, 1885 b; Petroff, 1884; Heck, Eppley, 1958; Plafker, 1969).

1884, January 25, 19:24. Fuchs mentions mistakenly a sea wave resulting from the earthquake on the coast at San Francisco (Fuchs, 1887 a). In fact, this relates to the registration of long-period seismic waves from a remote earthquake by instruments at the astronomic observatory at San Francisco (Townley, Allen, 1939).

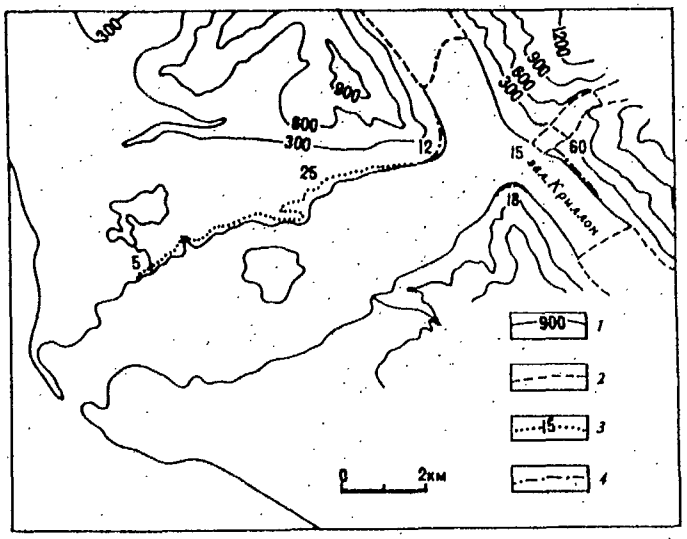


Fig. 60

The evidence of one or several waves in Lituya Bay between 1854 and 1916 (Miller, 1960a).
1- contours (m)
2- boundaries of the glacier
3- boundaries of the coastal flooding and the height of the rise of water (m)
4 - deforested sections of the mountain slopes after the passage of the tsunami

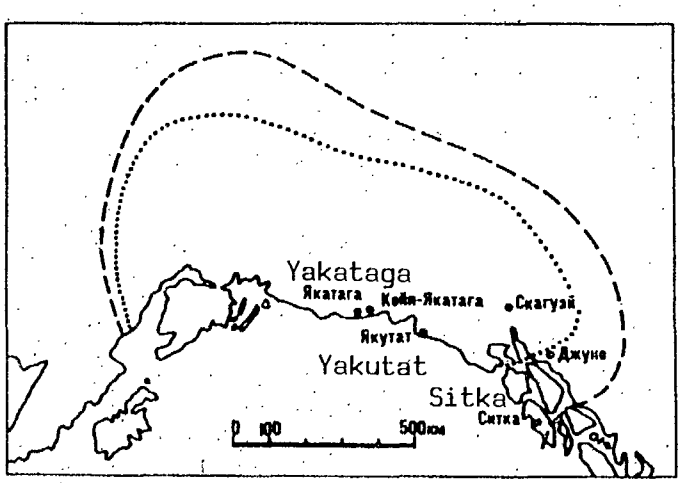


Fig. 61

The approximate areas over which were felt the earthquakes of 3 September 1899 (dotted line) and 10 September 1899 (dashed line) (Tarr, Martin, 1912).

1884, November 12. The tide gauge at Sansalito (San Francisco region) recorded movements of the water, probably caused by an underwater earthquake. They began at 8:00, continued until 11:00 and amounted to nine waves only a decimeter (a few inches) in height (Fuchs, 1885 b; Holden, 1898).

1885, November 19. The record of the tide gauge at San Francisco and the level readings by astronomical instruments from 13:00 to 20:00 show waves with a period of about 35 minutes, apparently from a remote earthquake (Detaillé, 1886; Fuchs, 1887 b; Holden, 1898; Milne, 1912 b; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967).

1887, July 8. A study of the tide bulletin of the Coast Guard station at Sansalito for July, shows that a distinct wave caused by an earthquake entered San Francisco Bay at 16:00. The oscillations gradually abated and disappeared at 19:30 (Detaillé, 1888; Holden, 1898).

1895, March 8/10 or 30. A small schooner, riding in the harbor at San Miguel Island, was damaged by a slide caused by an earthquake. Neither the earthquake nor the tsunami was noticed on the continental coast (Joy, 1968).

1895, October 14. The record of the tide gauge at Sansalito shows traces of a heavy storm or an earthquake. The irregular trend in level begins at 8:20 on the 14th and continues uninterrupted for 18 hours (Holden, 1898).

1896, December 17, 8:00. At Santa Barbara, a tidal wave, the strongest in the entire history of the city, surged on the littoral boulevard and washed away a section of the embankment and the expensive thoroughfare. The boulevard had been built five years ago to withstand waves. However, the waves which fell on it washed away, in retreating, the greater part of the asphalt covering, the solid masonry, and the heavy iron frame with a total area of 4.5 m^2 and a depth of 2.5 m. A large sandy hill, situated between the boulevard and the regular flood tide line, was completely washed out to sea (Holden, 1898; Iida et al., 1967; Joy, 1968).

1899, September 3, 15:03. There was a catastrophic earthquake with source near Cape Yakataga (Fig. 61).

At Cape Yakataga, trees rocked so heavily that their crowns broke off. Numerous slides occurred in the mountains. Visible waves on the earth's surface were reported. Buildings were not destroyed. The shore rose 1 m (3 feet). There were many recurrent shocks.

The earthquake occurred at the half ebb. The sea receded from shore, and its level fell to full ebb tide in 20 minutes.

The schooner "Bellingham" was situated 2 km (a mile) from Cape Yakataga. A strong seaquake was felt on board, and lasted about 2 minutes. On a stretch of coast at least 200 km (110 miles) long, from

Icy Bay to Kayak Island, clouds of dust could be seen rising in the air from numerous avalanches, slides, and collapses; this process spread from one end of the coast to the other in about 5 minutes. /149

An ebb tide, with a speed of about 3-4 knots, began from shore; a ship was dragged and the anchor chain stretched. After a rather long interval, the ebb tide was succeeded by a slow flood tide, which reached half the height indicated in the flood tide tables. During the day on the 4th, a ship approached Kayak Island with great difficulties.

The earthquake was felt over a very large area (see Fig. 61). In particular, at Seagway, homes and posts swayed noticeably; various objects were cast down; it was difficult to stand. Small flood tide waves in Lynn Canal 1/4-1/2 m (1-2 feet) high were reported [these were obviously seiches, not a tsunami] (Tarr, Martin, 1912; Davison, 1936; Cox, Pararas-Carayannis, 1969).

Richter (1963): 4.IX; 0^h22^m; 60° N., 142° W.; M=8.3.

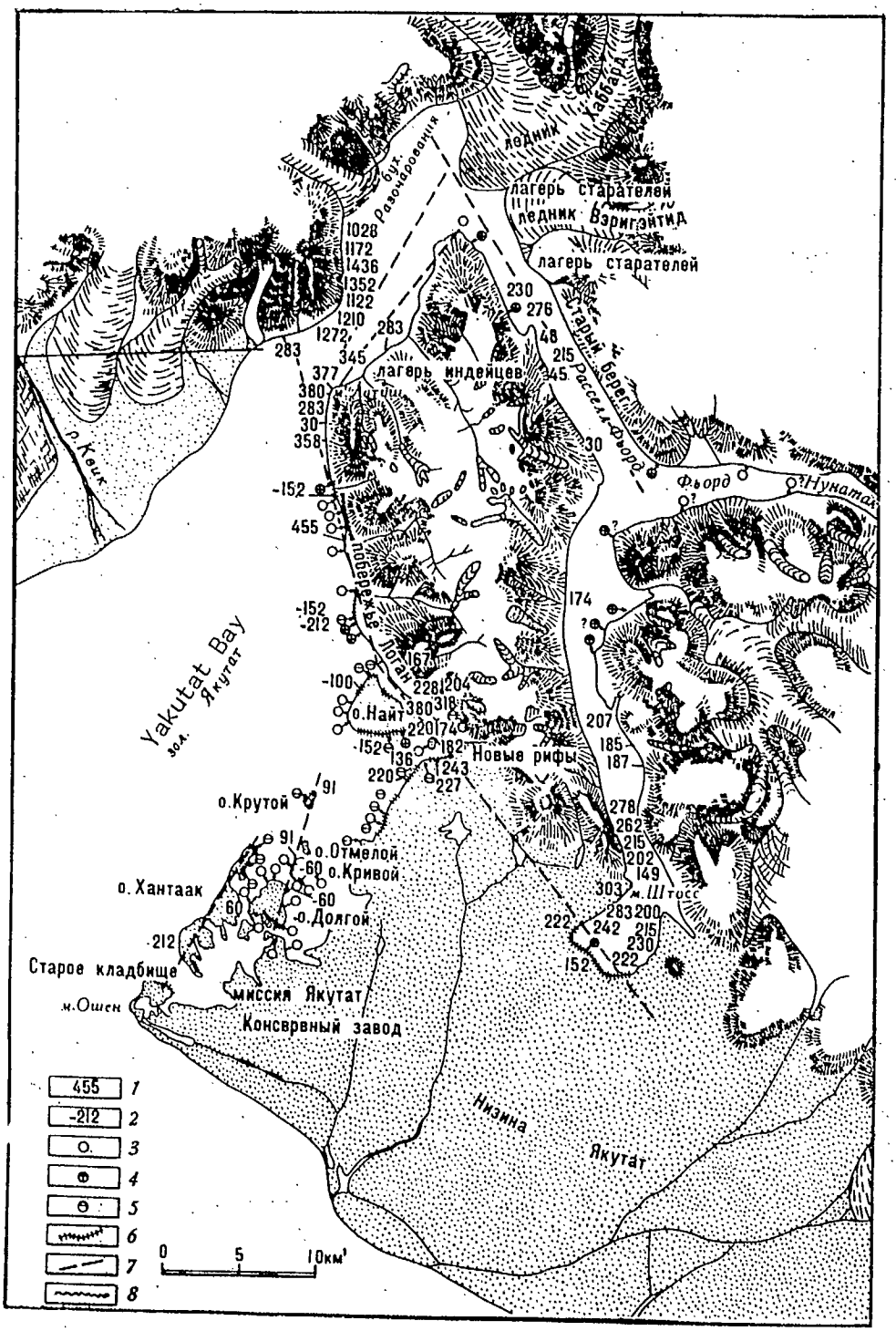
1899, September 10, 12:15. There was a catastrophic earthquake with source at the tip of Yakutat Bay. Large block dislocations occurred along the fault system. The main dislocation was apparently the elevation of the mountainous block of the eastern shore of Yakutat Bay relative to the floor of the Gulf and the lowlands at Ocean Cape by up to 15 m (Fig. 62). A secondary movement occurred along a smaller parallel fault, passing through Russel Fjord: its eastern shore rose somewhat above the western shore (as if the more continental block had shifted onto the littoral block of Yakutat Bay). The tectonic movements caused numerous large collapses and slides, including the breakup and collapse of glacier tongues. The earthquake was felt in the area shown in Fig. 61, based on the known data.

The tectonic movements and, to some extent, the collapse of large masses of ice and rocks into the water, were the cause of the appearance of a tsunami and seiches, about which the accounts of a few eyewitnesses and the findings of the field studies of Tarr and Martin in the summer of 1905 are available.

At the mouth of Russel Fjord, on its eastern bank, eight gold prospectors were situated in the moraine of the Hubbard and Variegated glaciers. Some of them were sitting in a tent. The shock was so great that one of them was thrown over the stove, while the others barely managed to hold onto the tent posts. Strong long-period oscillations lasted about 3 minutes. The tongue of the Hubbard glacier broke off on a stretch of 9 km (5 miles) and slipped 1 km (half a mile) into the bay. Water poured out of the small lake and rushed downwards.

Immediately after the flood, a roller 6 m (20 feet) high surged onshore. Individual splashes and streams of water about a meter (several feet) in diameter rose 12-16 m (30-40 feet). The first roller was followed by a second 6-9 m (20-30 feet) high. After the waves, a mass of dead fish remained on shore. Sailing in the next [few] days to Yakutat and /151

Fig. 62- Changes of the relief in Yakutat Bay after the earthquake of 10.IX.1899 (Tarr, Martin, 1912). 1-rise of the shoreline (cm); 2- drop of the shoreline (cm); 3- sections of the shore which without question did not alter their level; 4- a slight rise of the shoreline, the amount of which was not established; 5- a slight drop of the shoreline, the amount of which was not established; 6- parts of the shore recently submerged under water; 7- tectonic faults; 8- glaciers which had cracked and had moved ahead (up to 1906).



rounding Latouche Cape, the prospectors continued to see clear traces of the rise of water, here and there to a height of 12 m (60 feet).

At Yakutat, according to eyewitnesses, the water became very agitated after the earthquake, and at least until nightfall the level rose and fell 2 1/2-3 m (8-10 feet) every 8-10 minutes.

According to one account, as soon as the earthquake had ended, flood tides rolled in from the sea. There were at least three large waves. The water level rose from the ebb tide mark, which occurred at the time of the earthquake, to 0.3 m (1 foot) above the high tide mark, that is, it rose 4 1/2 m (15 feet). Eddies formed in the bay, in which trees, driftwood and all kinds of rubbish circled so rapidly that it was difficult to follow individual objects. The water foamed up and was covered with whitecaps on the whole expanse. Reaching the chute of the sawmill, the whirlpool tore it off and carried it away in an instant.

According to another witness, after the earthquake the water in the bay began to retreat stormily and passed the line of the lowest low tides. Soon afterwards, the water returned in a strong current and covered the shore over a considerable stretch. Everything around the Indian huts was flooded and washed away, and the huts themselves were very nearly washed away.

On September 12, one of the residents, sailing on a steamship from Yakutat to Juneau, noticed a belt of turbid water and a mass of floating t os in the sea between Yakutat and the Fairweather mountains.

At Katalla, situated at the top of Controller Bay, a flood tide 1 1/4 m (4 feet) high rose upstream along the Bering* River.

At Valdez, a wave up to 2 m (7 feet) high rolled onshore.

The records of the tide gauges at San Francisco and near the mouth of the Yukon River (see Fig. 77) showed no unusual oscillations in level.

On investigating the coast in 1905, clear traces of destruction by the tsunami were found on many sections of the coast, mainly near the line of the main fault of the earthquake.

In the region of Logan coast, approximately between Knight Island and Cape Latouche, the bench and more deep-sea regions were completely flooded. On a high terrace, where a mature forest had grown until 1899, there remained a dense almost impassable tangle of trees which had been uprooted, broken, twisted and tossed about; they were entangled with trees remaining standing, but tilted. All vegetation was destroyed up to a height of 12 m (40 feet). Even strong, 75 year-old trees were broken. Retreating, the water tossed about the trunks of felled trees on the lower terrace (the beach elevated in 1899) and on the new beach.

The tsunami was also destructive on the western shore of Yakutat

Bay, near the entrance to Disenchantment Bay, west of the main fault. The water encroached 1/2 km (1/4 mile) on land, rose to a height of 9 m (30 feet) and partly destroyed groves of poplars. Tree trunks were strewn along the edges of the flood zone at the boundaries of the surviving groves. Some willows between this line and the shore remained standing, but died; their branches and shoots were turned seaward by the retreating water and the bark was torn off the trees.

At the top of Russel Fjord, at Cape Stoss, the water passed over a sandy dike, joining the rocky island to the continent. Here much driftwood remained on the elevated places and for many hundreds of meters (yards) from the shore. There, and at other places on the coast, according to the Indians, large fields of strawberries perished.

In the delta of the Kwik River, the tsunami passed 1/2 km (1/4 mile) across the modern bar and lagoon to the old bar, on which grew a grove of poplars. Judging from the driftwood remaining, the water rose 4 1/2 m (15 feet) relative to the level of the beach, but the force of waves was insufficient to fell the trees. From here to the entrance of Disenchantment Bay, driftwood lay everywhere far beyond the reach of the highest regular waves.

At other places in the bay, traces of the tsunami were considerably fewer. In particular, a forest on lowlying Knight Island, almost reaching the water, did not suffer (Milne, 1900 b, 1912 b; Tarr, Martin, 1906, 1912; Montessus de Ballore, 1924; Davison, 1936; Heck, 1934, 1947; Gutenberg, Richter, 1949, 1954; Ponyavin, 1965; Iida et al., 1967; Cox, Pararas-Carayannis, 1969). /152

Milne (1912 a): 10.IX; 21^h38^m; 59° N., 140° W.

Richter (1963): 10.IX; 21^h40^m; 60° N., 140° W.; M=8.6.

1899. In Lituya Bay, a wave may have arisen and washed away the forest on the northeastern shore of Crillon Bay at a height of up to 60 m (200 feet), and to a lesser extent on some other selections of the coast of the bay. It is surmised that the wave was caused by a large avalanche as a result of the catastrophic earthquake of 10.IX.1899 (Miller, 1960 a; Cox, Pararas-Caryannis, 1969).

1899, December 25, 4:25. There was a strong earthquake in Southern California, apparently caused by a shift along the San Jacinto fault on its highest mountainous section, several miles southeast of San Jacinto, where many large cave-ins occurred. Almost all the brick buildings were damaged at San Jacinto. At Hemet, only two stoves remained standing. At Soboba Hot Springs, several miles east of San Jacinto, six Indians were killed and eight were injured by the collapse of the wall of an adobe. Strong tremors, with no destruction, were felt at Santa Ana, Anaheim, San Bernardino, Riverside, San Diego and at other places (Milne, 1900 b; McAdie, 1907; Townley, Allen, 1939; Richter, 1958; Richter 1963). Milne noted (1900 b) also, that a large high wave broke on the seacoast without doing any damage. /153

Milne (1900 b): 25.XII; 12^h25^m; 34° N., 117° W.

1904, March 30. There was an earthquake in the State of Washington, as a result of which, it appears, the water rose in Grays Bay (Fig. 63), and in the mouths of the Queet Quinault, Wishkah and Hoh Rivers (Oddone, 1907).

1905, July 4. Yakutat Bay, there was a slip of the Fallen Glacier* in Disenchantment Bay (see Fig. 62); waves up to 35 m high. At Russell Fjord, waves 4 1/2-6 m high lasted for half an hour (Miller, 1960 a; Cox, Pararas-Carayannis, 1969).

1906, April 18, 5:12. There was a catastrophic earthquake in California, which destroyed San Francisco. It was caused by a right-hand horizontal shift of the flanks of the San Andreas fault by up to 4 1/2-6 m on a stretch of 350 to 550 km, according to different estimates (Fig. 64).

The earthquake began with weak oscillations, and lasted, according to different estimates, from 1 to 3 1/2 minutes. At San Francisco, according to official data, 28,188 homes were destroyed; about 380 people died. The fire which broke out did more damage than the earthquake itself. The destruction from seismic oscillations was largely due to the settling of filled in ground. The settling varied from 10 cm to 1 m. At several places on the coast, homes slid downward towards the sea by up to 1/2 m (2 feet).

Everywhere on the high steep coast from Mendosino Cape to Cabo Delgada, on a stretch of many kilometers, slopes collapsed into the sea. On the lower coast between Shelter Cove and Point Arena, bedrocks and loose material slipped into the sea, and the water was turbid for several days after the earthquake.

At San Francisco, a tide gauge, set up 3 km (1 1/2 miles) east of Cape Fort, registered a drop in water level of a little more than 10 cm, 9 minutes after the earthquake (Fig. 65); the period of the disturbance was 16 minutes. This interval of time corresponds to the calculated time of travel of the tsunami from the underwater section of the San Andreas fault between Bolinas Bay and Mussel Rock* (see Fig. 64). There were no traces of vertical displacement of the flanks of the fault south of Mussel Rock*. In the region of Bolinas Bay and to the north, the eastern flank subsided relatively 0.3-0.6 m (1-2 feet). Apparently, one of the flanks of the fault [the eastern?] subsided slightly under the water as well. After this disturbance, the tide gauge record shows oscillations with a period of about 40 minutes, which is equal to the period of the transverse seiches of San Francisco Bay. /154

The tide gauge at San Diego showed no unusual oscillations in sea level.

There is only one report that a change in sea level after the earthquake was noticed visually.

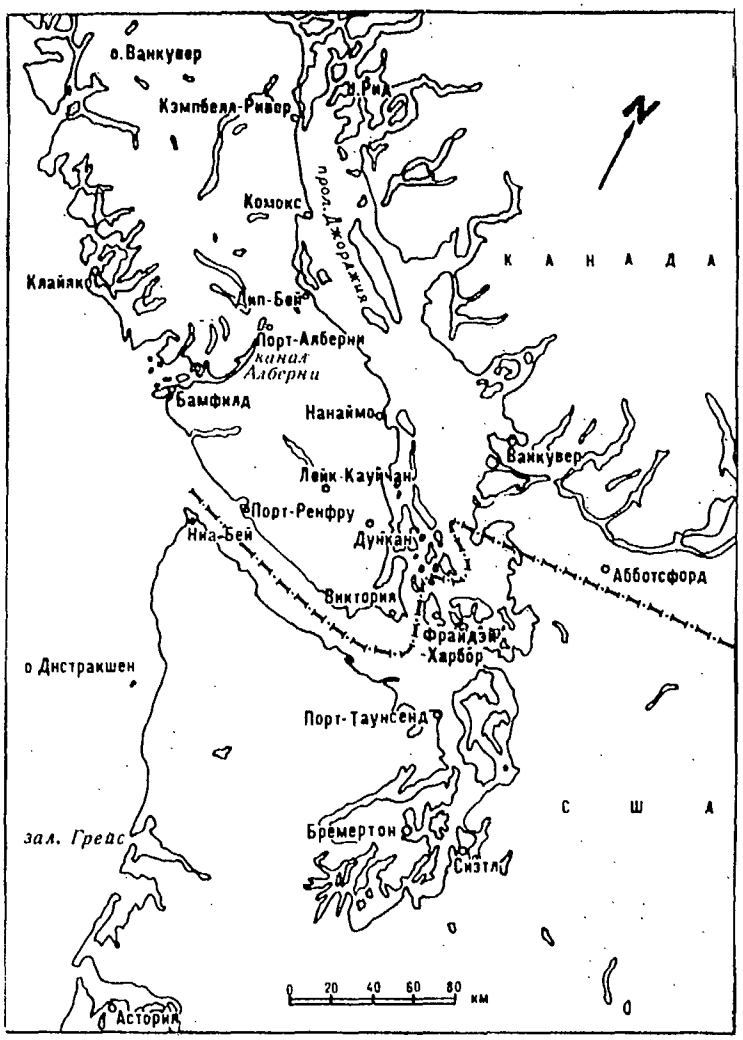


Fig. 63
General map of the border areas of Canada and the USA.

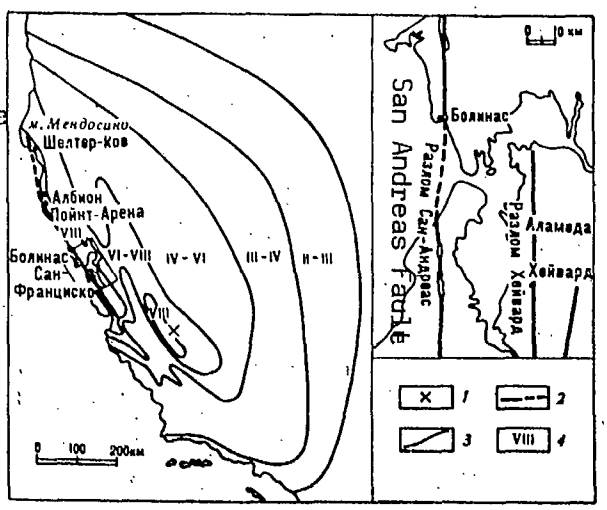


Fig. 64
Surface effect of the earthquake of 18.IV.1906 (Lawson et al, 1908).
1-instrumental epicentre;
2-surface faults, established and assumed;
3-isoseists;
4-force of the shocks in points on the R. F. scale.

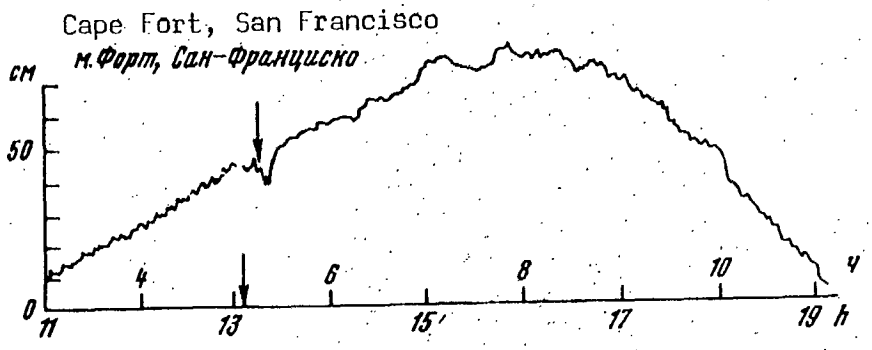


Fig. 65

Record of the tsunami of 18.IV.1906 (Lawson et al, 1908).

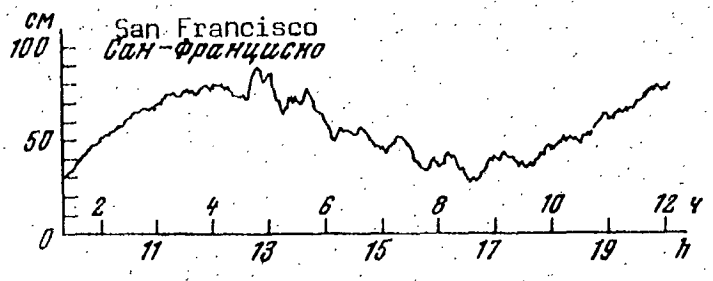


Fig. 66

Record of the sea level oscillations of meteorological origin of 21.XI.1910 (Marmer, 1930).

To be precise, in the mouth of the Navarro River, situated between Albion and Point Arena on the 18th at 8:00, several minutes after the earthquake, a section of low-lying flat coast, 4 hectares (10 acres) in area was flooded (Lawson, et al., 1908; Townley, Allen, 1939; Richter, 1958, 1963; Iida et al., 1967).

Gutenberg, Richter (1954): 18.IV; 13^h12^m; 38° N., 123° W.; M=8 1/4.

1906, November 6. The American schooner "Stanley," situated at the center (the "eye") of a cyclone at 46° 09' N., 125° 22' W., felt a sudden shock, which lasted 2-3 seconds. Soon afterwards, the captain saw three mountainous waves approaching from the southwest. When they fell on the ship, the schooner began to spin around, with its bow dipping into the water, so that it almost sank (Lawson, et al., 1908).

1907, September 24, 4:00. A shock lasting 3-4 seconds was felt at Skagway, Klakuan+, at the Point Sherman* lighthouse in the region of Lynn Canal. Many residents woke up. The dishes rattled, lamps swayed,

and the pendulums of clocks stopped. The shock was accompanied by a faint rumble. It was registered by the seismograph at Sitka.

A seaquake was felt on a ship situated 7 km (4 miles) north of Haines, and a small temporary change in the water level was noticed (Tarr, Martin, 1912; Heck, Eppley, 1958).

[These were probably seiches. Judging by the amplitude of the record of the shock at Sitka, its magnitude can be estimated at 5 1/2 $\pm$ 1/2.]

1908, February 14, 1:30. At Valdez, there was an earthquake lasting a minute. The steamship "Northwestern" felt strong tremors. Bottles, vases, tins and other objects flew about in the stores. Many residents ran to the street. There was no damage to buildings. After the earthquake, the underwater cables laid in Valdez Bay were broken at several places. It was later found that they had been buried under thick layers of detritus. There was no noticeable tsunami [in one place in the text cited, the term "tidal waves" is used incorrectly in describing the seaquake].

The earthquake was felt with approximately the same force everywhere in the region of Prince William Gulf: at Ellamar, Landlock, Cordova, Katalla, and on Latouche Island. It was registered at remote seismic stations (Tarr, Martin, 1912; Heck, Eppley, 1958; Cox, Pararas-Carayannis, 1969). [The magnitude of the earthquake was tentatively equal to 6, judging by the data of the seismic stations, cited in Tarr and Martin's paper].

1910, November 21. The tide gauge at San Francisco registered waves of the tsunami type of meteorological origin (Fig. 66), hypothetically caused by a rapid drop in pressure of 2 mm (0.1 inches) from 4:00 to 5:00 and a rapid rise by the same amount from 5:00 to 6:00 (Marmer, 1930). /155

1923, September. There was a sudden rise of water in California resulting in destruction at Jose de Cado* (Montandon, 1924 a).

[Apparently, waves of meteorological origin.]

1925, October 4, 4:15. The record of the tide gauge at Long Beach shows oscillations with an amplitude of 34 cm and a period of 43 minutes. Apparently, of meteorological origin (Iida et al., 1967). [Registered on the Hawaiian Islands.]

1927, January 1, 0:17. There was a strong earthquake with source in Imperial Valley, on the border of the USA and Mexico. It recurred with approximately the same force an hour later and was followed by a multitude of aftershocks. At Calexico, about 20 buildings were seriously damaged; fires broke out; the water main was broken; several residents were injured in collapses. At Mexicali, several buildings were destroyed and many were damaged; fires broke out. Damage was also done at other points. The earthquake was felt on an area of about 170,000 km^2

(50,000 square miles), including San Diego (SN, 1927, vol. 17, N 1; Townley, Allen, 1939).

Gutenberg, Richter (1954): 1.I; $8^h16^m45^s$; 32 1/2° N.; 115 1/2° W.; M=5 3/4.

Montandon (1928) adds [probably arbitrarily] the following to his description of this earthquake: "at...San Pedro, the port of Los Angeles, sea waves carried off part of the new embankment; the damage was estimated at 3 million dollars."

1927, October 24, 8:00. There was a strong earthquake, affecting the entire southeastern prominence of Alaska and adjacent regions of Canada. The tremors were felt on the coast at least from Lynn Canal to Wiah Point. At Chichagof and Soapstone Point*, window panes were shattered and a water main was broken. At Sitkan, clocks stopped, dishes rattled, and cracks appeared in building walls. Several windows were broken at Petersburg. Slight damage was done at Wrangell. At Juneau, hanging objects swayed. Small waves were observed in swimming pools in Seattle. There was damage to buildings at the settlements of Steel Creek and Chicken [?], but there were no casualties, since the residents, warned by the rumbling had taken to the streets. The earthquake may have been noticed to the north of Fairbanks (see Fig. 77).

The underwater army cable between Ketchican and Wrangell was broken near Wrangell. The cables were also broken between Petersburg and Wrangell and between Juneau and Skagway (SN, 1927, vol 17, N 4; Bois, 1928; Sommer, 1931). According to Bois's survey (1928), a "solitary" wave reached the Hawaiian Islands.

Gutenberg, Richter (1954): 24.X; $5^h59^m55^s$; 57 1/2° N., 137° W.; M=7.1.

1927, November 4, 5:51. There was a strong earthquake with source on the edge of the shelf on the northern boundary of the Murray fault zone (Fig. 67). Large slides took place on the coast in the Santa Barbara district, and the movement of traffic on the railway was interrupted. Flues were damaged at Lompoc and other coastal settlements. A /157
very strong seaquake was felt on the "Sokonia" 50 km (27 miles) from Arguello Point, on the "Alaska Standard", 25 km (15 miles) from the same cape and on other vessels.

A tsunami arose, which was observed on the coast of California and was registered on the Hawaiian Islands. An employee from Surf reported that there was a wave approximately 1 1/2 - 2 m (6 feet) high, which began with the crest. A railway employee at Port San Luis observed a fall and rise in water level of 1 1/2 m (5 feet) followed by oscillations in level for an hour. According to the lighthouse attendant, in the same port a rise occurred, followed by a drop of 1 1/4 m (4 feet), without subsequent substantial oscillations. An observer at Pismo Beach compared the tsunami with large storm waves.

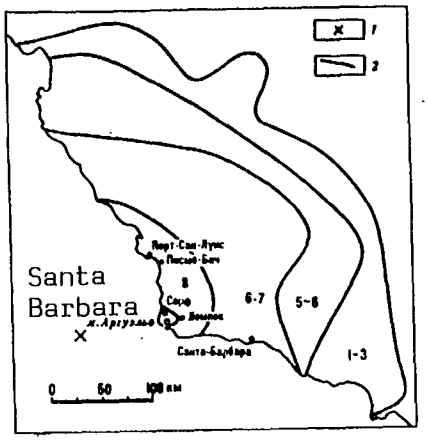
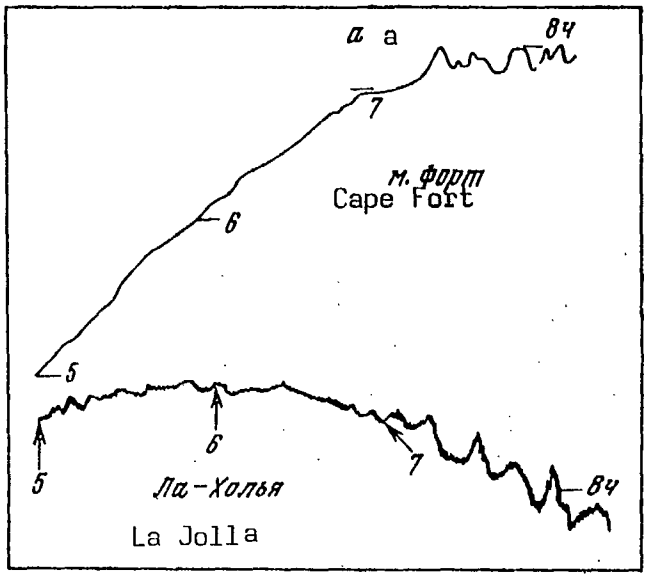


Fig. 67

Epicentre (1) and isoseists (2) on the 12 point scale (Byerly, 1930) of the earthquake of 4.XI.1927.



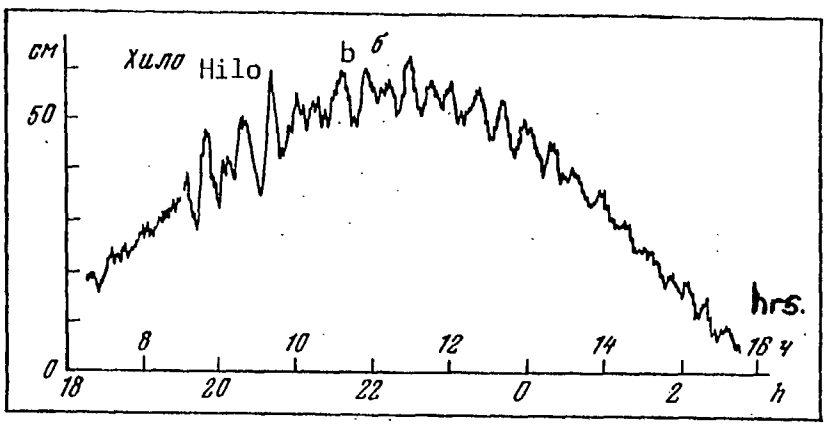


Fig. 68

Records of the tsunami of 4.X.1927 in USA (a) and on the Hawaiian Islands (b) (Wilson, 1928a; Byerly, 1930).

The tsunami was registered by the tide gauges at Cape Fort (San Francisco), at San Diego and at La Jolla (Fig. 68 a). On the first record, the oscillations began with a slow drop in level at 7:00, with a half period of 24 minutes. Then more rapid oscillations began with a period of about 15 minutes and a maximal amplitude of 4 cm. The sign of the first onset of the tsunami of the record at La Jolla is not definite. The oscillations had a period of 15 minutes, a maximal amplitude of 6 m and lasted about 13 hours.

At Hilo (Hawaiian Islands), the tsunami began 5.1 hours (at 8:33) after ebb tide, the maximal amplitude of oscillations was 10 cm, the period 12 minutes (Fig. 68, b). At Honolulu, the tide gauge registered weak oscillations with an amplitude of 2 cm and a period of 20 minutes (Wilson, 1928 a; Byerly, 1930; Jagger, 1931; Townley, Allen, 1939; Heck, 1934, 1947; Gutenberg, Richter, 1949, 1954; Shepard et al., 1950; Anon., 1961; Richter, 1963; Ponyavin, 1965; Iida et al., 1967; Joy, 1968).

Gutenberg, Richter (1954): 4.XI; $13^h50^m43^s$; 34.5° N.; 121.5° W.; M=7.3.

1928, February 9, 3:04. There was an earthquake with source in the region of Vancouver Island, apparently near the Alberni Canal (see Fig. 63). There were strong tremors at Port Alberni, Bamfield, on Cape Pachena, and weak ones at Vancouver, Nanaimo and Port Townsend. Tremors were also felt at Abbotsford, Duncan, Covichane*+, Victoria, Port Renfrew, on Tatoosh Island* and Destruction Island. Small tidal waves occurred ır Bamfield (Heck, Bodle, 1930; Milne, 1956). [No instrumental data on the earthquake.]

1929, May 26, 14:42. There was an earthquake, felt most strongly along the eastern shore of the Queen Charlotte Islands. At Masset, the water splashed out of reservoirs, trees and homes rocked crazily and people found it difficult to remain standing. Dishes were broken and clocks stopped at Queen Charlotte. Near Skidegate+, the ground on the coast cracked. At Sandspit, a low-lying stretch of coast 150 m (500 feet) long sank into the water. The top of a hill was moved at Lockeport, and flues collapsed near Rose Harbor.

A tidal wave 1 1/2 m (4 feet) [high] was reported at Queen Charlotte. The tsunami was also observed near Skidegate (SN, 1929, vol. 19, N 2; Milne, 1956; Iida et al., 1967).

Gutenberg, Richter (1954): 26.V; $22^h39^m54^s$; 51° N., 131° W.; M=7.0.

1930, August 30, 16:40. There was an earthquake with epicenter at point 33.9° N., 118.6° W.; M=5 1/4. In Santa Monica Bay, there were seiches 1/2 m (2 feet) high which were not observed at any other points on the coast (SN, 1930, vol. 20, N 4; Townley, Allen, 1939; Joy, 1968).

1933, March 10, 17:54. In Rothé's survey (Rothé, 1933), it is suggested that the known earthquake at Long Beach was accompanied by a tsunami. Iida et al., (1967) in their catalogue, indicated that waves

with an amplitude of 10 cm and a period of 19 minutes were observed in the Long Beach region, but it is noted that the data are unreliable.

Gutenberg, Richter (1954): 11.III; $01^h54^m08^s$; 33.6° N., 118° W.; M=6 1/4. /158

1934, August 21, 19:25. Enormous waves rolled onto the coast of California from Malibu Beach to Laguna Beach.

At Newport Beach, waves reached a height of 9-12 m (30-40 feet). The crests rolled 270 m (300 yards) inland, that is, 3 m (10 feet) above ordinary high tides. Part of the city was flooded to a depth of a metre (several feet). Many homes were damaged. Four people were trapped at the entrance to the harbor at the western pier and were injured. Debris weighing thousands of tons was tossed onshore.

Waves flooded the moorage at Balboa and detached a two-story, 25-room home from its foundations. The residents took to the streets screaming. Part of the pavement on the central avenue connecting the rich quarters, situated on the Balboa Peninsula, with the center of the city, were washed away, and the residents of this region found themselves isolated for a time. Tidal waves were observed at 25 minute intervals. At the time, an earthquake with an intensity of 3 degrees was recorded.

At Long Beach on the same day or later, on September 5, the outer part of the breakwater, with a large dance hall, was destroyed.

The earthquake was not felt anywhere except at Balboa; there was no wind; the cause of the waves is unknown (Heck, 1935).

1936, October 27. There was an enormous wave in Lituya Bay. Four witnesses were situated in the Bay: two in a little house on the western side of Cenotaph Island and two on the small ship "Main" riding at anchor off the northern shore of the bay, near Fish Lake Island and 2 km west of the above-mentioned little house (Fig. 69).

According to the fishermen, at approximately 6:20, 2 hours before sunrise, a dull, continuous rumbling was heard on board the ship. It appeared to come from the mountains located beyond the top of the bay. Because of the darkness, one could not make out what was happening. No tremors were felt. It was flood time. The rumbling lasted approximately until 6:50, when the first large wave appeared in the narrowest part of the bay. It was like a steep watery wall, stretching from shore to shore and having a possible height of 30 m (100 feet). Espying this wave, the fishermen weighed anchor and headed for Cenotaph Island. When the wave reached them 10 minutes later, they were situated 400 m (1300 feet) northwest of Cenotaph Island, at a depth of 20 m (70 feet). No drop in water level or other anomaly preceded the arrival of the wave.

The first wave lifted the ship about 15 m (50 feet) above the normal level. To the north and south, beyond the shelter of the island, the wave may even have been another 15 m (50 feet) higher. Immediately

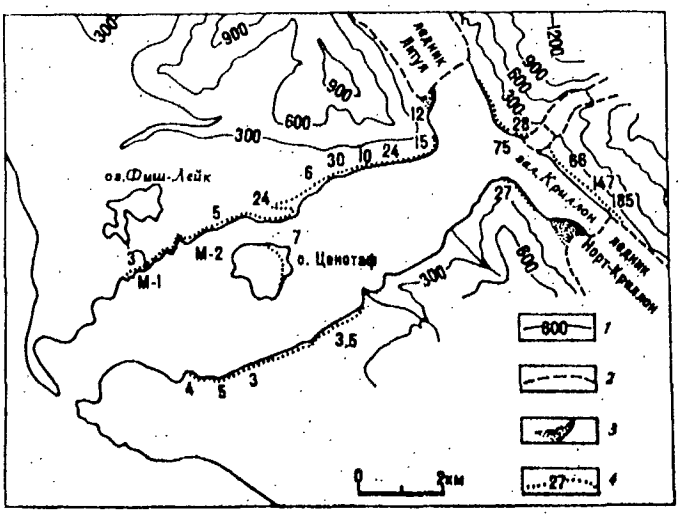


Fig.69- Inundation in Lituya Bay 27.X.1936 (Miller,1960a).
1- contours (m);
2- boundaries of the glacier;
3- core of activity;
4-boundary of the flooding of the shore and the height of the rise of water (m).

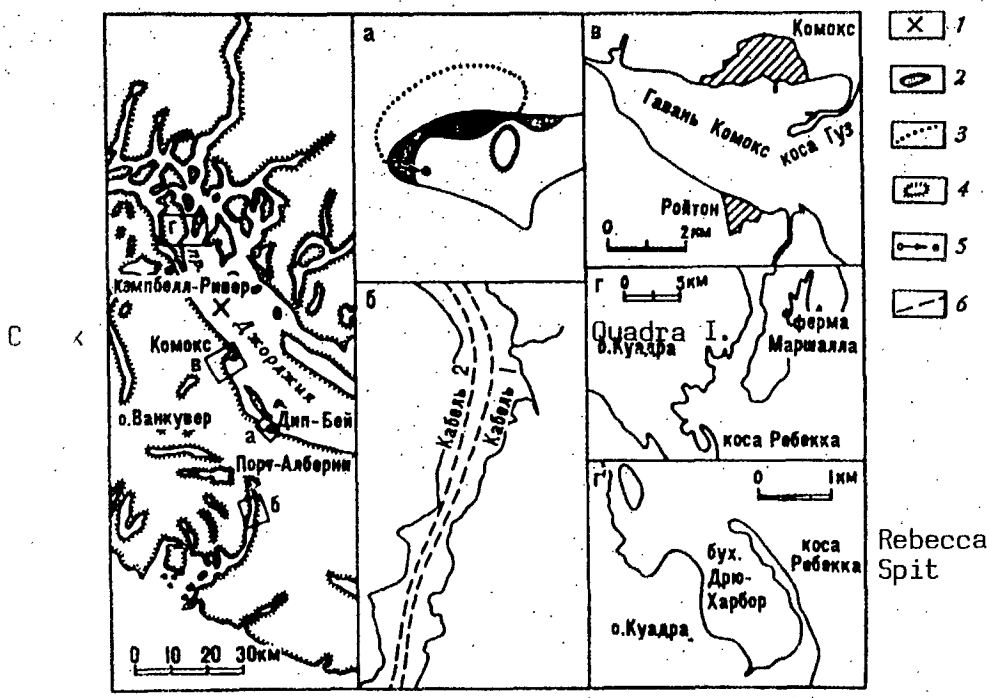


Fig.70

Some effects of the earthquake of 23.VI.1946 in the epicentral region (Hodgson, 1946).

a-d- sketches of the individual places

1-instrumental epicentre;

2-the part of Goose Spit which sank;

3-the boundary of the sunken bottom and the shore of Goose Spit;

4-a depression;

5-new location of the light house;

6-undersea cables.

after the passage of this wave, the water surface dropped below the normal level. A boat with a net, riding at anchor off Cenotaph Island at a depth of 14 1/2 m (48 feet) touched bottom. The first wave was followed /159
by a second and third at estimated 2 minute intervals, and each successive wave was larger than the preceding one. After each of these waves, the surface of the water again fell below the normal level. Small waves were observed during the half hour after the passage of the third wave. All the waves were directed towards the exit from the bay. After this, floating tree trunks and pieces of ice appeared around the ship. No surge of water was observed.

The fishermen in the little house were awakened at about 7:00 by a noise, like the droning of hundred airplanes flying at low altitude, and found that a wave was approaching their house. Taking to a high safe place, they saw three waves pass the island, growing in height, with a speed of about 20 knots. The maximal height of the waves was estimated at from 45 to 75 m (150-250 feet).

Subsequent geodesic, geographic and geological investigations of the bay, done in 1937-1953, made it possible to assess the height of rise of water along the coast of the bay (see Fig. 69). Trees were sheared and uprooted in the flood zone, and the soil was partly eroded.

According to current press accounts, the trees washed away by the water drifted 90 km (50 miles) south of the bay along the Pacific coast in the next several days. Some of the uprooted trees, according to witnesses, were left lying onshore with intact roots, branches, and bark. The greatest determined height of rise of water, 147 m (490 feet), occurred on the northeastern shore of Crillon Bay. The total flooded area of the shores of the bay (reckoned from the high high tide line) was 3 km^2 (0.8 square miles). The forest was not felled at the entrance to the bay, but the water flooded it to 1 km (1/2 mile) from the shore, and the fishermen later gathered crabs and shellfish here.

By all accounts, these waves arose at the top of Crillon Bay, but the cause of the wave cannot be reliably established. There are serious objections to all the hypotheses which have been advanced: a large subaerial or submarine slide or collapse, the calving of an iceberg from the tongue of the North Crillon glacier, a sudden slide of the tongue of the glacier, a breach in an ice-locked surface or sub-ice lake, etc. (Miller, 1954, 1960 a; Cox, Pararas-Carayannis, 1969).

1938, March 22, 7:22. There was a strong earthquake, felt on the Queen Charlotte Islands and on the southeasten prominence of Alaska Territory. Dishes were broken at Prince Rupert (Milne, 1956). About 3 hours after the earthquake, a light tsunami was apparently registered by the tide gauge at Santa Monica (USA) (Neumann, 1940). Iida et al., (1967) express doubt as to the existence of a link between the earthquake and the oscillations registered by the tide gauge.

Gutenberg, Richter (1954): 22.III; $15^h22^m14^s$; 52 1/4° N., 132° W.; M=6.3.

1941, February 9, 1:44. There was an earthquake with epicenter at point 40.9° N., 125.4° W.; M=6.6. There was an overall intensification of seiches in the harbor 14 hours later in San Francisco and San Diego; 36 hours later, the same occurred at Port Hueneme. There were no changes at La Jolla. The conclusions are based on tide gauge records (Joy, 1968).

1946, June 23, 10:13. There was a very strong earthquake in western Canada and northwestern USA with source in the central part of the eastern coast of Vancouver Island, approximately from Deep Bay to Campbell River and further to Quadra Island and Reid Island inclusively, (see Fig. 63, 70). In the epicentral zone, it lasted about a half minute and caused numerous slides and subsidences of the loose ground. Many points of low-lying accumulative coastal relief forms: beaches at steep cliffs, spits, etc., disappeared.

Thus, the end of the spit, which cuts off Deep Bay, disappeared under water. The depth of the water to the north of the spit increased from 1 1/2 to 30 m (from 5 to 100 feet). Apparently, the wave resulting from this slide reached the lighthouse situated to the east on Sisters /160
Rock*. According to the lighhouse attendant, a wave 2-2 1/2 m (7-8 feet) high rolled onto the little island 7 minutes after the earthquake; a second wave 1/4-1/2 m (4-5 feet) high moved in at a distance of 30 m (100 feet) from the first; the velocity of the waves was 10 knots.

A section of coast with a pier on Goose Spit which cuts off the entrance to Comox harbor (Fig. 70 c), subsided more than 1/2 m (2 feet). Waves about a metre (several feet) high were observed near the slide which occurred here.

Some sections subsided on Rebecca Spit, which cuts off Drew Harbor on the eastern coast of Quadra Island (Fig. 70 d,d^1). According to a forest worker, a moment after the earthquake, the water level oscillated between the high and low tide marks at another place on this island. The water, which had been clear, became turbid. The fish did not bite for two weeks. A large tract of agricultural lands on Reid Island dropped 6-9 m (20-30 feet).

In Alberni Bay opposite Franklin Creek* (Fig. 70 b), the water increased more than 30 m (100 feet) in depth. The underwater cable was broken and partially buried by detritus. In the words of an eyewitness, a roller 6-9 m (20-30 feet) high, arose on the surface of the water here. The roller then scattered along the axis of the bay and turned into small tidal waves, which were observed on its shores.

According to Hodgson, who carefully examined the epicenter zone of the earthquake, there were no real tsunami waves. Only these local waves arose, which were generated by collapses and suspension currents. A distinctive feature of this earthquake was the almost total absence of recurrent shocks (Anon., 1946; Hodgson, 1946).

Milne (1956): 23.VI; $17^h13^m19^s$; 49° 52' N., 124° 55' W.; M=7.3.

1949, August 21, 20:03. There was a strong earthquake with source /161
in the region of the Queen Charlotte Islands. It was felt from Portland to the south of Alaska. The epicentral zone has not been examined. From fortuitous data, it is known that a great many collapses and slides took place, cracks were formed in the ground, it was impossible to stand, many trees were broken or uprooted and material damage was done (Milne, 1956).

At Ketchikan (Alaska), a tidal wave 1/2 m (2 feet) high was observed. A very weak tsunami with a height of 7.5 cm (3 inches) and a period of 16 minutes may have been registered by the tide gauge at Sitka. The tide gauge at Hilo registered a tsunami 5.3 hours after the earthquake; the amplitude of oscillations was 10 cm, the period was 20 minutes (SN, 1949, vol. 39, N 4; Murphy, Ulrich, 1951 b; Hamamatsu, 1966; Iida et al., 1967; Cox, Pararas-Carayannis, 1969).

Gutenberg, Richter (1954): 22.VIII; $04^h01^m11^s$; 53 3/4° N., 133 1/4° W.; M=8.1.

1958, July 9, 22:16. There was an earthquake in Alaska, the strongest in North America since the California earthquake of 1906. Its epicenter was established on the northern coast of Cross Strait, near Palm Bay (Fig. 71). The greatest destruction occurred considerably to the north, at Lituya Bay, where the water rose 516 m above the normal level, and near Yakutat, where part of Khantaak Island collapsed. The area in which the earthquake was felt was more than 650,000 km^2, but the damage was, on the whole, negligible because of the low population density.

In the summer of 1958 and 1959, the focal zone was investigated by Miller, Don Tocher and others. The enormous length of the source, the severe natural conditions, the few people involved in the expedition, and the limited transport possibilities permitted only a general reconnaissance.

In the opinion of the members of the expedition, the earthquake was caused by the displacement of the flanks of the Fairweather fault, which extends from Palm Bay in the southeast to Nunatak Fjord in the /162
northwest, approximately along the Pacific coast, and separates the littoral piedmont zone from the Fairweather Range. The fault appears in many places in the relief as canyons and valleys. This fault is concealed either by thick glaciers, or by marine bays, or by loose glacial deposits on almost its entire length, and it passes through bedrock only in a few places.

The most favorable section for observation was that to the east of Crillon Lake*. Here, on a stretch of 0.5 km, investigators were able to trace a fresh fault on the surface. From scratches on the slicken sides and some other indirect evidence, it was noted that the southwestern (recumbent) flank of the fault had shifted 6.5 m to the northwest relatively to the northeastern (hanging) flank. In addition, fresh cracks were found on the steep slopes of Nunatak Fjord and off the southeastern tip of the fault. On the basis of these data, the American

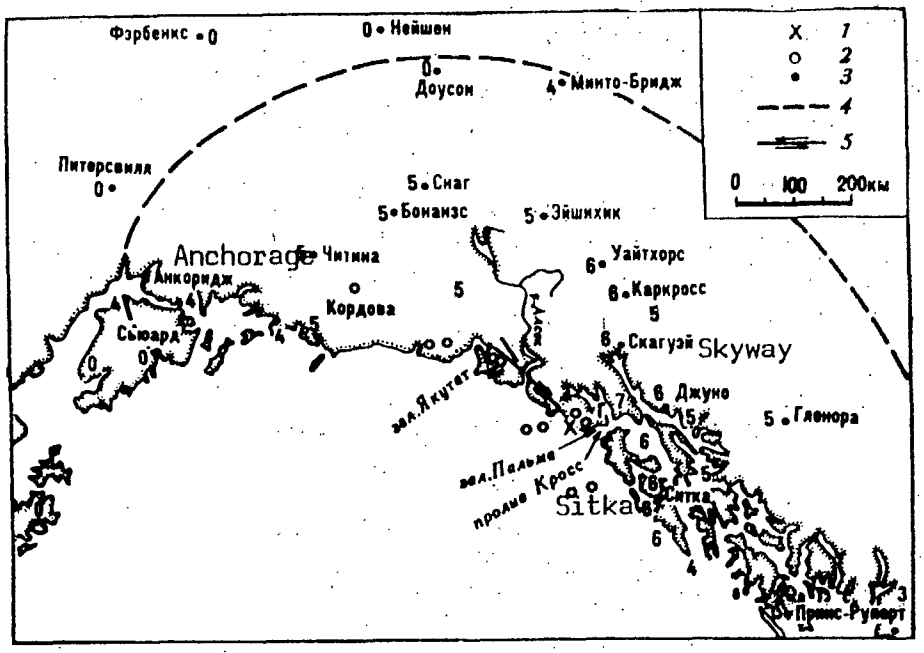


Fig.71
Surface effect of the earthquake of 9.VII.1958 (Soloviev,1962)

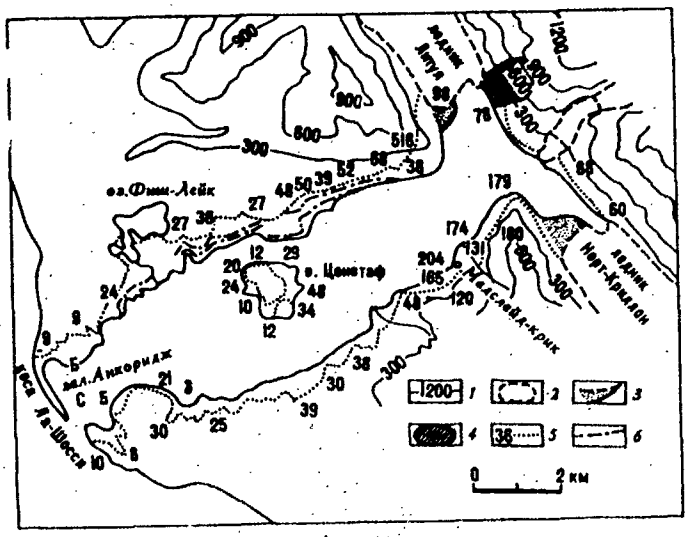


Fig.72

Inundation in Lituya Bay (Miller, 1960a).

1- contours (m);

2-boundaries of the glacier;

3-core of activity;

4-the part of the side of the fiord which slipped;

5-the boundary of the flooding of the shore and the height of the rise of water (m);

6-deforested sections of the mountain slopes after the passage of the tsunami.

investigators considered that the movement along the entire fault, that is on a stretch of about 200 km, was of the nature of a right side shift with an amplitude of relative displacement of up to 6 m; the seam "opened up" from southeast to northwest.

The earthquake caused numerous rock avalanches and slides. In Disenchantment Bay (see Fig. 62), a "chunk" weighing several tons broke off from a glacier descending to the water; waves 6 m high arose on the surface of the bay. On Khantaak Island (in Yakutat Bay), a coastal section about 300 m and 50 m wide went under water, baring the shore rocks to a height of 3-4 m. The avalanche buried three residents of Yakutat. The resulting sea waves also reached a height of 5-6 m. A collapse in the mouth of the Alsek River (see Fig. 71) caused a wave 1-2 m high, which spread upriver. In another part of this river, where its valley passes along the Fairweather fault, an ice dam was formed by the collapse of glaciers. The water level in the lower reaches dropped approximately 1 m; several hours later, the dam was breached and the shores of the river were flooded. On the Don* River, the earthquake "erected" a mud dam. A landslide, which collapsed from a height of about 50 m, covered the Laperouse*+ glacier which had a tongue about 100 m long and up to 800 m wide.

In Glacier Bay, rocks crashed down from the steep beaches, resulting in small waves no more than 1/2-1 m (2-3 feet) high. Similar waves were observed in Dixon Harbor* several minutes after the earthquake.

The most catastrophic events, unique in the history of strong earthquakes, occurred in Lituya Bay, which is the T-shaped bed of an ancient glacier that has been filled in with water (Fig. 72). The length of the bay is 11 km, with a width at the main external part of up to 3 km and a maximal depth of about 200 m. The outer part of the bay, which is separated from the sea by a detrital spit, first crosses a narrow coastal plain, then a low piedmont belt; the shores here are comparatively flat, and until 1958, were covered with dense forest. The inner part of the bay is part of the Fairweather Canyon. Here the bay is like a fjord and its steep walls rise to a height of 650 to 1800 m, and the depth is greatest. Two large glaciers, the Lituya and North Crillon, lying in the Fairweather Canyon, feed the internal part of the bay on both sides, falling respectively into Gilbert Bay and Crillon Bay. The usual range of flood tides in the bay is 2 m (7 feet), the maximal amplitude is 4 1/2 m (15 feet). The distinctive feature of the bay is the strong tidal currents at the throat, reaching 12 knots in velocity. At the time of the earthquake, ebb tide had begun in the bay, but the water level was still 0.3 m (1 foot) above the mean level.

At the time of the earthquake, about 300 million m^2 of rock collapsed into Gilbert Bay from the northeast shore (Fig. 72). The water extruded from the bay by the collapsing mass, splashed up on the opposite shore, reaching a colossal height. The movement of the water was so fast, that it uprooted a whole forest in the flood zone and stripped the bark and branches from the trees. Besides this gigantic splash, the collapse of this huge mass gave rise to a wave, which crossed the entire /163

Lituya Bay from Gilbert Bay to the sea with a velocity of 150-200 km/hr, that is, with the speed of gravity waves, and devastated the shores of the Lituya Bay. Three fishing launches in the bay were caught by the wave; one of them (C on Fig. 72) sank with two fishermen; the other crews were saved. The fishermen gave the following account.

Ulricht and his 7 year old son entered Lituya Bay at 20:00 on July 9 in the launch "Edri" and cast anchor at a depth of 9 m (5 fathoms) in a small inlet off the southern shore (Fig. 72). In the evening, he was awakaned by vigorous rocking of the longboat and went out on deck. The longboat was being shaken vigorously and tossed up. Collapses were occurring in the mountains at the top of the bay and avalanches were descending. About 2 1/2 minutes after the earthquake, a deafening crack was heard coming from the top of the bay. Soon after, a roller, like the moving tongue of a glacier, appeared from Gilbert Bay. When the wave was between the top of the Lituya Bay and Cenotaph Island, it was like a precipitous wall of water, perhaps 30 m (100 feet) high extending from shore to shore. Splitting up at the northern tip of the island, the roller closed up again at its southern shore. The wave approached the longboat about 2 1/2-3 minutes after it first appeared. Its front was very steep and had a height of 15-20 m (50-75 feet). Until the arrival of the wave, no drop in level or any other disturbance was observed, except that the longboat vibrated from the continuing earthquake.

The wave lifted up the launch, and the anchor chain snapped, although it was completely slack. The boat was carried forward, and would have been tossed across the spit, but then a reverse current carried it back to the center of the bay. The width of the wave crest was apparently 7.5-15 m (25-50 feet) and its back slope was considerably flatter than the front. After the passage of the gigantic roller, the water surface returned approximately to its normal level, but whirlpools and surges arose from one shore to the other. Steep sharp-pointed waves up to 6 m (20 feet) high were observed, moving in all directions. The agitation in the bay abated in 25-30 minutes.

Other witnesses, the Swensons, on the launch "Bedrock", entered the bay at 21:00 and cast anchor at the northern shore of Anchorage Bay at a depth of 7 m (4 fathoms) (Fig. 72). In the evening they were aroused by a strong vibration of the launch. Coming up top, Swenson saw a roller appear from behind the cape, cutting off Gilbert Bay, and strike the southern coast of the bay in the region of Mudslide Creek. As the roller passed Cenotaph Island, it had a height of about 15 m (50 feet) at the center and rose somewhat towards the shore. The wave passed the island approximately 2.5 minutes after its appearance and reached the launch in another 1.5 minutes.

Moving on the crest, with the stern forward and sinking in the water, the launch was lifted up and thrown across La Chaussee spit. Immediately behind the spit, in the sea, the crest collapsed and the launch hit bottom and sank. The Swensons were able to transfer to a boat and were soon picked up by a fishing vessel. /164

On the morning of the 10th, Miller flew over Lituya Bay in a small airplane, but visiblility was very poor because of a low fog. All the same, it was established that Gilbert and Crillon Bay and the entire inner part of Lituya Bay, on a stretch of 4.5 km (2.5 miles), were packed with driftwood and some rafts were strewn with rock debris, boulders and all kinds of rubbish. Parts and stems of trees, as well as chunks of ice, floated over the rest of the surface of the bay and in the sea in a 9 km radius (5 miles) from the entrance to the bay.

It was noted that the tongue of the Lituya Glacier had retreated about 300 m (1000 feet) and cracked on a stretch of a hundred metres (several hundred feet). The annular moraines at all the glaciers had disappeared, and the glaciers themselves appeared to have been "washed" by the water. For the rest, there were no changes in the position and shape of the glaciers.

A fresh scarp, from which rock continued to collapse, was found at the site of the above-mentioned huge slide. The main effect of the wave, as had already been mentioned, was the total destruction of vegetation in the littoral belt. On this flight and subsequent land studies, it was established that the maximal height at which the forest was washed away was 520 m (1720 feet) on the western shore of Gilbert Bay, directly opposite the collapse (see Fig. 72). The maximal width of the devastated zone was 360 m (1200 feet) at a height of 32 m (110 feet) near Fish Lake. The total area on which forest was washed away was 14 km^2 (4 square miles), while the total flooded area was apparently 17 km^2 (5 square miles). The soil cover, on the average at least 0.3 m (one foot) deep, was washed away in the flood zone, that is, a total of at least 3 million m^3 (4 million cubic yards) of loose deposits was washed off. All shellfish colonies in the littoral area were destroyed. The few structures and geodesic signs on the shore were washed away.

The part of the slope of Gilbert Bay which split off, according to rough estimates, represented a prism with a triangular cross section with sides of 900 and 720 m (3000 and 2400 feet), a maximal thickness of 60 m (200 feet) and a center of gravity at a height of 600 m (2000 feet). Only 2% of the potential energy of this mass was converted into the energy of the wave which crossed the mouth of Lituya Bay. The generation of the wave by the collapse was modelled in the laboratory (Wiegel, 1963). The wave which developed in Gilbert Bay should have been reflected first from the southern shore of Lituya Bay in the region of Mudslide Creek, then from the northern shore, and possibly, once again from the southern, and then should have passed out to sea.

The tectonic dislocations in the source of the earthquake, and possibly the wave emerging from Lituya Bay, gave rise to a small tsunami, which was registered on remote tide gauges. Thus, slight anomalous waves were registered by the tide gauge at Sitka; they began at 23:25, that is, 70 minutes after the earthquake, with oscillations 3 cm (0.1 feet) in height and lasted several hours; the maximal height, 10 cm (0.3 feet), was observed at 2:00 on the night of the 10th; the period of oscillations was 18 minutes. At Yakutat, the tide gauge registered waves with an

amplitude of up to 20 cm and a period of 27 minutes immediately after the earthquake. At Hilo, the tsunami was registered 6.7 hours after the earthquake with an amplitude of 10 cm and a period of 15 minutes (SN, 1958, vol. 48, N 4; Brazee, Jordan, 1958; Tocher, Miller, 1959; Brazee, Cloud, 1960; Davis, Sanders, 1960; Miller, 1960 a,b; Montandon, 1961; Rothe, 1961; Soloviev, 1962; Iida et al., 1967; Cox, Pararas-Carayannis, 1969).

[10.VII; $06^h15^m56^s$; 58.6° N., 137.1° W.; M=7.9.]

1963, March 30/31. In British Columbia, at Wiah Point (Langara Island) and at Port Simpson [30 km north of Prince Rupert], the water rose 4-5 m at night. There was no earthquake; a doubtful tsunami (Hake, Cloud, 1965; Iida et al., 1967).

HAWAIIAN ISLANDS

Hawaiian legend about Kilauea volcano (Fig. 73). This volcano /165
has burned constantly since the islands first appeared one night. However, its vicinity became inhabitable only after a flood at the time of Hin The Chief. Soon after this flood, the existing family of volcanoes moved to Hawaii from Tahiti or some other country (Westervelt, 1916).

1813, or 1814. The tsunami is mentioned in the memoirs of Ii, who was one of the first Hawaiians to be educated by the Christian missionaries. In addition, he happened to be a nephew of a retainer of the Hawaiian king. His uncle took sick and wished to return home to Hookena, Hawaii Island (Fig. 73). This was about 1813. On the advice of physicians, a hut was built for him from special palm leaves. While he lay in the hut, a strange rise in sea level occurred. The sick man was "soaked" but was not carried off. Only one rise of water took place (Ii, 1959; Iida et al., 1967; Pararas-Carayannis, 1969).

1854, January. Hawaiian Islands. Perrey reproduces a report from Hilo by the missionary T. Coan dated January 30, 1854, which says "The recently renewed oscillations in sea level off the coast of Hawaii Island made us think that an underwater eruption had taken place at the foot of the island or somewhere among the mountain chains or individual volcanoes hidden under the waters of the Pacific" (Perrey, 1872 a). [This may be the Aleutian tsunami of 18(16).I.1854.]

1860, December 1. Early in the day, the sea off the Hawaiian Islands suddenly "swelled" unusually in clear weather. Great damage was done to Maui and Molokai Islands. No earthquake or underwater eruption was observed.

At Kahului, water burst into the port and reached a level 2 1/2 m (8 feet) above the usual high tide mark. Many foulards were destroyed, but no more serious damage was done. Somewhat later, although it was full high tide time, the water in the bay receded, churning.

At Maliko, the water rose right up to the level of a small valley, where it flooded a group of huts of local residents. All the homes except one were overturned. Since the rise of water was gradual, the residents had time to save themselves and no one died (Perrey, 1862b).

1862, January 28. At Waialua village (Molokai Island) and its vicinity, there was a strange phenomenon. The sea rose slightly. The fish ponds were flooded and devastated. On the night of the 29th, an earthquake lasting more than 5 seconds was felt on the Hawaiian Islands (Perrey, 1864 b).

1868, April 2, 15:40. There was a destructive earthquake and tsunami with focus south or southeast of Hawaii Island. The earthquake was felt on all the Hawaiian Islands. Fig. 74 shows a simplified map of the surface effect of the earthquake. The magnitude M of the earthquake,

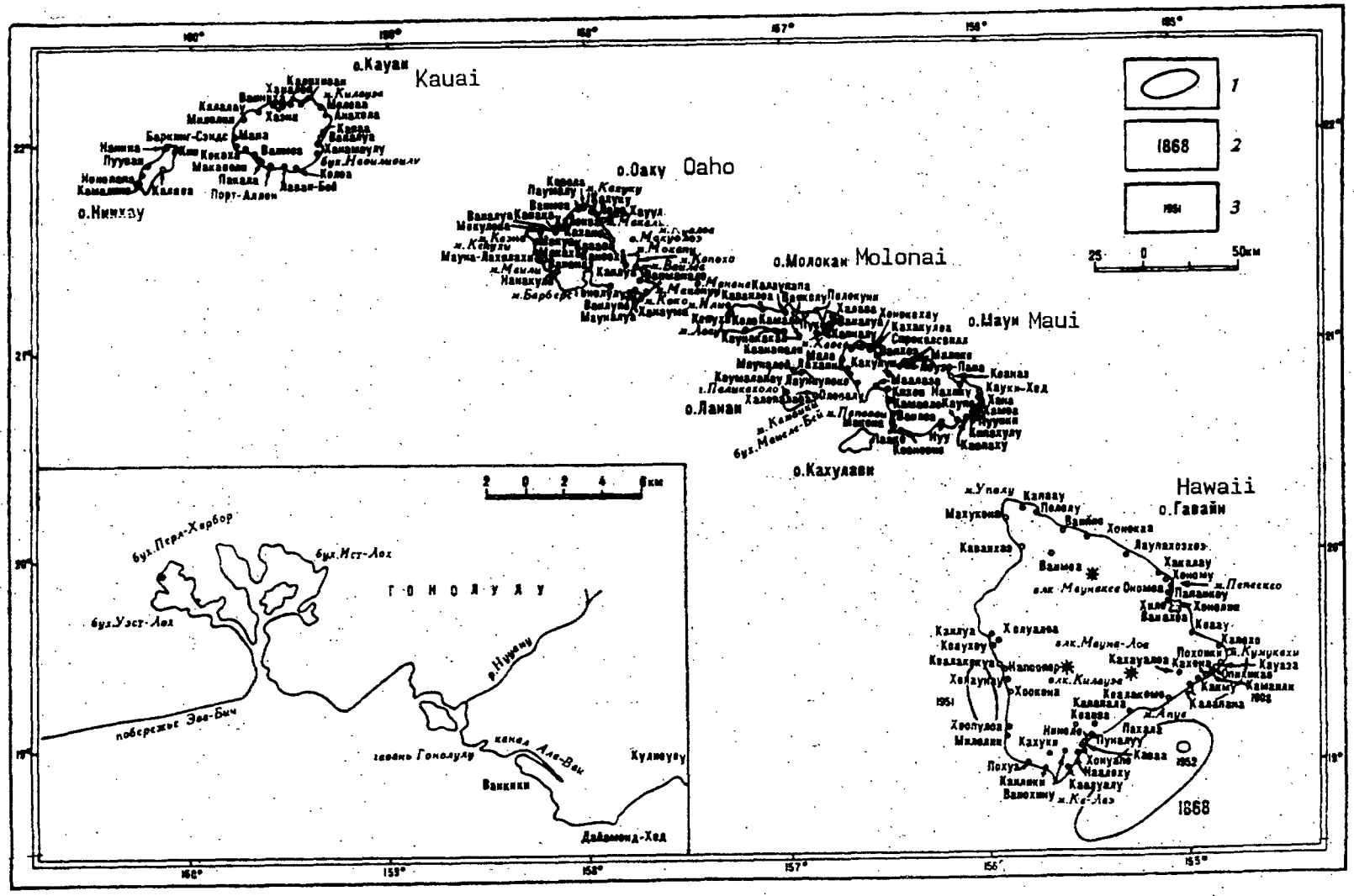


Fig. 73

Hawaiian Islands

1 - tsunami centres, confirmed and probable;

2-3-intensity of tsunami I: 2 - I=3 3 - I=0.

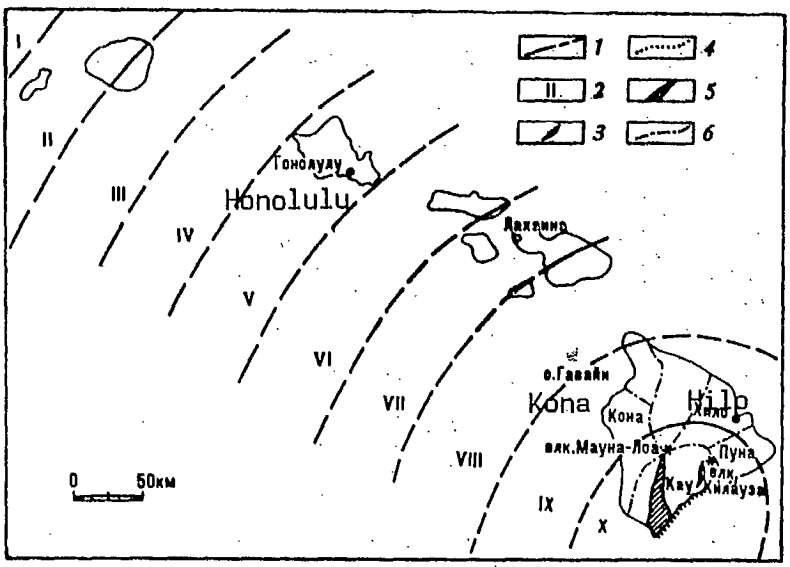


Fig. 74

Surface effect of the earthquake of 2.IV.1868 (Wood, 1914; Montessus de Ballore, 1924).

1-isoseists;

2-force of the shocks on the Rossi-Forrell scale;

3-sink;

4-the shoreline subjected to the most intensive tsunami;

5-subsequent lava flow;

6-the boundaries of the administrative regions on Island of Hawaii.

according to Furumoto's estimates, was 7 1/2 $\pm$ 1/4.

The events unfolded as follows. On March 27, light shocks began to be felt in the Kau and Kona districts. On the following day, they spread northwest to the boundaries of Kona district, and east to Hilo. Smoke and flames appeared in small volume in different places at the top of the Mauna Loa volcano on the 27th. The shocks became increasingly noticeable and the main earthquake took place on April 2 at 15:40. /167

On Hawaii Island, the earthquake took the form of prolonged (2-3 minutes) long-period oscillations, causing dizziness and symptoms of seasickness even at Hilo.

In Kau district, all stone and even more solid homes collapsed; the large stone church at Waiohinu collapsed in 10 seconds. People and

animals were thrown to the ground. The residents had to sit on all fours to keep from rolling. At Keaiwa+, Kahuki, Punaluu, Ninole+, Waiohinu and other settlements, according to accounts, wooden homes were torn from their foundations or overturned; straw huts with piles, dug into the ground, collapsed completely. At Kapapala+, a 280 ton (1700 barrels) cistern burst and scattered in bits. In all, the shocks resulted in the collapse of 46 homes. On a ship in the focal zone, the jib boom hit the water and broke.

In Kona district, the destruction was not so universal, although the tremors were strong. At Hilo, the only stone home collapsed, furniture shifted and people ran from their homes.

Along the entire south coast of the island and in the interior, numerous collapses, slides and rock falls took place. In Wood Valley* between Kapapala and Pahala+, a mud flow came down. It was 5 1/2 km (3 miles) long, 1 km (1/2 mile) wide at the middle and 2 km (a mile) wide at the head, with an average thickness of 2 m (6 feet), up to 6, 9 and 12 m (20, 30 and 40 feet) in places, such as in depressions of the relief. It covered a village of 10 homes; 31 people died.

In the basalt sheets west of Waiohinu, a crack was formed, along which a horizontal shift occurred. Cracks also developed at other places. The earthquake was accompanied by countless recurrent shocks, at least 2000, of which some were also destructive. Several days after the earthquake, st ng eruptions of the Kilauea and Mauna Loa volcanoes occurred. Lava flows destroyed 37 homes.

The earthquake gave rise to a tsunami, which had its greatest intensity on the southeastern coast of Hawaii Island, approximately from Ka Lae+ Cape to Kealakomo. According to reports, the first tidal wave on the coast of Kau and Puna districts had a height of 3-3 1/2 m (10-12 feet) above the usual high tide line. Then the sea level fell, at least 5 1/2 m (18 feet) below the low tide mark. Returning in an enormous tidal wave, the sea washed away a multitude (108) of homes on the coast, and 46 (according to other sources, 81) residents drowned. Flood and ebb tides were observed at least eight times.

The flooding was markedly greater at some places than at others, and the impression was created that this was due to the propagation of waves in a southwestern direction, at an angle of 45° to the coast. The level rose highest at the capes and the prominent parts of the coast, while the water penetrated furthest inland along lowlands where it encountered no obstacles.

There are descriptions of the effects of the tsunami at individual points.

At Punaluu, immediately after the earthquake or even simultaneously with it, the sea became very agitated, "as if enormous amounts of red hot lava had poured into it at some distance from the shore." The water churned and tossed in all directions. Soon an enormous wave rolled

onto the coast. When it receded, no traces remained of Punaluu. All the homes, the large stone church and even the coco palms, except for two, were washed away.

A fresh trench appeared, which went perpendicular to the shore. /168
The residents who were catching fish, some of whom were situated on shore, died. A large dune, which screened a pond and a spring with cold clear water, was washed out. At flood tide, the washed up sand blocked up the pond, and the shore line changed. Since the wave passed over the tops of the coco palms, its height was estimated at 18 m (60 feet). Drifting rubbish was carried 1/2 km (1/4 miles) inland.

The coast was devastated from Punaluu to Honuapo. Churches, homes, farm buildings, dikes, roads, fish ponds, canoes, nets, working implements, machines, domestic goods - everything was destroyed. In some places, the road running along the coast was washed away, in others, it was so littered with debris that it was impassable.

At Ninole+, Kawaa+ and Honuapo villages as well, not a single home remained standing to indicate the previous location of settlements, except for a small hut on the edge of the hill at Honuapo. It was reported that at Ninole+, one of the residents went into his home precisely when the wave surged onto the coast. It carried the house together with its owner several metres (feet) inland, and then, retreating, carried it out to sea. The Hawaiian was able to get hold of a large board from the remains of his home, and by using it skillfully he made it to shore on the next crest. The height of rise of the water at Ninole+ was estimated at 15-18 m (50-60 feet).

At Honuapo, as at Punaluu, a grove of coco palms was washed away.

At Kaalualu, the debris was carried 240 m (800 feet) inland; the water rose 7 1/2 m (25 feet).

At Kealakomo+, all the salt works were destroyed.

At Apua+, all homes, a section of beach and a good, small harbor for canoes were washed away. At Kaimu, various litter was tossed onto the meadow. Enormous boulders were washed away at Pokoiki.

With respect to the maximal height of the tsunami, other data have also been published. After measurements on palm trunks and shore slopes at the beginning of August, Coan came to the conclusion that the maximal rise of water at Punaluu and Honuapo was only 6 m (20 feet), that /169
is, it was 1/3 of the initial magnitude indicated by witnesses and in the press.

At Hilo Bay, the water retreated 30-60 m (100-200 feet) along the horizontal, and then rose 3 m ((10 feet) above the high tide mark and flooded the bridge at Waiakea+. Several homes suffered damage.

At Kealakekua, flood and ebb tides were observed for several

hours, after which fish were left stranded. The amplitude of oscillations in level was about 2 1/4 m (8 feet).

At Keauhou [east limit of Kau district], immediately after the earthquake, the sea fell on shore and washed away all homes and warehouses. The residents rebuilt on a higher site. The height of rise of the water was estimated at 12-15 m (40-50 feet).

At Kawaihae, flood and ebb tides began immediately after the earthquake. During ebb tide, the reefs dried up and during flood tide, the water rose above the high tide mark. There were 13 oscillations in level before the sea quieted down.

On Maui Island at Lahaina, at about 16:00-17:00, it was noticed that the sea had retreated from shore and that the bottom had dried up at many places between the shore and the reef. An observer noticed 13 oscillations in level, with an average period of 7-8 minutes.

At Honolulu, an ebb tide was noticed at 17:45. The water rose to the half high tide line at 18:00 and it again retreated to the ebb tide mark at 18:15. At 18:25, the water rose to the full high tide mark. The maximal range of oscillations in level was 1 1/2 m (5 feet) as against 1 m (3 feet) with the highest lunar high tides.

The tide gauge at San Diego (California) registered a tsunami with an amplitude of 10 cm and a period of 30 minutes; a tsunami was also recorded tide gauges at San Francisco and Astoria.

As a result of the earthquake, the entire southeastern shore of Hawaii Island sank by varying amounts. At Keahialaku+ (13 km southwest of Kapoho+), a small pond of brackish water, along which ran a stone dike, was submerged during high tide to a depth of 1 m (3-4 feet) and the water spread to the coco palm groves, where it had never been before. At Kaimu, the sea flooded the beach of volcanic sand and encroached 60 m (200 feet) into a young grove of coco palms.

At Kalapana, a sandy beach shifted 30 m (100 feet) inland, into groves of screw pine and coco palms; the trees were covered with sand to a height of 2 m (6-8 feet). The old stone church, previously 60 m (200 feet) from shore, was also washed out, so that there was water in it, even during ebb tides. The plain at Kalapana dropped 1 1/2 m (4-6 feet), and 8 hectares (20 acres) of what had been dry land was covered with a 1 m (3-4 feet) layer of water. The bathing cabins, in which there had previously been a space of 1-2 m (3, 4 and 6 feet) between the water and the roof, were completely filled with water. At Kealakomo+, a spring of cold water which flowed through the rocks was lowered. At Apua, on the site of the previous village, the water was 2 m (6 feet) deep. Much the same occurred at Keauhou, where the water was 2 m (7 feet) deep at the coco palms. The vast and previously safe anchorage here disappeared, and also a place where a large amount of pulu was dried, pressed and dressed for sale. At Punaluu, a new sandy beach was formed 30 m (100 feet) from the previous shore line (Coan, 1869, 1870; Fuchs, 1869, 1885 b; Perrey,

1870 b, 1872 a,b; Brigham, 1909; Hitchcock, 1909, 1912; Wood, 1914; Westervelt, 1916; Jagger, 1931; Heck, 1934, 1947; Sammons, 1950; Shepard et al., 1950; Macdonald, 1952; Ponyavin, 1965; Furumoto, 1966; Iida et al., 1967; Pararas-Carayannis, 1969; Furumoto et al., 1973).

1868, October 1. At Kawaihae (Hawaii Island), there was a strong underground shock, which made all the residents leave their homes. On the same day at 21:00, near Kahaualoa (Puna district), unusual flood tides were recorded which flooded slipways with pirogues, the fence, the church and many homes. The water rose considerably higher than on 2.IV.1868 (Griesbach, 1869; Perrey, 1870 b, 1872 a).

1869 (1868), July (?), 25. There was an unusual flood tide on the coast of Puna district. A wave 7 1/2 m (25 feet high) passed over the reefs, partially destroying them, and tossed debris weighing 1 to 3 tons on land. The water rose 9 m (30 feet) or 3-4 1/2 m (10-15 feet) higher than the tsunami of 2.IV.1868 and passed tens of metres (hundreds of feet) inland in a foaming roller. Homes which had survived the flooding of 1868 were washed away. Almost everything was destroyed on the high cliffs in the region of Kahanalea*+, while the cliffs themselves were abraded. The depth of the baths, situated in the ravine at Punaluu, doubled. /170

At Kalapana, the sea "reconquered" some of the land. Two new ditches were channeled into the beach. The flood tides began to flood the greater part of the previously cultivated plain around this settlement and passed over the old stone church, strewn deeply with sand and rocks carried by this tsunami.

The cliffs were abraded from Kamaili+ to Kapoho+, and everywhere traces remained of how the shore had been "picked" by the waves. The road running along the coast between the villages of Pohoiki and Opihikao were washed out on a 2 km (mile) stretch, which had never before been reached by high tides. The waves penetrated 300 m (1000 feet) inland southwest of Cape Kumukahi destroying several homes (Coan, 1870; Perrey, 1872 b; Shepard et al., 1950; Iida et al., 1967; Pararas-Carayannis, 1969).

[The surveys of perceptible earthquakes in the world for 1869 (Fuchs, 1870, 1885 b; Perrey, 1872 b) give no information about strong earthquakes along the Pacific coast on July 24-25. The description of events for Kalapana is identical to the description of the earthquake and tsunami of 2.IV.1868. Possibly the date is mistaken.]

1871, February 19 (or 18), about 22:00. On the Hawaiian Islands, there occurred one of the strongest earthquakes ever felt there. At Honolulu, first a brief vertical shock lasting 30-45 seconds was felt, followed by a series of horizontal tremors in a southwest - northeast direction, during which it was difficult to remain standing and which made many people nauseous like sea sickness. The shocks were accompanied by a terrifying roar which lasted 10 seconds. Cracks formed in many brick and stucco buildings, and stoves collapsed. A tsunami was observed in

the port.

On Lanai Island, where the earthquake of 2.IV.1868 was light, this earthquake, according to reports, was extremely strong. Cracks formed on the slopes of the peak, and enormous chunks of rocks collapsed. Palikaholo mountain partially collapsed into the sea; similar collapses occurred between Manele Bay and Kamaiki Point, as well as at Paupehe*+. In many places, numerous gaping crevices formed in the ground on the island. Almost all brick buildings were seriously damaged. Objects fell from shelves and broke.

Similar effects were produced by the earthquake on Molokai Island. The path leading to Kalaupapa and other roads were blocked by collapses and landslides and a fresh fracture 40 m long appeared. At Kalamaula*, a stone wall more than 1 m thick and 1 1/2 m high collapsed. The shocks lasted 45 seconds. The western part of Maui Island suffered more than the eastern part. At Lahaina, several adobe buildings collapsed; many adobe and stone buildings were heavily damaged. A schooner situated between Maui, Lanai and Kahoolawe Islands felt a sharp tremor.

On Hawaii Island, in the region of Kawaihae, stone boundary marks were damaged. At Hilo, the population was frightened, but no damage was reported. According to the French consul, the Mauna Loa volcano smoked. On Kauai Island, most of the residents were awakened by the shaking and noise but no damage was reported. The earthquake lasted 30-40 seconds.

Th were many recurrent shocks after the earthquake (Perrey, 1875 b; Milne, 1913; Furumoto et al., 1973).

Furumoto et al. (1973): M = 7.

1872, August 23 (mistakenly 27), 13:00. At Hilo, with still weather, the water in the bay quickly and quietly rose, like the onset of flood tide, to a height of 135 cm (4 feet 2 inches). In 6 minutes, it retreated to the lowest point and again returned, reaching a height of 90 cm (3 feet). It again retreated quickly and quietly; thus, in 1 1/2 hours, 14 oscillations occurred, each subsequent one being weaker than the last. In the end, the water returned to its normal state. No earthquake was felt (Coan, 1872; Hitchcock, 1909; Brigham, 1909; Jagger, 1931; Shepard et al., 1950; Anon., 1961; Iida et al., 1967; Pararas-Carayannis, 1969). It is possible that there was a tsunami with source off Chichizima Island (Soloviev, Go, 1974). Sapper's (1927) compendium mechanically connects the mention of the tsunami with the mention of the eruption of the Mauna Loa volcano in the same year.

1877, February 24. On February 14, there was a strong eruption of the Mauna Loa volcano with the ejection of smoke to a height of 5 km and the effusion of lava. The eruption lasted several days.

On the 24th, at about 3:00, an underwater eruption occurred 2 km (1 mile) from Kealakekua. It was accompanied by an earthquake, which was felt along the shores of the bay. The water mass was illuminated with a

varying red, dove-blue, then green light. Large chunks of hot lava floated onto the surface.

A crack arose between the site of the underwater eruption and the top of the Mauna Loa volcano. The crack extended inland 5 1/2 km (3 miles).

In the second half of the day, a strong earthquake occurred, which affected many islands of the archipelago and was accompanied by a strong underground rumbling. At approximately the same time, according to Coan, tidal waves were observed on the shore of Kona district (Fuchs, 1878; Hitchcock, 1909; Westervelt, 1916; Sapper, 1927; Sieberg, 1932; Pararas-Carayannis, 1969).

In Iida's compendium (Iida et al., 1967) it is surmised that it was not a tsunami which was observed, but a "boiling" of water over the source of an underwater volcano.

1877, May 4, 20:00. There was a very strong earthquake in the region of Mauna Loa volcano with a renewal of the large eruption, followed by a large tsunami (Fuchs, 1885 b).

1878, January 20. A large tsunami was observed on the north coast of Maui and Oahu Islands. The water rose 3 m; many homes were destroyed (Fuchs, 1879, 1885 b; Milne, 1912 b; Heck, 1934, 1947; Shepard et al., 1950; Ponyavin, 1965; Iida et al., 1967; Pararas-Carayannis, 1969).

1895, January 28. A strong wave, apparently of meteorological origin, broke on the coast of Maliko+ (Maui Island) (Pararas-Carayannis, 1969).

1903, October 5, noon. On the English ship "Ormsri" approaching the western shore of Hawaii Island, it was noticed that the sea began to churn as if mighty springs were acting under the water surface. The temperature rose markedly. The ship felt a shock like a tidal wave coming from the shore and was turned with the stern forward. On October 6, the Mauna Loa volcano ejected a column of smoke; lava possibly issued (Wood, 1904; Hitchcock, 1909).

[As is correctly noted in the compendia compiled at Honolulu (Iida et al., 1967; Pararas-Carayannis, 1969), this was apparently not a tsunami but a seaquake or convection currents.]

1903, October 8, at night. There was an ebb tide at Punaluu (Hawaii Island), succeeded on the following night by a powerful flood tide, which flooded the pier (Wood, 1904; Iida et al., 1967; Pararas-Carayannis, 1969). [Not a clear case.]

1903, November 24. The sea became agitated at Punaluu. Waves suddenly appeared on the previously quiet surface and lasted 10 minutes; their origin could not be explained. At the same time, a black column of

unusual size appeared above the Mauna Loa volcano (Hitchcock, 1909).

1903, November 29. A tidal wave flooded the northern coast of the islands of Oahu and Molokai and was registered by the tide gauge at Honolulu (Rudolph, 1905).

1908, September 20, 20:15. There was an earthquake with source south-east of Hawaii Island. There were tremors of 9-10 degrees in the district of Puna, at Kalapana, Kahena+, and Kauaea+, 6 degrees at Hilo, including the little island in Reeds Bay, and about 4 degrees at /172
the volcanic observatory near Kilauea Crater. It was felt in Kau district (at Punaluu), in Kona district (at Kailua, Holualoa+, Hoopuloa+) and on the north of the island (at Waimea, Kapaau+). It was felt lightly at Honolulu. The shore in the Puna district may have sunk 10 cm (a few inches). The water in the harbor and in the rivers of Hilo rose 0.3-0.8 m (1-2 1/2 feet) (Hitchcock, 1912; Sieberg, 1917, 1932; Iida et al., 1967; Pararas-Carayannis, 1969).

[21.IX; 6^h31^m; 19.4° N., 154.9° W.; M = 6.3.]

1919, January or April 9. Short-period tidal waves of a local nature arose on the third day after the volcanic eruption on Hawaii Island, during which the Alika* lava flow descended into the sea. Their height varied from 1 to 4 m (3-14 feet) and was maximal near the tongue of the lava flow. The pier was flooded at Hoopuloa (Jagger, 1931; Pararas-Carayannis, 1969).

191>, September - October. On September 26, the Mauna Loa volcano, which had been dormant since June 1916, revived. The eruption began at a height of 3300 m, that is, 600 m below the top of the volcano and was observed by Jagger from 18:00 on the 26th to 3:00 on the 27th. After two days of quiet, the eruption resumed at 2:00 on the 29th, but now at a height of 2300 m. A thick flow of lava issued from this lower crater. Less than 24 hours later, it filled up all irregularities of the relief, drove a road through the forest and reached the sea side approximately 28 km (15 miles) from the crater. For 10 days, the flow poured into the water, sometimes generating local tidal waves. On October 2nd, one family was washed into the water and was almost lost. Then the eruption began to subside, although volcanic activity was still noticeable on October 23 (SN, 1919, vol. 9, N 3; Pararas-Carayannis, 1969).

[This and the preceding description may apply to the same phenomenon.]

1921, December 16. According to unconfirmed sources, there was a tsunami on the Hawaiian Islands (Jagger, 1946; Iida et al., 1967; Pararas-Carayannis, 1969).

[Possibly the consequence of the strong earthquake on Guam Island.]

1924, May 30? A tsunami appeared on one of the last days of the

month at Kaumalapau Harbor and on Lanai Island. It reached 5 m and caused great damage. The same occurred at Nawiliwili (Kauai Island) (Montandon, 1924 b; Sieberg, 1932; Jagger, 1946; Shepard et al., 1950). [Montandon's data are not precise. Sieberg places a report of the tsunami after a description of the strong and prolonged eruption of the Kilauea volcano, which began on May 20 and had been preceded since May 16 by numerous seismic shocks. A number of investigators (Iida et al., 1967; Pararas-Carayannis, 1969) correctly express doubt about the existence of a link between the tsunami and the volcanic eruption. Shepard (Shepard et al., 1950) considers the tsunami to be a flood of meteorological origin.]

1925, October 4. The tide gauge at Honolulu registered waves with a period of 20 minutes and an amplitude of 10 cm. Possibly the waves were of meteorological origin (Iida et al., 1967, Pararas-Carayannis, 1969). [Registered in the USA.]

1926, January 24. There was an earthquake and tsunami in the Hawaiian Islands (SN, 1926, vol. 16, N 1; Jagger, 1946; Pararas-Carayannis, 1969).

1930, February. There was a tsunami in the Hawaiian Islands (Jagger, 1946).

1935 (or 1934), November 21, morning. An earthquake accompanied by a tsunami was felt in the Hawaiian Islands. The railway was damaged. There was considerable damage at Hilo. Many fishing vessels and yachts ran aground (Bois, 1935; SN, 1936, Vol. 26, N 1; Furumoto et al., 1973).

1947, January. At many places on the coast of the Hawaiian Islands there were storm waves higher than the tsunami of 1.IV.1946 (Shepard et al., 1950).

1951, August 21, 0:57. This was the strongest earthquake since 1868 on the Hawaiian Islands. Its source was located at sea off the western coast of Hawaii Island, within Kona district (Fig. 75). The earthquake lasted 3 minutes near the epicentre and had a magnitude of about 8 degrees (by different estimates, from 7 to 9 degrees). The greatest destruction occurred from Kealakekua to Hookena. Here 200 out /173
of 1000 homes suffered damage. At Hookena, 8 frame homes collapsed and 30 homes, a school and a warehouse were damaged. In the pleistoseismic zone, about 50 water reservoirs were destroyed and 150 were damaged; the power telephone networks were put out of commission; two small fires broke out. Two persons were injured. Cracks formed in the ground. A large avalanche fell into the water from a cliff at Napoopoo. There were many other avalanches, not so large. The earthquake was felt with a force of 4 degrees on the opposite, eastern side of Hawaii Island, 2 degrees at Honolulu. It was also felt on Maui Island.

After the earthquake many recurrent shocks occurred. Thus at Keei*, 109 tremors were felt in the first 8 hours after the main earthquake.

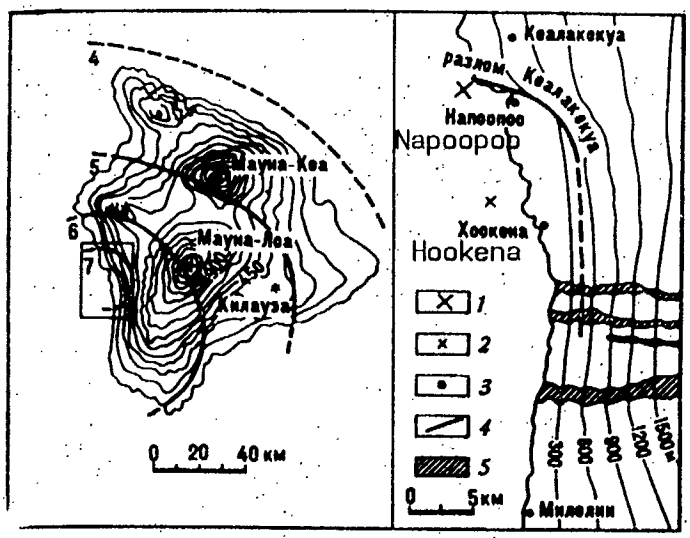


Fig. 75

The effects of the earthquake of 21.VIII.1951 (Macdonald, Wentworth,1951).
1-epicentre of the main shock;
2-epicentre of the strongest aftershock;
3-populated points;
4-isoseists on the 12 point scale;
5-lava flows.

At Napoopoo, the sea level fell 1.2 m (4 feet) after the earthquake, and then rose 0.6 m (2 feet) above the normal level. At Milolii, the level fell 0.9 m (3 feet) and then rose 1 m (3-4 feet) above the normal position, washing away canoes.

According to other sources, because of the collapse of the cliff at Napoopoo, the water rose 3.6 m (12 feet) and destroyed a boat shed.

A very slight tsunami was registered by tide gauges: 0.6 hours later, with a height of 10 cm and a period of 12 minutes at Honolulu, 0.7 hours later, with a height of less than 10 cm and a period of 15 minutes at Hilo; with a height of less than 10 cm and a period of 27 minutes at Port Allen (SN, 1951, vol. 51, N 4; 1952, vol. 52, N 1; Macdonald, Wentworth, 1951; Brazee, 1951; Murphy, Cloud, 1953; Rothe, 1954; Iida et al., 1967; Pararas-Carayannis, 1969; Furumoto et al., 1973).

Macdonald, Wentworth (1951): 21.VIII; 10^h57^m; 19.2° N., 156.1° W.; M=6.9.

1952, March 17, 17:58. From March 13 until the end of April, a swarm of earthquakes occurred with sources to the southeast of Hawaii Island (Fig. 76). The majority of shocks were registered only by seismic stations and were not felt on the island. The intervals between shocks rapidly decreased from March 13 to 20, and then began to slowly increase. The epicenters of the shocks were concentrated in a narrow zone, extending along the coast, apparently coinciding with a tectonic fault or a zone of faults, dislocations along which in fact probably caused the earthquakes described.

A strong shock on March 17 at 17:58, felt at Naalehu, caused a small tsunami. At Kalapana, about at 18:00, the water passed 180 m inland (600 feet) and reached the school yard. No damage at all was done, but it was decided to announce a tsunami alarm. The tide gauge at Hilo did not register any waves (Macdonald, 1952; Iida et al., 1967).

Macdonald (1952): 18.III; 3^h58^m; 19.1° N., 155.0° W.; M < 6.

1957, October 31. At 19:00, oscillations with an amplitude of 10 cm and a period of 12 minutes began on Midway Island (Fig. 77). Oscillations with an amplitude of less than 10 cm and a period of 14 minutes began at Nawiliwili; oscillations with an amplitude of about 10 cm and periods of 21, 25 and 27 minutes respectively began at Honolulu, Kahului and Hilo. There was no earthquake. Apparently, the oscillations were of meteorological origin (Iida et al., 1967; Pararas-Carayannis, 1969).

[At 10^h 07^m, there was an earthquake off the coast of Panama; 6 1/2° N., 83° W.; M = 6 1/2-6 3/4.]

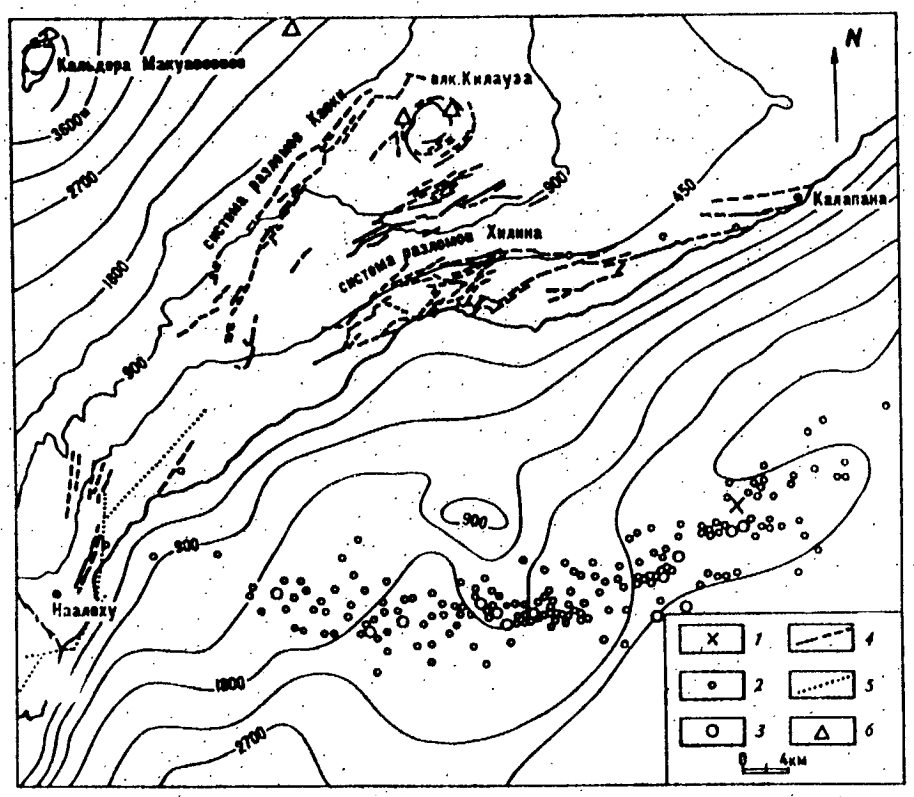


Fig. 76

Epicentral region of the earthquake of 17.III.1952 (Macdonald, 1952).

1 - epicentre of the main shock;

2 - epicentres of the aftershocks;

3 - epicentres of the strongest aftershocks;

4 - ruptures and breaks;

5 - assumed ruptures and breaks;

6 - seismic stations.

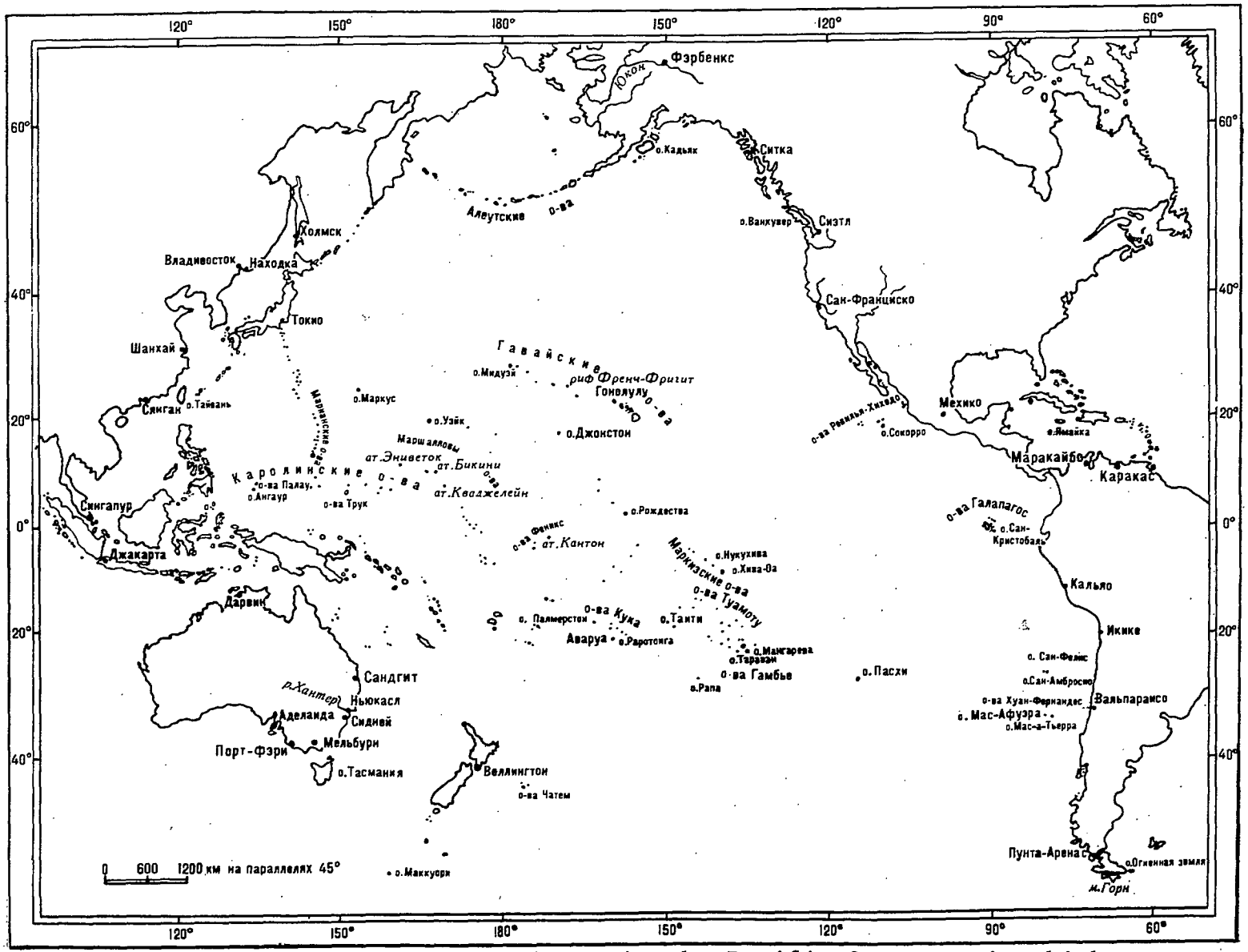


Fig. 77 A general map of places in the Pacific Ocean Basin which are referred to in the text but not shown on regional maps.

A LIST OF THE BASIC PARAMETERS OF TSUNAMIS
TSUNAMIS, CAUSED BY EARTHQUAKES

Date			Coordinates of the source (or place of occurrence)			Magnitude of earthquake M	Degree of Authenticity of Tsunami[1]	Intensity of Tsunami I
Year	Month	Day	Latitude	Longitude	Depth of source			
1	2	3	4	5	6	7	8	9
			Fiji Islands					
1953	IX	14	18.2° S.	178.3° E.	-	6 3/4	D	1
			Islands of Samoa, Tonga, Kermadec					
1848	VII	12	Tsunami on Tahiti and Hawaiian Islands		-	-	Q	-
1853	XII	--	Island of Tongatapu		-	-	Q	-
1865	XI	18	19 1/2° S.	173. 1/2° W.	-	8	D	3?
1881	XI	24	Island of Tongatapu		-	8	Q	-
1883	III	24	Samoa Islands		-	-	P	1
1917	V	1	29° S.	177° W.	-	8	D	3?
1917	VI	25	15 1/2°	173	-	8 1/4	D	3
1917	XI	16	29	177 1/2	-	7 1/2	P	1
1919	I	1	19 1/2	176 1/2	180	8	Q	-
1919	IV	30	19	172 1/2	-	8 1/4	D	1 1/2
1928	V	18	Island of Lifuka			-	P	1/2
1948	IX	9	21° S.	174° W.	-	7 3/4	D	-

1. Calculated on a 5-point scale: D - definite (the tsunami was recorded by at least one tide gauge or has many reliable visual observations); L - likely (it has a small number of comparatively reliable observations); P - possible (difficult to decide by the information held whether it was a tsunami or some other occurrence, such as a seiche, seaquake, wind generated waves, etc); Q - questionable (the description gives reason to believe that an occurrence other than a tsunami took place, but that the possibility of a tsunami is not completely excluded); E - erroneous indication of a tsunami entered into scientific literature.

1	2	3	4	5	6	7	8	9
1963	XII	18	24.8	176.6	45	7 1/4-7 1/2	P	1/2
1968	VII	25	30.8	178.4	60	7-7 1/4	P	1/2
				New Zealand				
			North Island. East and South Shores					
1845	VII	6	Wanganui		-	-	P	1/2
1848	X	16	41 1/4° S.	174 1/4° E.	-	6 1/2	P	1/2
1848	X	17/18	41 1/4	174 3/4	-	7	P	1/2
1855	I	23	41 1/4	175	-	8	L	3
1931	II	3	39 1/2	177	-	7 3/4	Q	0
1931	II	13	39 1/2	177	-	7	Q	0
1931	II	19	39 1/2	177	-	-	Q	-
1932	IX	16	39	177 1/2	-	6 3/4	P	0
1947	III	26	38 3/4	178 1/2	20	7	L	3?
1950	III	14	37.8	177.2	-	5 3/4	P	0
			Southern Island. East Shore					
1922	XII	25	43° S.	173° E.	-	6 1/4	L	0
			Southern Island. West Shore					
1913	II	22	41 3/4° S.	171 1/2° E.	6 3/4	6 3/4	L	1/2
1929	VI	17	41 3/4	172 1/4	-	7 1/2	P	1
			Southern Part of Pacific Ocean					
1924	VI	26	56° S.	157 1/2° E.	-	7 3/4	L	-
1958	XI	4	50	115° W.	-	6	Q	-
				Chile				
1562	X	28	38° S.	73 1/2° W.	-	8	P	3 1/2
1570	II	8	37	73	-	8	L	3
1575	XII	16	40	74	-	7 3/4	L	2 1/2
1633	V	14	North of Chiloe Island		-	-	L	1 1/2
1657	III	15	37° S.	73° W.	-	7 1/4	L	2 1/2
1657	VII	9	Valparaiso		-	-	Q	0
1730	VII	8	32 1/2° S.	71 1/2° W.	-	8 1/4	D	3 1/2
1737	XII	24	43	74	-	-	Q	-
1742	III	23	Concepcion		-	-	Q	-
1751	V	24	37° S.	73° W.	-	8 1/4	D	3 1/2
1765	-	--	Valparaiso		-	-	Q	2?

1	2	3	4	5	6	7	8	9
1811	XI	19		"	-	-	P	2
1819	IV	11	27° S.	71 1/2° W.	-	8	D	2
1822	XI	19	33	72	-	7 1/2	D	2
1835	II	20	37	73	-	8 1/4	D	3
1836	VII	3		Cobija	-	-	Q	1
1837	XI	7	42 1/2° S.	74° W.	-	8 1/2	D	3?
1838	V	7		Concepcion Bay	-	-	P	0
1849	XI	17	30° S.	71 1/2° W.	-	6 3/4	D	2 1/2
1851	IV	2		Valparaiso	-	-	E	-
1851	V	26	28° S.	70 1/2° W.	-	7 1/4	L	2
1855	VIII	11		Valparaiso	-	-	Q	0
1858	IV	24		Coquimbo	-	6 1/2	P	1
1859	X	5		Caldera	-	7	L	2 1/2
1868	IX	14		Talcahuano	-	-	P	1/2
1868	X	16		Valparaiso	-	-	P	1/2
1869	I	27		Tome	-	-	P	0
1869	II	6		Corral	-	-	P	0
1869	VI	25		Pisagua	-	-	P	0
1869	VIII	9		Coquimbo	-	-	L	1 1/2
1869	VIII	21	21° S.	70° W.	-	6 3/4	Q	0
1869	VIII	21	19	70 1/2	-	6 3/4	L	1 1/2
1871	III	25	35	72 1/2	-	7 1/2	P	1/2
1871	VIII	20		Valparaiso	-	-	P	1/2
1871	XII	28		Puerto Montt	-	-	P	1/2
1873	XI	19		Antofagasta	-	-	Q	2?
1877	V	9	21 1/2° S.	70 1/2° W.	-	8	D	3 1/2
1877	V	15		Huanillos	-	-	P	0
1877	VI	15		Pisagua	-	-	Q	0?
1877	VIII	23		Iquique	-	-	P	1/2
1877	X	9		Antofagasta	-	-	Q	1/2
1878	I	23	18 1/2° S.	70 1/2° W.	-	7	E	-
1878	II	14		Concepcion Bay	-	-	P	0
1878	III	12		Iquique	-	-	P	0
1878	IV	12	Iquique, Buchupureo		-	-	P	1/2

1	2	3	4	5	6	7	8	9
1878	VI	12(16)		Antofagasta	–	–	P	0
1880	VIII	15	31° S.	71 1/2° W.	–	7	Q	1/2
1881	VII	14		Iquique	–	–	L	1
1881	X	27-29		Pisagua	–	–	P	0
1882	II	23		San Antonio	–	–	P	0
1882	IX	14		Pisagua	–	–	P	0
1885	XI	12		Iquique	–	–	L	1/2
1898	VII	23	37° S.	74° W.	–	6 1/2	Q	0
1903	IX	26		Iquique	–	–	P	0
1903	XII	7	28 1/2° S.	71° W.	–	6 1/2	L	0
1906	V	7		Arica	–	–	P	0
1906	VIII	16	33° S.	72° W.	–	8 1/2	L	2
1909	VI	8	26 1/2	70 1/2	–	7 1/2	E	–
1918	XII	4	27	71	–	7 3/4	D	2 1/2
1920	VIII	20	38	73 1/2	–	7	L	1
1922	XI	10	29	71	–	8 1/4	D	2 1/2
1923	V	4	28 3/4	71 3/4	60	7	E?	–
1923	VIII	12		Arica	–	–	P	0
1926	XII	9	28° S.	71° W.	–	6	P	1/2
1927	XI	21	44 1/2	73	–	7	L	2
1928	XII	1	35	72	–	8	L	1/2
1930	XII	29	28 1/2	71	–	6	P	1/2
1933	II	23	20	71	40	7 1/2	Q	–
1934	XII	4	19 1/2° S.	69 1/2° W.	130	7	Q	–
1936	VII	13	24 1/2	70 1/2	–	7 1/4	D	1/2
1943	IV	6	30 3/4	72	–	8	D	0
1948	XII	26	22 1/2	69	100	7	L	0
1949	XII	17	54	71	–	7 3/4	Q	0
1955	IV	19	29.9	71.6	–	7	D	1
1960	V	21	37 1/2	73 1/2	–	8	D	-1
1960	V	22	41	73 1/2	–	8 1/2	D	4
1966	XII	28	25.5	70.6	47	8	D	1/2
1967	XII	20	21.7	69.5	33	7 1/2	L	0

Peru and the Southern Part of Ecuador

1	2	3	4	5	6	7	8	9
1513/1515	-	--		Callao?	-	8-8 1/2	P	3?
1586	VII	9	12° S.	77° W.	-	8 1/2	D	3 1/2
1590		--		Camana	-	-	P	1 1/2
1604	XI	24	17° S.	72° W.	-	8 1/2	D	3 1/2
1615	IX	16	18 1/2	71	-	7 1/2	P	1 1/2
1647	V	7		Callao, Arica	-	-	P	2
1678	VI	17	9° S.	79° W.	-	8 1/4	L	2 1/2
1687	X	20	13 1/2	76 1/2	-	8 1/2	D	3 1/2
1725	III	27		Camana	-	-	P	1 1/2
1746	X	28	12° S.	77° W.	-	8	D	3 1/2
1799	-	--		Callao, Arica	-	-	P	1
1806	XII	1			-	-	L	1/2
1828	III	20	12° S.	76 1/2° W.	-	7 1/4	E	-
1840	I	28		Chorillos	-	-	Q	0
1847	V	23		Callao	-	-	P	1 1/2
1852	XI	27		"	-	-	Q	-
1860	IV	23		"	-	-	L	0
1865	I	8/9		"	-	-	P	1 1/2
1868	VIII	13	17° S.	72 1/2° W.	-	8 1/2	D	3 1/2
1868	X	2	17	72 1/2	-	-	P	1/2
1869	IV	22		Callao?	-	-	Q	1
1869	VIII	19	16° S.	73 1/2° W.	-	6 1/2	E	-
1871	II	5-9		Chincha Islands	-	-	P	1
1871	VIII	21	13° S.	77° W.	-	7	P	1
1871	X	5		Arequipa	-	-	E	-
1872	I	10		"	-	6 1/2	Q	0
1877	V	14		Ancon	-	-	P	1
1878	II	4		Callao	-	-	Q	0
1913	VII	28	17° S.	74° W.	-	7	Q	0
1914	I	12		Callao	-	-	P	1 1/2
1914	II	26		Mollendo	-	-	Q	-
1928	IV	9	13° S.	60 1/2° W.	-	7	Q	1
1933	X	2	2	81	-	7	L	1 1/2
1940	V	24	10 1/2	77	60	8	P	1 1/2

1	2	3	4	5	6	7	8	9
1942	VIIi	24	15	76	60	8	D	1
1950	XII	9	14.6	76.3	80	7	P	0
1953	II	15	12	77 1/2	-	5 1/2	P	0
1953	XII	12	3 1/2	81	-	7 1/4	D	1/2
1958	IV	9		Callao	-	-	E	1 1/2
1959	II	7	4° S.	81 1/2° W.	-	7	Q	-2
1960	I	13	15 3/4	72 3/4	160	7 3/4	Q	3?
1960	XI	20	6.9	80.8	-	6 3/4	L	4?
1966	X	17	10.7	78.8	40	8	D	1 1/2
1967	IX	3	10.6	79.8	40	7	P	-1 1/2
			Northern Ecuador, Colombia and Panama					
1827	XI	16		Colombia	-	-	E	-
1868	VIII	16		Ecuador	-	-	E?	-
1877	X	11		Buenaventura and Esmeraldas	-	-	P	-
1882	IX	7		Panama	-	7 1/2	P	1
1884	XI	5/6		"	-	-	Q	-
1904	I	20		"	-	-	Q	-
1906	I	31	1° N.	81 1/2° W.	-	8 1/2	D	3
1906	II	7	1	81	-	-	P	1/2
1916	I	31		Panama	-	-	Q	-
1942	V	22	4 1/2° N.	75° W.	130	5 3/4	Q	1?
1958	I	19	1 1/2	79 1/2	60	7 1/2	D	2
			Central America and Mexico					
			Guatemalan Trough					
1537		--		Mexico	-	-	Q	-
1732	II	25		Acapulco	-	-	L	1 1/2
1754	IX	1		"	-	-	L	2
1773	VI	3		Guatemala	-	-	E	-
1787	III	28	16 1/2° N.	98 1/2° W.	-	8 1/4	D	2 1/2
1787	IV	3	15 1/2	97	-	7 1/4	P	1
1820	V	4	16 1/2	99 1/2	-	8	D	1 1/2
1833	III	10		Acapulco	-	-	L	1/2
1834	III	13/14		"	-	7	Q	0

1	2	3	4	5	6	7	8	9
1837	VIII	9		Acapulco	–	6 1/2	P	0
1837	X	18		"	–	7	P	0
1837	X	20		"	–	6 3/4	P	0
1837	X	21		"	–	6 1/2	P	0
1837	X	22		"	–	6 1/2	P	0
1845	IV	7	17 1/2° N.	101 1/2° W.	–	8 1/2	L	1 1/2
1852	XII	4	17	100	–	7	P	0
1854	VIII	4/7	8 1/2	83	–	7 1/4	P	1 1/2
1859	VIII	25	13	87 1/2	–	6 1/4	P	1 1/2
1859	XII	8	13 3/4	89 3/4	40	7	L	1 1/2
1875	II	24		Mansanillo	–	6 1/2	Q	0
1897	VI	20	16° N.	95° W.	–	7	P	0
1902	II	26	13 1/2	89 1/2	–	–	L	2
1903	VII	16		Acapulco	–	–	Q	0?
1905	I	--		Revilla-Gigedo Islands	–	–	Q	–
1907	IV	14	17° N.	100° W.	–	8	L	1
1909	VII	30	17	100 1/2	–	7 3/4	P	0
1915	IX	6	14° N.	89° W.	–	7	Q	1/2
1925	XI	16	18	107	80	7 3/4	Q	3?
1928	VI	16	16 1/4	98	–	7 3/4	D	1
1932	VI	3	19 1/2	104 1/4	–	8	D	2
1932	VI	18	19.2	104.2	–	7 3/4	D	1/2
1932	VI	22	19	104 1/2	–	7	D	1 1/2
1932	VI	29		Cuyutlan	–	–	P	0
1934	VII	17	8° N.	82 1/2° W.	–	7 3/4	L	1 1/2
1941	XII	5	8 1/2	83	–	7 1/2	D	-3
1941	XII	6	8 1/2	84	–	7	D	-4
1950	X	5	11	85	–	7 3/4	D	-2?
1950	X	23	14.3	91.7	30	7 1/4	D	-1?
1950	XII	14	17	97 1/2	–	7 1/4	D	-1 1/2
1952	V	13	10 1/2	85	–	6 3/4	P	-3
1957	VII	28	16.4	99.2	25	7 1/2	D	1/2
1962	III	12	8.1	82.9	–	6 3/4	D	-3

1	2	3	4	5	6	7	8	9
1962	V	11	17.2	99.7	–	7 1/4	D	0
1968	IX	25	15.6	92.6	140	7	Q	1?
			Gulf of California					
1852	XI	29	32 1/2° N.	115 1/2° W.	–	7	Q	1
1887	V	3	31	109	80	8	Q	1
1891	VII	30	25 1/2	103 1/2	–	–	Q	1
1902	VIII	--	Altata		–	–	Q	–
1948	XII	3	21.6° N.	106.7° W.	–	7	L	1 1/2
			USA California					
1812	XII	21	34° N.	120° W.	–	7 1/2	L	1 1/2
1840	I	16-18	Santa Cruz		–	–	E	–
1851	III-V	--	San Francisco		–	–	Q	–
1851	XI	13	San Francisco		–	–	Q	–
1854	V	31	Santa Barbara		–	–	Q	0
1854	X	26	San Francisco		–	–	Q	0
1855	III	19	41° N.	125° W.	–	6	P	0
1855	VII	10	34	118 1/2	–	6	P	0
1855	X	21	San Francisco		–	–	Q	0
1856	II	15	37 3/4° N.	122 1/4°W.	–	5 1/4	Q	-1
1859	IX	24	Half Moon Bay		–	–	Q	0
1861	V	5	San Francisco		–	–	Q	–
1865	X	8	37 1/4° N.	122 ° W.	–	6 1/4	Q	1/2
1868	X	21	37 3/4	122 1/4	–	6 3/4	Q	1/2
1869	II	13	San Francisco		–	–	Q	0
1879	VIII	10	Los Angeles		–	–	Q	0
1885	XI	19	San Francisco		–	–	Q	0
1889	XII	25	33 3/4° N.	116 3/4° W.	–	6	Q	1/2
1906	IV	18	38	123	–	8 1/4	D	-4
1927	XI	4	34 1/2	121 1/2	–	7 1/4	D	1
1930	VIII	30	33.9	118.6	–	5 1/4	Q	-1/2
1933	III	10	33.6	118.0	–	6 1/4	P	-3
1941	II	9	40.9	125.4	–	6 1/2	Q	0
			South-western USA, Canada, South-east Alaska					
1880	X	26	Sitka			7	P	1

1	2	3	4	5	6	7	8	9
1899	IX	3	60° N.	142.3° W.	-	8	L	0
1899	IX	10	60	140		8 1/4	D	3
1904	III	30	Grace Bay			-	P	1/2
1907	IX	24	Lynn Canal			5 1/2	Q	0
1908	II	14	Valdez			6	Q	-
1927	X	24	57 1/2° N.	137° W.		7	Q	-
1928	II	9	49	125		5 3/4	P	0
1929	V	26	51	131		7	L	0
1938	III	22	52 1/4	132		6 1/4	P	-
1949	VIII	21	53 3/4	133 1/4		8	D	0?
			Hawaiian Islands					
1868	IV	2	19° N.	155° W.		7 3/4	D	3 1/2
1868	X	1	Island of Hawaii			-	P	2?
1871	II	19	Honolulu; Island of Lanai			7	P	0
1877	II	24	Island of Hawaii, Kona			-	P	1/2
1877	V	4	Island of Hawaii			-	Q	1
1908	IX	20	19.4° N.	154.9° W.		6 1/4	L	0
1935	XI	21	Hawaiian Islands			-	Q	2?
1951	VIII	21	19.2° N.	156.1° W.	8-17	7	D	1/2
1952	III	17	19.1	155.0		5	P	0

TSUNAMI GENERATED BY VOLCANIC ERUPTIONS

Date			Volcano			Degree of Authenticity of Tsunami	Intensity of Tsunami i_o
Year	Month	Day	Name	Coordinates			
				Latitude	Longitude		
1905-1911	-	-	Matavanu	13.5° S.	172.4° W.	P	1/2
1866	IX	12	(underwater)	14.2	169.6	Q	-
1908(1907)	-	-	"	21.2	175.7	P	1/2
1839	II	12	"	33.6	76.8	Q	-
1967	XII	4	"	63.0	60.5	Q	0

GRAVITATIONAL WAVES CAUSED BY LANDSLIDES, CAVE-INS, SUSPENSION CURRENTS

Date			Place of Appearance	Source of Fall	Degree of Authenticity of Tsunami	Intensity of Tsunami i_o
Year	Month	Day				
1	2	3	4	5	6	7
1845	-	-	Alaska, Yakutat Gulf	Glacier Breakup	P	3?
1853-54	-	-	Alaska, Lituya Bay	-	P	4
1874	-	-	Same	-	P	4
1895	III	8/10	USA, San Miguel Island	Earthquake	Q	-
1899	IX	10	Alaska, Russell Canal Lituya Bay	"	D	2 1/2
1905	VII	4	Alaska, Yakutat Bay	Glacier Breakup	P	2 1/2
1919	I(IV)	9	South-western Island of Hawaii	Lava Stream	Q	-
1919	IX-X	-	Same	Same	P	2

1	2	3	4	5	6	7
1929	VI	17	New Zealand, Caramia	Earthquake	D	1 1/2
1936	X	27	Alaska, Lituya Bay	–	D	4
1942	VIII	24	Peru	Earthquake	P	1
1946	VI	23	Canada	"	D	1
1953	XI	14	Fiji Islands, Suva	"	D	1
1958	VII	9	Alaska, Lituya Bay	"	D	4
1964	III	28	Alaska, Prince William Bay	"	D	4

SEA LEVEL OSCILLATIONS OF TSUNAMI TYPE OF METEOROLOGICAL AND UNKNOWN ORIGIN AND SOLITARY WAVES IN THE OPEN OCEAN (FOR VARIOUS ZONES)

Date			Place of Occurrence	Degree of Authenticity	Intensity i_o
Year	Month	Day			
1	2	3	4	5	6
			Oceania		
1926	III-V	-	Palmerston Island	-	2 1/2
			New Zealand and Australia		
1856	III	-	South Canterbury Province	L	1/2
1858	IX	15	East South Island	P	1/2
1866	VIII	9	Sidney	Q	-1
1866	VIII	15-21	"	Q	-1
1867	VIII	5-13	"	Q	-1
1869	VIII	11-17	"	Q	-1
1870	VIII	12-22	"	Q	-1
1924	VII	21	Chatham Islands	Q	1
			South America		
1841	-	-	Callao	P	1
1865	III	1	"	P	1/2
1865	XI	25-27	"	Q	1
1877	IX	2	Valparaiso	P	1/2
1878	I	27	Callao	L	1 1/2
1878	I	18/30	Valparaiso - Pisagua	Q	1 1/2
1878	II	3	Iquique - Pisagua	Q	-
1878	VI	-	Border of Chile and Peru	P	0
1878	IX	-	Iquique - Chanaral	Q	1/2
1878	XI	23/25	Valparaiso	P	1/2
1879	VIII	8	"	P	1 1/2
1923	II	17	Constitucion	L	1 1/2
1923	III	4	San Felix Island	Q	4
1928	III	31	Antofagasta	Q	2
1929	VIII	9	"	P	2 1/2
			Central America and Mexico		
1860	III	17	Near Acapulco	Q	-

1	2	3	4	5	6
1883	III	12	Los Tres Marias Isles	L	2
1925	V	4	14° 35' N., 106° 06' W.	Q	2 1/2
1927	IX	6	Guaymas and Salina Cruz	Q	1 1/2
			USA and Canada		
1854	XI-XII	1(10)	San Francisco, Angel Island	P	0
1872	VIII	24	Astoria, San Francisco, San Diego	P	0
1872	IX	16/17	same	P	0
1877	IV	19	Cayucas	P	2
1878	XI	22	Los Angeles, San Luis Obispo	P	1 1/2
1884	I	25	San Francisco	Q	-
1884	XI	12	same	P	-3
1884	VII	8	"	D	0
1895	X	14	"	D	0
1896	XII	17	Santa Barbara	L	1 1/2
1906	XI	6	46° 09' N., 125° 22' W.	Q	-
1910	XI	21	San Francisco	D	-1 1/2
1923	XI	-	California	Q	-
1925	X	4	Long Beach	D	-1
1927	I	1	Los Angeles	Q	1
1934	VIII	21	South of Los Angeles	Q	3
1963	III	30/31	Langara Island	P	2
			Hawaiian Islands		
1813-1814		-	Island of Hawaii, Hookena	L	1
1854	I	-	Island of Hawaii	P	-
1860	XII	1	North of Maui and Molokai Islands	L	1 1/2
1862	I	28	North of Oahu and Molokai Islands	P	1
1869	VII	25	South-east Islands of Hawaii	Q	3
1872	VIII	23	Hilo	P	1/2
1878	I	20	North of Maui and Oahu Islands	L	1 1/2
1895	I	28	Islands of Maui, Maliko	P	1/2
1903	X	5	West of Hawaii Island	Q	0

1	2	3	4	5	6
1903	X	8	South-east, Island of Hawaii	Q	0
1903	XI	24	same	Q	0
1903	XI	29	North of Oahu and Molokai Islands, Honolulu	P	1/2
1921	XII	16	Hawaiian Islands	Q	0
1924	V	30?	South of Lanai and Kaui Islands	P	2
1925	X	4	Honolulu	D	-3 1/2
1926	I	24	Hawaiian Islands	Q	-
1930	II	-	same	Q	-
1947	I	-	"	Q	0
1957	X	31	"	D	-3

APPENDIX

Conversion of old measures into metric

English measures

Inch = 2.5 cm
Mile = 1853 m
Fathom = = 182 cm
Foot (f in text) = 30.3 cm
Chain = 19.85 m
Yard = 91 cm

American measures

Acre = 0.4047 hectares
Barrel = 163.56 liters

Dutch and Indonesian measures

Paal = 1507 except on Sumatra)
= 1852 m (on Sumatra)
Fathom (vadem) = 1.83 m
Foot (voet) = 30.48 cm

Russian measures

Fathom (sazhen') = 233.6 cm

Spanish measures

Vara = 83.5 cm
Cuadro = 115 m or 100 m
League (legua) post = 4000 m
sea = 5555 m
regular = 5572 m
Fathom (braza) = 167.8 cm
Foot (pie) = 33 cm

German measures

Fathom (faden) = 213.3 cm

French measures

Inch (pouce) = 2.7 cm
League (leue) sea = 4000 m
land = 4444 m
Fathom (brasse) = 162 cm
Toise = 1.945 m
Foot (pied) = 33 cm

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ABBREVIATED NAMES OF LITERATURE SOURCES

ACERM	- Annales de la Commission paur l'etude des raz de maree, Paris
AJSA	- American Journal of Science and Art
ASIND	- Annual Summary of Information on Natural Disasters, UNESCO
BAAS	- British Association for the Advancement of Science
BASLB	- Bulletin de l'Academie royale des sciences, des letters et des beaux-arts de Belgique
BBGOA	- Bibliographical Bulletin of American Geophysics and Oceanography, Mexico.
BCIS	- Bureau central international seismologique
BERI	- Bulletin of the Earthquake Research Institute, Tokyo University
BGSA	- Bulletin of the Geological Society of America
BHVO	- Bulletin of the Hawaiian Volcano Observatory, Hawaii
BSSA	- Bulletin of the Seismological Society of America
CSI	- Committee on Seismological Investigations
EN	- Earthquake Notes, Eastern Section of the Seismological Society of America, Washington
GJ	- Geographical Journal
ISS	- International Seismological Summary
JG	- Journal of Geography, Tokyo
MASAB	- Memoires de l'Academie des sciences, arts et belles-letters de Dijon
MCAB	- Memoires couronnes et autres memoires publies par l'Academie royal de Belgique
MEC	- Materiaux pour l'etude des calamites, Geneve
MPM	- Mineralogical and Petrographic Records, New Series, Vienna
NGWG	- Bulletin of the Imperial Society of the Sciences, Gottingen, Division of Mathematics and Physics
NJMGP	- New Yearbook for Mineralogy, Geology and Palaeontology, Stuttgart

NL - News Letter, International Tsunami Information Center, Honolulu
NZJST - New Zealand Journal of Science and Technology
PBCSI - Publications du Bureau central seismologique international, Strassbourg
PEICF - Publications of the Earthquake Investigations Committee in Foreign Languages, Tokyo
PGM - Petermanns geographische Mitteilungen, Gotha
PGSL - Proceedings of the Royal Geological Society of London
PTM - Proceedings of Tsunami Meetings, Associated with Tenth Pacific Science Congress, UGGL, Monographie N 24, Paris
QJS - Quarterly Journal of Seismology, Central Meteorological Observatory - Japan Meteorological Agency, Tokyo
REC - Revue pour l'etude des calamites, Geneve
SN - Seismological Notes
TAGU - Transactions of the American Geophysical Union, Washington
TGSL - Transactions of the Geological Society of London
TNZI - Transactions and Proceedings of the New Zealand Institute
UGGI - Union geodesique et geophysique international
USCGS - United States Coast and Geodetic Survey
USE - United States Earthquakes
VL - Volcano Letter, United States Geological Survey, Hawaii

SUPPLEMENTARY ABBREVIATIONS OF LITERATURE SOURCES FOR "A Catalogue of Tsunamis on the Western Shore of the Pacific Ocean"

GM - Geophysical Magazine, Tokyo
GSJJ - Journal of the Geological Society of Japan
JJAG - Japanese Journal of Astronomy and Geophysics
JMR - Journal of Marine Research, USA
JO - Journal of Oceanography, Kobe, Japan
TSSJ - Transactions of the Seismological Society of Japan

ABBREVIATIONS OF LIBRARIES

BAN - Library of the Academy of Sciences of the USSR, Leningrad
BIL - Library of Foreign Literature, Moscow
GBL - Lenin State Library, Moscow
GBS - Main Botanical Garden, Academy of Sciences of the USSR, Moscow
GGO - Main Geophysical Observatory (Voeikov), Leningrad
IG - Institute of Geography, Academy of Sciences of the USSR, Moscow
IO - Institute of Oceanology, Academy of Sciences of the USSR, Moscow
IFZ - Institute of Earth Physics, Academy of Sciences of the USSR, Moscow
LGI - Leningrad Mining Institute
Lima - National Library of Peru, Lima
L'v.l - Lvov State Universtiy
MGU - Moscow State Universtiy
M.O.I.P. - Moscow Naturalists' Society
MITsTs - International Tsunami Information Centre, Honolulu
MTsD - World Centre for Geophysical Data, Moscow

ONZ - Library of the Earth Sciences Department, Academy of Sciences of the USSR, Moscow
S-Shch - Saltykov - Shchedrin State Public Library, Leningrad
SakhKNII - Sakhalin combined Scientific Research Institute, Academy of Sciences of the USSR
TsVMB - Central Naval Library, Leningrad
TsSO - Central Seismic Observatory, Institute of Earth Sciences, Obninsk
VGB - All-union Geological Library, Leningrad
VGO - All-union Geographical Society, Leningrad
Zurich - City Library, Zurich

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