Catalogue of TSUNAMIS on the WESTERN SHORE of the PACIFIC OCEAN

S.L. SOLOVIEV & CH.N. GO

Canadian Translation of Fisheries and Aquatic Sciences

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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
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Abstract

A Catalogue of Tsunamis on the Western Shore of the Pacific Ocean (173-1968). S. L. Soloviev, Ch. N. Go, Moscow, "Nauka", 1974.

This monograph contains descriptions of about 600 tsunamis and related phenomena, observed on the northern and western coasts of the Pacific Ocean. Earthquakes and other processes which cause tsunamis are also described. As far as possible, estimates are given of the intensity of all tsunamis in degrees on a special scale, as well as the coordinates of the focus and of the energy (magnitude) of the earthquakes which generated the tsunamis.

The book will be of interest to seismologists, oceanographers, specialists in tectonic geology, volcanologists, geographers, and to the inhabitants of the Pacific coast of the USSR, and those involved in the development of various operations in the coastal areas of the Pacific Ocean.

129 illustrations, 66 tables, 556 reference items.

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

E. F. Savarenskii

INTRODUCTION

Objectives of the study. Tsunamis are specific marine flood waves, which are caused by submarine earthquakes and some other transient natural processes. They are a terrible natural catastrophe on the shores of the Pacific Ocean, including the coast of the USSR. Tsunamis do not occur frequently, but still at approximately eighteen-month intervals, at least one destructive tsunami takes place somewhere in the Pacific Ocean. This obliges us to study the tsunami phenomenon and to find means of protecting people and property from the destructive waves. The urgency of the problem constantly grows as the population increases and industry develops in the coastal regions.

In the USSR, the ncessity for detailed study of tsunamis became obvious after the catastrophic Kamchatka earthquake of November 5, 1952. This earthquake generated tsunami waves, which partly washed away Severo-Kuril'sk and other settlements on the north of the Kuril Islands and in the south of Kamchatka (Savarenskii et al., 1958).

At the present time, tsunami defense amounts mainly to two measures:

1) Tsunami zoning of the coast; that is, specifying the possible zone of flooding, with the aim, as far as possible, of removing structures from this zone.

2) Organizing tsunami warning systems for the inhabitants of coastal settlements.

Effective tsunami prediction services, created or substantially modernized in the post-war period in the largest countries in the Pacific basin (USSR, USA, Japan), taken together now cover the greater part of the Pacific.

For these services to work effectively, we must have a clear idea as to where precisely in the Pacific and how freqently tsunamis arise, and also as to how the probability of the generation of tsunamis by earthquakes depends on certain parametres of underground shocks. To answer these questions, we must collect and analyze all the data on tsunamis and strong earthquakes in the Pacific.

Such work was begun by the authors almost ten years ago. The first necessary stage was to collect the information about Pacific tsunamis, scattered in numerous publications, as a rule little known in the USSR. A detailed catalogue of Pacific tsunamis is thus offered to readers in this publication. This is the first time in the world such a detailed catalogue has been prepared. This book contains data on the

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

northern and western coasts of the Pacific Ocean, from the Alaskan peninsula to the New Hebrides Islands. Data for the southern and eastern coasts of the Pacific will appear in a subsequent book.

A tentative numerical parametrization of the tsunamis, complied in this catalogue (mainly an estimate of their intensity and focal coordinates) was done previously (Soloviev, Go, 1969). This parametrization, in turn, was used to obtain a tentative estimate of the frequency of tsunamis in the Pacific Ocean and to derive an approximate formula by which to calculate the probability of the generation of tsunamis by earthquakes occurring in the Pacific (Soloviev, 1972). At the same time, the papers mentioned make use of the data in this catalogue only in the roughest approximation. We hope that this catalogue will serve as a basis for many other diverse investigations into tsunamis. /4

General information on the tsunami phenomenon. Tsunamis have been known from very ancient times, but nevertheless their scientific study essentially began at the turn of the 20th century. Physically, tsunamis are long marine gravity waves, which, having periods of about 2 to 200 minutes, are intermediate between regular swells at sea and the diurnal tidal oscillations of the earth's hydrophere. Serious analysis of tsunamis became possible only after the great strides made in the development of general hydrodynamics (mainly by European scientists) at the end of the 19th century.

The overwhelming majority of tsunamis occur in the Pacific, and the eastern coast of Japan has the highest tsunami activity. It is therefore not surprising that the first specialized theoretical studies of tsunamis were carried out by Japanese specialists. They were done after the catastrophic Sanriku tsunami of 1896, the subsequent destructive Sagami tsunami of 1923 and the catastrophic Sanriku tsunami of 1933.

The term tsunami itself, which has found world usage, is of Japanese origin. In translation, it means "wave in the bay" (the eastern shore of Japan has many submerged valleys, and most settlements are situated at the heads of bays, where tsunamis are most intensive; unlike ordinary waves, tsunamis are not noticeable in the open sea). Other, less successful terms have previously been used for tsunamis: tidal waves (English), Flutwellen (German), vloedgolven (Dutch), sudden rise of water - raz de marée (French), hai-i (Chinese); seaquake - maremoto (Spanish), siesmic sea waves (English), vagues sismiques (French), etc. The present work makes use of the term tsunami*.

Interest in tsunamis arose in such a large Pacific rim country as the USA after the catastrophic Aleutian tsunami of 1946, which devastated the Hawaiian Islands, and after the underwater atomic explosions in the same year. This interest increases with each new large tsunami affecting

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*In neuter gender, since it refers to a phenomenon.

the coast of the USA and its territories. The destructive Alaskan tsunami of 1964 was studied in special detail.

In the USSR, special studies on tsunamis were organized after the above-mentioned catastrophic Kamchatka tsunami of 1952. Theoretical studies relied upon the general achievements of the Soviet school of hydrodynamics.

Isolated papers on tsunamis appeared in a number of European countries (England, France, Italy, etc.) and in some Pacific countries (Mexico, Australia, etc.) (Grigorash, 1964; Annotated bibliography..., 1964). However, the development of research in European countries was delayed by a lack of urgency, and in the Pacific countries by a shortage of scientists.

The large number of full-scale, theoretical and experimental studies, done mainly in Japan, the USA and the USSR, revealed many patterns of tsunami formation, propagation and run-up. Still, very much of the tsunami phenomenon remained unclear, primarily due to the lack, until very recently, of instrumental records of waves in the open sea.

A number of studies give rather complete surveys of contemporary concepts of the tsunami phenomenon (Takahasi, 1942; Ponyavin, 1965; Stoneley, 1967; Wadati, 1967; Soloviev, 1968 a; Van Dorn, 1968; /5
Preisendorfer, 1971; etc.). It is impossible to give an account of all these ideas in this book. We shall limit ourselves to listing the most basic properties of tsunamis.

For a tsunami to arise, it is necessary that the surface of the sea deviate from its equilibrium position on a sufficiently large area. This occurs, for example, during seismo-tectonic shifts of the sea bed during strong earthquakes, rapid anomalous changes in atmospheric pressure over isolated areas of the sea, vertical activation of the water layer by the application of impulses to the floor of a basin (for example, seismic impulses), underwater and above-water explosions, large avalanches, large turbidity currents, etc.

The main cause of destructive tsunamis are the abrupt vertical displacements of isolated areas of the bottom of a basin due to seismotectonic shifts. Detailed full-scale studies show that such, for example, was the generating mechanism of the destructive Niigata tsunami of 1964. "Piston" movements of the sea floor evidently generate the majority of strong tsunamis.

Many weak tsunamis probably arise only as a result of a seismic impulse or strong elastic oscillations of the sea bottom, not accompanied by residual deformation. For example, the waves generated by the very strong earthquake of 1911 in the region of the Ryukyu Islands with focus at a depth of 160 km, must have originated in this way.

Apparently, in a number of cases, a tsunami can be caused by a sudden horizontal shift of steep, extended underwater slopes or by a strong horizontal seismic impulse, transmitted through a vertical or inclined wall. It is possible that this was in fact the generating mechanism of a number of South American tsunamis, for example, the Chilean tsunami of 1922, which was generated by an earthquake whose source was situated mainly on land.

These three mechanisms of tsunami generation should often act together, since seismo-tectonic shifts are rarely oriented strictly vertically or strictly horizontally, and deformations of the bottom are always accompanied both by rather strong elastic displacements and by oscillations.

Rapid and substantial changes in the relief of the sea floor can in some cases by the result of catastrophic volcanic explosions, namely those in which a large part of an underwater volcanic structure is destroyed and ejected instantaneously. The waves observed near the volcanoes after the explosion of the Krakatau Volcano in 1883 and the Sakar Volcano in 1888 are examples of tsunamis due to such changes in floor relief. The waves, observed remotely from the volcanoes during such explosions, are of a different nature and represent joint oscillations of the atmosphere and the hydrosphere.

We mention once again that the strongest tsunamis arise as a result of a marked change in the relief of the sea bottom. In addition, the intensity of such a tsunami decreases comparatively slowly with distance. Many such tsunamis have been observed along the entire Pacific. A classic example is the Chilean tsunami of 1960, in which the water rose 1-7 m at the coast of the USSR.

Impulse-generated tsunamis are weaker, and their intensity decreases more rapidly with distance. Nevertheless, many tsunamis of this type can still be observed at a considerable distance from their source.

Tsunamis caused by natural (volcanic) and artificial (nuclear) explosions, collapses, landslides, etc., as a rule, are local and are observed only near their focus. It is true that in some conditions, for example, in closed bays, the local rise of water can reach a fantastic height during these processes, as happened for example, during the landslide in Lituya Bay (southeast Alaska) in 1958.

Theoretical analysis shows that, with distance from the source, /6
the intensity and shape of the tsunami depend essentially both on the nature of the process which gave rise to the tsumami, and especially on the ratio between the area of the source of the tsunami and the depth of the basin. Tsunamis from extended sources, to some extent, maintain their individuality over large epicentral distances. The shapes of tsunamis from sources whose dimensions are less than the depth of the basin, are almost entirely determined by the parameters of the medium of propagation. The shapes of tsunamis are especially distorted in basins with complex floor relief, and mainly over a continental (insular) slope and shelf.

The velocity of the propagation of tsunamis in open sea can be taken with a high degree of approximation as the speed of long waves, and expressed by the square root of the depth of the water and the acceleration of the force of gravity.

In view of the marked dependence of the speed of tsunamis on the depth of the basin, tsunamis always unfold towards shallows. For this reason, underwater elevations of isometric form act as collecting lenses, sometimes causing marked local intensification of tsunamis (for example, at Crescent City during the Alaskan tsunami of 1964, or off the shores of North Korea during the Niigata tsunami of 1964).

Tsunamis bend around small islands in open sea in such a way that shadow zones are not observed. On the contrary, the distribution of the height of rise of water along the coasts of islands with not very angular shape is cosinusoidal with maxima at the place of approach of waves and on the opposite side of the island and with minima in the middle.

Tsunamis are partially reflected from steps of the sea bottom, primarily from continental (insular) slopes; here losses of wave energy are approximately 25%. The energy of tsunamis is almost entirely reflected from steep shores.

On emerging onto the shelf, tsunamis experience marked refraction, and the wave fronts unfold almost parallel to the isobaths, and consequently, to the shore line. Due to the presence of pronounced boundaries at the shelf, the emergence of tsunamis onto the shelf causes natural oscillations of the water on the shelf (seiches), which substantially distort the shape of the tsunami, especially the tail part of the wave, primarily by increasing the duration of oscillations. To a large extent, shelves trap and keep to themselves the energy of tsunamis.

If the source of the tsunami is situated on the shelf itself, or if tsunamis coming from beyond the shelf have not quite flat fronts and approach the edge of the shelf not quite orthogonally (that is, the great majority of cases), marginal interference waves, which carry the bulk of the energy to the observation point, are formed on the shelf and slowly propagate along the coast.

Underwater ridges, both in open sea and on a shelf, serve as wave guides; the energy of tsunamis is concentrated above them. As is known, ridges usually emerge on the coast as rocky capes or peninsulas; the rise of the water intensifies at such capes. A typical example is the south coast of Japan; tide gauges set up at capes (at Kushimoto on Cape Omae, and other places) register tsunamis approaching from the south much more sensitively than instruments at other places on the coast.

As shown by preliminary calculations, the height of the strongest tsunamis at the source practically does not exceed one or several metres. In view of the very long length of the wave (hundreds and thousands of kilometres), one cannot observe a tsunami in open sea (except, perhaps for the front slope of the strongest tsunamis).

As the waves approach the coast, their height increases, due to the reduction of the thickness of the water layer, in approximately inverse proportion to the fourth root of the depth of the water. Thus, waves up to 10 m high, with some splashes up to 30-50 m high, can fall on
the coast. At isolated islands in the central part of the Pacific Ocean, /7
lacking a shelf and with steep underwater slopes, the height of rise of water is usually small.

Very frequently, it is not the first wave of the train which rises highest onshore, but one of the subsequent ones. The series number of the maximal oscillation depends on many factors, but in general, it is highest the further the observation point from the source.

Radiation of tsunamis from the source is clearly directional though the mechanism has not been completely understood or studied. The great majority of tsunami sources are extended along the nearest coasts of the Pacific. The maximum of radiation is usually directed either transversely to the source towards the nearest coast, or in the opposite direction. In the latter case, the direction of radiation is often clearly traced right up to the opposite shore of the ocean.

If tsunamis encounter obstacles in the path of propagation of the waves, for example, a coastal scarp, then the wave height markedly increases on the stretch facing the wave even if the stretch is small in length (for example, 1 km). At the same time, being long waves, the tsunamis easily bend around obstacles and enter bays and gulfs of the most intricate and ramified shape.

The appearance of tsunamis in bays, on whose coast most inhabited points are located, is varied. As a rule, in narrowing bays of triangular or funnel shape, the rise of water increases markedly from the entrance to the head due to reduction of the cross section of the bay. In closed bays with narrow entrances, the rise of water diminishes from the entrance to the head.

At the same time, exceptions to this rule are often observed. During not very strong, long-period tsunamis in short bays of triangular shape, the rise of water can be approximately the same at all places in the bay. On the other hand, prolonged tsunamis in closed bays, when their seiches resonate with the tsunamis, can give rise to exceptionally strong oscillations in level.

To an observer on the coast, because of the large wave length, the tsunami does not appear as a sequence of waves, but as comparatively rapidly alternating flood and ebb tides; that is, as changes in sea level as a whole. At the time, the appearance of a tsunami off the coast can vary, depending on the wave energy and the coastal relief, from a quiet rise (fall) in level to a mighty stream or wall of water several metres or even several tens of metres high approaching the shore. In the latter case, the tsunami has enormous destructive power and shears away all, even the most solid structures, leaving in its wake a bare expanse with no traces of previous settlement.

However, even weak and moderate oscillations in level, because of the large length of the tsunami, are associated with powerful flood and ebb currents, picking up ships, timber, building debris, shore ice, etc. To predict the destructive force of a tsunami on the coast, it is more important to know the rate of flow than the maximal height of rise of water. However, the relationship between these two values is ambiguous and has not been studied as it should. In some cases, a small rise of water can wash out the soil and the entire loose layer in rapid streams. In other cases, even a large rise of water takes the form of a quiet flood and cannot raise wooden homes, secured to a foundation.

The data on tsunamis accumulated to date are the result of observations by eyewitnesses and by means of ordinary coastal tide gauges of the well type. Visual estimates of the rise of water are always larger than those based on tide gauge records. To what extent this is due to shortcomings in the design of the instruments (including the damping effect of intake pipes), and to what extent to the profile of the water surface directly at the shore, has not been studied.

Flood and ebb currents affect the entire water mass, down to the bottom, with a speed reaching 10 knots or even more near shore. For this reason, when there is danger of a tsunami ships are advised to put out to /8
sea immediately, where they will be completely safe, and the population must immediately take to high spots outside the tsunami danger zone.

Tsunamis undoubtedly have a marked influence on the geological and biological evolution of the sea floor; however, this is still not realized and is almost completely unstudied.

It is practically impossible to fully protect the coast from the impact of tsunamis. However, breakwaters, shore dikes, coastal tree stands and structures built along the shore (for example, warehouses), undoubtedly weaken tsunamis, reducing their height on shore and the width of the flood zone.

At the same time, two facts must be taken into account. In the first place, an ebb of water on shore is usually stronger and more destructive than a flood (due to the force of gravity). For this reason shore dikes should be reinforced on the inside at least as strongly, if not more strongly, than on the outside. In the second place, the destructive effect of tsunamis is increased substantially by objects carried by the water, so excessive littering of the shore aggravates the consequences of a tsunami.

Experimental registration of tsunamis remote from the coast, in open sea, by means of special bottom tide gauges has begun only recently in the USSR and the USA [and are planned in Japan]'.

Tsunami records of littoral tide gauges are always complicated by the seiche oscillations of the various closed and semi-enclosed bodies of

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'Author's note.

water adjoining the observation point. For this reason, the spectra of different tsunamis are very similar for the same point, while the spectra of the same tsunami vary substantially at different points. With increase in the size of the source and the energy of the tsunami, the maximum spectrum intensity (as a rule, the spectrum is nearly linear), shifts to long-wave. Tsunamis arising in deepwater trenches, with other conditions equal, are more high-frequency than tsunamis arising on a shelf.

The direction of the first wave of a tsunami (rise or fall) is identical to the direction of the displacement of the sea floor at the focus of the tsunami. Often, elevation and subsidence of different blocks of the earth's crust take place simultaneously at the source. As a rule, the side facing the sea rises, while the side facing the shore subsides, but there are exceptions. Sometimes, apparently, only elevations or only subsidences take place. On the whole, generalizing from data on tsunamis, tectonic elevations at present predominate on the periphery of the Pacific.

The frequency of occurrence of tsunamis in the Pacific Ocean and the probability of tsunamis as a function of earthquake parameters has been discussed previously (Soloviev, 1972). We note only that the probability of the appearance of a tsunami on the coast depends on the tectonic features of seismically-active zones. The probability is greatest on shores off seismically active shelves, where dislocations of surface blocks are mostly vertical and earthquake sources (and tsunami sources) are situated close to shore. The probability is least on shores adjoining deepwater trenches, where earthquake sources are deep and remote from shore, and dislocations are largely horizontal. At the same time, the absolute frequency of occurrence of tsunamis is greatest and tsunamis have greatest force precisely in deep water trenches.

In conclusion, we repeat that much remains to be solved and studied about tsunamis, and specialists in seismology, hydrodynamics and oceanology have interesting and very necessary work to do here.

Collection and generalization of data on Pacific tsunamis. In historical times, hundreds of tsunamis of different sizes have occurred in the Pacific, from catastrophic waves appearing along the entire ocean coast, accounts of which appear in scores of articles and books, to weak local waves known only from fragmentary and often unreliable sources. /9
All this information is scattered in numerous publications of European countries and countries situated on the Pacific coast.

Until the beginning of the 19th century, in most countries and territories in the Pacific, earthquakes and accompanying tsunamis became known to the public mainly through discoverers, sea-goers, traders, hunters and other travellers. Most of these were remarkable men; they left many colorful descriptions of natural phenomena, including tsunamis. Materials of this kind on earthquakes the world over have been repeatedly collected and published by European scientists (Montbeillard, 1761; Hoff, 1840; etc.). The last and most complete catalogue of all known earthquakes of the world until 1842 inclusively, was compiled and published by the Englishman, Mallet (1853-1855).

In Japan and Latin America, beginning with the 15th-16th centuries, and much later at other places on the Pacific coast, information about earthquakes and tsunamis was compiled more or less systematically in state, local or church archives. They are gathered mainly in various national catalogues of earthquakes, including those along the western shore of the Pacific (Doroshin, 1870; Neumann, 1878; Mushketov, Orlov, 1893; Sekiya, 1898, 1899; Omori, 1900, 1901 a,b, 1913, 1919; Maso, 1910 a; Wichmann, 1918, 1922; Gondo, 1932; Repetti, 1939 a, 1946; Musya, 1951; etc.).

In the 19th century, the press and the systematic observations of individual residents -- amateurs or specialists -- became the main source of information about earthquakes and tsunamis. In 1843-1872, these data were carefully collected and published in the form of annual surveys by the Frenchman, Perrey (see references), who essentially carried on single-handedly a world seismic service for 30 years. In addition, Perrey compiled many detailed regional catalogues, covering almost the entire globe for the period up to 1843.

After Perrey, the publication of annual surveys to 1885 inclusively was continued by the German geologist, Fuchs (see references). Unfortunately, in completeness and detail, these compendia are greatly inferior to Perrey's annuals. In 1885-1889, still less complete and less detailed surveys of earthquakes of the world were published by Detaille in a French popular journal of astronomy (Detaille, 1886-1888, 1889). Then, until the beginning of the 20th century, no one systematically collected and published information about earthquakes. Data on tsunamis appear to be very incomplete for this period.

As for individual countries, the systematic collection of macroseismic information on earthquakes was organized in the second half of the 19th century by naturalists in Indonesia and then in the Philippines and in Japan.

The creation at the beginning of the 20th century, first of a number of national services, and then of a world instrumental seismic survey marked the beginning of an essentially new stage in seismology. All sufficiently strong earthquakes of the world began to be recorded without omissions. The lower energy level of reliably recorded earthquakes gradually decreased, and the accuracy of the determination of the coordinates of the earthquake hypocenter gradually improved.

The International Seismological Bureau, organized at the beginning of the 20th century at Strasbourg, prepared and published detailed catalogues of the world's earthquakes, including macroseismic data, for 1902-1908. Subsequently, the work of the bureau was arrested by the First World War.

Unfortunately, as instrumental observations on earthquakes developed, interest declined in the collection of macroseismic data in many countries of the world. This could not help but be reflected in the completeness of incoming data on tsunamis. Nevertheless, the regular collection of macroseismic data continued in the 20th century in Japan, in the Philippines and in Indonesia (with gaps during the Second World War in the latter two countries). The collection of data was organized in 1925 in the USA, and at about the same time in New Zealand, in 1951 in Canada, and later in most of the other countries and territories of the Pacific basin. /10

The first tide gauges began to function in the Pacific Ocean in the middle of the 19th century. However, only in the middle of the 20th century did the network of tide gauges become sufficiently dense to record, without substantial omissions, all comparatively strong tsunamis. Systematic examination of tide gauge records to detect tsunami traces has been done more or less regularly only in Japan and the USA, and has recently begun in the USSR as well.

Interest appeared long ago in the compilation of data about tsunamis. Rudolph (1887), compiled the first major compendium of sea-quakes, and was followed by Montessus de Ballore (1903) who published maps of the tsunami zones of the world. The Tsunami Commission, created by the International Seismological Association in 1930, and which existed until the end of the 30's, did much to interest the world scientific community in the tsunami phenomenon. The secretary of this commission, the Frenchman, A. Hubert, prepared and published five issues of the proceedings of the Commission, containing much valuable data.

In particular, the commission helped its president, the well-known Japanese seismolgist, A. Imamura, to prepare a catalogue of Japanese tsunamis and to publish a compendium of weak tsunamis, registered by the Japanese tide gauge network (Imamura, Moriya, 1939; Imamura, 1942, 1949). A member of the commission, chief of the U.S. Coast and Geodetic Survey and President of the International Seismological Association, N. Heck, compiled the first rather detailed catalogue of tsunamis of the world (Heck, 1934, 1947).

Heck's catalogue for a long time served as the main reference work for tsunami specialists. However, by the late 50's it became outdated. Moreover, it was very incomplete for the years which it covered. For example, it did not even include the tsunamis, which are mentioned in Sieberg's monograph (1932) on the Earth's seismicity. Finally, this catalogue is not altogether accurate and is so laconic, that it gives little basis for determining the intensity of tsunamis and the location of sources. Heck's catalogue was published in Russian with some additions as an appendix to I. D. Ponyavin's book (1965).

Descriptive catalogue of tsunamis. The necessity for an exhaustive compendium of tsunamis in the Pacific Ocean, brought up to date, became very acutely felt with the inception of the Soviet Tsunami Warning Service in the Far East, which in the end result led to this study.

This study was begun by the authors at the Sakhalin Integrated Scientific Research Institute of the Siberian Branch of the Academy of Sciences of the USSR in about 1964, and the first tentative results were reported in the fall of 1965 at an out-of-town session of the Council for Seismology of the USSR Academy of Sciences at Yuzhno-Sakhalinsk. In 1966, these studies were intensified. By 1967, the first version of the manuscript of the catalogue had been prepared, with the basic data on Pacific tsunamis. At the same time, the frequency of occurrence of tsunamis in the Pacific was estimated, and these results were presented by S. L. Soloviev in September 1967 at the XIV General Assembly of the International Union of Geodesy and Geophysics in Switzerland. The results were gradually improved and reported, in turn, in 1968 at the Geophysical Section of the United Science Council of the Siberian Branch of the Academy of Sciences of the USSR at Novosibirsk, at the Tsunami Commission of the USSR Academy of Sciences at Moscow, at the All Union Conference on the Tsunami Warning Service in the Far East at Yuzhno-Sakhalinsk, and in 1969 at the International Tsunami Symposium at Honolulu. In the fall of 1965, the substantially enlarged and corrected catalogue of the basic data on tsunamis in the Pacific was reproduced on the rotaprinter of the "Obninsk" Central Seismic Observatory of the Institute of Earth Physics of the USSR Academy of Sciences (Soloviev, Go, 1969). Supplementation of the catalogue continued in 1970-1973.

Somewhat earlier than the authors, in 1961-1962, the Japanese seismologist, K. Iida, had begun the collection of data about tsunamis in the Pacific and the compilation of a catalogue. Later, the American specialists, D. Cox and G. Pararas-Carayannis, joined this work. At the end of 1967, the preliminary catalogue of Pacific tsunamis, which they had compiled (Iida et al., 1967), was published on the press of the Hawaiian Institute of Geophysics. These authors studied in detail and analyzed the Japanese material, as well as data from other countries for the 20th century, especially for the last decade. Nineteenth century and earlier materials are not given adequate attention in the catalogue. /11

In compiling the descriptive catalogue, we made use of the above-mentioned sources, as well as the studies abstracted in the International Tsunami Bibliography (Annotated Bibliography, 1964), compiled with the participation of S. L. Soloviev, and the bibliography of Z. K. Grigorash (1964). In addition, the subject indices of the following libraries were checked: the V. I. Lenin State Library of the USSR, the Saltykov-Shchedrin Public Library, the library of the Academy of Sciences of the USSR, a number of scientific libraries in Moscow and Leningrad, including the All Union Geological Library, the libraries of Moscow University, the Moscow Naturalists Society, the Earth Sciences Branch of the USSR Academy of Sciences, the Earth Physics Institute of the Academy of Sciences of the USSR, the International Geophysical Data Center, the Institutes of Geography and Oceanology of the Academy of Sciences of the USSR, the Geographic Society of the USSR, the Voeikov Main Geophysical Observatory, the Central Naval Library, the library of the Leningrad Mining Institute and some others, as well as the libraries of the Sakhalin Integrated Scientific Research Institute of the Far East Science Center of the Academy of Sciences of the USSR and the "Obninsk" Central Seismic Observatory of the Institute of Earth Physics.

All accounts of tsunamis found were translated into Russian from English, French, German, Spanish and Dutch by S. L. Soloviev; and from Japanese by Ch. N. Go.

It should be kept in mind that the catalogue includes practically no accounts of several of the strongest tsunamis, for which a vast amount of data is available, namely: 27.VIII.1883 (Indonesia), 3.III.1933 (Japan), 1.IV.1946 (Aleutian Islands), and 27.III.1964 (Alaska). The publication of material for these tsunamis requires another approach than that which has been adopted in this catalogue. Brief information is given about the strong Japanese earthquakes and tsunamis of 1.IX.1923, 7.III.1927, 4.III.1952, 16.VI.1964, 16.V.1968, and some others.

The catalogue also includes no descriptions of tsunamis on the Pacific coast of the USSR. The reader can find data on tsunamis on the Pacific coast of the Soviet Union in the studies of A. Butakov (1884), I. V. Mushketov and A. V. Orlov (1893), A. E. Svyatlovskii (1957), E. F. Savarenskii et al. (1958), S. L. Soloviev and M. D. Ferchev (1961), S. L. Soloviev (1965, 1968 a), S. L. Soloviev and Ch. N. Go (1969) and in the annuals "Earthquakes in the USSR" for 1962-1968.

The accounts compiled in the catalogue are given in chronological order for different zones, which are arranged counterclockwise, beginning with Alaska and the Aleutian Islands. For the Indonesian Archipelago, since the literature sources cover both, tsunami accounts are included for both the coast of the Pacific and the coast of the Indian Ocean.

More than 90% of the tsunamis described in the cataloge were caused by underground earthquakes, and about 6% were caused by volcanic eruptions. A few descriptions of solitary waves in open sea, tsunami-type waves of unknown or meteorological origin, or waves connected with some events at sea, most likely not tsunamis, have been included in the catalogue. These accounts crop up in the literature together with descriptions of tsunamis and have been included in the catalogue to attract attention to unusual phenomena at sea, although the selection of these phenomena is, for the most part, random.

For each zone a general map[1] is given which shows, first, the /12
geographic points[2] mentioned in the descriptions, and second, the tsunami focuses, to the extent that these could be established on the basis of the materials collected in the catalogue.

For each event, the discussion, as a rule, follows the same order: first the year and time (local) of the earthquake is given, then

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1 All the general maps are given at the end of the book.

2 Unfortunately, it was not possible to establish the location of all points; for this reason, some places mentioned in the accounts are not shown on the maps. [In the text they are noted by asterisks - Author's note.]

the earthquake is described, and finally, the tsunami data are given. The descriptions of the earthquakes, and especially of the tsunamis, are as faithful as possible to the original source, as there exist many cases in the history of seismology when a careless editorial correction has greatly impoverished or even distorted the description of a phenomenon.

Local time, which is used as standard for both earthquakes and for tsunamis, is given in the usual symbols: hr (hour), min (minute), sec (second), [or numerically in translation, e.g. (10:46)]; h,m,s, are used respectively for universal (Greewich) time. The many estimates of earthquake intensity in degrees, found in the sources, have been converted to the MSK-64 twelve-degree scale, which practically coincides with the standard scale adopted in the USSR. The original estimates of intensity in degrees are given in brackets as a check.

The following abbreviations are used: R.F. is the 10-degree Rossi-Forel scale; JMA is the 7-degree scale of the Japanese Meteorological Agency.

All the values mentioned in the descriptions have been converted into metric, although the original value is also sometimes given in brackets as a check (see Appendix).

One of the main aims of the compilation of the catalogue is the subsequent quantitative description of the process of tsunami generation. For this reason, special attention has been paid to the data on the height and other dynamic parameters of tsunamis. It must, however, be noted that different sources use different concepts of "tsunami height," some of which are not always understood. The authors themselves have used this term as is usual in oceanology, to denote the difference in levels of the wave crest and trough. Sometimes (primarily in tables) this value is also called the range of oscillations in level. At the same time, some sources apparently use the term "tsunami height" to mean the semirange of oscillations in level, that is, the conventional tsunami amplitude. In addition, in some accounts, "tsunami height" is used to mean the height of rise of water on shore, which is, generally speaking, a value of different significance than tsunami height.

To evaluate the tsunami height or the height of rise of water on shore, it is necessary to know the undisturbed position of sea level before the arrival of the tsunami. The original accounts far from always estimate the rise of water relative to the undisturbed position of the water level. The authors of descriptions were often concerned only with the practical side of the matter, that is, with how far the rise of water exceeded the usual flood tide mark. In such cases, the map of flood tides in the Pacific (Map XII) can be used to estimate the height of the tsunami. It is worth noting that for the U.S. Coast and Geodetic Survey and some other organizations, the basic level datum for the estimation of the rise of water is the so-called mean lower low water, that is, the average mean level of extremal spring ebb tides.

At the end of the texts cited, we indicate the primary source from which the description of the earthquake and tsunami is taken, and the later compendia, which mention the event. The primary souces, which contain the original information about the phenomenon, or the most complete of the compendia (in cases where the primary sources were not accessible) are underlined; when necessary, the year is also underlined. /13

Since many descriptions of tsunamis are contained in little-known publications, the list of references indicates the libraries in which the publications can be found. The abbreviations of literature sources and libraries are given at the end of the reference list.

If the phenomenon described is mentioned in "Seismological Notes," which is regularly published in the Bulletin of the American Seismological Society, then the relevant publication data are cited directly in the text. A similar approach has been used for mentions of tsunamis in the "Newsletters" of the International Tsunami Information Center.

Accounts of tsunamis in the 20th century end with a citation of the basic parameters of the earthquake, obtained from instrumental observations and contained in any of the main compendia of the world.

Commentaries about the primary sources and notes by the authors of this book, are enclosed in square brackets.

The chapters on the Japanese and Ryukyu-Taiwan Island arcs, the coast of the Asian continent, the Nampo, Mariana, Caroline and Marshall Islands were prepared by Ch. N. Go and S. L. Soloviev; the other chapters by S. L. Soloviev.

List of basic tsunami parametres. The book ends with a list of all the tsunamis described in it with an indication of their basic parameters. The tsunamis have been grouped by the methods of their generation. The first main group includes tsunamis caused by earthquakes. The second group includes tsunamis arising as the result of volcanic eruptions, as well as some underwater eruptions, which though not causing a tsunami, were accompanied by small changes in the sea surface. The third group includes some tsunamis and other gravity waves resulting from large collapses, landslides and turbidity currents; caused by or unconnected with earthquakes. The fourth group includes tsunami-type waves of meteorological or unknown origin and solitary waves in the open sea. Some accounts of these phenomena cropped up in the literature, and although the list, of course, is not exhaustive, generalization of the assembled data appeared useful. Some of these phenomena are perhaps tsunamis from remote earthquakes.

The tsunamis of seismic origin have been grouped by zones in accordance with S. L. Soloviev's map (1972); that is, in more detail, than in the main text of the book. Tsunamis of volcanic origin are presented in order of the geographic location of the volcanoes, counterclockwise. Waves from collapses are shown in chronological order for the whole of the western part of the Pacific Ocean. Waves of meteorological and unclear origin are arranged in the same zones as in the text.

Tsunami dates are given in local time and according to the Gregorian Calendar (that is, according to the new style; for some Alaskan and Aleutian tsunamis the dates are also given in the old style*).

In the list of tsunamis caused by earthquakes, the column "coordinates of focus" indicates the following values: a) for events in the 20th century, the coordinates of the hypocenter of the relevant earthquake, determined from the observations of seismic stations; b) for earlier events, the coordinates of the centre of the source of the earthquake and the tsunami, based on the macroseismic information contained in the book. In the absence of data to locate the macroseismic epicentre, only the site of occurrence of the tsunami is indicated.

The (a) values are taken, as a rule, from the monograph of Gutenberg and Richter (1954), or are based on the authors' data; the accuracy of the epicenters varies from 1-2° for earthquakes in the beginning of the 20th century to 0.1-0.3° for recent earthquakes. The (b) values for earthquakes in Japan have been taken from the works of Japanese authors. As in the originals, these values are specified with an accuracy of up to 0.1°, although the real error in the estimates is /14
undoubtedly higher, and in the best cases is evidently at least 1/2-1°. The macroseismic epienters of earthquakes in other zones have been located by S. L. Soloviev. Individual errors in estimates of coordinates are not given for technical reasons. On the average, the error of these estimates is, of course, high and varies from 1/2-3°.

The country is indicated only for the first epicenter. Only for zones crossed by the equator or the 180° meridian are the coordinates of [all the epicentres, specified by points of the compass]'. Unfortunately, data on depth of focus are not very precise either for old earthquakes, obtained by N. V. Shebalin's nōmōgrams (1968), or for recent earthquakes, found by computer matching of travel time curves.

The magnitude of earthquakes, M, determined from the displacements of the earth's surface in seismic surface waves, for earthquakes of 1907-1968, have been taken from the compendium of Gutenberg and Richter (1954) or else have been obtained by the authors. The magnitude of earthquakes in Japan up to 1901 have been taken from Japanese authors. The magnitude of old earthquakes in other zones has been estimated by S. L. Soloviev from the surface effect of earthquakes using N. V. Shebalin's nōmōgrams (1968). In some cases, the magnitude was estimated from the duration of the earthquake by means of the empirical formula derived by S. L. Soloviev (1970). The mean accuracy of estimates of magnitude is 1/4 ± for earthquakes of the first category,

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* Refers to the Julian calendar, used in Russia until 1917. - Transl.

' Author's note.

±1/2 for the second and third category and ±1 for earthquakes of the last category.

A special five-point scale (see List...) has been used to evaluate the authenticity of tsunamis.

Tsunami intensity I was determined on S. L. Soloviev's scale (1972). By generalized intensity I is understood the intensity of the tsunami i_o, which it would have had on the coast nearest to the source, if the wave energy had radiated uniformly from the tsunami source. The intensity of the tsunami on the coast i was determined as the logarithm to base 2 of $\sqrt{2}$ times the average height of the flood or the average amplitude of the tsunami based on tide gauge records on the given area of coast. The values of intensity I determined in this way differ little from the tsunami "magnitude," m, on the Imamura-Iida scale (Soloviev, 1972). S. L. Soloviev in some cases has revised the intensity I for tsunamis of the Japanese Island arc and has determined it for tsunamis of all the other zones. The accuracy of the estimate of intensity varies from ±1/2 to approximately ±1 1/2, depending on the completeness of input data.

The list of tsumamis of volcanic origin, in addition to the location of the volcano, the dates and authenticity of the tsunami, also indicates the intensity of the tsunami on the coast nearest to the volcano, which in all cases is also the maximal known intensity i_o.

The list of waves from collapses, besides giving the date, place of occurrence, authenticity and intensity i_o of the tsunami, also indicates what caused the collapse.

The list of wave of meteorological and unclear origin indicates the date, place of appearance, authenticity and intensity i_o of the event.

The authors are sincerely grateful to all their colleagues, both in the USSR and abroad, who helped in the preparation of the catalogue.

ALEUTIAN-ALASKA ISLAND ARC

1788, July 22 (or 27). A catastrophic earthquake occurred with a source apparently extending from the Sanak Islands to Kodiak Island (Map I). It was impossible to remain standing on Unga and Kodiak Islands; on Unga Island, "many mountains crumbled." The subsequent shocks, at least two or three or more per day, were felt for at least a month on Kodiak Island. The coast of the island may have subsided somewhat.

"Before we had come to our senses after the tremor, a flood came in from the sea." In Three Prelates Harbor at Kodiak Island, several buildings were washed away, and the soil was partially washed out and littered; two large waves were observed. On Unga Island, the water rose 115 m (50 fathoms) [?], and many Aleutians died. "The water passed over Sanak Island in strong, uncommon rollers;" some swine brought to the island drowned. The tsunami was also observed at Pavlov village, but with considerably less force. There were no noticeable waves on the northern side of Unimak Island (Veniaminov, 1840; Grewingk, 1850; Dall, 1870; Mushketov, Orlov, 1893; Plammer, 1896; Holden, 1898; Sapper, 1927; Sieberg, 1932; Heck, 1947; Ponyavin, 1965; Iida et al., 1967; Soloviev, 1968 b; Cox, Pararas-Carayannis, 1969).

1796. I. D. Ponyavin (1965) erroneously refers to a tsunami which accompanied the appearance of the volcanic Bogoslov Island. I. V. Mushketov and A. V. Orlov (1893) make no reference to a tsunami.

1820, March 1 or the night of 2-3. A powerful volcanic eruption occurred on the northern tip of Umnak Island. The ashes spread as far as Unalaska and Unimak Islands. The eruption was accompanied by a strong earthquake. "At dawn, it was observed that the sea had become more agitated" (Perrey, 1865 b).

1825. A powerful eruption of the Shishaldin volcano on Unimak Island began at the end of 1824. In the middle of March 1825, the sound of underground explosions was heard from Unalaska Island to the Alaskan Peninsula. The volcano disgorged flames, ashes and streams of water, mixed with rubble, which inundated the southern coast of the island for 4 km (2 miles). The outpouring did not last long, but the sea was still agitated even in the following fall (Perrey, 1865 b).

1827. Heck (1947) erroneously mentions a tsunami on the Aleutian Islands. In fact, an earthquake not accompanied by a tsunami did take place in the Commander Islands (Soloviev, Ferchev, 1961; Iida et al., 1967; Cox, Pararas-Carayannis, 1969).

1854, January 16, soon after 9:00. There was an earthquake lasting more than a minute in Pavlovskaya Harbor (Saint Paul Harbor) on Kodiak Island. Then up to six perceptible oscillations were felt for an hour and weak ones were felt all day. The earthquake recurred twice on the night of the 17th, and weak oscillations were felt until January 21.

"At the first peal of the underground thunder on January 16th, the water in the harbor advanced and receded uncommonly at 2 and 3 minute intervals and there was a strong eddy" (Doroshin, 1870).

[This was observed on the Hawaiian Islands?]

1856, July 26. There was a volcanic eruption in Unimak Pass, apparently near 54° 35' N., 165° W. It is described by Neville, the captain of the whaler "Alice Fraser."

Crossing the pass on his ship with six other whalers, he observed that as a result of the volcanic eruption, enormous masses of dense black smoke were rising over the conical peaks of the mountains on the adjacent islands. /16

He and the captains of the other whalers made ready to round the eastern tip of Unalaska Island, in order to get a good look at the eruption, which was accompanied by a prolonged dull roar and tremors, which by that time they had already felt repeatedly. At precisely this instant, the strong breeze which had been blowing completely died down, and the ships found themselves at the mercy of the eruption, in danger of being run aground.

The eruption, lasting several hours with variable intensity, then appeared to reach its climax. The thunder of the euption and the underground rumble rapidly intensified and became ever more ominous. The air was so still that dense black smoke was ejected straight up into the sky, without deviating in the slightest. It spread out above, at cloud level, and ashes, like flakes of snow, fell down in abundance.

After 12 hours of still, a light breeze arose from the south, enabling the ships to move away from the volcano. But this breeze carried the column of smoke to the water surface, and a pitch darkness set in over a distance, as was later established, of more than 180 km, and the ships lost sight of the shore.

The ashes fell like snow in a blizzard, covering the ships with gray substance from the deck to the top of the masts, blinding and choking all those on deck.

Sailing west and north of the eastern shore, the ships tore out of the cloud of smoke. When they were near the northern base of the volcano, a prolonged dull rumble pealed out under them, and an underwater eruption occurred almost right in the centre of the flotilla.

First the water churned and began to rise stormily in the form of disorderly waves. Then it rushed up, as if ejected from an enormous spring, forming a dazzling column of water of colossal height, which gradually disintegrated. Then a shaft of fire and smoke rose from the bottom upwards with peals of thunder. Lava and stones from a walnut to a cannon ball in size were disgorged, and fell on deck.

This lasted no more than an instant, and the eruption ended as quickly as it had began. The water rushed into the abyss which had formed, forming a colossal whirlpool. The noise was like Niagara Falls.

The ships rushed to safety, leaving the volcano in a state of regular alternation of relative calm and eruptions (Perrey, 1859 a, 1865 b; Mushketov, Orlov, 1893). This event is mentioned very briefly in a number of publications (Sieberg, 1932; Iida et al., 1967; Cox, Pararas-Carayannis, 1969).

1868, May 15. There was an earthquake on the Alaskan Peninsula. During this earthquake, the water in the port on the northern side of Unga Island was very agitated. At some places, the level rose 6 m (20 feet) (Perrey, 1875; Fuchs, 1885 b).

1878, August 29. On Unalaska Island, Makushin was destroyed by an earthquake and tidal waves (Fuchs, 1879; Heck, 1934, 1947; Heck, Eppley, 1958; Ponyavin, 1965; Iida et al., 1967; Cox, Pararas-Carayannis, 1969).

1880. A strong earthquake occurred with the formation or renewal of a surface fracture on Chirikof Island (Plafker, 1969). [There was a tsunami at Sitka in the same year.]

1883, October 6. An eruption began of the Augustine volcano which forms Augustine Island (the former name was Chernoburyi Island), situated in the western part of Cook Inlet.

The nearest American settlement, Port Graham, was situated near the southern tip of the Kenai Peninsula, 90 km east of the volcano. The weather that morning was exceptionally clear, so that the opposite northwestern shore of Cook Inlet could be seen; a light southwesterly wind was blowing.

At about 8:00, the residents of the settlement and the fishermen in the harbor heard a muffled explosion. From the peak of the volcano there shot up a large dense cloud of ash, which began to move slowly in a northeastern direction. According to later accounts of Aleutians, who at the time of the eruption were hunting in Kamishak Bay, where the volcano was situated, a column of white steam, which seemed to come from the sea near the volcano, rose up at the same time as the ash. The steam rose slowly and gradually mixed with the clouds. The sea was extremely agitated and churned so that it was impossible to approach the island, or on the other hand, to leave it. /17

The column of smoke and ash, as related by eyewitnesses from Port Graham, spread to all sides as it rose, covering completely the visible horizon and eclipsing the day. Soon very fine ash began to settle on the settlement. The final thickness of the layer of ash was 10-12 cm. According to some sources, the fall of ashes was observed very far from the volcano at Ilyulyuk settlement on Unalaska Island.

About 25 minutes after the beginning of the eruption, a colossal wave, an estimated 7 1/2 to 9 m (25-30 feet) high, fell on Port Graham in the form of a wall of water and flooded homes. The first wave was followed, at about 5 and 10 minute intervals, by two other large waves, whose height was an estimated 5 1/2 and 4 1/2 m (18 and 15 feet). Large irregular waves occurred in the harbor all day long.

The first wave carried all the fishing boats onshore and, retreating, carried them back out to the bay. In the end, the ships were run aground. Fortunately, it was full ebb time, which saved the residents of the settlement from destruction, since the height of the flood and ebb tide at these places is about 4 m (14 feet).

A tsunami also occurred on Kodiak Island and must have been registered by the tide gauge established there. For many days following, one could see from Port Graham ashes being ejected from the volcano, and flames in the darkness.

On November 10, Captain Cooley approached the volcano from Port Pavlov* (Kodiak Island) on his ship. He found that the volcano had been sundered into two parts by a through crack, running from west to east, and the width of the passage was such that had it been filled with water, a ship could have passed through it. The northern half of the mountain, right up to the level of the cliff, had disappeared (Fig. 1). At the same time, a new small island 2.8 km (1.5 miles) long and 22.5 m (75 feet) high appeared on the western side of the volcano, in the strait separating it from the continent, previously 18 m (10 fathoms) deep.

Previously the volcano had always been covered with a deep layer /18
of snow at this time of the year. Now, in contrast, the rocks were totally bare.

Before the eruption on Augustine Island, seven or eight Aleutians had landed to hunt otter in the winter. Two women who came with them refused to stay on the island, being frightened by the loud rumble coming from the bowels of the volcano. After the eruption, no traces could be found of the hunters who remained on the volcano (Davidson, 1884; Sapper, 1927; Iida *et al.*, 1967; Cox, Pararas-Carayannis, 1969).

A very brief, and apparently less precise account of the events is given by Fuchs (1885 a), where the following is related.

October 6, 15:30. There was a large earthquake during the eruption of the Augustine Volcano. As a result, a tidal wave 10 m high arose, followed by a second 6 m high.

October 8. There was still another earthquake and a tsunami from 5 to 6 m high during the eruption in Cook Inlet. Large waves formed at 8:30, and less strong waves arose all day long.

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* Spelling approximate - Transl.

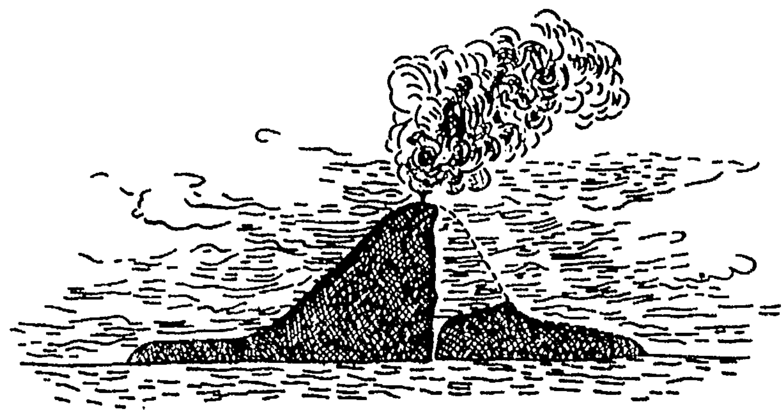

Fig. 1

The Augustine volcano after the explosion of 6.X.1883. From a sketch by Captain Cooley made on 10.XI.1883. The dotted line shows the original profile of the volcano (Davidson, 1884).

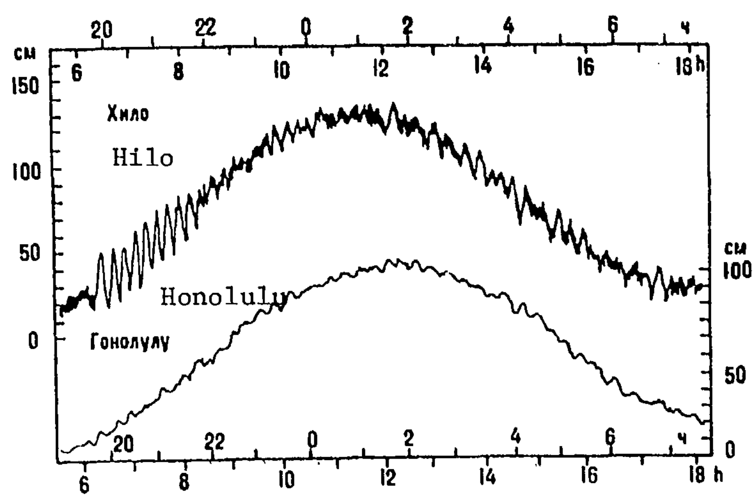

Fig. 2

Records of the tsunami of 6.III.1929 of the Hawaiian Islands (Jagger, 1930). On this and subsequent figures, the horizontal axis shows local time on top and Greenwich time on the bottom.

Fuch's data was later reproduced still more briefly (Milne, 1912 b; Sieberg, 1932; Heck, 1947; Ponyavin, 1965).

[According to Davidson, we can apparently assume that one tsunami occurred on October 6th. It was formed as the result of a directed explosion; the exploded northern half of the volcano shifted west and fell into the sea extruding a large volume of water.]

1901, December 30-31. There was an earthquake on the Kenai Peninsula. It apparently caused some destruction (Milne, 1912 a). There was a strong volcanic eruption in Cook Inlet (Reid, 1912). The earthquake was accompanied by several tidal waves (Reid, 1912; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Cox, Pararas-Carayannis, 1969).

[The instrumental data do not agree with the macroseismic data - Milne (1912 a): 30.XII; 22^h34^m; 52° N., 160° W.; Richter (1963): 31. XII; $9^h2.5^m$; 52° N., 177° W.; M=7.8.]

1911, September 21, from 17:01 to 18:38. An earthquake occurred in Prince William Sound and on the Kenai Peninsula. There were large rock falls at the top of the sound. There were many dead fish, evidently as a result of the seaquake. The peak intensity of tremors on land was 8 degrees. There was slight damage at Valdez. It was felt on an area of 350,000-400,000 km^2. In Wells Bay, the water became very agitated (Wood, 1966; Cox, Pararas-Carayannis, 1969).

Gutenberg, Richter (1954): 22.IX; $5^h1.4^m$; 60 1/2° N., 149° W.; 60 km; M=6.9.

1925, February 23, 13:54. There was an earthquake at Valdez, after which the gangplanks were torn away by a wave (Cox, Pararas-Carayannis, 1969).

[$23^h53^m36^s$; 60° N., 146° W.; M=6.8.]

1929, March 6, 14:35. There was a strong earthquake with source near the Fox Islands. Dutch Harbor felt a severe tremor. A strong seaquake was felt for a minute on Japanese steamships and other ships between 165° and 171° W. ("Sihara Maru" at 51° 17' N., 171° 16' W.; Yokohama Maru" at 51° 32' N., 169° 31' W.; "President Madison" at 49° 55' N., 165° 3' W.).

A tsunami arose and was recorded by instruments on the Hawaiian Islands (Fig. 2). According to the record of the tide gauge established at the first dock in Hilo Bay, the waves began to be registered at 19:45 Hawaiian time (6^h15^m on the 7th) at ebb tide. They were followed by up to ten rhythmic oscillations; their amplitude was almost 20 cm, period 13 minutes. The tsunami snapped the hawsers in a ship lying at the second dock. At the mouth of the Wailua River, the range of oscillations was also estimated at 40 cm (16 inches); the maximum of oscillations was observed between 20:00 and 21:00; the oscillations began to abate

gradually after 22:00. According to Jaggar's personal observations, flood currents were observed at 20:20, 20:31, and 20:38, and ebb currents were observed at 20:27 and 20:34. The tsunami was also registered at Honolulu about 4.7 hours after the earthquake with an amplitude of 5 cm /19
and a period of 15± minutes (Jaggar, 1929, 1930; Heck, Bodle, 1931; Heck, 1947; Shepard et al., 1950; Anon., 1961; Ponyavin, 1965; Iida et al., 1967; Cox, Pararas-Carayannis, 1969).

Gutenberg, Richter (1954): 7.III; $01^h34^m39^s$; 51° N., 170° W., 50 km, M=8.1.

1938, November 10, 10:19. There was an earthquake with source near the Alaskan Peninsula. Slight damage or no damage at all was reported from the regions of the peninsula closest to the source, which however, were very sparsely settled. The greatest known intensity (6 degrees) was recorded at Falls Pass. The earthquake was felt on a large area, including Port Moller, Naknek and Anchorage. A tsunami occurred, and was recorded by at least six tide gauges (Fig. 3). At remote stations, the tsunami apparently began with the flood tide. Table 1 gives the basic parameters of the record (SN[1], 1938, vol. 28, No. 4; Jaggar, 1938; Neumann, 1940; Heck, 1947; Gutenberg, Richter, 1949; 1954; Anon., 1961; Ponyavin, 1965; Iida et al., 1967; Cox, Pararas-Carayannis, 1969; /20
Pararas-Carayannis, 1969).

Gutenberg, Richter (1954): 10.IX; $20^h18^m43^s$; 55.5° N., 158° W.; M=8.3.

1946, April, 1, 1:59. A rather strong earthquake occurred with source to the south of Unimak Island, causing one of the most destructive tsunamis in the Pacific Ocean. The rise of water was 30 m in the Aleutian Islands (Unimak Island), 17 m on the Hawaiian Islands (Island of /21
Hawaii), 9-10 (?) m in the Marquesas Islands and the Juan Fernandez Islands, 3 m in the USA (Santa Cruz and Half Moon Bay), no more than 1 m in Japan (Ayukawa). No account of the events is given here. One can find brief accounts of the tsunami in Iida's catalogue (Iida et al., 1967).

Gutenberg, Richter (1954): 1.IV; $12^h28^m54^s$; 52.75° N., 163.5° W.; 50 km; M=7.4.

1946, November 1, 1:15. There was a strong earthquake near the Aleutian Islands. At about the expected time, observers on the Hawaiian Islands supposedly noted a small rise in sea level (Anon., 1946 b).

1949, September 27. In Alaska, at Seward, the tide gauge registered tremors, but there was no tsunami (Murphy, Ulrich, 1951b; Iida et al., 1967; Cox, Pararas-Carayannis, 1969).

Gutenberg, Richter (1954): 27.IX; $15^h30^m45^s$; 59.75° N., 149° W.; 50 km; M=7.

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[1] See references, abbreviated names of sources.

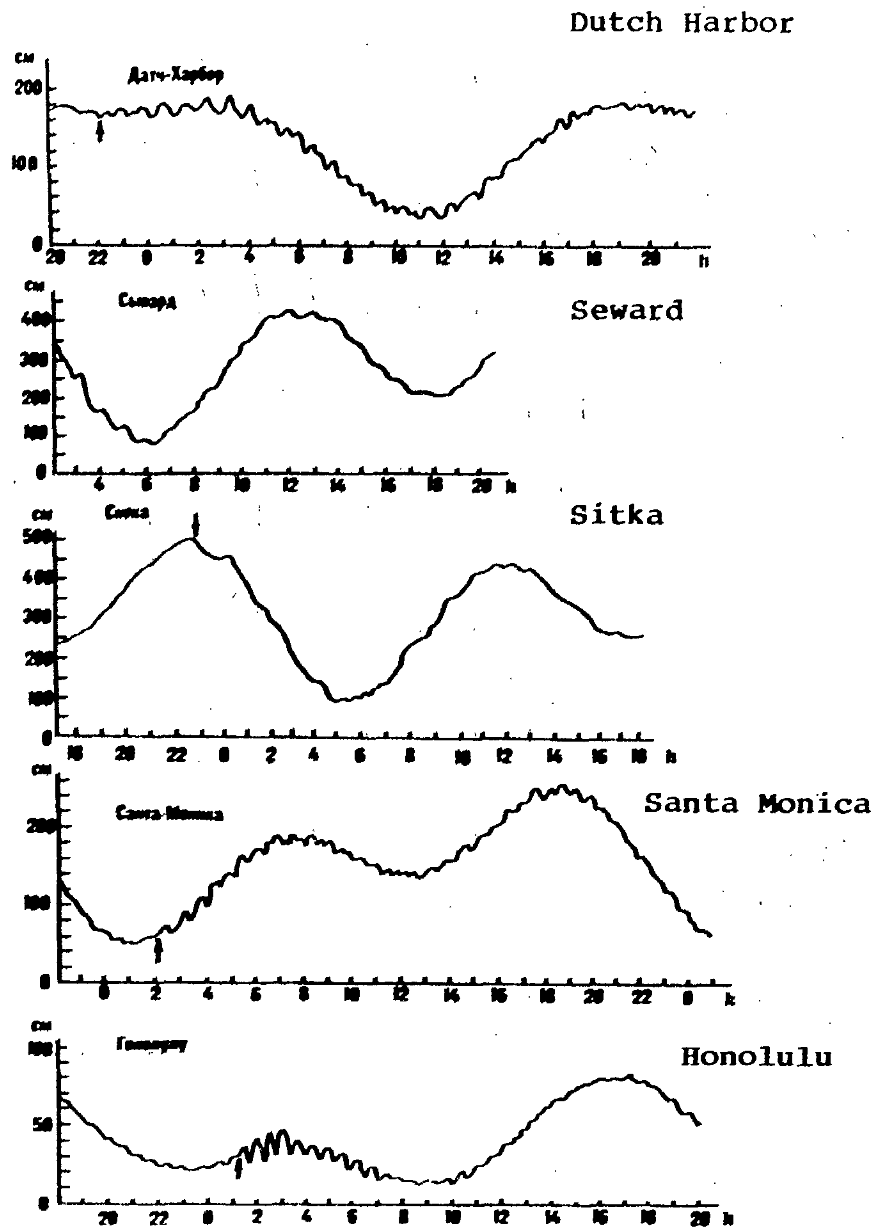

Fig. 3

Records of the tsunami of 10.XI.1938 (Neumann, 1940).

Here and on subsequent tide gauge records, the arrows on the oscillograms show the beginning and the direction of the leading wave of the tsunami.

1957, March 9, 4:23. There was a strong earthquake and tsunami with source to the south of the Andreanof Islands. There were no victims. Judging by the size of the zone of the epicentres of the numerous aftershocks, the source of the earthquake was stretched out in an arc for more than 600 km, bounded on the west by Amchitka Pass and on the east by the Unimak Pass.

On Adak Island, the earthquake and tsunami did great damage. Cracks appeared in the roads. Some of these cracks, according to accounts, were up to 5 m wide; structures were destroyed, as well as two bridges. Many piers suffered serious damage. According to reports, an 8-metre (26 foot) wave was observed in Sand Bay*. All structures at the fuel and oil dock were washed away up to the 4 m contour, and the oil pipelines were damaged. The rise of water was 2.7 m in Sweeper Cove at 15^h50^m, when the inquiry came from Honolulu, and the peak rise of water was 4 m.

Two docks and a concrete mixer were destroyed on Umnak Island. Mount Vsevidof (volcano), which has been dormant for 200 years, became active. On Unimak Island near Scotch Cape, where the lighthouse was washed out in 1946 a wave had a height of 12 m (40 feet), according to other sources 15 m and may have been due to a local landslide.

The tsunami, spreading along the entire Pacific, caused damage or was observed visually on the Hawaiian Islands, in Japan and on the coast of North and South America. It was registered by more than 150 tide gauges (see Table 2, Fig. 4).

The greatest damage, amounting to 5 million dollars, was done on the Hawaiian Islands (Fig. 5). Strong waves fell on the north shore of Kauai Island, causing a maximal rise of water of 16 m at Haena. At Wainiha, four homes were washed away. At Kalihiwai, several homes were completely detroyed. On the south coast of the island, four sampans were overturned or tossed onto the breakwater by a 3-metre wave. Bridges were washed out and highways were flooded. Small, funnel-shaped Nawiliwili Bay alternately filled with water and then dried up. Rapid turbulent flows rushed to and from shore. Buoys periodically sank underwater. A submarine (the "Wahoo"), coming out of the bay with a speed of 15 knots, was turned with the stern forward by an ebb current. The losses on the island were 1.5 million dollars, or twice as much as in 1946.

On Oahu Island, the water rose 7 m; at least 50 homes were flooded, 30 buildings were dislodged from their foundations, and considerable damage was done to bridges and other structures. The water crossed the highway at Haleiwa.

Kahului Harbor on the north shore of Maui Island dried up during the retreat of the water. The most intensive record of the tunami in the entire Pacific was obtained on the tide gauge here (height 3.6 m, see Fig. 4).

On the coast of the Island of Hawaii, the peak rise of water /23

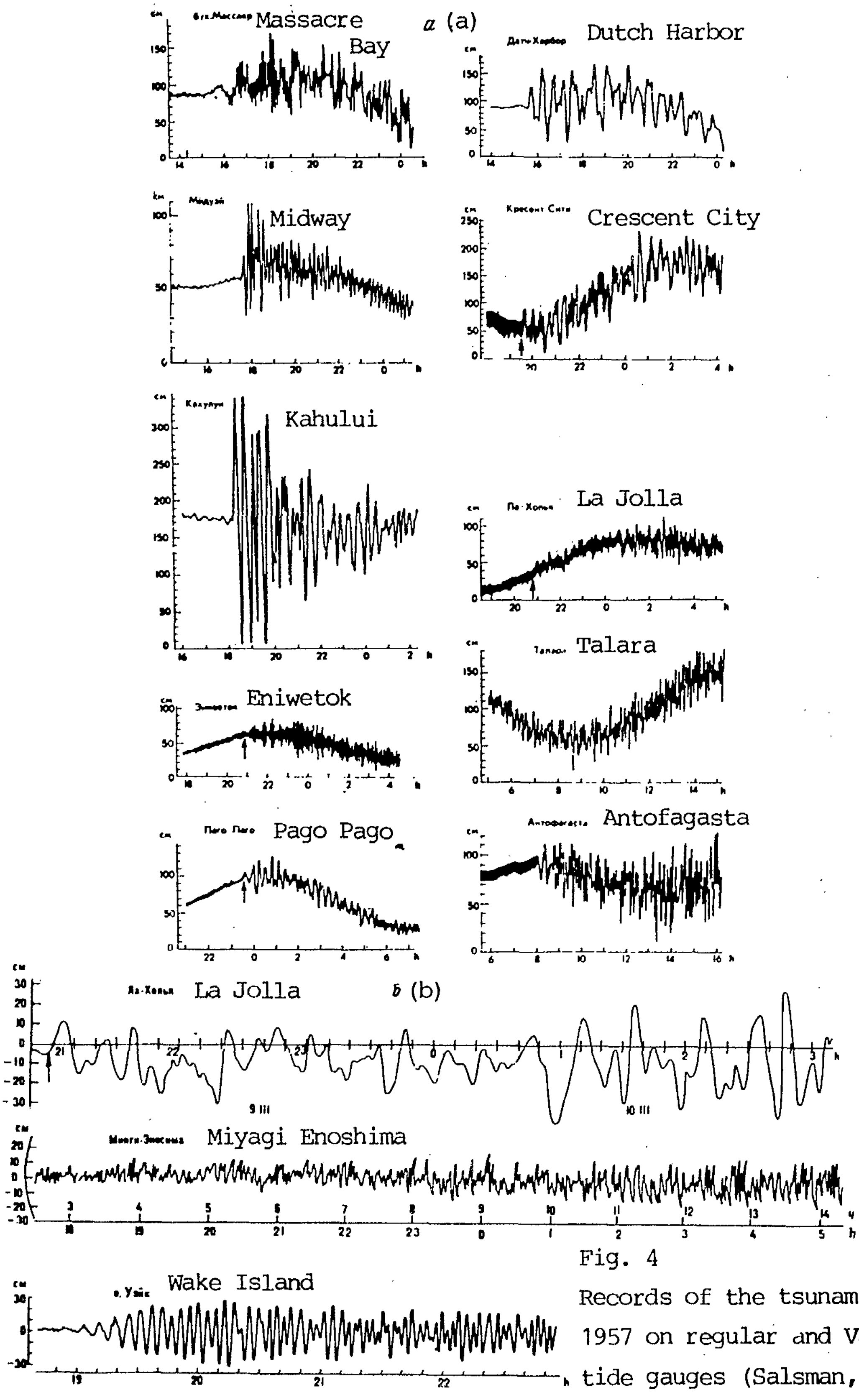

Fig. 4

Records of the tsunami of 9.III. 1957 on regular and Van Dorn tide gauges (Salsman, 1959; Van Dorn, 1963; Hatori, 1965e).

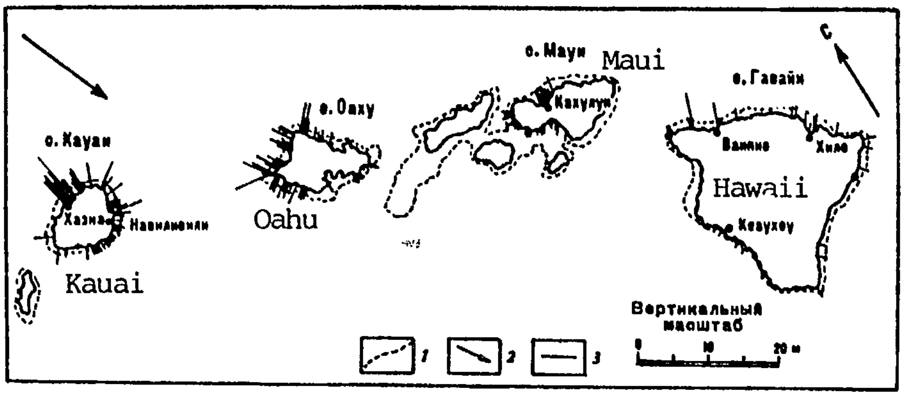

Fig. 5

The tsunami of 9.III.1957 on the coast of the Hawaiian Islands.

1 - boundary of shelf

2 - direction of approach of the wave

3 - rise of water on shore (in m) in accordance with vertical scale

a - vertical scale

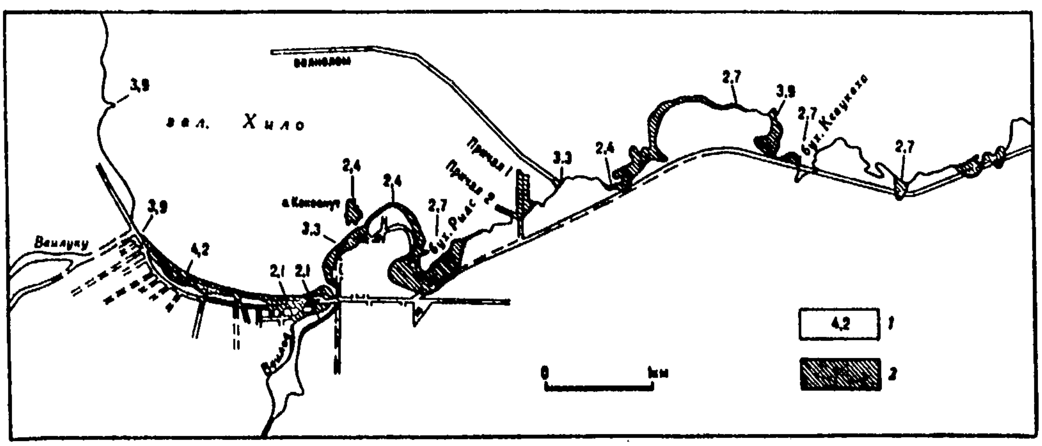

Fig. 6

The tsunami of 9.III.1957 at Hilo (Frazer et al, 1959).

1 - rise of water (in m)

2 - flooded areas of coast

(ignoring some occasional splashes) varied from 1 to 9.7 m relative to the usual ebb tide line. The rise was greatest on the northeastern shore and fluctuated 2.4 to 9.7 m with a mean value of 3 m. It varied from 1 to 3 m with a mean of 2 m on the southeast shore, and from 1.5 to 2 m with a mean of 1.8 m on the western shore.

Hilo suffered most (Fig. 6). The wave appeared at the outer edge of dock No. 1, where there was a tide gauge, at 19^h17^m. At 19^h19^m, the warning siren alerted the residents and at 19^h24^m, the wave reached the western part of the bay.

According to A.G. Abbot, who observed the tsunami from several favorable positions on Cocoanut Island, the following oscillations in level occurred: at 9:21 (19^h21^m), rise of water by 0.3 m (1 foot); 9:22, rise of 0.6 m; 9:25, rise of 0.9 m (first maximum); at 9:30, the water fell 1.5 m, the shore strip of bottom dried up; at 9:36, a rapid rise of water, turbulent currents; 9:37, a very rapid rise, height, 1.8 /24
m; 9:38, the road was flooded, height of water, 2.4 m (second maximum); at 9:40, the water retreated; at 9:42, a flood tide with a maximum rise of 1.8 m; at 9:44, high turbulence in the bay; 9:46, ebb tide; the breakwater was partially dried up; at 9:50, the water was higher than the usual level and flooded across the breakwater; 9:51, the harbor was flooded, no turbulent currents; 9:56, the highest wave poured over the dike; height of flood tide, 2.7-3.0 m, a restaurant was washed away; at 10:00, the floor was flooded to a depth of 15 cm at the Naniloa Hotel, then the water retreated; at 10:02, the water poured over the breakwater; 10:07, ebb; 10:10, a quiet flood, 0.6 m; 10:20, more flood, another 0.6 m; 10:25, the flood continued, the water rose another 0.3 m; 10:26, the water receded 0.3 m; 10:27, the water receded another 0.3 m. In the Wailua River, noticeable oscillations, accompanied by a small bore, were observed for 30 hours.

In the centre of the city, situated between the Wailua and Wailuku Rivers, the water rose to a height of 4.2 m. It flooded the coastal road and passed under the fence into the park, gave out on a small elevation and filled in the site of the districts washed out in 1946. The embankment and the park had in fact been created to protect the central part of the city from future tsunamis. The water reached the main alley of the park and littered it with pebbles and rubbish, which was the extent of the damage in this part of the city. Part of the water joined with the overflowing waters of the Wailua River, and the vicinity of the bridge across the river for some time turned into an island. The water rose to the edge of the pavement in the flooded places. It also partly penetrated along the sewage system. The main damage was done in the estuary of the Wailua River and to the east, as far as dock No. 1. Several fishing boats, riding at anchor in the estuary capsized or ran aground; the buildings on the shore were heavily damaged. A marine dry dock was destroyed, and the boats and equipment were tossed in an eastern direction onto the restaurant building, which also suffered heavy damage. A wave 1 m high passed over Cocoanut Island, and the bridge leading to the island was damaged.

At dock No. 1, the water rose 3 m, submerging it by 0.6 m, and largely spoiled the goods in the warehouses. The breakwater was flooded several times, but did not suffer serious damage.

Some damage was also done to the east of Hilo Bay. At Keaukaha Bay, a shed was shifted 6 m by a 2.4 m wave. Fifteen metres of wall was detroyed on the Kalanianole* Highway.

The wave also did damage at some other points on the northeastern shore with unfavorable relief. In the Waipio Valley, homes and farm buildings situated at a height of 1.8 m, 270 m from the shoreline, were hit by the water and flooded. The windows and doors were knocked out, a home was submerged by 1 m; one of the buildings was destroyed. Agricultural land and fish ponds were ruined. There was no damage on other sections of the coast of the island, if one ignores the light damage to the moorage at Keauhou.

According to unconfirmed reports, on the 10th at 5:00, a recurrent wave 1.5-1.8 m high was observed at Keauhou. It was surmised that it has been formed by reflection of the main wave from the Asian continent.

At Lanikai*, also on the western coast of Hawaii Island, the water left the bay several times, but the bay did not dry up completely.

On the Marquesas Islands, according to the captain of the "Gilbert," a tidal wave was noted at 13:56. The maximal rise of water was observed at 16:10, with a range of oscillations of 6 m.

In Japan, according to police reports, waves 1.8 to 3 m high were recorded on the coast of Hokkaido Island. Storm rollers, caused by a low pressure zone to the east of Hokkaido Island, contributed to the rise of water. In Hakodate district, at least 32 homes were flooded, 18 boats were damaged, dikes and roads were destroyed. To the east, in Kushiro district, 9 homes were destroyed and 19 homes were damaged. On the northeast of Honshu Island, 83 homes were damaged and 19 boats were /25
washed away. There were no victims.

In the USA, 5 hours after the tsunami alarm, a torrent of water unexpectedly burst into San Diego Bay. It smashed the building slips on Shelter Island*, ripped off the hawsers on a former marine hunting ship (the "Halcyon"), and damaged seven small ships.

In Mexico, according to the members of the joint expedition of the Institute of Geophysics of the University of Mexico and the Scripps Institute of Oceanography, at about 17:30 on the 9th, bathing sailors noticed a rapid retreat of water, which was caused by the arrival of strong tsunami waves.

At another place, a group of geologists, situated on a shore scarp, were filling bottles with water from a spring. Suddenly, flood and ebb tides began; the spring began to flood. The geologists estimated that the period of the waves was 5-6 minutes, and the amplitude was about 4-5 m, which evidently is overestimated. Slight damage was done at Acajutla (El Salvador).

The parameters of the tsunami, based on tide gauge data, are given in Table 2. The wave period varied considerably from station to station, ranging from 7 to 55 minutes with an average value of about 17 minutes for the first onset of the wave, which generally speaking, is small for a source of such impressive size. The tsunami began with the flood tide at all the stations with very few exceptions (Antofagasta, and perhaps Wake Island). The surface of the Pacific oscillated for five days until full quiet.

Studying the attenuation of the oscillations on the record of a special tsunami register set up on Wake Island, Van Dorn estimated the energy of the tsunami at 2.5 X 10^{22} ergs (SN, BSSA, 1957, vol. 47, No. 3; Merino y Coronado, 1957; Salsman, 1959; Brazee, Cloud, 1959; Fraser *et al.*, 1959; Anon., 1961; Berninghausen, 1962; Richter, 1963; Hatori, 1963 a, 1965 b; Van Dorn, 1963; Iida, 1963 a,b; Ponyavin, 1965; Hamamatsu, 1966; Iida *et al.*, 1967; Cox, Pararas-Carayannis, 1969; Pararas-Carayannis, 1969).

[9.III; $14^h22^m28^s$, 51.3° N., 175.8° W.; M=7.9.]

<u>1964, March 27, 17:36</u>. There was a catastrophic earthquake and tsunami with source off the eastern tip of the Aleutian-Alaska Island arc. The maximal rise of water was 20 m at the source, 10 m at the southeastern prominence of Alaska and in Canada, 6 m in the USA, 5 m on the Hawaiian Islands, and 1 m in South America. Large coastal collapses caused local surges up to 30 m high near Valdez, 18 m near Whittier, 9 m in Seward. No description of the events is given here. A brief account of the tsunami can be found in Iida's catalogue (Iida *et al.*, 1967).

<u>1965, February 3, 19:01</u>. There was a strong (6 degrees) earthquake on the Rat Islands and the Andreanof Islands. On Adak Island, a booming underground rumbling was heard; the oscillations began gradually and were regular; many residents were frightened; hanging objects fell from the walls; slight cracks were formed in some prefabricated wooden homes. On Attu Island, the oscillations began suddenly and consisted of both regular oscillations, as well as short-period trembling; lockers and wall pictures shifted; hairline cracks appeared in the landing strips at the naval base of the frontier guard. On Shemya Island, all unfastened objects rocked or fell; drawers came out of desks and cupboards; cracks appeared in the asphalt pavement; the stucco cracked. A seaquake was felt on the "Ohio" at 50° 48' N., 179° 15' E. Many aftershocks were registered.

A tsunami arose. On Adak Island, the sea level fell 0.3 m (1 foot) in 15 minutes. On Attu Island, the level rose and fell 2 1/2 m (8 feet) relative to the normal position. On the southern coast of Shemya Island, the height of rise of the water was estimated at 9-10 m (30-35 feet). Here the warehouse was flooded and a part of the coastal road was washed out. Slight damage from the tsunami was reported from Amchitka Island.

In Japan on the Sanriku coast, slight damage was done to the oyster beds, although the rise of water was only a few tens of a centimetre.

The tsunami was registered by many tide gauges in the Pacific. /27
The published data of instrumental observations are presented in Table 3 and in Fig. 7. On the coasts of the USSR and Japan, the tsunami began with a tidal wave, the mean period of which was 25.5 minutes. The maximal amplitude of oscillations was observed in Japan 4-6 hours after the arrival of the first wave, regardless of the epicentral distance of the station.

Hwang et al., surmising that there was an instantaneous ellipsoid elevation of the bottom at the source of the earthquake, calculated the spread of the resulting tsunami over the Pacific Ocean. A distinct maximum of radiation turned out to follow a line orthogonal to the Aleutian arc, passing between Japan and the Hawaiian Islands (Hatori, 1965 c,d; SN, 1965, vol. 55, No. 3; Hake, Cloud, 1967; Iida et al., 1967; Cox, Pararas-Carayannis, 1969; Pararas-Carayannis, 1969; Hwang et al., 1972).

[4.II; $5^{h}01^{m}20^{s}$; 51.2° N., 178.6° W.; 40 km; M=8.7.]

1965, March 29, 16:27. An earthquake, felt on Amchitka and Adak Islands, caused a tsunami registered by tide gauges on Attu Island with an amplitude of 20 cm and at Hilo with an amplitude of 10 cm. The tsunami arrived at the latter point in 5.4 hours (Hake, Cloud, 1967; Iida et al., 1967; Cox, Pararas-Carayannis, 1969).

[30.III; $2^{h}27^{m}07^{s}$; 50.6° N., 177.8° E.; 51 km; M=7.5.]

1965, July 2, 10:59. An earthquake was felt with a force of up to 6 degrees on Umnak Island, where in one home the crockery was broken and books were scattered all over the room. It was felt by almost everybody in Cold Bay; a light crackling sound was heard; buildings swayed; lamps rocked 10-15 cm on a west-east axis; the duration of the oscillation was 40 seconds. A tsunami with an amplitude of 15 cm was recorded on Unalaska Island (SN, 1966, vol. 56, No. 1; Rothé, 1966; Hake, Cloud, 1967; Iida et al., 1967; Cox, Pararas-Carayannis, 1969).

[2.VII; $20^{h}58^{m}36^{s}$; 53° N., 167.6° W.; 60 km; M=7.6.]

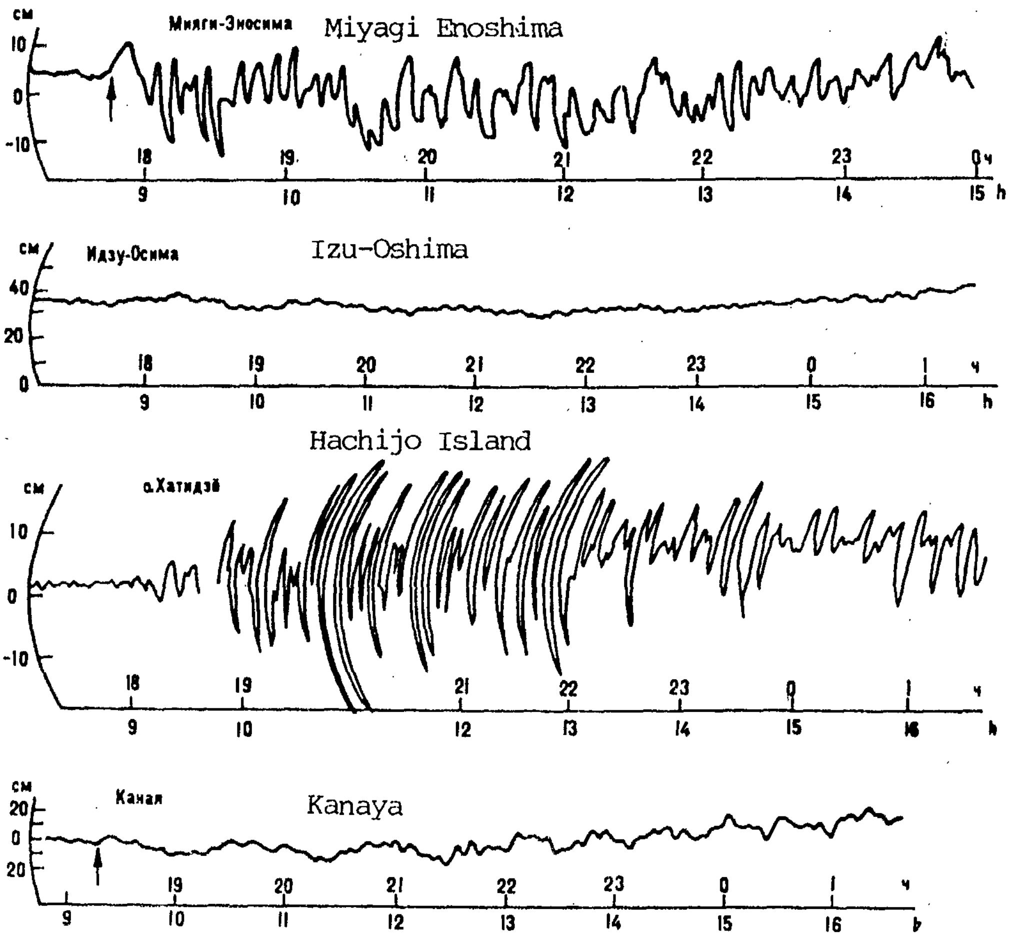

Fig. 7

Tide gauge records of the tsunami of 3.II.1965 on Enoshima Island, Miyagi Prefecture (Van Dorn System) and on Oshima Island off the Izu Peninsula (Takahasi System, ERI-IV), on Hachijo Island (Takahasi System, ERI-III), and at Kanaya (Takahasi System, ERI-I). (Hatori, 1965e).

JAPANESE ISLAND ARC

Pacific Coast

684, November 29. A strong earthquake occurred in the prefectures (from west to east) of Ehime, Kochi, Tokushima, Wakayama, Nara, Mie, Aichi and Shizuoka (Map II). The tremors were especially strong in Kochi Prefecture.

There was a tsunami which was most intensive on the coast of Kochi Prefecture. About 12 km^2 of land with two villages went underwater. Where this occurred is unknown, but it may have been on the coast of Tosa Bay, in the region of Urado Inlet (the coast also subsided in the vicinity of Urado during the strong earthquake of 1707) (Mallet, 1855; Perrey, 1862 c; Sekiya, 1898, 1899; Anon. (J), 1899 a,b; Omori, 1900, 1901 a,b; 1913, 1919; Honda *et al.*, 1908 a,b; Gondo, 1932; Sieberg, 1932; Heck, 1934, 1947; Imamura, 1942, 1949; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Hakoda, 1962; Ponyavin, 1965; Katsumata, 1966; Iida *et al.*, 1967; Watanabe, 1968).

Iida (1956): 32.5° N., 134° E.; M=8, m=3. Iida *et al.* (1967): M=8.4, m=4.

765?, July?. There was a volcanic eruption and short-period tremors on Kyushu Island, north of Kagoshima Bay (Osumi Peninsula) at Shinzoshinto*. According to some chronicles, the island subsided. People were washed away. This probably refers to a mud flow, and not to a tsunami (Gondo, 1932; Musya, 1951; Iida *et al.*, 1967).

799?, September 18. There were oscillations in sea level, about 2 m high, at Hitachi (Ibaraki Prefecture), on the east of Honshu Island. The same oscillations may have occurred at Nakaminato, Kuji and Kashima.

It is possible that this was a tsunami from an earthquake at Sanriku, a remote earthquake or storm waves (Imamura, 1942, 1949; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Ponyavin, 1965; Iida *et al.*, 1967).

818, August?. There was strong earthquake in the prefectures of Tokyo, Saitama, Ibaraki, Gumma, and Tochigi; and there was a tsunami in Sagami Gulf (Anon. (J), 1899 a,b; Imamura, 1949; Yamaguti, 1954; Iida, 1956; Ponyavin, 1965; Katsumata, 1966; Iida *et al.*, 1967; Watanabe, 1968; Hatori *et al.*, 1973).

Iida *et al.* (1967): 35.2° N., 139.3° E.; M=7.9, m=1.

855?, June?. There was a tsunami at Kumano (Kii peninsula, Mie Prefecture), but no details are known, and no earthquake is reported. This was probably a tsunami from a remote source or storm waves (Musya, 1951; Iida *et al.*, 1967).

869, July 13. A strong earthquake causing great destruction and with many victims occurred on the territory of Aomori, Iwate and Miyagi prefectures. "Gleaming bands of light flared up several times, illuminating all objects as if in daylight. People could not stand and could do nothing but shout for help. Some were crushed by fragments of collapsing homes and some were swallowed up by enormous cracks in the earth. Cows and horses milled about in terror, bumping into each other. An extraordinary number of temples, warehouses, gates and walls were thrown to the ground. Prolonged rumbling sounds, like thunder, were heard."

A tsunami fell on the Sanriku coast (general name for the Pacific coast of the prefectures of Aomori, Iwate and Miyagi) on a stretch of hundreds of kilometres. The earthquake and tsunami were especially strong in the vicinity of Sendai; a wave reached the Takajo* fortress here. About 1000 people died; hundreds of villages were destroyed (Neumann, 1878; Anon. (J), 1899 a,b; Omori, 1913, 1919; Musya, 1934; Heck, 1934, 1947; Imamura, 1934, 1949; Musya, 1951; Takahasi, 1951; /31
Yamaguti, 1954; Iida, 1956; Ponyavin, 1965; Katsumata, 1966; Iida *et al.*, 1967; Watanabe, 1968, 1969).

Iida (1956): 38.5° N., 143.8° E.; M=8.6, m=4; Iida *et al.* 1967: m=5.

887, August 26, about 16:00. There was a strong shock in the Kyoto region, causing great destruction and some victims. At the same time, there was a strong earthquake in the prefectures of Osaka, Shiga, Gifu, and Nagano. A tsunami flooded the coastal locality, and some people died. The coast of Osaka and primarily Osaka Bay suffered especially heavily from the tsunami. The tsunami was also observed on the coast of Hyuga-Nada.

The hypocenter and pleistoseismic zone of this earhtquake have not been precisely established. It is possible that this earthquake, like the strong earthquake of 1707, affected the islands of Honshu, Shikoku and Kyushu. However, the occurrence of landslides in Nagano Prefecture and the destruction of dams on the Saigawa and Chikuma Rivers is similar to what was observed during the strong earthquake of 8.V.1847 in central Japan (Neumann, 1878; Anon. (J), 1899, a,b; Honda *et al.*, 1908 a,b; Omori, 1913, 1919; Gondo, 1932; Sieberg, 1932; Tsuboi, 1935; Imamura, 1942, 1949; Heck, 1934, 1947; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Ponyavin, 1965; Hakoda, 1962; Katsumata, 1966; Iida *et al.*, 1967; Watanabe, 1968).

Iida (1956): 33° N., 135.3° E.; M=8.6, m=3. Iida *et al.* (1967): m=4.

[These may have been events of the same type as those of 18.I. 1586.]

922. An earthquake occurred on the coast of Kumano-Nada. There was a tsunami on the south coast of the Kii Peninsula (Imamura, 1949;

Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Hakoda, 1962; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968).

Iida (1965): 33.8° N., 136.7° E.; M=7, m=1.

1088, May 13. There were nine shocks in the vicinity of Miyako (Iwate Prefecture) from 20:00 until the following morning. Large waves ran up on the coast three times before 1:00. The wave periods were greater than 1 hour (Imamura, 1899 a,b).

1096, December 17. There was an earthquake at Kinki (Map II) that was also felt at Kyoto. A tsunami was observed on the coast of Mie and Shizuoka Prefectures where more than 400 homes and temples were washed away (Anon. (J), 1899 a,b; Imamura, 1942, 1949; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Hakoda, 1962; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968).

Iida (1956): 34.2° N., 137.3° E.; M=8.4, m=2.

Iida et al. (1967): m=2 1/2.

1241 (erroneously 1240), May 22. There was a large earthquake on the south of Kanagawa Prefecture. It was felt strongly at Kamakura. It was accompanied by a tsunami on the coast at Kamakura. In particular, a sea wave destroyed part of the Hachiman Shinto temple on the Yuigahama coast. More than ten ships were damaged (Anon. (J), 1899 a,b; Omori, 1919; Imamura, 1942, 1949; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Matuzawa, 1964; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968; Hatori et al., 1973).

Iida (1956): 35.3° N., 139.3° E.; M=7, m=1.

1257, October 9. There was a strong earthquake in the southern part of Kanto (Map II), homes and temples were damaged. There was a tsunami on the coast of Sagami Bay. The earthquake is mentioned in a number of papers (Mallet, 1855; Neumann, 1878; Anon. (J), 1899 a,b; Omori, 1919). A tsunami was observed at Kuji and Noda (Iwate Prefecture) (Imamura, 1942, 1949; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968; Hatori et al., 1973).

Iida (1956): 35.2° N., 140.9° E.; M=7, m=1.

1293. There is an erroneous reference in some sources (Krümmel, 1911; Daly, 1926; Heck, 1947) to a catastrophic tsunami in Japan (Iida et al., 1967).

1360, July and August. Some sources give an erroneous date for the tsunami of 3.VIII.1361 (Gondo, 1932; Iida et al., 1967).

1360, November 22. An earthquake occurred in Osaka and Wakayama Prefectures. The epicenter was located at sea near Kii Strait. The first shock occurred on November 21. The second earthquake, at about midnight on the 22nd, caused a tsunami, which was observed at dawn on the 23rd on the coast of Wakayama Prefecture and in Osaka Bay. There were many victims (Imamura, 1942, 1949; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968). /32

Iida (1956): 33.4° N., 135.2° E.; M=7, m=2. Iida et al. (1967): m=2.5.

1361, August 3. There was a strong earthquake in Tokushima, Osaka, Wakayama, and Nara Prefectures and on Awaji Island. It was also felt rather strongly, but without consequences, at Kyoto.

A tsunami was observed on the coast of Tokushima and Kochi Prefectures, in Kii Strait and in Osaka Bay. A tidal wave, like a large mountain, approached Yuki Bay, which is on the southeastern coast of Tokushima Prefecture, and 1700 homes were washed away in Yuki Port; several hundred people died. At Naruto, in Tokushima Prefecture, the water retreated from shore. The bottom of the inlet in the Naniwa region (Osaka, Fig. 8) was bared for a large distance, and people began to gather fish. A large wave then approached and several hundred people died. The settlement of Naniwa suffered damage (Anon. (J), 1899 a,b; Honda et al., 1908 a,b; Omori, 1913, 1919; Heck, 1934; 1947; Imamura, 1937; Imamura, 1942, 1949; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968).

Iida (1956): 33° N., 135° E.; M=8.4, m=3.

Iida et al. (1967): 33.4° N., 135° E.; m=4.

1369. An erroneous date is given by Milne (Milne, 1908) for the tsunami at Kamakura.

1403, December. There was an eathquake on the coast of Kumano-Nada. The epicenter was at sea. There was a tsunami on the southern coast of Kii Peninusla and at Kamakura (Mallet, 1855; Imamura, 1942, 1949; Musya, 1951; Takahasi, 1951; Iida, 1956, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968).

Iida (1956): 33.7° N., 136.5° E.; M=7, m=1.

1408, January 21. There was a strong earthquake in Osaka Prefecture. The epicenter was at sea, at Kumano-Nada. A tsunami was observed on the south coast of the Kii Peninsula, at Kamak'ura and at other places (Mallet, 1855; Anon. (J), 1899 a,b; Honda et al., 1908 a,b; Milne, 1912 b; Imamura, 1942, 1949; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Matuzawa, 1964; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968; Hatori et al., 1973).

Iida (1956): 33.8° N., 136.9° E.; M=7, m=1.

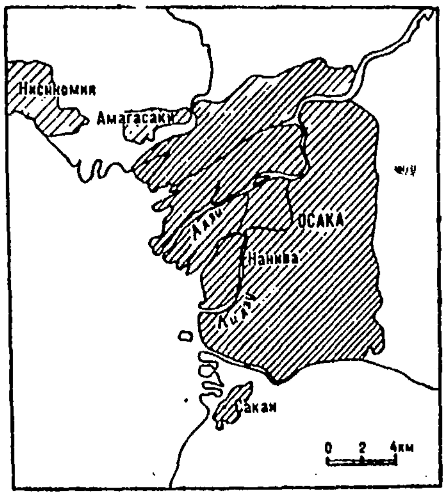

Fig. 8
Diagram of Osaka City.

[The accounts of this and the preceding events are very similar. One surmises that they refer to the same event.]

1420, September 6. Nine waves were observed in 4 hours in Ibaraki Prefecture. Imamura estimates that the height of the waves was about 2 m. There is no reference at all to an earthquake, and it is considered that the tsunami came from a distant source (Imamura, 1942, 1949; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Ponyavin, 1965; Iida et al., 1967).

Iida (1956): m=1.

1433, November 7, about midnight. There was a strong earthquake on the southeast of Honshu Island. About 30 shocks, causing victims, were felt through the night at Kamak'ura. Aftershocks of the earthquake continued for another 20 days. There was much destruction in the region of Aizuwakamatsu (Fukushima Prefecture). The tremors were felt rather strongly in Yamanashi Prefecture. The earthquake was felt at Kyoto. /33

There was a tsunami on the south coast of the Kanto district. A reverse current was observed in the Tone River (Omori, 1913; Musya, 1951; Takahasi, 1951; Iida, 1956; Sagisaka, 1964; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968; Hatori et al., 1973).

Iida (1956): 34.9° N., 139.5° E.; M=7.1, m=1.

1495 (1494), September 12. There was an earthquake in the region of Sagami Bay. There was a tsunami at Kamak'ura. The Daibutsu* temple was destroyed and 200 people died (Milne, 1908; Gondo, 1932; Imamura, 1942, 1949; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Matuzawa, 1964; Ponyavin, 1965; Iida et al., 1967).

Iida (1956): 35.5° N., 139.2° E.; m=2.

Iida et al. (1956): m=2.5.

[It is possible that the date is confused and the description applies to the tsunami of 20.IX.1498. For instance, in a catalogue of Japanese earthquakes (Anon. (J), 1899 a), only a weak earthquake at Kyoto is mentioned for 12.IX.1495.]

1498, September 20, about 8:00. There was a catastrophic earthquake which was felt in the prefectures of Wakayama, Nara, Mie, Aichi, Shizuoka, Yamanashi, Kanagawa, Tokyo, Saitama, Chiba, Gumma, Tochigi, Ibaraki and Fukushima (Map II).

The pleistoseismic zone included the prefectures from Mie to Kanagawa and had a length of about 360 km (Fig. 9). However, the main damage was done not by the earhtquake itself, but by the tsunami waves which were observed from the Kii Peninsula to the Mi'ura Peninsula.

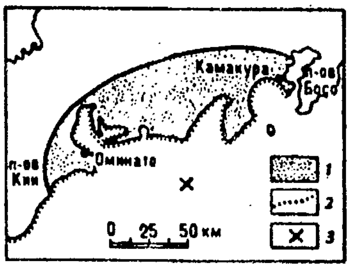

Fig. 9

Pleistoseismic zone of the earthquake and tsunami of 20.IX.1498 (Omori, 1913).

1 - approximate zone of destruction

2 - coast on which destructive tsunami was observed

3 - macroseismic epicenter of earthquake

At Ominato, Mie prefecture, 1000 homes were flooded and washed away and 500 people died. The spit, separating Hamana Lake from the sea, was breached. At Kamak'ura, the wave reached the Daibutsu* temple; 200 people died. On Hachijo Island, one person died as a result of the tsunami (Neumann, 1878; Sekiya, 1898; Anon. (J), 1899 a,b; Honda et al., 1908 a,b; Omori, 1900, 1901 a,b, 1913, 1919; Milne, 1912 b; Gondo, 1932; Fukutomi, 1936; Imamura, 1942, 1949; Heck, 1934, 1947; Musya, 1951; Yamaguti, 1954; Iida, 1956; Hakoda, 1962; Sagisaka, 1964; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968; Hatori et al., 1973).

Iida (1956): 34.1° N., 138.2° E.; M=8.6, m=3.

Iida et al. (1967): m=4.

1500, July 10. Some sources (Milne, 1912 b; Heck, 1934, 1947) apparently erroneously refer to a tsunami in Japan (Iida et al., 1967).

1510, September 21, about 2:00. There was a strong earthquake which caused destruction at some places in Osaka Prefecture. There were many aftershocks.

A tsunami was observed on the coast of Osaka Bay. At Naniwa (Osaka region), a high tidal wave damaged homes (Neumann, 1878; Anon. (J), 1899 a,b; Honda et al., 1908 a,b; Omori, 1913; Gondo, 1932; Sieberg, 1932; Tsuboi, 1935; Imamura, 1942, 1949; Heck, 1934, 1947; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Hakoda, 1962; Iida et al., 1967; Watanabe, 1968).

Iida (1956): 34.6° N., 135.7° E.; M=6.7, m=0.

1510, October 10 (mistakenly 1). There was a sea wave at Totomi-Nada (Shizuoka Prefecture). There was no earthquake. The wave destroyed the dam which separates the lagoon from the sea. According to Imamura, /34
the waves were of storm origin (Anon. (J), 1899 a,b; Honda et al., 1908 a,b; Milne, 1912 b; Imamura, 1942, 1949; Heck, 1934, 1947; Musya, 1951; Iida et al., 1967).

1512, October ?. A tsunami was observed on the coast of Tokushima Prefecture (Shikoku Island). More than 3700 people drowned in the flood. However, there was no earthquake. It is possible that the waves were of storm origin, although Imamura (1949; erroneously indicates 1521) considers that the description refers to the tsunami of 31.I.1605 (Imamura, 1942, 1949; Hakoda, 1962; Iida et al., 1967).

[It is also possible that this refers to a tsunami of distant origin, for example, from an earthquake in Peru.]

1520, April 4. There was an earthquake on the eastern shore of the Kii Peninsula (at Kumano-Nada). A tsunami was observed on the coast of the southern part of the Kii Peninsula. Several homes were washed away (Imamura, 1942, 1949; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Hakoda, 1962; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968). Iida (1956): 33.6° N., 136.3° E.; M=7, m=1.

1545, February 7. According to some vague data, there was an earthquake and tsunami on the Izu Peninsula (Imamura, 1942, 1949; Musya, 1951; Iida et al., 1967).

1562, July 26 (or 25). There was a tsunami from a remote source or waves of storm origin at Yatsushiro, Kumamoto Prefecture (Higo) on the west of Kyushu Island (Honda et al., 1908 a,b; Imamura, 1942, 1949; Heck, 1934, 1947; Musya, 1951; Iida, 1956; Iida et al., 1967).

1585, June 11. There was a tsunami on the coast of Motoyoshi District, Miyagi Prefecture. It is possible that the date is mixed up, and this refers to the tsunami of 18.I.1586 or to an effect of the Peruvian tsunami of 9.VII.1586 (Imamura, 1949; Musya, 1951; Iida, 1956; Iida et al., 1967).

1586, January 18, 23:00. There was a strong earthquake in Kagawa, Hiogo, Kyoto, Osaka, Nara, Mie, Aichi, Gifu, Fukui, Ishikawa and Shizuoka prefectures. It is impossible to establish the precise pleistoseismic zone from the records of this earthquake, but the zone where there was some degree of destruction presumably extended from Nara and Osaka prefectures in the southwest to the prefectures of Toyama in the northeast and Shizuoka in the east. Fires broke out in places. There was considerable destruction at Kyoto.

[The Japanese literature reports a colossal landslide without indicating the exact location. It apparently occurred in the region of Biwa Lake, since it is known that Nagahama was washed out. The vent is described as follows by a Christian missionary.

"In 1586, such a terrible earthquake was sent by heaven, that there had been nothing like it before in Japan. The tremors ceased only after 40 days and extended from Sakata District to Kyoto Prefecture. Sixty homes collapsed at Sakai...At Kyoto, many buildings collapsed, including a famous temple with many idols...In Gifu Prefecture, a fortress was situated on a high mountain. After numerous strong shocks, the earth opened up and swallowed the mountain and the fortress. In their place appeared a lake. The same occurred in Ika District as well...The palaces at Osaka felt very strong tremors, but nevertheless were not toppled...

In Shiga Prefecture at the town of Nagahama, which had about a thousand homes and was often visited by traders, a fire broke out and destroyed half the city. Terrible tremors lasted many days. Then the sea (Lake Biwa) surged on the city with such force that the water pushed over all the buildings and carried them off together with all the inhabitants. Not a trace remained of the rich trading city, except for the castle, and even that was underwater."

The data about this wave in the Japanese literature are apparently so vague, that different specialists have mistakenly attributed the tsunami to the Pacific or to the Sea of Japan [coast of Honshu Island] (Kämpfer, 1729; Perrey, 1862 b; Anon. (J), 1899 a,b; Omori, 1900, 1901, 1913, 1919; Honda et al., 1908 a,b; Gondo, 1932; Heck, 1934, 1947; Musya, 1951; Iida et al., 1967).

Iida et al. (1967): 36° N., 136.8° E.; M=7.9.

1586, September. There was a very strong earthquake. The sea flooded the coast, carrying away homes and their residents. The city of Nangasuma (Nangashima?) was completely destroyed (Mallet, 1855; Heck, 1934, 1947). [The information in Kämpfer's book (1729) has been misinterpreted. The matter relates to the events of 18.I.1586 at Nagahama on the coast of Biwa Lake, Shiga Prefecture.] /35

1596, September 4 (mistakely July 22, September 1), 20:00. There was a strong earthquake on the coast of Bungo Strait. There were landslides, and cracks formed in the earth's surface. In Kagoshima Prefecture, strong tremors were felt, which did not cause much damage. The earthquake was rather strong at Kyoto. The source was apparently situated inside Beppu Bay. Oscillations in water level resulted. Three large waves were observed in the vicinity of Oita. A section about 600 hectares in area on the coast of Beppu Bay subsided underwater. At Saganoseki, about 60 hectares of fields were washed out. Two villages, numbering 70-80 homes, were inundated.

After the earthquake, Urujima* Island, having a circumference of about 12 km and situated 400-500 m from Oita, subsided under the water (the present small island of Kantan* is thought to be a remnant of Urujima* Island). Seven hundred and eight persons died. A strong aftershock was felt on September 4 (Perrey, 1862; Neumann, 1878; Anon. (J), 1899 a,b; Honda et al., 1908 a,b; Omori, 1913, 1919; Imamura, 1942, 1949; Heck, 1934, 1947; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Hakoda, 1962; Matuzawa, 1964; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968).

Iida (1956): 33.3° N., 131.7° E.; M=6.9, m=2.

Iida et al. (1967): m=2.5.

1602, February 7. A landslide came down into the sea from the Boso Peninsula, in Chiba Prefecture. The water retreated 300 m and returned on the following day (?). Many people and animals drowned (Gondo, 1932; Iida et al., 1967).

1603. There was a tsunami at Kumano on the Kii peninsula. No details are available. No earthquake is reported. It is possible that this was a tsunami of remote origin or waves of storm origin (Mus̆ya, 1951; Iida et al., 1967).

1605, January 31 (February 3), 20:00. There was a catastrophic earthquake at Nankaido-Tokaido. Coastal mountains on the Boso Peninsula collapsed, piling up in the sea and forming elevations. The earthquake affected (from east to west) the prefectures of Chiba, Saitama, Tokyo, Kanagawa, Shizuoka, Aichi, Mie and also the islands of Shikoku and Kyushu

(Fig. 10). There are reports that a slight shock was felt on the Kii Peninsula. An earthquake was felt in Kochi Prefecture, but no damge is reported.

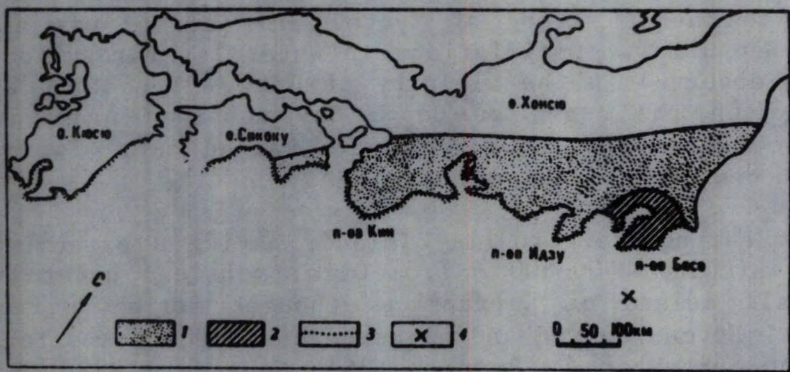

Fig. 10

Known areas of occurrence of the earthquake and tsunami of 31.XII.1605 (Omori, 1913).

1 - approximate location of the zone of strong tremors

2 - approximate location of the zone of great destruction

3 - coast on which destructive tsunami was observed

4 - macroseismic epicenter of earthquake

An enormous tsunami with a maximal known rise of water of 30 m was observed on the coast from the Boso Peninsula to the eastern part of Kyushu Island. The eastern part of the Boso Peninsula, the coast of Tokyo Bay, the coast of the prefectures of Kanagawa and Shizuoka, and the southeastern coast of Kochi Prefecture suffered especially heavily. /36

On the eastern shore of the Boso Peninsula, the sea retreated and exposed the bottom on an area of about 30 hectares. There was some destruction.

At Mi'ura (Misaki, Mi'ura Peninsula), 153 people died. On the Izu Peninsula, a wave reached Nishina village, about 1.2 km from shore.

At Hashimoto*, near Arai (Hamana Lake, Shizuoka Prefecture), 80 of 100 homes were washed away; there were many victims; ships ran aground.

In Ise Bay in many inlets, there were ebbs to a distance of several hundreds of metres from shore in the two hours following the earthquake.

At Hiro village (south of Yuasa, Wakayama Prefecture, western shore of Kii Peninsula), 700 of 1700 homes were washed away.

The tsunami was apparently not observed in Osaka Bay.

At Shishikui, the wave had a height of about 6 m; more than 1500 residents died (according to other reports, more than 3700).

At Kanno'ura (Kochi Prefecture), there were more than 350 victims; there were more than 400 victims in the vicinity of Cape Muroto.

There were also victims on Kyushu Island.

Accoring to available information, a strong tsunami was observed on Hachijo Island. However, there are no data about an earthquake; apparently, no strong shock was felt on the island. The tsunami waves completely washed away the homes situated in the valley on the island; 57 people died. About half of the fields on the island became unsuitable for cultivation (Mallet, 1855; Anon. (J), 1899 a,b; Omori, 1900, 1901, 1913, 1919; Honda *et al.*, 1908 a,b; Milne, 1912 b; Gondo, 1932; Heck, 1934, 1947; Fukutomi, 1936; Imamura, 1942, 1949; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Hakoda, 1962; Katsumata, 1966; Iida *et al.*, 1967; Watanabe, 1968; Hatori, 1973; Hatori *et al.*, 1973).

Iida *et al.* (1967): 31.I; 34.3° N., 140.4° E.; M=7.9, m=5.

In some catalogues (Iida, 1956; Watanabe, 1968) it is considered that two strong earthquakes occurred almost simultaneously in 1605: one at Tokaido and one at Nankaido with the following approximate epicenter coordinates: 34.3° N., 140.3° E; 33° N., 134.9° E.

<u>1611, December 2, 10:00.</u> There was a strong earthquake on the

Sanriku coast. The direct destruction from the earthquake was slight, and there was no damage at all at some places. However, the tsunami resulting from the earthquake did great damage. The earthquake also did no damage on the eastern coast of Hokkaido Island, but there were victims from the tsunami.

The entire northeast shore of Honshu Island, from Sendai Bay and to the north, and the southeastern shore of Hokkaido Island, were affected by the tsunami. The length of the coast which suffered damage was greater than in the Sanriku tsunami of 1896. The height of waves was 25 m at Yamada and Taro in Iwate Prefecture. This tsunami was one of the strongest in Sanriku. The following facts give an idea of the scale of the phenomenon.

At Date (Uchi'ura Bay, Hokkaido Island), 1783 people died. On the coast of the southern part of the Tsugaru Peninsula in Aomori Prefecture, about 3000 people drowned along with many horses. At Taro in Iwate Prefecture, the water advanced 1.2 km inland. There were victims at Senkamatsu* village, which is located 4 km from shore, and near Iwanuma, in Miyagi Prefecture (Anon. (J), 1899 a,b; Honda et al., 1908 a,b; Milne, 1912 b; Omori, 1913, 1919; Gondo, 1932; Imamura, 1934, 1942, 1949; Heck, 1934, 1947; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Hewitt, 1957; Seismicity in Hokkaido..., 1962; Sagisaka, 1964; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968; Hatori, 1973).

Iida et al. (1967): 38.2° N., 143.8° E.; M=8.1, m=5.

1616, September 9, about 11:00. There was a strong earthquake in the Sendai region. The walls of the castle, and some monuments were damaged. The epicenter was situated at sea near Miyagi Prefecture (Anon. (J), 1899 a,b; Omori, 1913). /37

A weak tsunami was observed on the coast of this prefecture (Milne, 1912 b; Imamura, 1934, 1942, 1949; Heck, 1934, 1947; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Watanabe, 1964, 1968; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Hatori, 1973).

Iida et al. (1967): 38.1° N., 142° E.; M=7, m=1.

1616, December 6. There was a tsunami on the coast of Iwate Prefecture. An earthquake and tsunami occurred during the fair at Yokamachi*. Several hundred people died at Kamaishi and Ozuchi (Musya, 1951; Iida et al., 1967).

Iida et al. (1967): m=1?.

1633, March 1, about 5:00. There was a strong earthquake in the Odawara region, Kanagawa Prefecture. The pleistoseismic zone apparently extended from the northern shore of Suruga Bay to Odawara (Omori, 1919).

A tsunami was observed on the coast of Sagami Bay and the eastern part of the Izu Peninsula. Homes and fishing gear were washed away at Atami (Anon. (J), 1899 a,b; Honda et al., 1908 a,b; Heck, 1934, 1947; Musya, 1951; Takahasi, 1951; Iida, 1956; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968; Hatori, 1973; Hatori et al., 1973).

Iida et al. (1967): 1.III; 35.6° N., 139.2° E.; M=7.1, m=1.

1640, July 31. There was a strong eruption of the Komagatake volcano on Hokkaido Island. The ejected ashes were carried by the wind right up to Niigata Village. The layer of ashes was 2 m deep at the foot of the volcano. A tsunami was observed; the waves reached the coast of Tsugaru Strait in the regions of Hidaka and Tokachi (Hokkaido Island). More than 100 ships gathering seaweed were washed away on the coast of Uchi'ura Bay; more than 700 people died. Twenty homes were washed away.

It is assumed that the tsunami was due to the falling of the ejecta into the sea, or to an earthquake which was felt simultaneously with the eruption. Imamura surmises that the epicenter of the earthquake was situated to the east of the volcano, while Musya considers that it was situated at sea near Cape Shiriya (northern tip of Honshu Island) (Imamura, 1921, 1934, 1949; Sapper, 1927; Sieberg, 1932; Heck, 1934, 1947; Musya, 1951; Yamaguti, 1954; Iida, 1956; Kuno, 1962; Seismicity in Hokkaido..., 1962; Watanabe, 1964, 1968; Katsumata, 1966; Iida et al., 1967; Hatori, 1973).

Iida et al. (1967): 31.VII; 42.1° N., 140.7° E.; m=1.

1649, July 30. There was a strong earthquake in Tokyo and Saitama Prefectures, and also at Nikko in Tochigi Prefecture. It caused damage and destruction; several people were killed. The epicenter was on land and closer to Tokyo (Edo) than to Nikko, presumably within 40 km north of Tokyo. The parameters of the earthquake are: 36.1° N., 139.7° E.; M=7.1 (Anon. (J), 1899 a,b; Omori, 1913; Iida et al., 1967). Sieberg's catalogue (1932), probably mistakenly, indicates that there was a tsunami (Iida et al., 1967).

1651. A tsunami was observed in Miyagi Prefecture on the coast of Watari district, south of Iwanuma, about which oral legends have survived. A report on a Chilean tsunami (Anon., 1961), considers that the tsunami came from a remote origin, presumably from a South American earthquake. Imamura considers this case to be waves of storm origin (Imamura, 1949; Musya, 1951; Anon., 1961; Iida et al., 1967).

[There are no references to a tsunami in South America in 1651 in the earthquake catalogues of Chile, Peru or other countries.]

1662, October 20. A tsunami was observed on the coast of Iwate Prefecture. Only one report mentions a shock and a tsunami. Possibly, the tsunami had a very local nature, although Musya and Imamura do not share this point of view (Imamura, 1949; Musya, 1951; Iida et al., 1967).

Iida et al. (1967): m=0.

1662, October, on the night of the 30–31. A strong earthquake was felt in Miyazaki and Kagoshima Prefectures. The tremors were especially strong along the entire coast of Hyuga-Nada. The earthquake caused some changes in coastal relief on a stretch of 160 km. At Sadowara, the gates of the castle were destroyed, as well as homes and temples; in all, about 800 homes collapsed in the rural locality; there were human victims; cracks up to 1 m appeared in the ground; avalanches occurred. There were many aftershocks, which continued on the following day. Near Miyazaki, 90 homes were destroyed and 120 were half-destroyed. A stretch of coast 32 km long near Kaeda and Hongo subsided under the sea. /38

A tsunami followed the earthquake. The entire southeast coast of Kyushu Island suffered to some degree, most of all the coast between the Oyodo and Kaeda Rivers. One thousand two hundred and thirteen homes were destroyed. On the Osumi Peninsula, ten ships loaded with rice were sunk. Five residents died at Beppu, and in all about 200 people died. The tsunami may have been observed on the Izu Peninsula (Mallet, 1855; Anon. (J), 1899 a,b; Omori, 1913, 1919; Gondo, 1932; Heck, 1934, 1947; Imamura, 1949; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Hakoda, 1962; Matuzawa, 1964; Sagisaka, 1964; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968; Hatori, 1973).

Iida et al. (1967): 31.X; 31.7° N., 132° E.; M=7.6, m=2.5.

1666, May 31. There was an earthquake at Tokyo. On the same day, a tsunami was observed on the coast of Chita Peninsula (Ise Gulf). There was some destruction. Imamura considers the waves to have been storm waves, but such waves are very rare in May (Imamura, 1949; Musya, 1951; Iida et al., 1967).

Iida et al. (1967): m=1.

1670, September. There were tsunami-type waves of storm origin on the coast of the Osaka Bay (Gondo, 1932; Iida et al., 1967).

1676, November. There was a tsunami on the coast of Ibaraki, Fukushima and Aomori (?) Prefectures. Homes were flooded, people and animals drowned. The report is muddled. It was apparently a tsunami of remote origin (Musya, 1951; Iida, 1956; Iida et al., 1967). [More likely, the data relate to the tsunami of 13.IV.1677.]

1677, April 13, about 22:00. There was a strong earthquake in Aomori and Iwate Prefectures. There was a catastrophic tsunami on the Sanriku Coast.

There were 25 shocks during the night at Morioka, although they were all weak and did no damage.

Nine shocks were registered at Miyako until morning. Some time after the first shock, a weak tsunami approached the coast, and three large waves were observed from about 24:00 for 4 hours. Several homes were washed away at Kuwagasaki. The people had time to escape before the arrival of the wave.

Two hours after the strong shock, waves approached a village situated on the northern coast of Kamaishi Gulf, 500 m from shore, and 2 out of 60 homes (according to other sources, 20) were damaged. There were no victims, since the residents also had time to escape (Anon. (J), 1899 a,b; Honda et al., 1908 a,b; Milne, 1912 b; Omori, 1913, 1919; Heck, 1934, 1947; Imamura, 1934, 1949; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Sagisaka, 1964; Watanabe, 1964, 1968; Katsumata, 1966; Iida et al., 1967; Hatori, 1973).

Iida (1956): 38.7° N., 144° E.; M=8.1, m=2.

Iida et al. (1967): m=2.5.

1677, November 4. There was an earthquake with source near Chiba and Ibaraki Prefectures. A multitude of aftershocks were recorded on the Boso Peninsula.

A destructive tsunami occurred. It was observed from the Kii Peninsula to Miyagi Prefecture.

At Iwanuma (Miyagi Prefecture), more than 400 homes were washed out and 123 people died.

Eighty people died at Onahama (near Iwaki, Fukushima Prefecture).

On the coast of Mito region (Ibaraki Prefecture), 189 homes were destroyed, 36 people died, and 353 boats were washed away.

On the Boso Peninsula, 223 homes were destroyed, and 261 people died. /39

Twenty-five boats were washed away or smashed on the northwestern shore of Ise Bay (Aichi Prefecture).

A tsunami was also observed on Hachijo Island. A high wave was recorded in the valley of the island, where ten fishing boats were washed away.

In all, as a result of the tsunami, more than 1000 homes were washed away and more than 500 people died (Gondo, 1932; Imamura, 1949; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Watanabe, 1964, 1968; Matusawa, 1964; Sagisaka, 1964; Katsumata, 1966; Iida et al., 1967; Hatori, 1973; Hatori et al., 1973).

Iida (1956): 4.XI; 36.6° N., 141.5° E. or 34.7° N., 141.2° E.; M=7.4, m=2.

Iida et al. (1967): m=2.5.

1680, September 28?. There was an earthquake at Totomi-Nada

(Aichi and Shizuoka Prefectures). There was a tsunami on the coast of Totomi-Nada and Fukushima Prefectures. Many homes were washed out and many people drowned. Imamura considers this tsunami to have been of storm origin, although the available historical materials suggest that it may, in fact, have been caused by an earthquake (Imamura, 1949; Iida et al., 1967).

Iida et al. (1967): m=2.

1689. Iwate Prefecture. An oral legend recounts a weak tsunami, during which many people died. There was no earthquake. This perhaps relates to the tsunami of 4.XI.1677 (Imamura, 1934, 1949; Musya, 1951; Iida et al., 1967).

1696, July 25. There was a tsunami on the coast at Onahama (Iwaki region, Fukushima Prefecture). There were many victims. There was a strong wind. There was no earthquake. Imamura considers it to have been a storm tsunami (Imamura, 1949; Musya, 1951; Iida et al., 1967).

Iida et al. (1967): m=2.

1696, November 25. A tsunami was observed on the coast at Ishinomaki (Miyagi Prefecture). Three hundred boats were washed away. There were victims. No earthquake is reported. It may have been a distant tsunami, although it is more likely from the description that the waves were of meteorological origin (Imamura, 1949; Musya, 1951; Iida et al., 1967).

1697, February 26. There was a tsunami on the caost of Iwate Prefecture. The date may be confused and the facts may relate to the tsunami of 25.XI.1696 (Imamura, 1949; Iida et al., 1967).

1698, December 22. A tsunami was observed on the coast of Bungo Strait and Oita Prefecture. There are no details. Possibly the date is mixed up and the data relate to some other tsunami (Imamura, 1949; Musya, 1951; Iida et al., 1967).

1699, March?. There was a landslide on Kyushu Island. A tsunami was observed on the coast of Nagasaki and Saga Prefectures (Gondo, 1932; Iida et al., 1967; Watanabe, 1968).

[Similar to the events of 1.IV.1700.]

1699, September 8. A tsunami was observed on the coast of Suruga Gulf (Shizuoka Prefecture). Imamura and Musya consider this a storm tsunami (Imamura, 1949; Musya, 1951; Iida et al., 1967).

1700, January 27. An unusually high tidal wave was observed on the coast of the Kii Peninsula and at Ozuchi (Iwate Prefecture). There are no reports about an earthquake. Was this a tsunami of remote origin (Imamura, 1949; Musya, 1951; Hakoda, 1962; Iida et al., 1967).

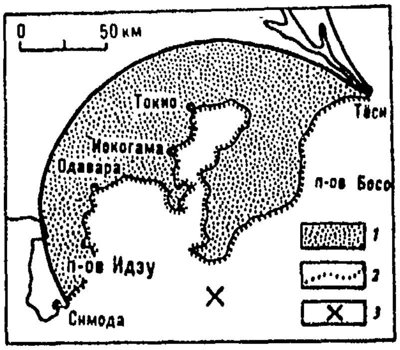

Fig. 11

Pleistoseismic zone of the earthquake and tsunami of 31.XII.1703 (Omori, 1913).

1 - approximate location of the zone of damage and destruction

2 - coast on which destructive tsunami was observed

3 - macroseismic epicenter of earthquake

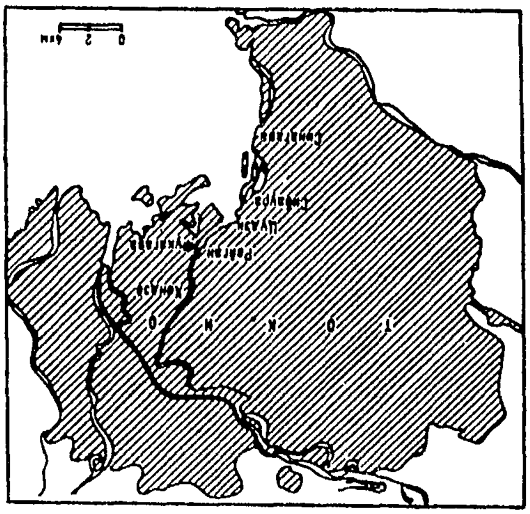

Fig. 12

Diagram of Tokyo City.

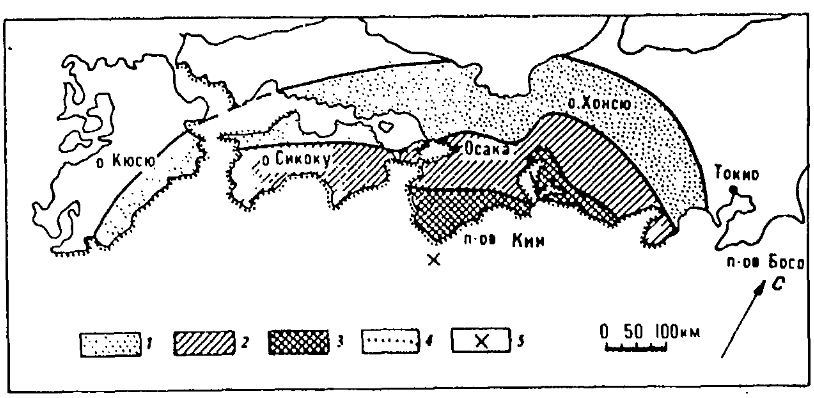

Fig. 13

The earthquake and tsunami of 28.X.1707 (Omori, 1913).

1 - approximate location of the zone of strong tremors

2 - approximate location of the zone of destruction

3 - approximate location of the zone of great destruction

4 - coast on which destructive tsunami was observed

5 - macroseismic epicenter of earthquake

Iida et al. (1967): m=2.5.

1703, December 31 about 2:00. There was a strong earthquake (Genroku) in the prefectures of Fukushima, Tochigi, Ibaraki, Chiba, Saitama, Tokyo, Kanagawa, Yamanashi and Shizuoka (Fig. 11). The greatest destruction took place in Kanagawa Prefecture (Kamak'ura, Katase, Fujisawa, Hiratsuka, Oiso, Shinjuku, Odawara, Hakone and other places) and in the Shinagawa region (Tokyo, Fig. 12). There was no destruction at Nikko. A weak shock was felt at Kyoto. A rather strong earthquake was felt on Hachijo Island. It was accompanied by a loud underground /40
rumble, although there was no destruction of any kind.

The tsunami which arose after the earthquake was observed from the Sanriku Coast to the Kii Peninsula and on the Bonin Islands. There were dead and injured on the Sanriku Coast. The tsunami was especially strong on the coast of Chiba Prefecture, where it caused great destruction, and on the northwestern shore of Sagami Gulf. The tsunami caused numerous human victims in Chiba Prefecture on the eastern shore of the Boso Peninsula (Kujukuri Region), on a stretch of about 400 km. For instance, at Onjuku (Ishumi District), the wave height reached 6-10 m; homes were destroyed and washed away. In all, 440 homes were destroyed and more than 20 people died in the villages of Ishumi District.

Two hundred seventy homes were washed out at Kominato. About 100 residents died in front of the gates of the city, and almost everything except for a few temples, was washed out. The wave carried off part of the Tanjoji* temple. The assumed height of rise of water was 6 m.

In the Chik'ura Region, the sea floor dried up for 800-900 m. Twenty-eight people drowned. The assumed height of rise of water was 5 m.

The southern half of the Boso Peninsula subsided; 1020 homes were destroyed; 125 people died. There were many victims at Mera.

At Ichikawa, 300 homes were washed away. The height of rise of water was about 5 m.

In Tokyo Bay, only a small tsunami was observed, and there was no damage. Large waves (about 2 m) reached the Edo* Bridge in the Reigan region (Tokyo). In the Honjo region, the water level rose 0.9-1.5 m. The wave penetrated to the Shinagawa region and had a height of about 2 m.

The tsunami was destructive in Kanagawa Prefecture along the coast of Sagami Gulf. At Kamak'ura, where four waves were observed, there was considerable damage, and 600 people died. The wave reached the gates of the Yuigahama temple. The assumed height of rise of water was 8 m. Homes were washed out and destroyed at Katase, where the height of rise of water was about 6 m. Waves up to 4 m high were observed in the Fujisawa-Hiratsuka area. The tsunami caused large waves in the Banyu River (now the Sagami River). The ferry was halted. Odawara and Kata'ura were affected by the tsunami. The height of rise of water in this region was 4 m. At Odwara, 230 people died, and homes and ships were /41 washed away at Kata'ura. In Shizuoka Prefecture, at Atami, the waves carried away homes and fishing gear and flooded the fields. Here the rise of water was about 5 m. A wave about 5 m high was observed at Shimotaga. A field was inundated. At Usami, the height of the rise of water was 5 m; homes were washed away, 300 people died. At ebb tide, the bottom of the sea was exposed for 500-600 m. At Kawana*, a wave 4 m high reached the third step of the stone stairway of the Kaizo temple (the height of the flood was approximately 2 m less than during the Kanto tsunami in 1923). Thirty-seven people died at Shimoda; 58 homes and 18 ships were washed away. The wave reached the large gates of the Hoofukuji temple. The height of the wave was about 3 m. At Minato, a sea wave reached the Waseda temple; a field was covered with sand.

On Oshima Island at Okada village, 18 ships and 58 homes were washed away and 56 people died. At Habuminato village, on the south of the island, a pond linked up with the sea and turned into an inlet. The height of waves on the island was about 10 m.

In Aichi Prefecture, at Hosoya village, a flood tide was observed. At 11:00, according to the local physician, the basement of a home was flooded on Cape Kuki (Mie Prefecture).

On Hachijo Island, some time after the underground shock, a tsunami about 3 m high was observed. One person died.

The source of the earthquake and tsunami apparently was situated to the southeast of the Boso Peninsula.

Some settlements suffered not only from this earthquake and tsunami, but also from the large fires which broke out as a result of the shocks. An especially large fire broke out at Odawara. In Kanagawa and Shizuoka Prefectures, in all, 8,007 homes were destroyed, 563 homes burned down, and 2,291 people died (the bulk of the data apply to Kanagawa Prefecture).

In all, according to official data, 20,162 homes suffered damage and 5,233 people died in the country as a result of the seismic shocks, the tsunami and the fires (Mallet, 1855; Neumann, 1878; Anon. (J), 1899 a; Imamura, 1899 a, 1942, 1949; Honda et al., 1908 a,b; Omori, 1913, 1919; Anon. (J), 1929 a; Gondo, 1932; Heck, 1934, 1947; Fukutomi, 1936; Imamura, 1937; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Hakoda, 1962; Sagisaka, 1964; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968; Hatori, 1973; Hatori et al., 1973).

Iida (1956): 31.XII; 34.7° N., 139.8° E.; M=8.4, m=3.

Iida et al. (1967): M=8.2, m=1.

1704, January?. There was a rough sea on the caost of Suruga Bay, Shizuoka Prefecture. No details are available. There are also no reports about an earthquake. That the waves were of storm origin is unlikely, despite the fact that there are many floods in this season.

The source of information is also unknown. It is possible that it has been confused with another event (Musya, 1951; Iida et al., 1967).

1704. There was a tsunami on the south of Kii Peninsula, in the vicinity of Nachikatsu'ura. Thirty homes were washed away at Miwasaki and Taiji. However, nowhere is an earthquake mentioned. It was, perhaps a tsunami of remote origin (Neumann, 1878; Imamura, 1949; Iida, 1956; Hakoda, 1962; Iida et al., 1967).

1707, October 28, between 14:00 and 14:30. There was a catastrophic earthquake, one of the strongest in Japan, in terms of the size of the area on which it was felt and the extent of destruction. The earthquake affected the western part of Yamanashi Prefecture, the central and eastern part of Shizuoka Prefecture, the territory to the south of Nagano Prefecture, as far as the areas of Tokai and Kinki (Fig. 13). The earthquake was also felt all over Shikoku Island and on the eastern part of Kyushu Island. At Kyoto, the earthquake lasted rather long (10-15 minutes). Recurrent shocks were registered for 7-8 months after the main earthquake.

The Tokai locality, the coast of Ise Gulf, and the Kii Peninsula, suffered especially badly. The southeastern part of the coast of Totomi-Nada, the southern part of the Kii Peninsula, and the Muroto Peninsula rose. This elevation was 1-2 m on Cape Owase, 1.2 m at Kushimoto and 1.5 m on Cpae Muroto. A section of area about 20 km^2 subsided 2 m in the eastern part of Kochi Prefecture.

The entire coast from the Izu Peninsula to Kyushu Island was /42
affected by the tsunami. The tsunami waves passed through Kii Strait and reached Osaka Bay and the western part of the Inner Sea of Japan* (Setonaikai).

On the coast of the Izu Peninsula, 1,168 homes were destroyed or washed away. Eleven people died. The rise of water was 3.6 m at Shimoda. In Suruga Gulf, 1,343 homes were destroyed or washed out and 13 people died. The tsunami was weak at Kigomideru*. The wave reached a height of 5-5.5 m at Sagara.

On the coast of Totomi-Nada (south of Shizuoka and Aichi Prefectures), 2,002 homes were destroyed or washed away and 20 people died. Fields were flooded on a large area. At Toyohashi (Atsumi Bay), 124 ships were washed away.

Further west, on the coast of Aichi and Mie Prefectures, 505 homes were destroyed or washed away and 32 people died. Fields were flooded on a large area. At Toba (Mie Prefecture), the fourth wave was the largest and reached 11.5 m [in height]. More than 1,000 people died at Owase.

Nine homes were destroyed or washed out on the coast of Wakayama Prefecture. One person died.

The coast of Osaka Bay suffered heavy damage. About 600 homes were destroyed or washed away and about 400 people died. Bridges were destroyed and fields were flooded on a large area. The tsunami caused great disaster in Osaka, in the region of the river mouth and in the city itself.

The greatest damage was on the coast of Kochi Prefecture. From 1-1.5 hours after the earthquake, strong tsunami waves fell on this coast. They had a height of 6.5 m at Cape Muroto. At Tanesaki, the largest wave, the third, reached a height of 21-24 m; the period of oscillations was about 1 hour 8 minutes, or 2 hours and 30 minutes according to another record. The water rose 26 m at Kure.

The tsunami passed through the Bungo Strait, showing up on the western shore of Ehime Prefecture, and also reached the coast of Yamaguchi Prefecture. It was registered on Hachijo Island.

In all, 2,900 homes were destroyed or washed away, and about 4,900 people died as the result of the tsunami.

It is useful to remember that the south coast of Shikoku Island, specifically Sakinohama and Shishikui suffered greatly from the tsunami in 1605. In this tsunami [1707], Sakinohama was hardly affected, while there were a few vicims at Shishikui. Thus, the direction of approach of these two tsunamis was different. Apparently, the tsunami of 1605 approached the island from the east, while the tsunami of 1707 approached from the south, passing afterwards through Kii Strait and flooding the coast of Osaka Bay (Neumann, 1878; Sekiya, 1898, 1899; Imamura, 1899 a, /43
1935, 1938 a,b, 1940, 1942, 1949; Anon. (J), 1899 a,b, 1929 a,b, 1930; Omori, 1900, 1901 a,b, 1913, 1919; Honda *et al.*, 1908 a,b; Milne, 1908, 1913 a; Gondo, 1932; Tsuboi, 1935; Fukutomi, 1936; Imamura, 1937; Heck, 1934, 1947; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Hakoda, 1962; Matuzawa, 1964; Sagisaka, 1964; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968; Hatori, 1973; Hatori *et al.*, 1973).

Iida (1956): 28.X; 33.2° N., 135.9° E.; M=8.4, m=4.

Iida *et al.* (1967): m=4.8.

1708, February 13. There was an earthquake in Mie Prefecture. A tsunami was observed on the coast of Ise and Atsumi Bays and on Hachijo Island. The water rose at Fukiage* (region of Ujiyamada) (Imamura, 1949; Musya, 1951; Iida, 1956; Iida *et al.*, 1967; Watanabe, 1968).

1711, December 20. An earthquake occurred at Takamatsu, Kagawa Prefecture; 1,713 homes were destroyed; about 1,000 people died. About 30 recurrent shocks were recorded in the following 24 hours. Ten tsunami waves were observed during the day (Imamura, 1949; Iida, 1956; Hakoda, 1962; Katsumata, 1966; Iida *et al.*, 1967; Watanabe, 1968).

Iida *et al.* (1967): 20.XII; 34.3° N., 134° E.; M=6.7, m=1.

1715, December 29. A tsunami was observed on the northeast of Kyushu Island in Beppu Gulf. There are no details available (Musya, 1951; Iida et al., 1967).

1716. The publications of Sapper (1927) and Heck (1947) mention that a tsunami was observed on Oshima Island. The Japanese sources do not mention a tsunami (Iida et al., 1967) [evidently a mistake].

1718, October 5. A tidal wave was observed on the coast of Mie Prefecture. Musya and Omori consider it to have been a tsunami. Omori states that there is a link between the tidal wave and the shock felt on land in the Shinano valley. However, it is clear from Musya's description that this was a wave of storm origin (Omori, 1913; Musya, 1951; Iida et al., 1967).

1722, September 24. A destructive tsunami was observed in Ise Bay on the coast of Aichi Prefecture and the Kii Peninsula. The water reached the temple at Atsuta. There was no shock. Imamura considers the wave to be of storm origin (Gondo, 1932; Imamura, 1949; Musya, 1951; Hakoda, 1962; Iida et al., 1967).

1731, October 7. There was a strong earthquake at Koori (Fukushima Prefecture) which caused destruction of roads, bridges and homes. The epicenter of the shock was apparently on land; its hypothetical coordinates were 37° 52' N., 140° 30' E. (Anon. (J), 1899 a,b; Omori, 1913).

Imamura, Musya and others (Imamura, 1942; Musya, 1951; Takahasi, 1951; Iida, 1956; Ponyavin, 1965) report a tsunami on the coast of Fukushima Prefecture. The assertion is based on an account of the destruction at the mouth of the river, but this destruction might also have been caused by an earthquake. There was probably no tsunami (Iida et al., 1967).

Iida et al. (1967): 7.X; 37.9° N., 140.6° E.; M=6.6.

1732. There was a flood on the coast of the Izu Peninsula and Hachijo Island. There are no details available. These were probably waves of storm origin (Musya, 1951; Iida et al., 1967).

1747, March?. There were waves on the coast of the Izu Peninsula and Hachijo Island. Fishing boats were sunk or washed away on the coast of the Ogago* region (Hachijo Island). No earthquake is reported. This was a tsunami from a remote source or of storm origin (Imamura, 1949; Musya, 1951; Iida et al., 1967; Hatori et al., 1973).

Iida et al. (1967): m=0.

1751, July 24. There was a tsunami on the Ojika Peninsula and in Kesennuma Gulf (Miyagi Prefecture). There are no reports of an earthquake. This was a tsunami from a remote source or of storm origin. Most likely, the date is mixed up and the report concerns an effect of the

Chilean tsunami of 25.V.1751 (Imamura, 1942, 1949; Musya, 1951; Takahasi, 1951; Iida, 1956; Ponyavin, 1965; Iida et al., 1967).

Iida (1956): m=0.

1763, January (mistakely September) 29. An earthquake occurred with source at sea off the coast of the eastern part of Aomori Prefecture. It was felt on the south of this prefecture. There were many recurrent shocks.

A tsunami was observed on the eastern coast of Aomori Prefecture /44
and Hokkaido Island. There was much destruction at Hachinohe and Hakodate. Seven boats were washed away at Minato village (at Hachinohe) and 13 boats were washed away at Taneichi and Kuji (Imamura, 1934, 1942, 1949; Musya, 1951; Takahasi, 1951; Iida, 1956; Watanabe, 1964, 1968; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Hatori, 1973).

Iida et al. (1967): 29.I; 40.8° N., 142° E.; M=7.4, m=1.

1763, March 15. There was an earthquake with source in the open sea off the coast of the eastern part of Aomori Prefecture. Recurrent shocks continued through March and April.

A tsunami was observed along the Sanriku Coast. At Minato village (north of Hachinohe), homes were washed away, and there were many victims (Musya, 1951; Takahasi, 1951; Iida, 1956; Ponyavin, 1965; Katsumata, 1966, Iida et al., 1967; Watanabe, 1968).

Iida et al. (1967): 40.7° N., 142° E.; M=7.1, m=1.

[This may have been a strong recurrent shock from the preceding earthquake (Watanabe, 1968) or it may be identical to the preceding event.]

1769, August 29, about 15:00. There was a strong earthquake at Hyuga-Nada. Six homes were destroyed in the village of Murakaku, situated on the coast approximately 4 km north of Miyazaki, while there was only slight destruction in Miyazaki itself. The earthquake was also felt at the same time at Odawara, Kanagawa Prefecture (Anon. (J), 1899 a,b; Omori, 1913).

A tidal wave was observed on the Satsuma Peninsula (Kagoshima Prefecture). An earthquake occurred during a typhoon, and Japanese specialists surmise, considering the location of these places, that the wave was of storm origin (Heck, 1934, 1947; Imamura, 1949; Iida, 1956; Ponyavin, 1965; Iida et al., 1967; Watanabe, 1968; Hatori, 1973).

Iida et al. (1967): 32.3° N., 132° E.; M=7.4, m=0.

1778, July?. There was a rough sea off the coast of Kumamoto Prefecture. There is no report of a shock or any wind, but the waves were probably of storm origin (Iida et al., 1967).

1780, September 9. A tsunami was observed on the coast of Kagoshima Bay (south of Kyushu Island). It was caused by an explosion of the Sakurajima volcano (Iida et al., 1967; Watanabe, 1968).

Iida et al. (1967): m=0?

1780, October 31. There was an explosion of the Sakurajima volcano (Kyushu Island). A tsunami caused by this explosion was observed on the coast of Kagoshima Bay (Musya, 1951; Iida et al., 1967; Watanabe, 1968).

Iida et al. (1967): m=0?

1781-1787. A tsunami was observed on the coast of Iwate Prefecture. The height of the water was 0.6 m above the usual flood tide level. However, no earthquake is reported. This could have been a tsunami from a remote source, or, it may have been an effect of the tsunami of 22.VIII.1782 at Sagami (Musya, 1951; Iida et al., 1967).

Iida et al. (1967): m=1.

[The distant tsunamis of approximately this period include the Urup tsunami of 1780 (Soloviev, Ferchev, 1961).]

1781, April 11. An explosion of the Sakurajima volcano caused a tsunami in Kagoshima Bay (Kyushu Island). Fifteen people died and six ships sank or were damaged (Imamura, 1949; Musya, 1951; Iida, 1956; Iida et al., 1967). According to Kuno (1962), in November 1779, several small islands were formed off the northeastern coast of Sakurajima Island as a result of underwater eruptions and the elevation of the bottom. Underwater eruptions recurred several times here, accompanied by tsunamis, until early in 1782.

Iida et al. (1967): 31.6° N., 130.7° E.; m=1.

1782, August 23 (or 22), about 2:00. There was a strong earthquake in the region of Tokyo and Kanagawa Prefectures. There was a landslide on Hakone Mountain. There were many aftershocks. Odawara, where there was much destruction, suffered especially heavily. Homes were damaged at Tokyo (Anon. (J), 1899 a,b; Omori, 1913).

A tsunami was observed on the coast of Kanagawa, Chiba, and Iwate Prefectures. The data on these events are contradictory (Gondo, 1932; /45
Imamura, 1949; Musya, 1951; Takahasi, 1951; Iida, 1956; Watanabe, 1964, 1968; Ponyavin, 1965; Iida et al., 1967; Hatori, 1973; Hatori et al., 1973).

Iida et al. (1967): 23.VIII; 35.1° N., 139.7° E.; M=7.3, m=1.

1791, September 13. An earthquake occurred with source in Osaka Bay. A tsunami was observed at Sakai. This may have been a tsunami of storm origin, as thought by Imamura and Musya (Imamura, 1949; Musya, 1951; Iida et al., 1967). m=1.

1792 (mistakenly 1793), May (April) 1 [2]. In the winter of 1791-1792, there was a strong eruption of Unzen volcano (Nagasaki Prefecture, Kyushu Island), which lasted four months. It did great damage to the vicinity of the volcano and was accompanied by frequent underground shocks, as a result of which homes collapsed here and there. Some people were killed. The side of the mountain collapsed at the end of the eruption, and this caused a destructive tsunami. The accounts of the eruption in the Japanese literature are somewhat contradictory, especially with respect to dates. The approximate sequence of events can be related as follows.

On November 13, 1791, tremors of the volcano began, rumbling was heard, and collapses occurred. On the night of February 10 (or 12), 1792, loud "shots" rang out from the very highest peak of Fugen mountain (1498 m above sea level), and these were heard at Shimabara. Near the chapel at Fugen, fumaroles formed, ejecting hot steam, mud and rocks. Then all gradually began to die down, although the rumbling did not stop. The shocks continued from time to time. On March 1, when the Fugen eruption had almost completely stopped, a new vent opened 1 km to the north-northeast of the peak, and began to disgorge lava. The lava travelled about 3 km. The volume of the flow was 0.1 $\pm$ km^3.

The shocks recurred, gradually intensifying, at 15:00 on April 21 (March 1)[1]. The rumbling became more frequent. The shocks caused collapses and landlsides on the mountain sides. The earthquakes were especially strong from the evening until 6:00 on April 22. At Shimabara, homes and structures were destroyed; several residents were injured. Cracks up to 3 cm wide formed in the ground.

Then it became quieter. On April 29 (March 9), when clear weather set in, the south slope of Maeyama Mountain (height 876 m) 215 m long and 90-100 m wide, at Nakakiba village, suddenly collapsed into a gorge. After this, the shocks abated, and people were reassured. Some residents who had left their homes began to return.

On May 21 (April 1) at 18:00, the earth again "shook" strongly twice, and in an instant, the steep southern slope of the Maeyama Mountain, from the peak to the foot, 2 km^2 in area, and apparently about 0.5 km^3 in volume, collapsed. Rocks and earth completely buried the ports of Shimabara and Antoku. The locality to the south of the main gates of the city of Shimabara were also covered with a layer from several tens of centimetres to 3 metres deep.

The collapse generated an enormous tsunami, more than 6-9 m in height in places, in Shimabara Bay. The height of the wave was estimated at 35-55 m at Shimabara. The length of coast, affected by the destruction of the tsunami, was 75 km. Homes and castles were washed out in

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1 The dates in brackets are according to the lunar calendar.

the coastal cities, and fields were flooded at 17 villages. In all, 380 homes were washed away; 9,745 people were killed or disappeared without a trace, and 707 people were injured as a result of the tsunami and the collapse; 496 head of cattle died. Three small islands situated near the coast disappeared. At the same time, the mud and sand washed out to sea formed a few score new small islands in the region of Minato port.

The tsunami also caused great destruction on the other shore of Shimabara Bay, in Kumamoto Prefecture. There were more than 1,100 victims in Ashikita* district, and 4,000 in the two adjacent districts of Uto and Tamana. There was also considerable destruction and 343 residents drowned on the Amakusa Islands. The height of the wave on the Amakusa Islands was estimated at 5-15 m. Underground shocks then continued /46
for another two months (Perrey, 1862 c; Neumann, 1878; Anon. (J), 1899 a,b; Honda et al., 1908 a,b; Omori, 1901 a,b, 1907 b, 1913, 1919; Sapper, 1927; Gondo, 1932; Imamura, 1942, 1949; Heck, 1934, 1947; Musya, 1951; Takahasi, 1951; Iida, 1956; Kuno, 1962; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968).

Iida et al. (1967): 1.V; 32.8° N., 130.3° E.; M=6.4.

1792, August 29. There was an earthquake with source in Ise Bay. A tsunami was observed at Futami (Ise Bay, Mie Prefecture). There were about five waves (Imamura, 1949; Musya, 1951; Iida, 1956; Iida et al., 1967).

Iida et al. (1967): 34.5° N., 136.7° E.; m=0.

1793, February 17. There was an earthquake at Sanriku, which caused catastrophic tsunami waves on the coast of Iwate and Miyagi Prefectures (at Ozuchi, Ryoishi, Kamaishi, Ofunato, Kesennuma, Okachi and other places).

One hundred homes were washed away and 720 residents died in Iwate Prefecture, including 17 homes washed away and 12 or 13 people killed at Ozuchi. The height of the wave was 3 m at Ofunato, and apparently 0.6 m at Okachi (Imamura, 1934, 1942, 1949; Heck, 1934, 1947; Musya, 1951; Takahasi, 1951; Iida, 1956; Sagisaka, 1964; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968; Hatori, 1973).

Iida et al. (1967): 38.3° N., 142.4° E.; M=7.1, m=2.

1808, August 8. There was an earthquake in Tokushima Prefecture, which caused tsunami waves on the coast of the prefecture. A wave 1.5 m high was observed at the Naka River (Imamura, 1942, 1949; Musya, 1951; Iida, 1956; Iida et al., 1967).

Iida et al. (1967): m=1/2.

1808, December 4?. There was a tsunami at Kumano (Kii Peninsula). There are no details available. Apparently, it has been mixed up with the tsunami of 8.VIII.1808 in Tokushima Prefecture (Musya, 1951; Iida et al., 1967).

1816, December ?. There was a flood at Matsuzaki (Izu Peninsula) during a heavy rain. These may have been waves of storm origin, an overflow of the river, or waves from a landslide (Gondo, 1932; Musya, 1951; Iida et al., 1967).

1828, May 26 (December 18). There was an earthquake in Chachibana Bay or at Amakusa-Nada. It was supposedly accompanied by an "underwater disturbance" and waves on the coast of Nagasaki Prefecture and the Amakusa Islands (Iida et al., 1967).

Iida et al. (1967): 37.6° N., 138.9° E.; M=6.9.

1835, July 20. There was a very strong earthquake and tsunami in Miyagi and Iwate Prefectures. A castle at Sendai was completely destroyed and 400-500 homes were flooded and washed away by the sea; many people died. One of the points where the tsunami occurred was Hanabuchi* near Seandai (or Hanasaki on Hokkaido Island) (Neumann, 1878; Honda et al., 1908 a,b; Gondo, 1932; Sieberg, 1932; Heck, 1934, 1947; Imamura, 1949; Musya, 1951; Takahasi, 1951; Iida, 1956; Watanabe, 1964, 1968; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Hatori, 1973).

Iida (1956): 37.9° N., 141.9° E.; M=7.6.

1835, August 19 (or September). A strong earthquake, affecting a vast area occurred on the northeast of Honshu Island (Sendai, Tsugaru Peninsula) and on Hokkaido Island (Nemuro).

There was enormous destruction from a tsunami in Sendai Bay. A wave was also observed on the coast of Hokkaido (Nemuro Peninsula, Hanasaki), where more than 50 homes were destroyed (Anon. (J), 1899 a,b; Sieberg, 1932; Iida et al., 1967).

Iida et al. (1967): 37.9° N., 141.9° E.; M=7.6, m=2.

[It is possible that this account relates to the same tsunami as that of 20.VII.1835.]

1836, September 5?. There was an earthquake at Sendai. Many homes were destroyed in the city (Omori, 1913). A tsunami wave was observed on the coast at Sendai (Miyagi Prefecture) (Honda et al., 1908 a,b; Milne, 1912 b; Musya, 1951; Takahasi, 1951; Iida, 1956; Iida et al., 1967).

Iida et al. (1967): 37.7° N., 142° E.; M=5.9?, m=1.

[This may be the same wave as the two preceding ones.]

1839, May 1. There was an earthquake at Kushiro (Hokkaido Island) and on the Tsugaru Peninsula. Musya's report about a tsunami is probably mistaken: the words "Tsugaru" and "Tsunami" were confused (Musya, 1951; /47

Iida et al., 1967).

Iida et al. (1967): M=7.3.

1845, September ?. Rumors appeared at Tokyo, that a tsunami had fallen on Nagasaki. Musya considers the report to be doubtful. It is possible that there were waves of storm origin (Musya, 1951; Iida et al., 1967).

[Perrey (1857 c, 1866) cites a report about a mild earthquake at Nagasaki on September 17, 1845 at 14:30. The next earthquake was recorded at Nagasaki on September 27 at 4:00.]

1846, March. A tsunami 1.8 m high was observed at Kuwagasaki (Iwate Prefecture). The shore was flooded for about 200 m (Imamura, 1949; Musya, 1951; Iida, 1956; Iida et al., 1967).

Iida (1956): m=0. Iida et al. (1967): m=1.

1847, August 27. Tsunami waves were observed on the coasts of the districts of Kesen (Iwate Prefecture), Motoyoshi, Monoo and Ojika (Miyagi Prefecture). Seventy-five ships were sunk; 333 people died. There was no earthquake. According to Imamura, the waves were of storm origin (Imamura, 1949; Musya, 1951; Iida et al., 1967).

Iida et al. (1967): m=1.

1859, July 20. There was a loud noise and a tsunami on the coast of Iwate Prefecture. The data are very doubtful (Musya, 1951; Iida et al., 1967).

1854, December 23, about 9:00. There was a very strong earthquake in the Tokai area. It was felt on an enormous area, including (from east to west) the prefectures of Tochigi, Kanagawa, Yamanashi, Shizuoka, Nagano, Aichi, Gifu, Mie, Shiga, Fukui and Nara. The zone of greatest destruction had a length of 260 km and a width of 120 km. The zone where the earthquake was especially strong and where the majority of cities and villages were destroyed, represented a strip 120 km long, extending from the northwestern tip of the Izu Peninsula over the coast of Suruga Gulf to the mouth of the Tenryu River (Shizuoka Prefecture) with an area of 1800 km^2 (Fig. 14). Many regions suffered from fires which broke out. An intensification in the discharge of some springs was observed before the earthquake.

A large tsunami appeared after the earthquake along the entire coast from the Boso Peninsula in the east to Tosa Bay in the west; less strong waves reached the eastern coast of Honshu Island and the southeastern coast of Kyushu Island. The tsunami had a height of 4.5 m on the Bonin Islands.

The damage done by the earthquake and tsunami has not been exactly established. According to available data, 8,300 homes were destroyed and washed away and about 600 homes burned down. About 300 people died in the earthquake and about the same number died in the tsunami. However, it is possible that the real number of victims was greater.

The tsunami did not do much damage in Tokyo and Osaka Bays, and also in Tosa Bay; however, the sea level rose 1-3 m above the normal mark, and oscillations in level lasted until evening. The tsunami was stronger on the coast of Suruga Gulf, but even here it was not so strong as to wash away homes; however, a large ship was damaged in Shimizu Port. The western coast of Ise Gulf (near Matsuzaka) and the coast of Aichi Prefecture (Atsumi region) suffered considerably from the tsunami. Here homes and ships were destroyed and washed away and dikes were damaged.

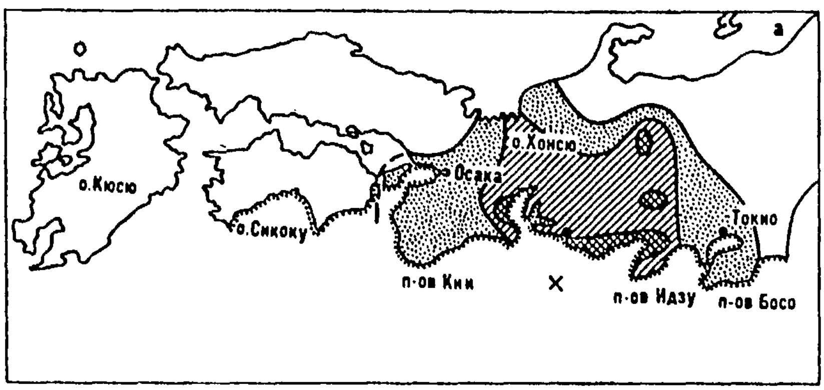


Fig. 14 (a)
The earthquake and tsunami of 23.XII.1854.

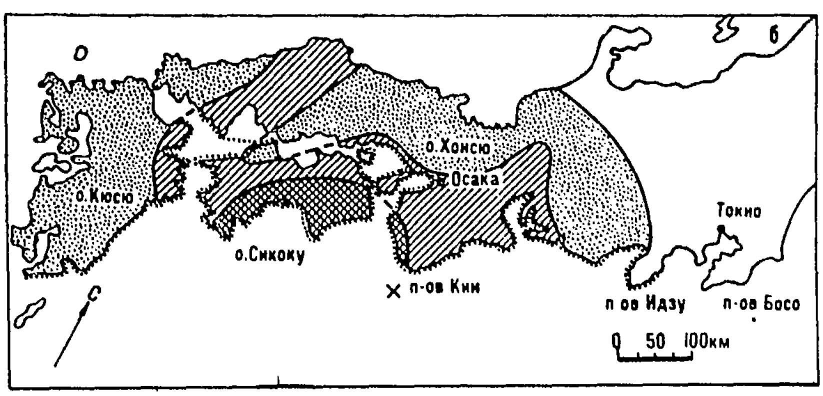


Fig. 14 (b)
The earthquake and tsunami of 24.XII.1854 (Omori, 1913).

Key to figures the same as in Fig. 13.

The port of Shimoda, situated on the southern tip of the Izu Peninsula, in a bay open to the southwest, and the southeastern coast of Mie Prefecture from Toba Inlet to Kumano Inlet, suffered especially greatly. This submerged coast abounds in small bays and inlets, opening towards to the sea, and the width of the entrance is no more than 8 km.

The first tsunami wave reached Shimoda 15 minutes after the shock, and the third wave was the greatest. At Toba, the fourth wave was the strongest. Despite the great height of the tsunami, the number of victims at Shimoda was only 90 people or 1/46 of the entire population (on the average there was one victim for each ten houses washed away). There were 74 dead at Toba (one victim for each eight homes washed away). The small number of victims in this tsunami is explained by the timely /48
evacuation of the population after the strong shock.

At about 17:00, strong oscillations in sea level were supposedly observed at Kwangchou and other ports in China.

On December 23, a tsunami with a height of 0.2 m was registered by tide gauges on the coast of North America (Fig. 15). A wave with a period of 35 minutes was recorded at San Francisco 12.2 hours after the earthquake. A wave with a period of 31 minutes was recorded at San Diego 12.6 hours after the earthquake.

Given below are some detailed data on the effects of the tsunami at different points in Japan.

Tokyo and Kanagawa Prefectures. The Shumida* River overflowed at Tokyo. Ships were damaged on Oshima Island. The tsunami waves approached Enoshima Island at Katase several times.

Shimoda. The port city of Shimoda is situated on a bay having a width of 1 to 1.6 km and a length of about 2.4 km (Fig. 16). Two small islands are situated in the bay: Bishako Island (Kamomejima) and Inubashiri Island. The mouth of the Inozava River is at the top of the bay on the western side. The city of Shimoda is situated on the western shore of the mouth of the river. The village of Kakisaki is situated on the northeastern shore of Shimoda Bay.

The earthquake destroyed all stone and clay structures in the city. Cracks appeared in places in the ground, and mud fountains gushed out of them. The shocks began to cease gradually, and the people began to return to the homes which they had left. But after some time, a black wall of water surged in from the sea and fell on the city. Panic broke out anew in the city, but only some residents quickly took to the /49
mountains. However, the first wave quickly retreated, so that most of the people had time to evacuate. At this time fires broke out in the city in the Daiku* region and on the shore of the Aji* River. Soon, a second big wave appeared, which fell on the coast at the village of Kakisaki. Then the wave crossed the dike into Shimoda Harbor, putting out the fires at the two places mentioned. In an instant, about 900 homes were washed away. On the south part of the shore, only 20% of the

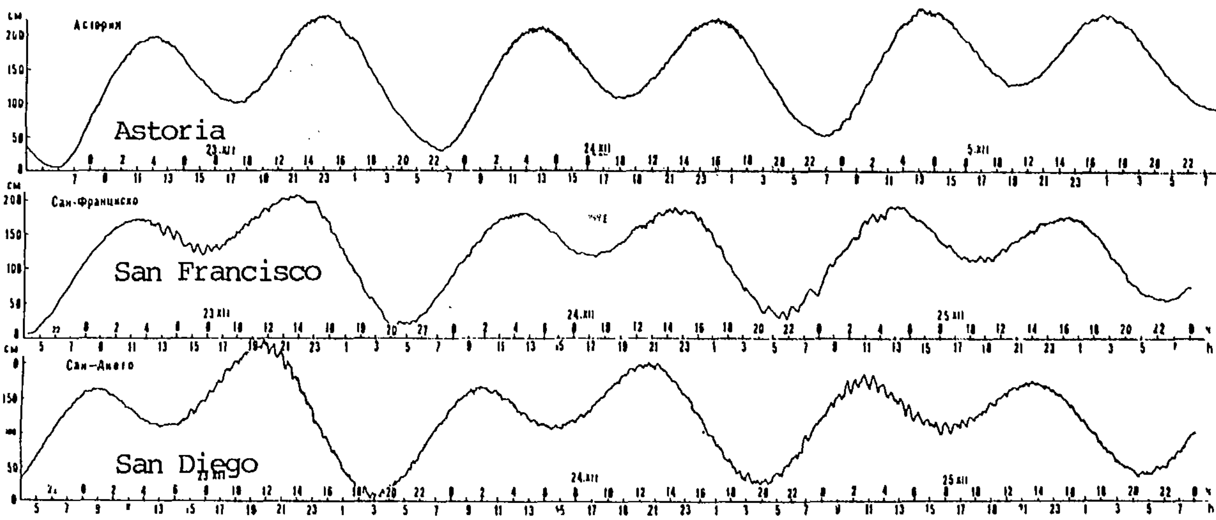


Fig. 15

Records of the tsunami of 23 and 24.XII.1854 in USA (Bache, 1856).

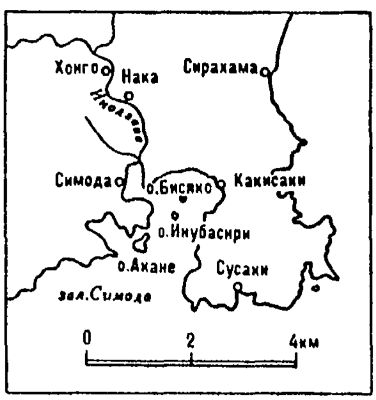


Fig. 16

Diagram of Shimoda Bay (Omori, 1913).

previous structures remained; all the rest were underwater. Many ships were capsized by the wave and sank. Many destroyed homes floated in the sea, and much debris piled up at the dike. The wave carried 13 ships with a displacement of more than 150 tons for a distance of 1.5 km up the Inozava River and left them in fields at the villages of Okagata and Hongo and in the villages themselves.

The Russian naval frigate "Diana," riding at anchor in Shimoda Bay, was torn loose from one anchor and found itself between Inubashiri and Bishako Islands, but was returned to its previous position by the retreating wave.

At the same time, a third wave appeared, which again fell on Kakisaki and in an instant washed away that village, which consisted of more than a hundred homes. Eighteen ships with a displacement of 90-150 tons, tied to the moorage, were scattered over Naka village and smashed. The water began to retreat towards Shimoda, where already hardly a single home remained, and reached the villages of Okagata (being a part of the modern city of Shimoda) and Hongo, and even the foot of the mountains. At this time, the Russian frigate suffered heavy damage from blows against the bottom and was again carried off towards Bishako Island. The people on the island, left desolate by the earthquake and tsunami, were very happy to see the approaching ship. They went to the top of the mountain and began to shout for help. Fortunately, the fourth, fifth and sixth waves were much weaker, and by noon, the poeple were able to come down from the mountain and receive first aid, water and food.

At Shimoda, tsunami waves were observed nine times in 3 hours; that is, a new wave approached every 20 minutes. The second wave was rather large, but the third wave, almost completely washing out the city, was the highest. Of 859 homes, 816 were washed away, and 25 homes were half destroyed. Eighty-five of 3,907 residents died. In addition, there were many victims among the guests. At other places, 112 homes were washed away at Okagata, 111 at Kakisaki, 67 at Hongo and 12 at Naka; the village of Matsusaki* was completely washed out. About 35 large ships were smashed and washed away.

Reconstructing the approach of the tsunami to Shimoda Port, one can assume that the wave fell first on Kakisaki, and then, being reflected, approached Shimoda (see Fig. 16), and reached Hongo Village up the Inozawa River. The maximal height of the wave at the top of the bay was at least 10 m.

Here are some excerpts from the report of Putyatin, the captain of the "Diana," who describes in detail the sequence of events and the fate of the frigate.

"At about 10:00 [one should read 9], while in the cabin, I felt a light trembling, which was felt still more in the crews' lounge. Fifteen minutes after this earthquake, the water near the city seemed to boil - the suddenly intensified current of the river produced breakers and surges in the shallow places. At the same time, at sea, the water began to rise greatly, and taking on a dirty look, boiled up around Inubashiri Island and the capes; the water level began to rise rapidly. Our boats /50
were immediately secured to the frigate; at the same time, the water dropped rapidly and the second anchor was cast. Following this, but before the drop in water level had begun to abate, a new rise began, as a result of which the frigate began to turn first to one side then to the other by several compass points, and when the rise picked up force, the frigate made a full turn in a few seconds. From then on, flood and ebb tides alternated rapidly, the water level continually rose and fell, and a veritable whirlpool formed between the shore and the island. The rapidity of these movements can be judged by the fact that when it began to spin, the frigate made 42 full turns in 30 minutes...Junks riding in

the bay were carried every which way. One of these ships ran onto our cables...and added to the pressure of the current on them, until its poop smashed up. Two Japanese were taken from it, and junk was carried away from the frigate and soon sank. Then, after dropping the third anchor, another junk fell upon the right bilge...

The second roller of the flood tide was the most disastrous for the city of Shimoda. Rising about three fathoms [about 7 metres] above its usual level, the sea covered the entire settlement; for several minutes, only the roofs of the temples could be seen. The ensuing ebb tide filled the bay with parts of homes, junks, whole roofs, domestic goods, human corpses, and people clinging to debris; all this was washed out of the city in a turbid torrent, with unbelievable speed...At about this time, smoke appeared above the valley of the city, and a sulphur smell spread in the air. After this second roller, there followed another four, which washed away any trace of the city of Shimoda.

The flood and ebb tides alternated with such rapidity that the depth changed by more than a fathom [2-2.5 m] in half a minute; the leadsmen barely had time to call out the number of feet, and the greatest difference in low and high water levels reached 5.5 fathoms [13 m]...

In the 12th hour, the frigate was turning more slowly, but it was being dragged to the northern shallow shore with each new flood tide... Getting ready for anything, the order was given to secure the cannons, but the crew had not had time to finish when the frigate began to list to the left, and the listing soon became so dangerous that the "all hands on deck" whistle was blown. It looked like the frigate was capsizing...The frigate lay on its side and creaked in all parts. This lasted, it seemed, about a minute...With the new tide, the frigate began to rise... The oscillations of the sea continued until 16:30...

Thus it was, with a clear sky and little wind, on its anchors, only by terrible oscillations of the sea, that the frigate was nearly wrecked." (Lesovskii, 1855.)

After the tsunami, the contours of the bay were almost unchanged, but the silt lining the bottom of the bay was completely washed away, so that great difficulties arose in berthing foreign ships, for which a port had just been opened.

<u>Shizuoka Prefecture (except Shimoda)</u>. At Hara, about five homes were destroyed, all stone columns and posts fell, and a tsunami was observed on the coast. A small tsunami, not causing much damage, was observed at Seikenji. Shimizu Port was completely destroyed and burned. Waves damaged several ships. A tsunami 5 m high was observed at Kawasaki and Sagara.

More than half the homes were destroyed at Kaketsuka, and a tsunami did extensive damage. At Maisaka, all the homes (260) were flooded, but not washed away (according to other sources, up to five homes were washed away). There were no victims, since people had time to go to the central part of the city, which was on an elevation. The height of the wave was about 5 m. The tide was also observed at Tsuboi village, situated 2 km east of Maisaka.

The Kega region suffered heavy damage. After the arrival of the tsunami, much of the fields was left underwater. Then the water began to retreat gradually, but had still not left entirely by December 29.

Aichi Prefecture. In some places in Atsumi district, as a result of the earthquake, the protective dikes subsided 3.9-4.2 m; a tsunami fell on the coast. /51

Toyohashi and the nearby vicinity suffered rather heavily from the earthquake and a fire. The large bridge across the Toyakawa River was damaged, and traffic over it became impossible. At Toyahashi and on the coasts of the districts of Atsumi, Yana, Hoi, Nukata, Kamo, Shikuchi*, and Joto*, on an enormous area, fields were hard hit by the earthquake and tsunami; 663 homes were destroyed, 847 homes were half destroyed, and four homes were washed away; 218 non-domicile structures were destroyed. In all, 882 people were injured. A dike 55 km long was destroyed; 120 ships were washed away and destroyed. As a result of the earthquake 14 people died, one was injured, and 14 people drowned.

At Yoshida village, and also at Takashima*, Oshima and Ainokishima* villages, situated near Yoshida, and on the coast of Hazu district, many homes and barns were destroyed, then flooded by a high wave. Dikes were breached at several places. Due to the impossibility of repairing the dikes in time, and the consequent constant floods, due to sea tides, the situation was very bad for several days.

In Chita Bay, several weak shocks were felt following the main shock. After this, a tidal wave 1.2-1.5 m high was observed, which did not do much damage. A weak tsunami was observed on the coast at Kira*. The damage was slight. At Narumi, homes were destroyed, and a small tsunami was observed on the coast.

Mie Prefecture. At the city of Tsu, the first tsunami wave arrived after the strong earthquake. At about noon, a second, higher wave arrived, which flooded the canal in the region of the bay. In Tsu itself, 50 homes were destroyed, 421 homes were half destroyed and damaged, two temples were destroyed, 13 homes were washed away, and four people died. A protective dike was breached on a stretch of 900 m in the vicinity of Tsu, and it subsided on a stretch of 35 km. Twenty-five bridges and 107 homes were destroyed, 492 homes were half destroyed, 43 homes were washed away and five people were injured.

At Matsuzaka, more homes were destroyed than at Tsu. The tsunami raised ships at the mouth of the river and destroyed the bridge.

On the road from Kusube village (near Furuichi) to the village of Katagami, some structures were overturned, but there was no heavy damage. The road from Katagami village to Toba was washed out by tsunami waves on a stretch of 600 m. The protective dike on the coast at Katagami was destroyed. According to the priest at the Kannon temple, the first wave reached a tree standing at the temple. The second wave was about the same as the first. The third wave passed this tree and flooded the courtyard of the temple, and the fourth wave inundated the temple and washed it away.

At Toba city, the earthquake was felt more strongly inside homes than on the street. The city is situated on the western shore of a bay, extending southwest to northeast, with an average width of about 2.2 km and a length of 8 km. After the shocks, a rumble was suddenly heard from the northeast entrance to the bay. The people took to the hills. A wave arrived and submerged the embankment by 0.9-1.2 m. Soon the water receded, but then another wave came, of lesser height than the first. Calming down and deciding that the waves were weakening, the people began to come down from the hills. However, soon a loud thunderous rumble was again heard from the northeast and a high wave, ten times greater than the first, then appeared. The homes situated on the shore were washed clean away. Much the same happened to the homes on the mountainside. In the city of Toba itself, five homes were washed away, two were destroyed and 113 were half destroyed; 441 homes were flooded with water. Ninety ships were washed away and damaged and two people died. The waves reached a height of 4.5-4.8 m in Toba, 6-9 m on one stretch of coast, and even flowed across a hill more than 21 m high. The Ichishikan* district in Ujiyamada City suffered more from the tsunami than did Toba.

In Koga village, situated on the eastern shore of Mie Prefecture, at the top of a bay which was open to the east, the earthquake destroyed homes and other structures, and tsunami waves were observed five times after the shock. In three cases, the water retreated far, exposing the bottom for a distance of 110-130 m. After this series of oscillations in level, a large wave came and washed away Koga and the other coastal settlements and villages. The sea began to calm down by 14:00, and had calmed completely by evening. The wave reached a height of 10.5 m on the coast. The water penetrated up to 2 km inland. Eleven people died, 134 homes were washed away, 11 homes were destroyed and 29 homes were half destroyed; 222 other structures were washed away and 15 structures were half destroyed; a protective dike about 700 m long was destroyed. According to an eyewitness travelling along a mountain path in the vicinity of Koga, the shock was very strong. When he was passing the locality of Uchihashimoto* (vicinity of Koga), it was still wet from the first wave. At this time, a second wave about 3 m high appeared. Then, when he approached Hamada* (near Koga), a third wave, about 6 m high, arrived, and he had to go up the mountain. From the mountain, he could see that the water had become turbid for a distance of 2.2-2.3 km from shore, while further out the sea was clean and blue. The village of Kofu, about 2 km from shore, hardly suffered. /52

The villages and settlements of Nakiri, Funakoshi, Katada, Fuseda and Goza situated on the south and east of the small Goza Peninsula (12 km by 2 km) and even Hamajima, situated near the peninsula, also hardly suffered from the tsunami. However, the two villages of Wagu and Koshika were destroyed. At Wagu, 270 homes were washed away by the wave; 44 of the 400 residents died. With the arrival of the first wave, people took refuge, but some came down to save their belongings and were drowned. At Koshika, 70 homes were washed away, and seven people died.

The coast of the small Kowa Bay, situated on the southeast of Mie Prefecture, was hit by a strong tsunami after the earthquake. The people immediately began to take refuge after the shock, and there were no more than 6 victims. However, only about 20 of 250 homes remained. The rest were washed away.

About 40 of 300 homes were washed away in Nishiki Bay.

In Nagashima Bay, situated to the west of Nishiki Bay, three large tsunami waves were observed after the earthquake. The first wave washed away many homes, but the second was the largest and had a height of more than 10 m. The third wave was already weaker. Then the sea began to calm down gradually. At Nagashima, 450 of 900 homes were washed away; 24 people drowned. Eighteen people drowned at the village of Nigo; there were no homes washed away.

The coast between Nagashima and Owase also suffered heavy damage from the tsunami. At the village of Mi'ura, 40 of 70 homes were washed away; five people died. At the village of Shira, about 40 of 100 homes were washed away, and only 10 homes were left undamaged. At Kaino village, the tsunami did only slight damage.

In each of the three villages, Nikishima, Atashika and Odomari, situated between Yoshita* and Kimoto Bays, the tsunami washed away about 80% of the homes. The straight coast between Kimoto and Shingu, about 24 km long, did not suffer from the tsunami. Kimoto also did not suffer.

Wakayama Prefecture. Shingu, situated at the mouth of the Kumanokawa River, was only slightly affected by the tsunami, and only a few homes were destroyed here. The tsunami caused much destruction at Temma, situated near the mouth of the Nachi* River. At Koza, 61 homes were washed away.

At Tanabe, landslides and collapses occurred in places and old homes and structures were destroyed. The tides were higher than usual, which alarmed the residents. However, the sea gradually returned to normal. A tidal wave had a height of 2.4-2.7 m and was observed seven or eight times before evening. Up to five recurrent shocks were felt on the evening of December 23.

Osaka Prefecture. At Tarui, the tide was higher than usual.

Kochi Prefecture. At Tei port, the water retreated so far that /53
one could catch eels. In Kishimoto Bay, the difference between the rise and fall of water was about 1.8 m.

A strong prolonged earthquake was felt at Kochi. Cracks appeared in the walls of some structures. However, some pedestrians and people working in the fields at that time did not feel the shock. The shocks recurred three times at night.

At Susaki and Kure, the shocks were very strong, and flood and ebb tides were observed three times on the coast at 14:00. The tsunami caused destruction at Kashiwajima, next to Komame.

Bonin Islands. The earthquake was felt on the Chichijima Islands as a light shock; half an hour after the earthquake, a tsunami appeared in Futami Bay (Port Lloyd) on Chichijima Island (Peel). The sea rose 4.5 m (15 feet) above the highest flood tides, and then quickly retreated, drying up the reefs. The ship "Wet Cheer" was dragged with its anchors and swung about its axis. The oscillations recurred with gradually diminishing intensity every quarter of an hour. Homes were damaged more or less, and several homes were washed away altogether (Lesovskii, 1855; Perrey, 1855 a,b, 1862 a,b, 1864 a; Bache, 1856; Goncharov, 1874, 1949; Neumann, 1878; Sekiya, 1898, 1899; Anon. (J), 1899 a, 1929 a,b, 1935, 1939 a, 1940 c; Imamura, 1899 a, 1935, 1938 a,b, 1942, 1949; Omori, 1900, 1901 a, 1913, 1919; Hondo et al., 1908 a,b; Krümmel, 1911; Milne, 1908, 1912 b, 1913 a; Nakakura, 1923; Kawasaki, 1930; Gondo, 1932; Sieberg, 1932; Tsuboi, 1935; Fukutomi, 1936; Townley, Allen, 1939; Heck, 1934, 1947; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Hakoda, 1962; Sagisaka, 1964; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968; Hatori, 1973).

Iida et al. (1967): 23.XII; 00^h00^m; 34.1° N., 137.8° E.; M=8.4, m=4.

1854, December 24, about 17:00. There was a catastrophic earthquake at Nankaido (see Fig. 14), accompanied by a destructive tsunami. This was one of the strongest earthquakes in the south of Japan. The last earthquake of this strength occurred here in 1707. The earthquake affected an enormous territory, namely: all of the prefectures (from east to west) of Mie, Nara, Wakayama, Tokushima, Kagawa, Kochi and Ehime; half of the prefectures of Aichi, Shiga, Kyoto, Okayama, Tottori, Hiroshima, Yamaguchi, Oita; and part of the prefecture of Hiogo. The earthquake was also felt at other places on Kyushu Island, and in the east in the vicinity of Tokyo.

The pleistoseismic zone of the earthquake extended from Ise Bay in the east to the northeastern tip of Kyushu Island in the west, having a length of about 560 km and an area of about 66,400 km^2. The earthquake was especially strong in the prefectures of Kochi and Tokushima, and also in the western part of the Kii Peninsula, in a zone about 280 km long with an area of 10,330 km^2. In this zone, structures were seriously damaged or destroyed, and in some places, fires broke out after the shock. The number of homes completely destroyed by the earthquakes was about 10,000, and the number of homes half destroyed was about 40,000. Almost 6,000 homes were damaged by the fire.

A stretch of coast about 640 km long (along a straight line) was affected by a strong tsunami caused by the earthquake. The tsunami was slight on the Boso Peninsula and on the eastern coast of Kyushu Island. Rather high tidal waves were observed on the coast of Shizuoka Prefecture and in the northern part of Ise Bay, in the vicinity of Atsuta and Yokkaichi. In places on the section from the Izu Peninsula to Kumano-Nada, homes were washed away or seriously damaged by the flood.

The western coast of the Kii Peninsula and the coast of Tosa Gulf west of Akaoka and Urado suffered especially heavily.

Having devastated the coast of Nankaido, the tsunami crossed the Kii Strait into Osaka Bay, where it also did considerable damage, even causing human victims. The tsunami reached the vicinity of Urado about 30 minutes to an hour after the earthquake, and Osaka in 2 hours. Some of /54
the waves penetrated to Harima-Nada through the straits at Naruto and Akashi and did damage at Ako. The waves also crossed the Inner Sea of Japan through the Bungo Strait and reached the vicinity of Mitsuhama (Ehime Prefecture).

The tsunami did enormous damage. In Kochi, Wakayama and Osaka Prefectures, about 15,000 homes were washed away. The total number of human victims on December 24 was 3,000, of which the majority perished in the tsunami. In addition, many ships, fishing boats, monuments, temples, roads and dikes were washed away or destroyed. Cultivated fields also suffered on an enormous area.

The tsunami of December 24 was also registered on the Hawaiian Islands and on the coast of North America (see Fig. 15). In San Francisco, a wave 0.3 m high with a period of 64 minutes was registered 12 hours after the earthquake, and a wave 0.3 m high with a period of 34.7 minutes was observed at San Diego. The oscillations of the water at Astoria (Oregon State) were smaller than at the other two points.

The Nankaido earthquake was accompanied by numerous aftershocks. Almost 1,000 were felt before December 1855. At the same time, the earthquake of December 24 itself appears to have been a continuation of the Tokaido earthquake of December 23.

The earthquake of December 23 was evidently weaker than the earthquake of December 24. The length of the zone of maximal intensity of the earthquake of December 23 was half as much, while the total area affected by the earthquake was 3.5 times smaller than the earthquake of December 24. The damage and destruction of structures during the latter was greater; the total number of destroyed homes on December 24 was three times greater and the number of victims 5 times greater than on December 23.

The epicenters of the earthquakes, judging by macroseismic data, were 380 km from each other.

Let us present the data on the effects of the tsunami at different places.

Shizuoka Prefecture. At Shimoda, the tsunami wave appeared about 18:30 and reached Shimoda and Okagata* village (now part of the city of Shimoda). However, there was nothing to be washed away here, since not a single home remained after the tsunami of December 23. The second tidal wave passed about 1 km inland. The height of the wave was 4.8-5.7 m. At Kakisaki, the height of the wave was 6.7 m.

At Mera, about 100 out of 145 homes were flooded. Five homes were washed away and destroyed. Many ships were destroyed. The height of the wave was 4.5-4.8 m. At Ko'ura, about 100 out of 140-150 homes were flooded. Six homes were washed away. Many ships were destroyed. Two people died. The height of the wave was 5.3-6.1 m. At Matsuzaki, 340 homes were flooded. Many ships and boats were washed away and destroyed. The height of the wave was 3.0-3.6 m.

At Doi, 56 homes were flooded and two were washed away; many ships and boats were washed away and destroyed; 13 people died and 22 were injured. The height of the waves was 4.4 and 5.0 m.

At Maisaka, on December 24 at about 17:00 and 18:00, a loud rumble was heard from the southwest, and then a strong flood tide was observed. At Arai, 26 homes were destroyed. Fourteen people drowned (apparently, the crew of a ship). One person died in the earthquake. The height of the wave was about 3 m.

Aichi Prefecture. At Atsuta, the wave reached the Demma* region. At Nagoya, on the evening of December 24, a loud rumble was heard. Clear signs of a tsunami were not observed; nevertheless, many small ships were destroyed on a tributary of the Horikawa* River.

Mie Prefecture. Fires did not break out at Yokkaichi. A high flood tide was observed on the entire coast, after which the waves gradually began to weaken. Slight damage was done to wood and clay structures. There were no victims.

Wakayama Prefecture. On December 24 it was clear weather in Tanabe Bay, which has a width of about 6 km and opens to the west. Since the preceding day, slight shocks had been felt often, and at about 17:00 a strong earthquake occurred, which caused destruction in Tanabe City. A /55
rumble like cannon shots was heard from the sea, and then a high wave appeared, which flooded the city and its vicinity. When the wave rose upriver, it clouded over all around as in a fog, but soon the water retreated about 100 m. Four large waves were observed, the third of which was the strongest. Small ships, riding at anchor in the mouth of the river, were carried upriver against the current by the wave. Hitting a large bridge, they destroyed it; the western half of the bridge was carried by the water to Koizumi*, and the ships were run aground. The shocks continued in the evening and another rather strong shock occurred at about 20:00. Although it was much weaker than the main earthquake, it was also accompanied by a tsunami. In the city, 335 homes burned down and five homes were washed away. About 100 other structures were destroyed, and 383 burned down. Four people died and five people drowned.

Homes were also washed away at many other settlements in Tanabe Bay. The northwestern coast of the bay, and south of the bay, the mouth of the Tonda River suffered especially. The height of the tsunami was 6 m at Hiro, north of the bay.

Osaka Prefecture. Many homes were destroyed at Sakai. The tsunami waves ran ships into the mouth of the river, and bridges were damaged at four places as a result of collisions with the ships. A ship with a displacement of 150 tons was run aground.

At Osaka on December 24, the weather was clear and still, and no underground shocks had been felt since morning. At about 17:00, a strong earthquake occurred, with about the same intensity as on the preceding day. Soon after the shock, a loud rumble like thunder was heard five times, and a tsunami wave arrived at about 20:00. In the region of Shinden*, the water flowed across the shore dike. Ships riding at anchor in the mouths of the Kizu and Aji Rivers (see Fig. 8) were lifted up and carried upriver. They destroyed 25 bridges, as well as homes situated on both banks of the rivers. In all, about 262 assorted ships were smashed and 51 residents drowned at the mouth of the Aji River, and about 1,234 assorted ships were smashed and 341 resident drowned at the mouth of the Kizu River. The relatively large number of victims is explained by the fact that after the shock many residents of Osaka, frightened by the earthquake and its possible consequences, had taken to boats and ships.

Hiogo Prefecture. A strong shock was felt at Amagasaki. Then a tsunami was observed; homes were destroyed and damaged. There was no particular destruction at Itami, but people were so frightened, that they lived outside the settlement for a time. The tsunami was not observed on the coast at Imazu, Nishinomiya and Nada.

At Ako, only slight destruction was done. A salt field at Ako was damaged by the tsunami; 11 homes were destroyed there.

The tsunami was observed at Fuk'ura Village (Aji Island), where the residents organized a temporary shelter in the mountains.

Tokushima Prefecture. At Okazaki, which is a part of Muya city (Naruto), the tsunami wave washed out several homes. Only about 30 out of 1000 homes remained at Komatsushima after the earthquake and tsunami.

Kochi Prefecture. Urado and Kochi suffered heavily from the earthquake. Strong tremors also affected the water in Urado Bay. The oscillations of the water which developed in the bay caused small waves onshore, which did not do any damage. However, an hour after the shock, a tsunami wave rolled onto the coast of Tosa Bay, causing great damage to the settlements of Tanesaki and Mokawa*, situated at the entrance to Urado Bay. Passing these settlements, the water then entered the bay and flooded the coastal regions. On December 26, about 14:00, the dike was breached in the region of Shimoji village, and the Shin* region (situated at the mouth of the river at the city of Kochi) and its vicinity were submerged to a depth of more than 30 cm. The water receded only several weeks after the completion of the restoration of the dike. The temple at Urado hardly suffered, but the water reached the foot of the mountain, and rose to a height of 1 m over the floor in homes on the coast. The height of the wave was 11 m at Tanesaki.

The locality of Katsurahama* (the area of the coast on the south of Urado Bay, in the region of Urado) was completely washed out and turned into a flat field, but the people had time to escape to the mountains and only one person died. /56

The settlements of Tei, Usa, Susaki, Tosashimoda and Shimonokae, the greater part of which was washed away, also suffered greatly from the tsunami. A wave 8.5 m high was observed in Usa Bay. A wave reached a height of 12-16 m in the region of Kure.

The damage done by the earthquake and tsunami in Kochi Prefecture was as follows: 1) homes burned, 2,481, washed away, 3,202, destroyed, 8,765, half destroyed, 9,274; 2) wooden and clay structures burned, 805, washed away, 588, destroyed, 1,687, half destroyed, 880; 3) population, 372 dead and 180 injured.

Ehime Prefecture. The tsunami flooded the castle region at Uwajima. A small wave was observed at Mitsuhama.

On the Chichijima Islands, the rise of water surpassed the highest high tide mark by 3 1/2 m (12 feet). Noticeable oscillations in level stopped only on the morning of the 26th (Perrey, 1855 b, 1862 a,c, 1864 a; Bache, 1856; Neumann, 1878; Sekiya, 1898, 1899; Anon. (J), 1899 a,b, 1929 a,b, 1930, 1935, 1939 b, 1940 c; Omori, 1900, 1901 a,b, 1913, 1919; Honda et al., 1908 a,b; Milne, 1912 b; Nakamura, 1923; Gondo, 1932; Sieberg, 1932; Heck, 1934, 1947; Imamura, 1935, 1938 a,b; Tsuboi, 1935; Fukutomi, 1936; Imamura, 1937, 1940, 1942, 1949; Musya, 1951; Yamaguti, 1954; Iida, 1956; Hakoda, 1962; Sagisaka, 1964; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968; Hatori, 1973).

Iida et al. (1967): 24.XII; $8^{h}00^{m}$; 33.2° N., 135.6° E.; M=8.4, m=4.

1855, November 11, 22:00. There was a strong earthquake in the vicinity of Tokyo. It destroyed many homes and 54 or 57 temples and killed 3,000 people in the eastern half of Saitama Prefecture, the northeastern part of Kanagawa Prefecture, the central and western parts of Chiba Prefecture and in several places in the southwestern part of Ibaraki Prefecture. The ground opened up at many places and swallowed whole quarters. The earthquake was also supposedly very strong in the ports of Hakodate and Shimoda (as related to Europeans by the translators of these cities).

After the earthquake, weak tsunami waves were observed at Kisarazu and the village of Mibuchi (western shore of the Boso Peninsula). The flood tide began at Kisarazu at midnight, but the sea had completely quieted down by 10:00 of the following day. Since presumably the source of the earthquake was on land, seiche oscillations of water in the bay apparently resulted (Perrey, 1857 c; Omori, 1913, 1919; Iida et al., 1967).

Iida et al. (1967): 35.8° N., 139.8° E.; M=6.9.

1856, August 23. Three rather strong shocks were registered at Hakodate, on Hokkaido Island, on August 19, and two shocks on August 20. On the 23rd at about 13:00, there was a strong earthquake with a source probably at sea near Shiriya Cape. It was felt on the southern and eastern coasts of Hokkaido and on Sanriku. The intensity of tremors on the south of Hokkaido was 7 degrees (V - JMA)'. On the west of the Tokachi region, the road running along the coast was blocked by falling rocks. There was no destruction, heavy damage to buildings, or victims. However, a rather strong tsunami was observed after the earthquake, and did considerable damage.

At Urakawa, two ships with a displacement of 75 tons were sunk. At Saru, there were collapses, and a strong tsunami was observed. A shock was felt at noon on the coast of Yufutsu district, and tidal waves were observed at about 14:00. A strong shock was felt at noon at Yakumo village. After a while, a wave approached and flooded a strip of land 80 m wide, but the sea soon returned to normal.

On the coast at the village of Usujiri, at about 14:00, the water suddenly rose to a height of 1.8 m and flooded the streets, but everything returned to normal about an hour later. At the village of Todohokke, the sea retreated 1 km, and ships, riding at anchor, ran aground. After the earthquake and tsunami, according to the residents, the sea became shallower in this region.

A relatively strong tsunami was registered north of Cape Esan. A /57
strong tsunami appeared on the coast at Cape Shiokubi, and a weak one occurred on the coast at Shirikishi.

At Hakodate, a tsunami occurred an hour after the underground shock. At 14:00, the water level rose 3 m above normal and part of the city was flooded. Flood tides were observed about 20 times. The height of the first waves was 2.1-2.4 m, while the maximal height of the tsunami was about 3.6-3.9 m (at about 16:00). A ship with a displacement of 75 tons was run onto a road in the urban region of Tsuruoka*, and the low-lying region of Dizo* was flooded by a wave 1.2-1.5 m high. The water penetrated 600 m inland. Some homes were washed away.

The sea level rose 1.2 m above normal on the coast at Kamiiso, but no damage of any kind was done.

The coast of Sanriku, as was mentioned, also suffered from the earthquake and tsunami. On the Tsugaru Peninsula, cracks formed in the

' See Introduction - Transl.

ground, but there were no human victims. At Aomori, strong oscillations of the ground destroyed two barns and damaged the building of the local administration.

At Hachinohe, structures were considerably damaged. At Minato village, some homes were flooded or washed out to open sea, and domestic utensils, tackle and boats were washed off.

At Noda, the wave had a height of 6 m. In the Miyako Region, more than 100 homes were destroyed and washed out. At Yamada, the wave came over the isthmus separating Yamada Bay from Funakoshi Bay. At Ozuchi, the tsunami had a height of about 4 m. A tsunami 3 m high was observed at Ryoishi, Kamaishi and Ryori. The tsunami reached a height of 5 m at Tano'ura.

In the Sendai region, only slight damage from the tsunami was recorded.

At Hachinohe and Shizukawa, the fifth wave was the largest.

According to investigations, in all as the result of the tsunami, 93 homes were washed away, 100 homes were destroyed and 238 homes were damaged. Twenty-six people died.

The Komagatake volcano erupted three days after the earthquake (Perrey, 1859 a, 1862 c; Anon. (J), 1899 a,b; Omori, 1901 a,b, 1913, 1919; Honda *et al.*, 1908 a,b; Milne, 1908; Imamura, 1921, 1934, 1942, 1949; Gondo, 1932; Heck, 1934, 1947; Fukutomi, 1936; Musya, 1951; Takahasi, 1951; Anon., 1953; Yamaguti, 1954; Iida, 1956; *Seismicity in Hokkaido...*, 1962; Sagisaka, 1964; Watanabe, 1964, 1968; Ponyavin, 1965; Katsumata, 1966; Iida *et al.*, 1967; Hatori, 1973).

Iida *et al.* (1967): 23.VIII; 42° N., 141.1° E.; M=6.9, m=2.

1856, September ?. A "storm tsunami" was observed on the coast of Tokyo Bay and the vicinity (Gondo, 1932; Iida *et al.*, 1967).

1861, October 21, 2:30. There was an earthquake at Hakodate, which lasted 3 1/2 minutes. A tsunami was observed on the southern part of the Sanriku coast (prefectures of Miyagi and Iwate). It caused slight destruction. The height of the wave was 4 m at Ryori (Perrey, 1864 b; Musya, 1951; Yamaguti, 1954; Iida, 1956; Matuzawa, 1964; Watanabe, 1964, 1968; Katsumata, 1966; Iida *et al.*, 1967; Hatori, 1973).

Iida (1956): 37.6° N., 141.7° E.; M=6.4, m=0.

Iida *et al.* (1967): 37.7° N., 141.6° E.; m=2.

[1881, October 25. There was a tsunami on Kuhashia Island at Nemuro and Kushiro (Utsu, 1968)]

1884, November 15. A "storm tsunami" was observed at Tamashima and Kasaoka (Okayama Prefecture) (Gondo, 1932; Iida et al., 1967).

1894, March 22, 19:23. There was a destructive earthquake on the northeastern coast of Hokkaido Island, also affecting the south of the Kuril Islands (Kunashir Island). After the earthquake a tsunami was observed on the coast of Hokkaido Island and at Sanriku.

The tremors were especially strong at Akkeshi (Hokkaido Island), where 11 homes were completely destroyed and 17 were half destroyed and one person was injured. The tremors were weaker at Nemuro. Almost no homes were destroyed. However, almost all the brick chimneys collapsed, /58
and cracks formed in the ground. Destruction of the soil cover was recorded on the coast at Tofutsu. Four residents were injured and 70 homes were damaged. At Kushiro, one resident died and one was injured. Cracks appeared in walls, sheds were destroyed and some homes tilted.

A weak tsunami was observed on the east coast of Hokkaido Island, at Nemuro and Kushiro. The height of the waves was only 1.2-1.5 m at many places. The tsunami approached Kushiro 20-30 minutes after the earthquake. Ebb and flood tides recurred about ten times with a period of 20-30 minutes.

One home and two warehouses were destroyed by the earthquake in the vicinity of Kiritappu. According to unreliable data, there was also damage from a tsunami.

A tsunami occurred in the Kuril Islands. On Kunashir Island, it damaged 12 homes, carried away four boats and sank three boats. Bridges were destroyed.

The height of the waves was 3 m at Hakodate and Kamaishi, 1.5 m at Taro, 4 m at Miyako, 1.5 m at Ofunato, and 0.3 m at Ayukawa with a period of 20 minutes (Fig. 17). The travel time of the tsunami was 20-30 minutes to Kushiro, 26 minutes to Hanasaki, 42 minutes to Miyako, 53 minutes to Hachinohe, 64 minutes to Ayukawa, and about 1 hour to Tyatino (Kunashir Island). Hatori made an attempt to outline the source of the tsunami (Anon. (J), 1894, 1899 a,b; Omori, 1895 a,b, 1901 a,b, 1919; Imamura, 1899 a,b, 1934, 1942, 1949; Honda et al., 1908 a,b; Sieberg, 1932; Imamura, Moriya, 1939; Heck, 1934, 1947; Musya, 1951; Yamaguti, 1954; Iida, 1956; Seismicity in Hokkaido..., 1962; Watanabe, 1964, 1968; /59
Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Hatori, 1970 b, 1971 a,b; Hatori, Koyama, 1971).

Iida et al. (1967): 22.III; 10^h03^m; 42.3° N., 145.1° E.; M=7.9, m=2.

[1895, May 25. Seiches in Nagasaki (Annotated bibliography..., 1964, N 2).]

1896, January 9. There was an earthquake on the coast of Kashima-Nada (Ibaraki Prefecture), which did damage at Nakaminato. It

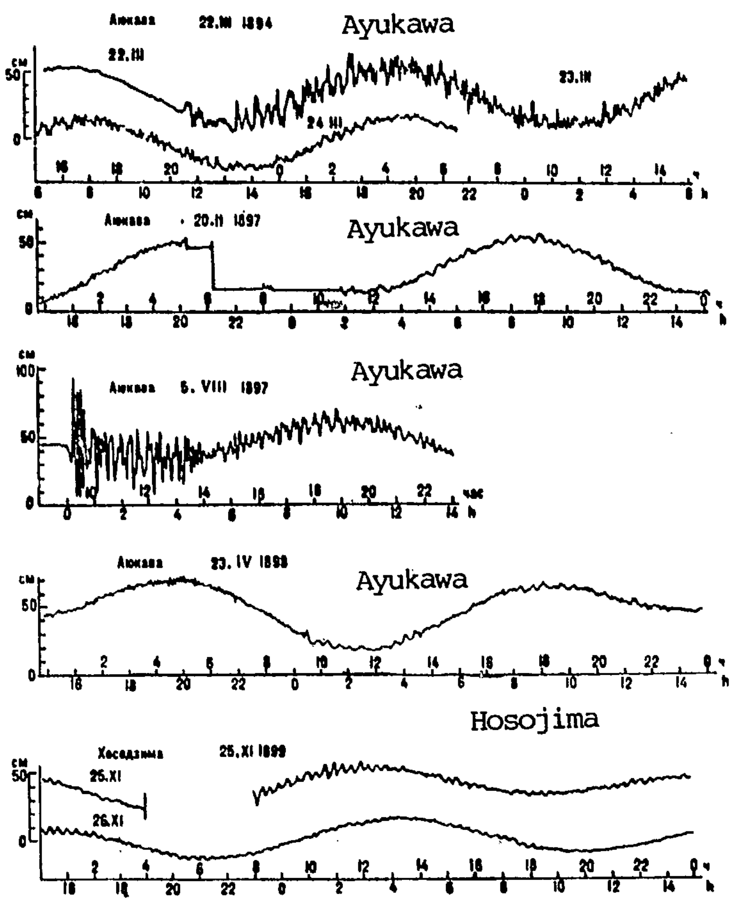


Fig. 17
Records of the tsunamis of 22.III.1894, 20.II.1897, 5.VIII.1897 and 23.IV.1898 at Ayukawa and 25.XI.1899 at Hosojima (Omori, 1901b).

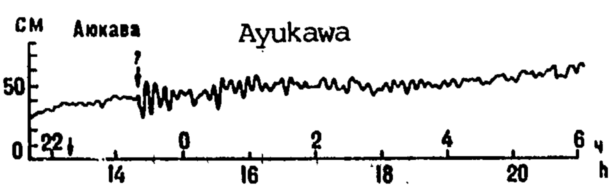


Fig. 18
Record of the tsunami of 9.I.1896 (Imamura, Moriya, 1939). Here and on subsequent tide gauge records the arrow on the time axis shows the time of appearance of the earthquake.

was accompanied by a tsunami. Waves may have been observed on the coasts of Kanto and Tohoku. At Ayukawa, a wave 25 cm high with a period of 8 minutes (Fig. 18) arrived 63 minutes after the earthquake. The wave arrived at Onahama 28? minutes, at Choshi 28? minutes, and at Mera 40? minutes after the earthquake (Imamura, Moriya, 1939; Iida, 1956; Iida et al., 1967; Watanabe, 1968; Hatori, 1970 b; Hatori, Koyama, 1971).

Iida et al. (1967): 36° N., 141° E.; M=7.3, m=0.

1896, June 15, 19:33. There was a strong earthquake on the northeast of Honshu Island, in the Sanriku region, and on the south of Hokkaido Island. It was felt on an enormous area (Fig. 19). It was accompanied by a catastrophic tsunami, one of the strongest in Sanriku. According to official accounts, 10,617 buildings were washed away, 27,122 people died and 9,247 people were injured.

The greatest destruction from the eathquake took place in Iwate Prefecture, which was closest to its source. Many homes were destroyed at Miyako, Yamada, Kamaishi and nearby settlements. There was lesser damage in a vast zone, extending from Miyagi Prefecture to the regions of Hidaka and Tokachi on the south coast of Hokkaido island. The earthquake took the form of slow, undulating, not very strong, but prolonged oscillations.

Before the earthquake, the water level in a number of wells dropped 30-60 cm, and at other places, hot springs dried up two or three days before the earthquake.

According to some accounts, on about June 11, a slight anomaly of the earth's magnetic field began in the Sanriku area, and on June 14, the field markedly changed. On the same day, small anomalies of the magnetic field were also recorded at Tokyo and Nagoya.

The tsunami was observed at least from the south of Hokkaido Island /60 to the Bonin Islands, and also on the Hawaiian Islands and in North America. The Sanriku coast on a stretch of more than 400 km from Kinkazan Island in the south to Cape Shiriya in the north, suffered most of all (Tables 4, 5; Fig. 20).

At most places on the Sanriku coast, the tsunami began with a noticeable ebb tide. The exact time of the beginning of the ebb tide in the pleistoseismic area is unknown. According to the data of the hydrometeorological station at Miyako and the accounts of some eyewitnesses, the ebb tide began at nightfall, 15-30 minutes after the earthquake. The first tidal wave arrived immediately after 20:00. Consequently, the time difference between the beginning of the ebb tide and the arrival of the tidal wave was 30 minutes. The magnitude of the ebb tide naturally depended on the depth of the sea: in shallows, the water retreated a great distance, while at deep places, it retreated a small distance. Thus the water retreated 350 m at Horiuchi, 350-550 m at Ryoisi and Ooya, 500 m at Minatohama and 35 m at Tadaide.

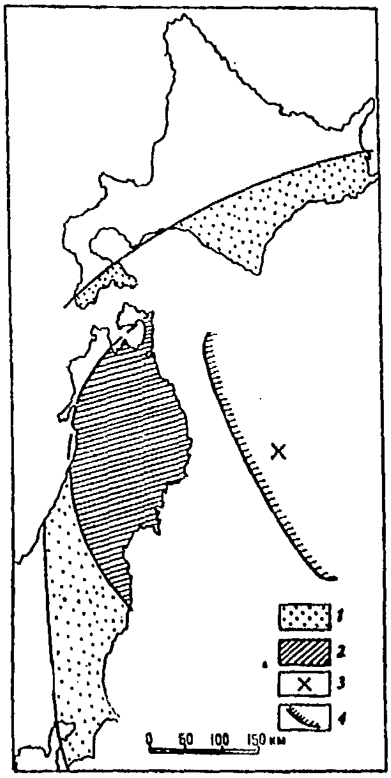


Fig. 19

The earthquake and tsunami of 15.VI.1896.

1 - approximate location of the zone of perceptible tremors

2 - approximate location of strong tremors (Omori, 1901b)

3 - epicenter of earthquake

4 - boundary of tsunami source (Hatori, 1967).

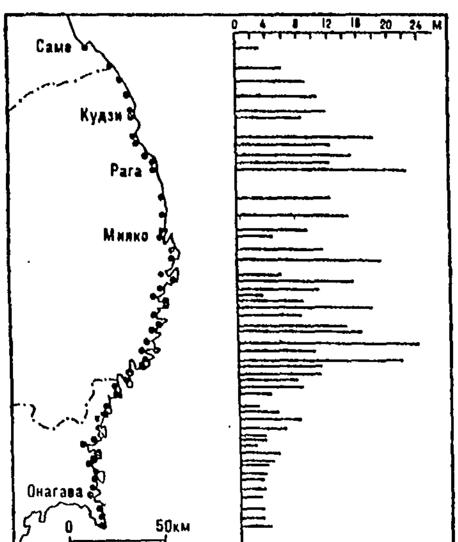


Fig. 20

Distribution of heights of rise of water alo Sanriku coast during tsunami of 15.VI.1896.

Before the flood tide, a loud rumble like thunder or the noise of a squall could be heard from far at sea. The wave appeared simultaneously with the rumble on the coast of Kesen district, Iwate Prefecture, while it appeared soon after the rumble at other places. It is said that it was even heard in the prefectures of Akita and Yamagata.

It is also very difficult to establish the time of arrival of the tidal wave. The time, estimated by the hydrometeorological station at Miyako, 20:07 can be considered the most precise. According to the report of this station, the tsunami began 18 minutes after the first underground shock. A flood tide began at about 20:00, and a wave of great height, accompanied by a loud rumble, arrived at 20:07. Then the flood tides recurred six times: at 20:15, 20:32, 20:48, 20:59, 21:16 and 21:50. The second, the largest wave, washed away many people and carried homes out to sea.

The average period of oscillations on the Sanriku coast after the arrival of the tsunami was about 15 minutes. The intensity of the waves began to gradually abate after 22:00, but small oscillations in sea level were still being observed at noon of the following day. The greatest height of rise of water was registered at Yoshihama and Ryori. The second, greatest wave was 24 m high at Yoshihama and the water rose 30 m at Ryori.

On June 15, the residents of the prefectures on the Sanriku coast were celebrating a national holiday in the streets; there was no work that day. After the ebb tide, with which the tsunami began, some hurried away from the water, but the majority continued the festivities. Practically the entire population of the flooded zone, except for a few individuals miraculously spared, perished in the roller which fell on the Sanriku coast. In addition, the fishermen who had gone out to sea were saved; returning home in the morning, knowing nothing about the events, they saw a horrible picture: the sea was strewn with debris of homes and corpses for several kilometres from shore and heaps of ruins or bare expanses remained in place of the previous coastal villages and cities.

Off the southern tip of Hokkaido Island, noticeable flood tides began in the interval from 20:30 to 21:30 and finished in the interval from 23:30 to 1:00 of the following day. The tsunami approached the island /62 from the south and hit Cape Erimo, and then passed along both sides, appearing almost simultaneously at Horoizumi and Saruru. First a rumble was heard, then 20 or 30 minutes later, the ocean floor was exposed for tens of metres. Then a large tidal wave appeared, which flooded the littoral part of the land [horizontally] also for tens of metres. The first three waves were the largest and did much damage. The second wave flooded the locality between Utabetsu and Kogosi for 2.4-4.5 m, Horoizumi for 3 m, and the locality between Shoya and Saruru for 0.9-3.6 m [in vertical].

At about 20:00, a loud rumble was heard from the sea on the coast at Moyori and at the same time a strong underground shock was felt. At 23:00, the sea retreated several metres; the wave which then arrived flooded the coast. Several waves were observed; they gradually diminished. The tsunami also made a strong appearance on the southeastern coast of the Tokachi region.

At about 22:00, the water level gradually began to rise on the southwest of Hokkaido Island, at Hakodate. In the interval between 24:00 to 1:00, the water flooded the land for 30 m from shore. At 4:00, the oscillations began to abate, and the sea returned to normal. /63

The actual distribution of the rise of water along the coast of Sanriku (see Fig. 20, Table 4) to a large extent depended on the configuration of the shore line, the degree of coincidence of the axes of bays with the direction of propagation of the tsunami from the source, the shape of the bays, the degree of coincidence of the period of their seiches with the period of the tsunami, the presence or absence of a shallows zone, and other factors. The waves penetrated far inland at many places. The greatest flooding of the land was observed at the village of Omoto, where the water passed about 3.3 km up the beach. The water rose to different heights at different places in the same bay. The effect of screening in particular was felt. Thus the height of rise of water was considerably less on the western shore of the Ozika Peninsula than on the eastern coast, and it gradually diminished from south to north. On the open coast of Sanriku, the height of rise of water gradually increased to the north from the Ozika Peninsula, reaching a maximum near Yoshihama (Yoshihama Bay) and Koshirahama. Further north, the height of waves gradually diminished, but again increased from the coast of Shimohei district to the coast of Kunohe district. The rise of water was considerably less in the region of Sannohe district, while near /64
Hatinohe it was almost the same as on the coast of the Ozika Peninsula. According to Hatori's reconstruction, the maximal rise of water at the source of the tsunami was 2 m.

The tsunami was recorded by all of the few tide gauges existing at that time on the Pacific coast of Japan (Fig. 21).

The tide gauge at Hanasaki on the northeastern tip of Hokkaido Island, like all the other remote tide gauges, registered a tidal wave first, 66 minutes after the earthquake; soon afterwards, however, the instrument broke down. The tide gauge at Hakodate also stopped working immediately after the arrival of the tsunami and resumed work only several hours later; the predominant periods of oscillations were 30-35 minutes. The travel time of the tsunami to Choshi was 52 minutes.

The tide gauge at Ayukawa on the Sanriku coast began to register the tsunami 40 minutes after the earthquake, with a small ebb, which was succeeded by a large flood. The maximal range of oscillations was 2.4 m, their duration was about 50 hours.

Tide gauges on the southern, screened coast of Japan, at Aburatsubo, Kushimoto and Hosojima, practically did not register the direct waves of the tsunami, but only marginal (shelf) waves with a range of only 5-15 cm.

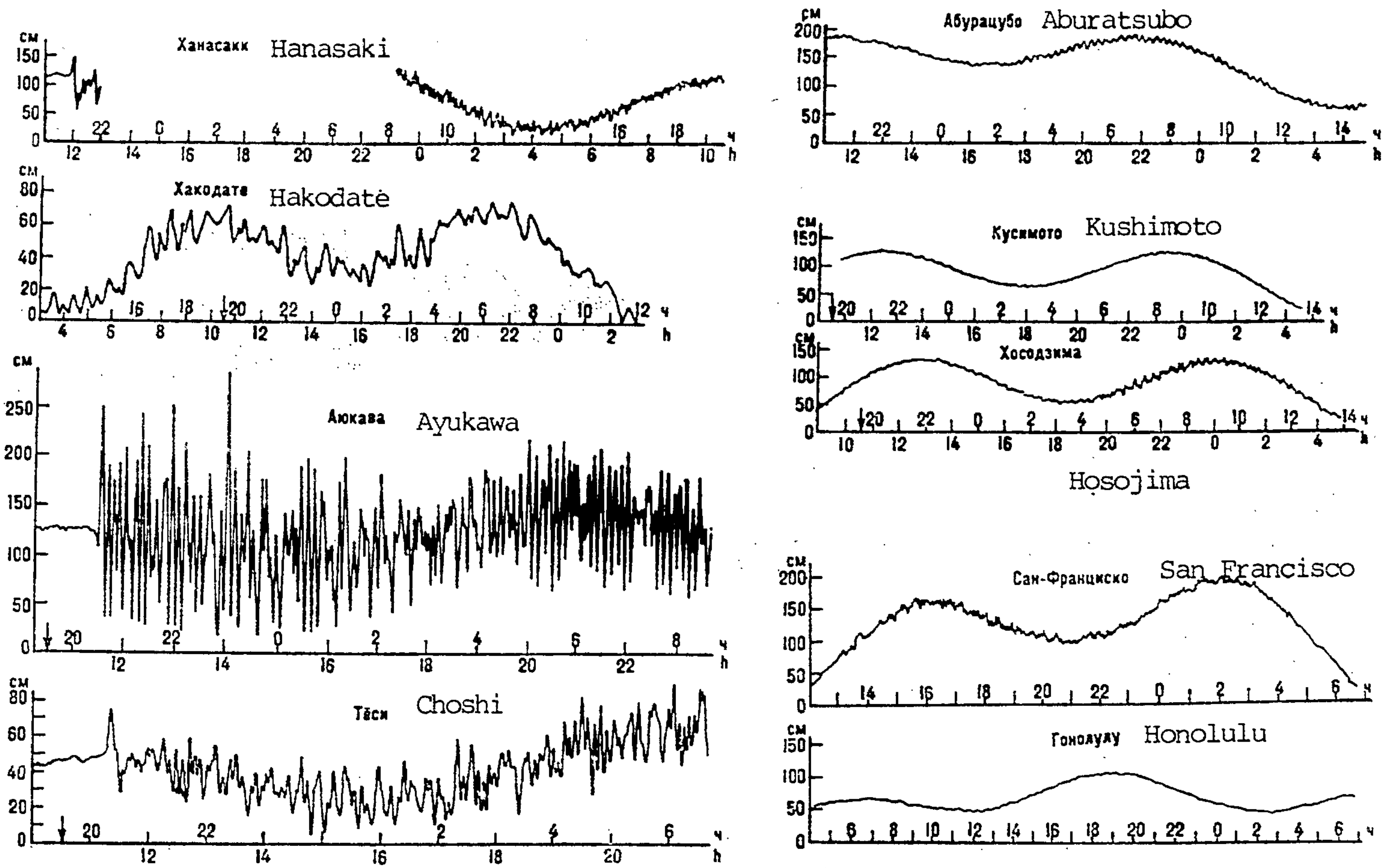


Fig. 21

Records of the tsunami of 15.VI.1896 in Japan and the USA (Honda et al, 1908a,b).

From the few available data on the travel time of the tsunami, T. Hatori attempted to outline the western boundary of the source of the tsunami (see Fig. 19); an ellipse 400-450 km long was obtained.

As has already been mentioned, the tsunami also appeared on the Bonin Islands. On Chichijima Island, at Futami Port, an unusual flood tide was observed at 4:00 on June 16, and the level had risen 0.9-1.2 m higher than usual by 5:00. An unusually high flood tide was observed at Ogim'ura, Susaki, Kitafukurozawa and Minamifukurozawa, situated on the eastern shore of the island, and at points on its western shore.

At about this same time, a flood tide 0.9-1.2 m high was observed on Ototoshima Island. It was stronger on the northern and southern coasts, and weaker on the eastern and western coasts. There were several tidal waves.

A rather high tidal wave was also observed at almost the same time at Okim'ura and Kitam'ura ports on Hahajima Island. A pier was destroyed at Okim'ura, while coastal homes were flooded at Kitam'ura, located in a lowland.

On the Hawaiian Islands at Honolulu, the tide gauge registered a sudden flood tide 3 cm high at 7:45 on June 15 (local time), although an ebb tide was due at 7:38 (see Fig. 21). The wave reached its maximal height, 9 cm, at 9:00. The oscillations had abated by 15:00. Fourteen flood tides were observed in 14 hours.

The tsunami arrived at Kawaihae, on the western coast of the Island of Hawaii on June 15 at 8:15. Ebb tide began at 8:30 at Kailua, but a large wave soon appeared, and reached a height of 2.4 m in the bays. The coastal relief of the western shore of Hawaii was changed after the tsunami. The waves reached a height of 2.4 to 9.0 m on the eastern shore of the Kona district. A wave 2.4 m high with a period of 6 minutes was observed at Hilo. The travel time of the wave was 7.9 hours.

The tsunami was also observed in the USA, in particular at Santa Cruz, south of San Francisco. Early in the morning on June 15, a wave 1.5 m high suddenly appeared at sea here and destroyed the protective dike. The wave rose far upriver and did great damage to a ship moored to the pier. At San Francisco, the tide gauge registered a wave 20 cm high with a period of 18 minutes 20-30 hours after the earthquake (see Fig. 21).

A sudden rise in sea level was observed on the Cook archipelago, on Rarotonga Island, on June 17 between 14:30 and 16:30. The coast of the island was flooded on a stretch of several tens of kilometres. During the ebb tide, the bottom was exposed in almost all the harbours of the island. The phenomenon was observed several times. It is likely that this was also the Sanriku tsunami (Anon. (J), 1896, 1897 b, 1939 b; Iki, 1896; Milne, 1896 a,b; Anon., 1897; Imamura, 1897, 1899 a, 1905, 1934, /66
1942, 1949; Holden, 1898; Omori, 1900, 1901 a,b, 1913, 1919; Davison, 1900, 1936; Honda *et al.*, 1908 a,b; Krümmel, 1911; Nakamura, 1923; Gondo,

1932; Sieberg, 1932; Heck, 1934, 1947; Imamura, Moriya, 1939; Shepard et al., 1950; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Svyatlovskii, 1957; Hewitt, 1957; Hatori, 1963, 1967, 1970 b; Watanabe, 1964, 1968; Sagisaka, 1964; Matuzawa, 1964; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967).

Iida et al. (1967): 15.VI; 39.6° N., 144.2° E.; M=7.6, m=4.

1897, February 20, 5:20. There was a destructive earthquake with source off the Sanriku coast, 260 km southeast of Miyako (Iwate Prefecture). It was strong in the prefectures of Iwate, Miyagi and Fukushima, where it destroyed old homes, bridges and monuments. In particular, many homes were destroyed at Sendai. The radius of the area in which the earthquake was felt was 700 km.

A weak tsunami was observed on the coast at Sanriku. The sea level rose about 1 m at Sakari, in Ofunato Bay.

The pen stopped on the tide gauge at Ayukawa (see Fig. 17) after the beginning of the earthquake, as a result of the strong oscillations. The record resumed 6 hours later. The record showed that the sea level was oscillating in a way typical of tsunamis. The mean period of oscillations was 20-25 minutes and the maximal amplitude was 5 cm. The assumed travel time of the tsunami to Ayukawa was 15 minutes, to Onahama 60 minutes (Anon. (J), 1899 a,b; Omori, 1901 a,b, 1919; Milne, 1912 b; Heck, 1934, 1947; Iida, 1956; Ponyavin, 1965; Iida et al., 1967; Watanabe, 1968; Hatori, 1970 b; Hatori, Koyama, 1971).

Iida et al. (1967): 19.II; $20^h20^m38^s$; 38.1° N., 141.5° E.; M=7.8, m=0.

1897, August 5, 9:12. There was an earthquake with source off the coast of Sanriku. It caused a tsunami which was observed all along this coast and which caused minor destruction. The basic data on the wave heights, based on visual observations, are presented in Table 6. /67

The tsunami was registered by at least ten tide gauges (Fig. 17, 22) and had the following parameters (Table 7) according to Japanese investigators (Imamura, 1899 a,b, 1934, 1942, 1949; Honda et al., 1908 a,b; Imamura, Moriya, 1939; Heck, 1934, 1947; Takahasi, 1951; Yamaguti, 1954; Iida, 1956, 1963 c,d; Watanabe, 1964, 1968; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Hatori, 1970; Hatori, Koyama, 1971).

Iida et al. (1967): 38° N., 143.7° E.; M=7.7, m=1.

1898, April 23, 8:37. There was a strong earthquake at Ichikawa, Fukushima, Akita, Aomori, Yamagata, Utsunomiya, Maebashi, Kumagai, Niigata, Yokohama and other places on the northern half of Honshu Island. A house was flattened at Maizawa (Iwate Prefecture); the ground cracked at many places at Nanamikino; buildings were damaged at Satokanaguchimachi and Kuji. Homes and temples were damaged and two persons were injured at Sanuma (Miyagi Prefecture). Many buildings

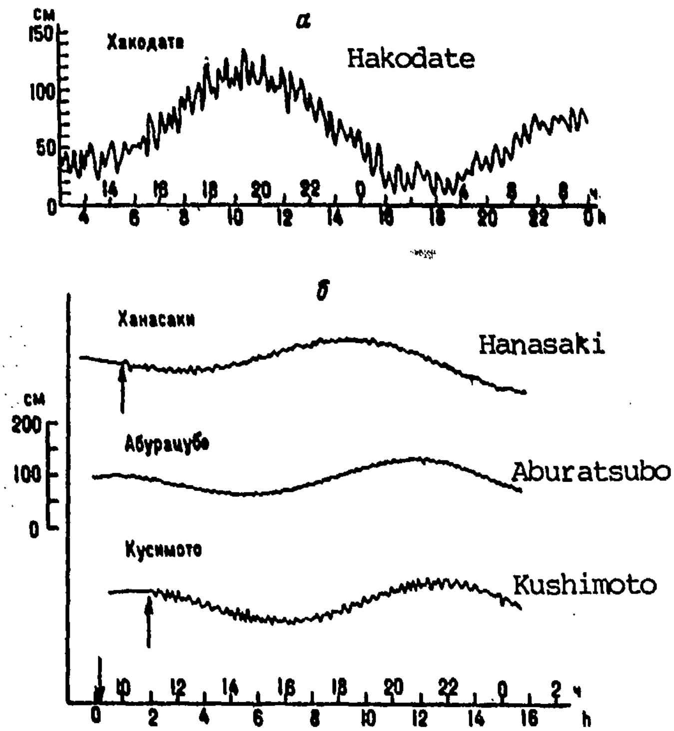


Fig. 22

Records of the tsunami of 5.VIII.1897 at Hakodate (a) and at Hanasaki, Aburatsubo and Kushimoto (b) (Honda et al., 1908a, b; Imamura, Moriya, 1939).

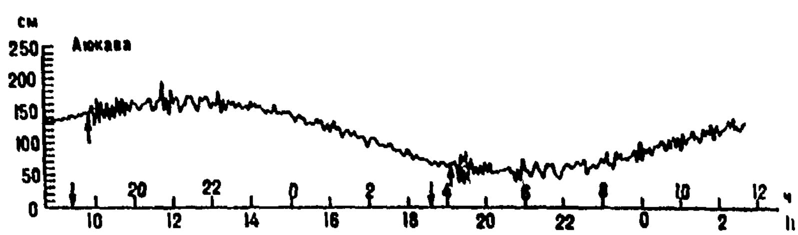


Fig. 23

Record of the tsunamis of 9 and 10.VIII.1901 (Imamura, Moriya, 1939).

suffered more or less damage, and a statue of the Buddha collapsed at Sendai. The regions of Ishinomaki, Fukushima and the vicinity also experienced considerable damage. At Sakata, the water became very rough in all the rivers and flooded the shores. The earthquake was felt lightly in the regions of Tokachi, Mito, Kofu, Nagoya, Yakosuka and very lightly at Nemuro, Fukui and Namazu. The radius of the area in which it was felt was 650 km. /68

No visible tsunami was reported, but the tide gauge record at Ayukawa (see Fig. 17) shows that a slight tsunami did occur. A wave arrived 50 minutes after the earthquake, and had a height of 10 cm and a period of 25 minutes. The assumed travel time of the tsunami to Miyako was 25 minutes (Milne, 1900 a; Omori, 1901 a,b; Iida et al., 1967; Watanabe, 1968, 1969; Hatori, 1970 b; Hatori, Koyama, 1971).

Iida et al. (1967): 22.II; 23^h30^m; 39.5° N., 143.6° E.; M=7.8, m=-1.

[1899, October 7. Tsunami in Tagomura (Annotated bibliography..., 1964, N 1176).]

1899, November 25, 3:40. There was an earthquake on Kyushu Island. The tide gauge at Hosojima registered a tsunami (see Fig. 17) with a height of 10 cm in its latter stage, and a period of 20 minutes. The assumed travel time of the tsunami was 20 minutes to Aburatsu and 40 minutes to Tosashimizu (Omori, 1901 a,b; Iida et al., 1967; Hatori, 1970 b; Hatori, Koyama, 1971).

Hatori (1970 b): 31.9° N., 131.4° E.; M=7.1?, m=0.

1901, August 9, 18:23. There was a strong earthquake in the eastern part of Aomori Prefecture. The district of Sannohe suffered most of all. Hachinohe and Nekishi also suffered. Considerable damage was done to the railway between Shiriuchi and Shimoda. There was also damage at places in the prefectures of Akita and Iwate (Omori, 1919). The earthquake was felt at Miyako and Kushiro (Milne, 1912 b).

The earthquake generated a small tsunami on the coast of Japan.

The height of the waves was no more than 0.6 m at Miyako and Nemuro. Seven or eight waves were observed. According to the tide gauge at Ayukawa (Fig. 23), the tsunami began with a flood tide 27 minutes after the earthquake; the maximal amplitude of the waves was only 23 cm; the oscillations lasted at least 9 hours, until the arrival of the next tsunami.

In addition, a wave about 1.2 m (4 feet) high appeared at Kailua on the western coast of Hawaii at 11:30 local time. The pier was covered with water for 1 m three times. At Keauhou, 10 km to the south, a home was washed away. No unusual oscillations were noted at other points on the Hawaiian Islands (Imamura, Moriya, 1939; Imamura, 1949; Shepard et al., 1950; Iida, 1956, 1963 a,b, 1970; Watanabe, 1964, 1968, 1969;

Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Hatori, 1970 b; Hatori, Koyama, 1971).

Iida et al. (1967): 9.VIII; 9^h24^m; 40.5° N., 141.5° E.; M=7.7, m=0.

1901, August 10, 3:34. There was a strong earthquake in the prefectures of Aomori, Iwate and Akita. As a result of this and the preceding earthquake in Aomori Prefecture, in total, 18 people died, eight homes were destroyed and 615 homes were damaged, eight bridges, a paved road 10 km long and a railway at 16 places on a 1 km stretch were destroyed (Omori, 1919). It was felt at Miyako and Hakodate (Milne, 1912 b).

A weak tsunami may have been observed after the earthquake. There are no data of visual observations. The tide gauge at Ayukawa (see Fig. 23) began to register a tsunami about 25 minutes after the earthquake; the maximal amplitude of the waves was 25 cm, the duration of /69
oscillations was 20 hours (Imamura, Moriya, 1939; Imamura, 1949; Yamaguti, 1954; Iida, 1956, 1963 a,b, 1970; Watanabe, 1964, 1968; Katsumata, 1966; Iida et al., 1967; Hatori, 1970; Hatori, Koyama, 1971).

Iida et al. (1967): 9.VIII; 18^h34^m; 40.5° N., 141.5° E.; M=7.8, m=0.

1912, June 8, 13:42. There was an earthquake in Iwate Prefecture. The source was situated at sea. A weak tsunami was observed on the Sanriku coast after the earthquake. Detailed data are not available on this tsunami (Takahasi, 1951; Iida, 1956, 1963 a,b, 1970; Ponyavin, 1965; Iida et al., 1967; Hatori, 1970 b).

Iida et al. (1967): 8.VI; 4^h42^m; 39.3° N., 143.3° E.; m=0.

1914, January 12, 18:29. There was an earthquake connected with an eruption of the Sakurajima volcano and accompanied by a tsunami.

In the fall of 1913, at Yoshino, north of Kagoshima, springs, a pond and several wells dried up. On November 8 and December 9, the Kirishima volcano erupted. The seismic station at Kagoshima registered 91 earthquakes in 1913, compared to a previous annual total of 34.

From January 9, a swarm of earthquakes began to be registered and felt in the area of the Sakurajima volcano. Five strong shocks were felt on the 10th. Ten were felt on the 11th. The number of shocks registered increased 4-5 times from morning to evening on the 11th. At Kagoshima, on the 11th, shocks were felt every 20 minutes, every 10 minutes until 3:00 on the 12th, and every 5 minutes from 3:00 to 5:00. Then a pause ensued; at the same time, the underground rumble stopped. Continuous rapid explosions were heard beginning at 9:00. The main explosion occurred at 10:05, and a new crater appeared on the western slope of the volcano. A column of ash rose 9 km, and was then "bent" to the east by the wind. Ten minutes later, a second column of smoke arose on the eastern slope and joined the first. An hour later, the ash began to fall on Kagoshima, but for the most part it fell on the sparsely settled Osumi Peninsula and scattered all over central Japan (it fell on Osaka on the 13th, on Tokyo on the 14th). The depth of the layer of ash was 1 3/4 m near the volcano.

The eruption began to abate at 17:00, at about this time, several strong shocks were felt.

The main earthquake, at 18:29, caused the collapse of homes and dikes at Kagoshima, rock falls and slides. The railway was out of commission for a day, the telegraph line for three days. The collapses buried several refugees. In addition, a tsunami wave 3 m high occurred (according to some sources, 1 1/2 hours after the earthquake), and did serious damage to the boats in the harbor. Thirty-five people died (15 at Kagoshima and 20 at other places) and 112 were injured.

At the same time as the earthquake, the gleam of lava was observed in the column of smoke. On the evening of the 13th, a scorching cloud appeared, setting fire to the homes at the foot of the volcano. The volcano was active for a month; new craters were formed; lava poured out, reaching the sea; new islands appeared.

The lava flow on the western slope of the volcano had a length of more than 5 km and a width of 2-4 km. The heavier eastern flow issued from three pairs of openings, extending in a line. In each pair, the explosion cone was situated on top and the lava issued from below. The strait between the volcano and the Osumi Peninsula, 60 m deep, was filled in with lava, which blocked the strait on February 1. In a month, this tongue rose another 50 m above the water level.

As a result of the eruption, the geodetic surface of the volcano rose 7 m, while the floor of the bay north of the volcano subsided 3 m. The shore of Kagoshima Bay, which had been rising for 20 years, subsided 1-2 m (several feet).

The total loss due to these events was estimated at 19 million dollars (Jaggar, 1924; Iida et al., 1967; Watanabe, 1968; Iida, 1970).

Iida et al. (1967): 12.I; 9^h29^m; 31.1° N., 130.4° E.; M=6.2, m=1.

1915, November 1, 16:25. There was an earthquake with source at sea near Ishinomaki (Miyagi Prefecture), where especially strong tremors were felt. Minor destruction occurred at some adjacent points. The earthquake was felt at Tokyo. /70

After the earthquake, a weak tsunami observed on the coast of Miyagi Prefecture, from Shizukawa to Arahama. The height of the wave was about 1 m in Shizukawa Bay. There was no damage at all. The hypothetical travel time of the tsunami was 26 minutes to Miyako and 30 minutes to Ayukawa (Omori, 1919; Heck, 1934, 1947; Takahasi, 1951;

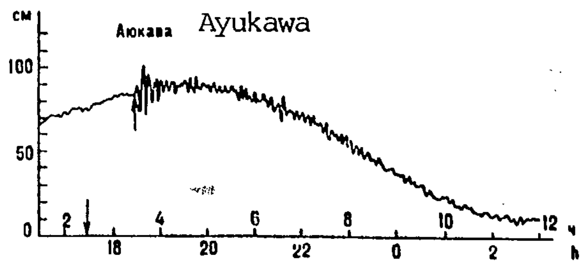


Fig. 24

Record of the tsunami of 2.VI.1923 (Imamura, Moriya, 1939).

Yamaguti, 1954; Iida, 1956, 1963 a,b, 1970; Watanabe, 1964, 1968; Ponyavin, 1965; Katsumata, 1966; Iida *et al.*, 1967; Hatori, 1970 b; Hatori, Koyama, 1971).

Iida (1956): 1.XI; 7^h25^m; 38.9° N., 143.1° E.; M=7.5, m=1.

Gutenberg, Richter (1954), Iida *et al.* (1967): 7^h24^m; 39° N., 142.5° E.; M=7.7, m=1.

1923, June 2, 2:25. There was an earthquake with source at sea off Ibaraki Prefecture, near Kashima, accompanied by a weak tsunami. It was registered by the tide gauge at Ayukawa (Fig. 24) 60-70 minutes after the earthquake. The tsunami began with a tidal wave. The maximal height was 30 cm, the duration of oscillations was 5.5 hours. The assumed travel time of the tsunami was 30 minutes to Choshi and 34 minutes to Onahama (Imamura, Moriya, 1939; Iida, 1956, 1958, 1963 a,b, 1970; Watanabe, 1964, 1968; Katsumata, 1966; Iida *et al.*, 1967; Hatori, 1970 b; Hatori, Koyama, 1971).

Iida (1956): 1.VI; 17^h25^m; 36° N., 141.4° E.; M=6.3, m=-1.

Gutenberg, Richter (1954), Iida *et al.* (1967): 1.VI; 17^h25^m; 35.75° N., 141.75° E.; M=7.2, m=-1.5.

1923, September 1, 11:59. There was a catastrophic earthquake in the Kanto region. The source of the earthquake, and the moderate tsunami which it generated, included Sagami Gulf and the Boso Peninsula, as well as adjacent areas of the sea and land (Fig. 25), and apparently was oriented latitudinally. The assumed length of the source was 150-200 km.

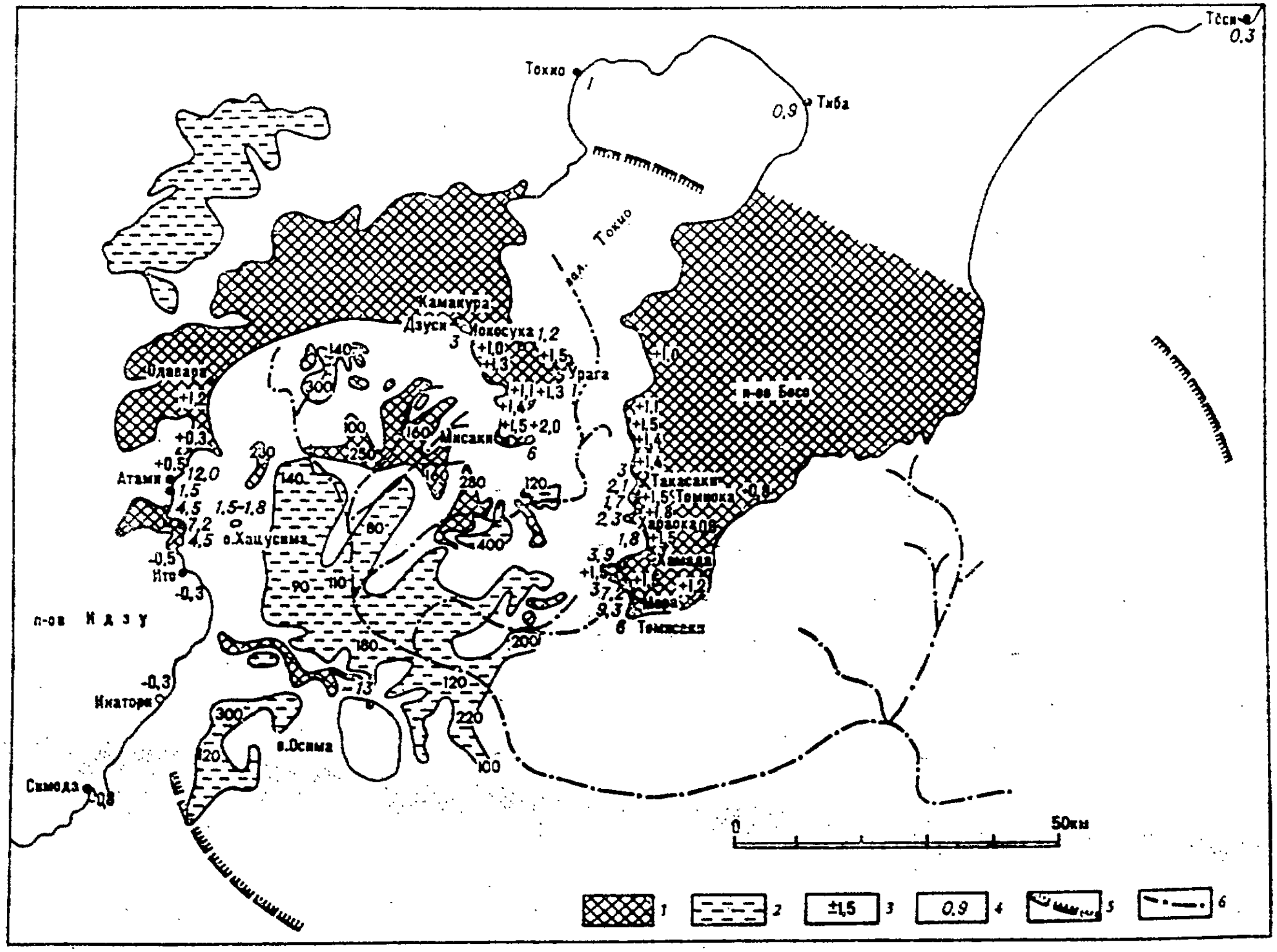


Fig. 25

The focal zone of the earthquake and tsunami of 1.IX.1923 (Utida, 1925; Hatori, 1966).

1 - zone of tectonic elevation

2 - zone of tectonic subsidence

3 - amount of tectonic elevation and subsidence

4 - height of rise of water (in m)

5 - boundary of source of tsunami

6 - underwater canyons

In the pleistoseismic zone, the earthquake was preceded by an underground roar, like peals of distant thunder. Then began abrupt vertical shocks, which became horizontal oscillations, lasting 6 minutes. People could not remain standing, trees broke or were uprooted. A cloud of smoke was ejected from the Mihara volcano on Oshima Island.

The area of destruction included the prefectures of Kanagawa, Tokyo, Chiba, Shizuoka and part of Saitama, Yamanashi, and Ibaraki. Homes caught fire at 134 places in Tokyo after the shocks. The enormous conflagration which broke out raged for three days and destroyed three quarters of the city. Fire storms also developed, in one of which, 38,000 people assembled in the city square died. Petroleum storage tanks burst at Yokohama and Yokosuka; the oil spreading on the ground and water took fire; some of the residents who were taking refuge from the earthquake on ships and boats were burned.

According to official data, 695,000 homes in Japan suffered damage: 55% of these were burned, 12% collapsed completely, 13% collapsed partly, about 20% suffered seriously from the tremors, and 0.2% were washed away by the tsunami waves. Of the total number of structures, the number of damaged homes was: 86.5% in Kanagawa Prefecture, including 96% at Yokohama, and 81% at other places; 48% in Tokyo Prefecture, including 73% in Tokyo itself, and 12% at other places; 6.5% in Chiba Prefecture; /74
6.3% each in Saitama and Shizuoka Prefectures; 3.5% in Yamanashi Prefecture; 0.2% in Ibaraki Prefecture. Brick and stone homes suffered especially, mainly in the foreign quarters. Almost 100,000 people died, and at least 47,000 were injured; 2,144 people died and 166 were injured in washed away homes. There were many residents of Tokyo who were holidaying on the Pacific Coast among the drowned. The losses amounted to more than 5 billion yen. Many artistic, historical and scientific valuables were lost.

The earthquake was accompanied by numerous aftershocks. Forty-four perceptible shocks were felt in the first 12 hours, 88 in the next 12 hours, and 60 and 47 in the next two 12-hour periods. The low-sensitivity seismographs at Tokyo registered 1700 shocks in the first three days.

The earthquake was caused by complex tectonic shifts, not fully determined. In the western half of the source, immediately south of its large axis, the graben which is represented on the floor of Sagami Bay by the Sagami trench and on land by the depression of the Sakawa River, deepened (by about 1/2 m). In the northern (northeastern) half of the source, the earth's surface rose, so far as one can judge from measurements on land, by up to 2 m, and was displaced 4.5 m to the southeast. In the first few days after the earthquake, the displaced blocks slowly returned to their original position, but then the deformation stabilized. The nature of the shifts in the southern half of the source is not completely clear, but here and there elevations were also registered. We surmise that the axis of the source coincided with a large tectonic fault, which divided the main zones of elevation and subsidence and is parallel to the Sagami canyon. Many secondary fractures arose on land along and near the axial line, gas shows were observed, new hot springs arose and the activity of existing springs was intensified. According to Ando and Kanamori, who correlated the geodetic and seismometric data, the earthquake was caused by an upthrow fault-shift of the northern flank to the southeast. The modulus of the vector of displacement of the flanks is estimated at 6-7 m on the basis of geodetic data, and at 2 m from seismometric data.

The large, almost instantaneous displacements of the floor of Sagami Bay may have caused suspension currents in the system of canyons. All these, and possibly other processes as well, led to the substantial redeposition of sediments and to a change in the relief on the floor of the bay.

The vertical and horizontal tectonic displacements, possibly complicated by some secondary processes, caused the tsunami waves. That the tectonic movements were mainly responsible is demonstrated by Aida's calculations. They show that with Ando and Kanamori's models of the source, a tsunami arises, similar in shape and intensity to that actually recorded.

As a rule, a tidal wave came first on the elevated areas of the coast, while an ebb tide came first on the subsided areas. The tsunami begins with a flood tide on the records of distant tide gauges (Fig. 26, Table 8). The source of the tsunami, as outlined by Hatori, was considerably larger than the source of the earthquake.

The greatest oscillations in water level took place at the axial part of the source. Thus, the maximal rise of water was 12 m at Atami, on the western coast of Sagami Gulf, in a zone of depression, 13 m at Oshima Island, and 9-10 m at Ainohama off the southern tip of the Boso Peninsula. On the north coast of Sagami Bay and in the southern part of the source of the tsunami, as far as Shimoda, the mean rise of water was 3 m, and the maximal rise was 6-9 m; in Tokyo Bay, the rise was 1-1.5 m. At most places, the first wave was maximal, and the second and subsequent waves were weaker. In Sagami Bay, many reflected tsunami waves were observed in addition to the direct tsunami waves.

In Japan, beyond the source, the tsunami was weak (Fig. 26, Table 8), although it was recorded on the Bonin Islands. In addition, it was registered on the Hawaiian Islands, and possibly in New Zealand.

Given below are some details on the occurrence of the tsunami at /75
different places (from east to west).

Chiba Prefecture. The tsunami was so weak on the eastern coast of the prefecture, in the Choshi region, that it was not noticed by the population, and was only registered by the tide gauge (Table 8, Fig. 26). Between Choshi and Nojima Cape, the height of rise of water (in m) was estimated as follows: Takagami*, 1.5, Katsu'ura, 1.2, Matsube, 1.5, Kominato, 1.8, Chik'ura, 1, Shirahama, 1.5.

It was mainly the southern tip of the Boso Peninsula which suffered from the tsunami. Especially large damage was observed, as was remarked above, at Ainohama, where the height of waves, according to different estimates, was 4.5-9 m, and in its vicinity (Mera and Fujiwara). At other places, the height of waves was 2-3 m, as can be seen from Table 9.

In this region, the tsunami began, as a rule, with an ebb tide apparently connected with an elevation of the shore. The magnitude of the ebb varied at different places.

At Ainohama, according to a municipal worker, a wave appeared on the horizon, about 4 km away, advancing on shore, immediately after the shock. It arrived at Ainohama in about 5-6 minutes. In this time, the eyewitness had time to run home (the home was 300 m from the city hall), help evacuate the child and mother and return to work. The wave arrived about 10 minutes after the shock.

Having flooded Ainohama and being reflected from the shore, the waves spread in different directions: some towards Sakataru, and some towards Mera, where they caused destruction. We surmise that the reflected waves were higher than the direct waves at these places.

At Mera, according to the data of the meteorological station, the ebb tide began at 12:05. According to visual observations, the water retreated 25 m from the shore line. A tidal wave arrived about 5 minutes later. According to less reliable accounts of eyewitnesses, this wave arrived about 15-16 minutes after the shock, while other stated that the wave appeared even about 30 minutes after the shock.

After the earthquake, the water retreated about 50-60 m from the coast at Tomisaki, and also at Toyooko.

The homes washed away at Ainohama and vicinity for the most part were carried back to the coast of Heisa'ura Gulf, but some of them floated to the east. This debris was found on the coast as far as Chik'ura.

At Tateyama, according to the meteorological station, an ebb tide began at 12:00, and a flood tide at 12:05.

In all, 48 homes were washed away in Chiba Prefecture.

Kanagawa Prefecture. On the eastern coast of the Mi'ura Peninsula, the rise of water (in m) was estimated as follows: Otsu, 1.2, Uraga, 0.8, Tsukui, 1.8, Kaneta, 3, Makuchi, 4.5, Matsuva, 1.5. On the south coast of the peninsula at Misaki (now Mi'ura), at the start of the earthquake the strait, 300 m wide and 3 m deep between the urban region of Hinode* and Djogashima Island, dried up. The 2-3 m high tidal waves which rolled onto the city caused only slight damage.

On the western coast of the Mi'ura Peninsula, the height of rise

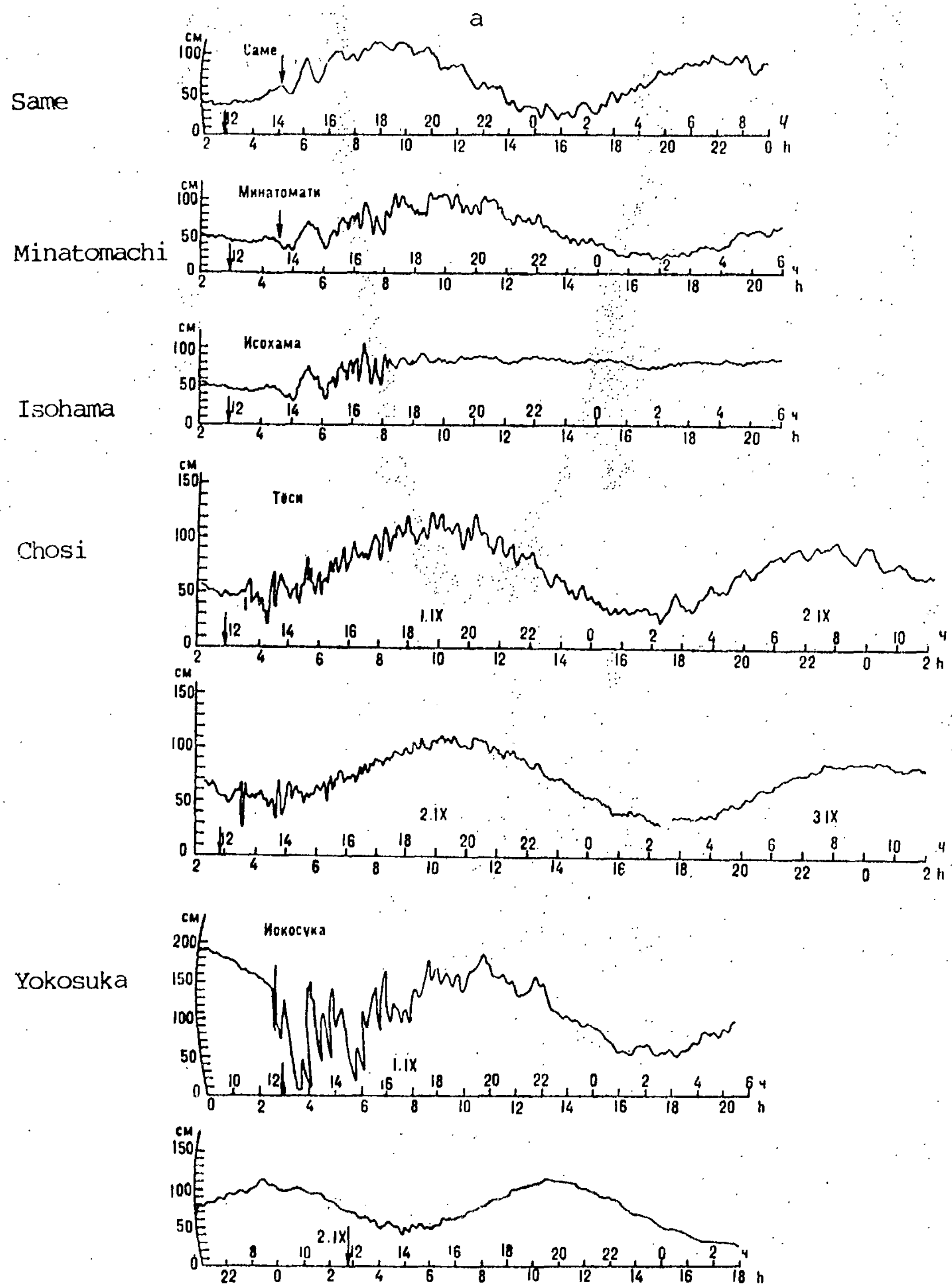
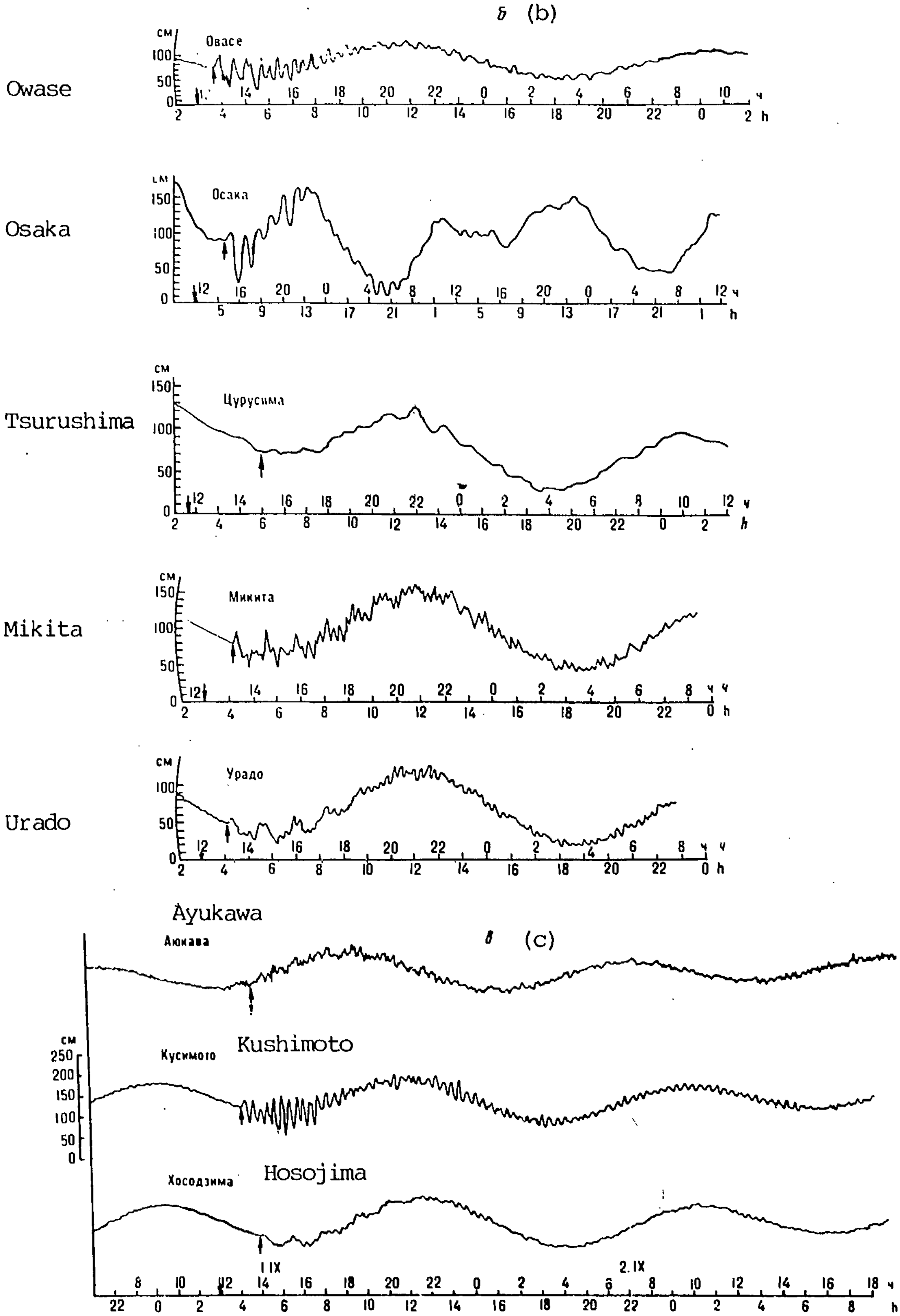


Fig. 26

Records of the tsunami of 1.IX.1923 on tide gauges situated north of the source (a) and south of the source (b) and remotely (c) (Anonym, 1925).

Fig. 26 (continued)



of water was 3 m, but the consequences of the tsunami were minor. The rise of water (in m) at different points was estimated as follows: Aburatsubo, 1.8, Koajiro, 1.8, Nagai, 1.2, Ijiri, 1.5, Akiya, 3, Nishi'ura, 1.8, Horiuchi, 3.

At Hayama and Zushi, the water rose 5 m. At Kotsubo*, near Zushi, about 80 homes were destroyed by shocks in the fishermen's quarter; their debris was washed up by the tsunami waves at the foot of the hills. The situation was similar at Hayama and Nishi'ura* villages.

On the coast of Yuigahama, waves 6 m high carried off about a hundred bathers. Several tens of homes were destroyed, and their debris was washed away. On the coast of Shichirihama, 1 km of the shore dike was destroyed. A long wooden bridge, connecting Katase with Enoshima Island was washed away with 50 pedestrians. The rise of water was estimated at 6 m at Kamak'ura, Katase and Kugenuma and at 1.5-5 m on Enoshima Island.

The coast between Kamak'ura and Odawara suffered little. The /76
height of the tsunami was 1.8 m at Oiso. Losses were also small on the steep rocky coast between Odawara and Atami; the height of the tsunami was estimated at 2 m in the Izumisan* region. However, the water rose to a height of 6 m at Imam'ura and Manazuru.

<u>Shizuoka Prefecture</u>. At Atami, according to the chief physician at one of the hospitals, the water began to retreat about 5-6 minutes after the earthquake. The magnitude of the ebb was about twice the
magnitude of the maximal usual ebb. However, soon afterward, a tidal /77
wave approached and washed away the homes on shore. A second, stronger wave appeared in about 5-6 minutes.

At the top of the bay, which has a V-shape, the height of rise of water was 12 m, halfway from the entrance to the top it was 4.5 m, and at the entrance it was only 1.5 m.

The tsunami approached Atami from the northeast, and homes were carried off in the same direction; they were later washed ashore at Yoshihama and Fuku'ura.

At Kamitaga, the height of rise of water was 3.5-4.5 m. At Wadaki, trees standing 4.5 m above sea level were flooded. At Shimotaga Niikama, on the coast of Ajiro Bay, homes and trees at a height of 7.2 m above sea level were flooded.

At Usami, the height of the tsunami was estimated at 7.5 m. At Ajiro, three waves were observed, including one reflected from the top of Sagami Bay. The largest was the third, the reflected wave, which reached a height of 3.6-3.9 m (6-8 m according to other estimates). The first two waves, whose assumed height was 3 m, did not damage the city.

At Ito, after the start of the tremors, the residents took to the shore, where they were covered by surging waves 9 m high. Coastal homes were washed away. Two strong waves were recorded. A wave more than 9 m high was observed at Kusumi, and more than 300 homes and structures were carried off.

A small tsunami 1.5-1.8 m high was observed on Hatsushima Island, situated 8 km northeast of Ito (see Fig. 25). This island underwent an elevation of 1.8 m in places.

On the coast between Ito and Simoda, the height of waves was no more than 3 m and the effects of the tsunami were slight. At particular points, the rise of water (in m) was estimated as follows: Arai*, 3; Kawana*, 4-6; Futo*, 0.6; Akazawa*, 3; Okawa*, 2.2-4.1; Katase*, 1.5; Shirota*, 3.6. It was mainly homes and fields situated along the mouths of rivers which suffered. Only at Inatori was there a wave more than 6 m high, which destroyed homes and structures along shore. South of Inatori, the following data were obtained on the height of the tsunami (in m): Mitaka*, 3.6-4.5; Kawatsu*, 3; Shirahama, 2.7-3.6; Kakisaki, 4.6.

At Soto'ura, a wave about 4-6 m high was observed. There was destruction and some victims. At Shimoda, the height of the water was 2.1-2.5 m; several hundred homes were flooded. In addition, heavy damage was done to roads, bridges and dikes.

On Oshima Island at Okada, the water rose 12 m; four homes were washed away; 14 people were killed or injured.

Tokushima Prefecture. On the coast at Muya (now Naruto) and Okazaki, the height of the waves was 0.6 m above the regular flood tide. An ebb tide and flood tide 0.6-0.9 m high was observed two or three times on the coast at Shiga.

In the Kawauchi and Tsurushima regions, an ebb tide was observed after the earthquake, and then a wave began to arrive. The water level surpassed the height of the highest annual September flood tide by 0.5 m.

Kochi Prefecture. At Kochi, at about 14:00, fishing vessels prepared to go out. Suddenly, a strong ebb began, and it was forbidden to put out to sea. Many residents of the coastal region were evacuated. The sea returned to normal by evening.

Oita Prefecture. The flood tide was 0.6 m higher than normal at Oita and Hiji, 0.2 m higher at Mi'ura and it was somewhat higher than normal at the lighthouse on Hima Island and at Takata.

Ryukyu Islands. A tidal wave flooded the coast on Tanegashima Island between 13:00 and 14:00 at an unexpected time for the flood tide. No changes at all in sea level were noticed on Okinawa Island.

Bonin Islands. Many residents of the islands (Chichijima, Hahajima /78
and other islands) felt an earthquake. A tsunami with an amplitude of 0.9 m and a period of 30 minutes was observed on Chichijima Island at Futami at 15:00. Floating pumice was found in Futami Port on September 2.

Hawaiian Islands. The tide gauge at Honolulu registered oscillations in level with a period of 21 minutes and a height of 3 cm.

New Zealand. On the 4th at Wellington, there were oscillations in water level possibly caused by the Kanto earthquake (Ito, 1924; Neumann-Navarro, 1924; Suda, 1924; Imamura, 1925, 1942, 1949; Terada, Yamaguti, 1925; Utida, 1925; Fujisawa, 1926; Suzuki, 1935; Fukutomi, 1936; Hirono, 1936; Imamura, 1937; Suzuki, 1937; Heck, 1934, 1947; Takahasi, 1951; Laing, 1954; Yamaguti, 1954; Iida, 1956, 1958, 1963 a,b, c,d; Hakoda, 1962; Matuzawa, 1964; Katsumata, 1966; Iida *et al.*, 1967; Watanabe, 1968, 1969; Hatori, 1966, 1970 a,b; Aida, 1970; Ando, 1971; Hatori, Koyama, 1971; Kanamori, 1971 a; Leonidova, 1972; Hatori *et al.*, 1973).

Iida *et al.* (1967): 1.IX; $2^h58^m49^s$; 35.25° N., 139.5° E.; M=8.2, m=3.6.

1923, September 2, 9:47. There was an earthquake with source at sea off the Boso Peninsula, which caused a weak tsunami. It was registered on the coast of Chiba Prefecture at Katsu'ura and off Cape Sunosaki, at Kamak'ura in Kanagawa Prefecture, and at Atami and Ito in Shizuoka Prefecture. The height of the wave was 0.3 m at Sunosaki Cape. The assumed travel time of the tsunami was 20 minutes to Mera and 40 minutes to Choshi (Iida, 1956, 1958, 1963 a,b, 1970; Katsumata, 1966; Iida *et al.*, 1967; Watanabe, 1968; Hatori, 1970 b; Hatori, Koyama, 1971; Kanamori, 1971 a).

Gutenberg, Richter (1954), Iida *et al.* (1967): 2.IX; 2^h47^m; 35° N., 139.5° E.; 20 km; M=7.7, m=0.

1927, August 6, 6:14. There was a strong earthquake with source at sea off the coast of Miyagi Prefecture. It was accompanied by a series of aftershocks. It caused a weak tsunami, which was registered only by tide gauges (Table 10, Fig. 27) (Iida, 1956, 1958, 1963 a,b, 1970; Watanabe, 1964, 1968; Katsumata, 1966; Iida *et al.*, 1967; Hatori, 1970 b; Hatori, Koyama, 1971).

Iida *et al.* (1967): 5.VIII; 21^h13^m; 38° N., 142° E.; 20 km; M=6.9, m <-2.

1927, August 19, 4:28. There was a moderate earthquake with source at sea off the Boso Peninsula. It was accompanied by aftershocks and a weak tsunami, which was registered by the tide gauges at Choshi and Mera (Fig. 28). Still another weak tsunami of unclear origin was registered approximately 80 minutes later. It was difficult to associate it with any aftershock, and for this reason Wadati and Iida surmised that it was formed as the result of some reflection of the first tsunami. Data on both waves are given in Table 11 (Iida, 1956, 1958, 1963 a,b, 1970; Watanabe, 1964, 1968; Ponyavin, 1965; Katsumata, 1966; Iida *et al.*, 1967; Hatori, 1970 b; Hatori, Koyama, 1971).

Iida *et al.* (1967): 18.VIII; 19^h28^m; 34.2° N., 142° E., 20 km, M=6?, m=-2.

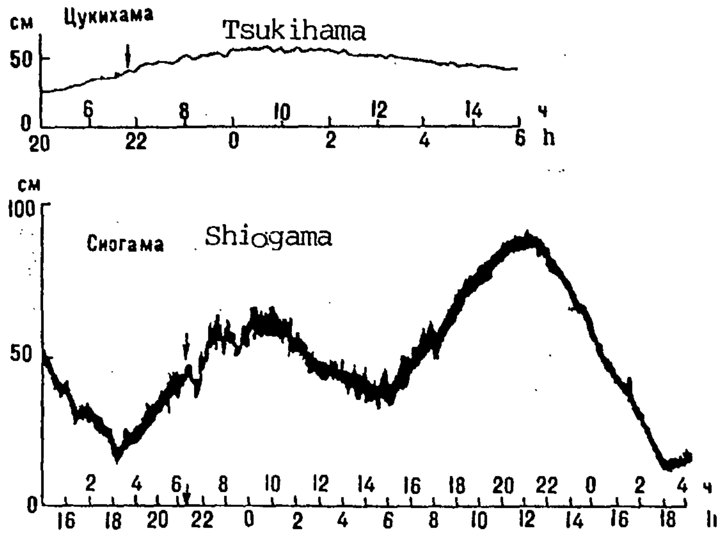


Fig. 27
Records of the tsunami of 6.VIII.1927 (Iida, 1956).

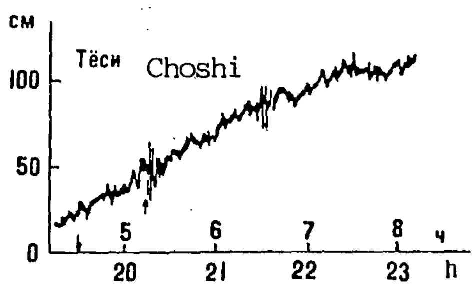


Fig. 28
Records of the tsunami of 19.VIII.1927 (Iida, 1956).

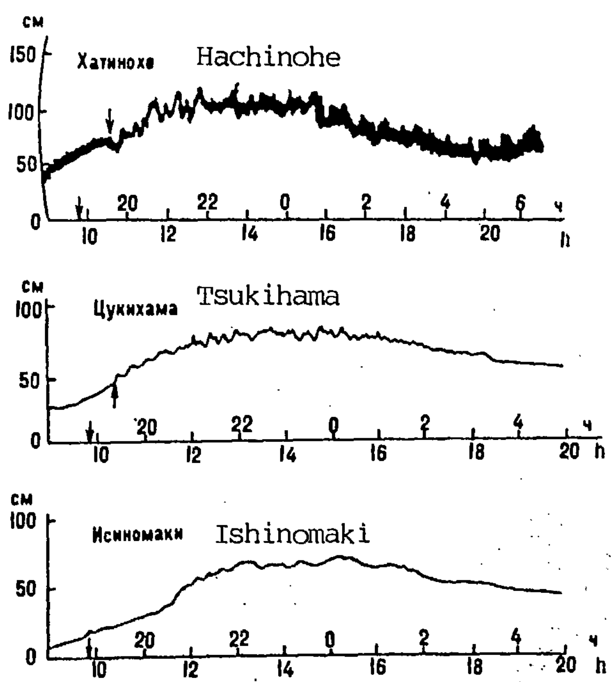


Fig. 29
Records of the tsunami of 27.V.1928 (Iida, 1956).

1928, May 27, 18:50. There was an earthquake with source at sea off the coast of Iwate Prefecture. It was followed by aftershocks. It caused a weak tsunami, which was recorded by tide gauges (Table 12, Fig. 29) (Iida, 1956, 1958, 1963 a,b, 1970; Watanabe, 1964, 1968; Ponyavin, 1965; Katsumata, 1966; Hatori, 1966, 1970 b; Iida *et al.*, 1967; Hatori, Koyama, 1971).

Iida *et al.* (1967): 27.V; $9^{h}50^{m}$; 40° N., 143.2° E.; 0-10 km; M=7, m $<$-2.

1928, May, about the 30th. A tsunami appeared at Sapporo and a fleet of fishing vessels was destroyed (Montandon, 1931).

[These appear to be very distorted data on the tsunami of 27. V. 1928.]

1929, May 22, 1:35. There was a shock on the south of Miyazaki Prefecture, causing considerable destruction in Miyazaki and vicinity. A loud rumble was heard at the same time as the shock, and according to doubtful sources, a typhoon occurred. Homes were shaken to such an extent that they almost collapsed, and it was difficult to move about inside the homes. The frightened people ran to the street. The city was plunged into darkness due to breakage of the cables of the power network, /80
and the residents spent the whole night on the street. There were about another ten shocks after the main one.

A strong earthquake was felt in the region of Takachiho, at Oita and Kumamoto (clocks stopped). A mild earthquake was felt at Kagoshima (the walls of homes creaked) and at Matsuyama, in Ehime Prefecture.

According to the Miyazaki seismic station, the epicenter of the earthquake was situated 60 km southeast of Miyazaki, near the coast of Hyuga-Nada.

Tsunami waves were registered on this coast. Fortunately, the tsunami did no damage at all (Anon. (J), 1929 b).

[21.V; $16^{h}35^{m}$; 31.8° N., 131.8° E.; 30 km; M=7.1. The account of this earthquake (Anon. (J), 1929 b) apparently gives an incorrect date for the earthquake which caused the tsunami.]

1931, March 9, 12:49. There was an earthquake with source at sea /81
to the east of Aomori Prefecture. It was felt on most of Hokkaido Island, in Tohoku and Kanto regions, even as far as Kofu (Yamanashi Prefecture) and Hikone (Shiga Prefecture). There was minor destruction at Hakodate (Sieberg, 1932; *Seismicity in Hokkaido...*, 1962). It was followed by aftershocks.

A weak tsunami was registered after the earthquake (Table 13, Fig. 30) (Iida, 1956, 1958, 1963 a,b,c,d; Watanabe, 1964, 1968; Hatori, 1963, 1966; Katsumata, 1966; Iida *et al.*, 1967; Hatori, Koyama, 1971).

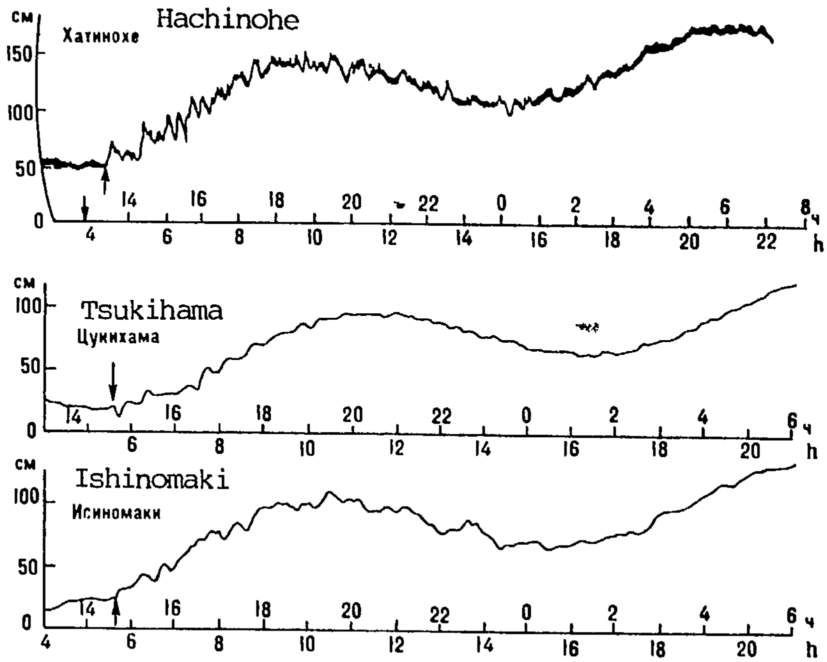


Fig. 30

Records of the tsunami of 9.III.1931 (Iida, 1956).

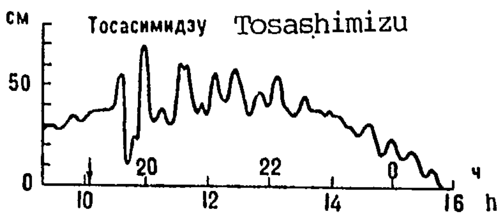


Fig. 31

Record of the tsunami of 2.XI.1931 (Hatori, 1969a).

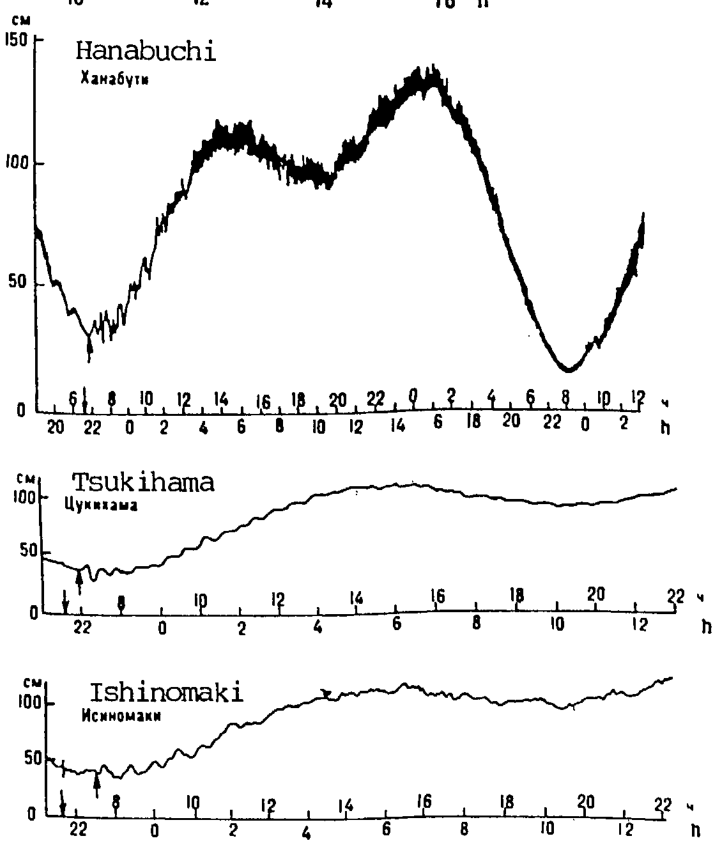


Fig. 32

Records of the tsunami of 19.VI.1933 (Iida, 1956).

Iida *et al.* (1967): 9.III; 3^h49^m; 41.2° N., 142.5° E.; 0 km; M=7.6, m=-2.

1931, November 2, 19:03. There was an earthquake with source off the coast of Miyazaki Prefecture. It had a magnitude of 6-7 degrees (IV JMA) in the Prefectures of Miyazaki, Kumamoto, Oita and on the southwest of Shikoku Island. Fourteen homes were destroyed and one person died. There were fore- and aftershocks. It was accompanied by a weak tsunami, which was registered on the coast of Kyushu and Shikoku Islands and the Kii Peninsula (Table 14, Fig. 31) (Hayata, 1932; Iida, 1956, 1958, 1963 a,b, 1970; Takahasi, Aida, 1963; Ponyavin, 1965; Hatori, 1963 b, 1970 b, 1971 b; Katsumata, 1966; Iida *et al.*, 1967; Watanabe, 1968, 1970; Hatori, Koyama, 1971). /82

Iida *et al.* (1967): 2.XI; 10^h03^m; 32.2° N., 132.1° E.; 20 km; M=6.6, m=-0.3.

1933, March 3, 2:31. There was a strong earthquake and catastrophic tsunami with source off the Sanriku Coast. The maximal rise of water was 28 m on this coast, 9 m on the south of Hokkaido Island, and 3 m in the Hawaiian Islands. More than 3,000 residents died in Japan. More than 6,000 structures and 12,000 ships and boats were washed away and destroyed. The events are not described here in detail. A brief account of the tsunami can be found in Iida *et al.*, 1967.

1933, June 19, 6:37. There was a strong earthquake with source off Kinkazan Island (Miyagi Prefecture). It was accompanied by aftershocks and a weak tsunami,which was registered by tide gauges on the Sanriku Coast and on the south coast of Hokkaido Island (Table 15, Fig. 32) (Iida, 1956, 1958, 1963 a,b, 1970; Watanabe. 1964. 1968; Ponyavin, 1965; Hatori, 1966, 1970 b; Katsumata, 1966; Iida *et al.*, 1967; Hatori, Koyama, 1971).

Iida *et al.* (1967): 18.VI; 21^h37^m; 38.1° N., 142.3° E.; 20 km; M=7.1, m=-2.

1935, July 19, 9:50. There was a strong earthquake with source off the coast of Kashima Nada (Ibaraki Prefecture). It was accompanied by aftershocks and a weak tsunami, which was registered by the tide gauge at Onahama with a height of 18 cm and a period of 12 minutes, 20 minutes after the earthquake. The assumed travel time of the tsunami was 40 minutes to Choshi and 50 minutes to Ayukawa (Fig. 33) (Iida, 1956, 1958, 1963 a,b,c, 1970; Watanabe, 1964, 1968; Ponyavin, 1965; Katsumata, 1966; Iida *et al.*, 1967; Hatori, 1970 b; Hatori, Koyama, 1971). /84

Iida *et al.* (1967): 19.VII; 0^h50^m; 36.7° N., 141.3° E.; 0 km; M=6.5, $m \leq -2$.

1935, October 13, 1:45. There was a considerable earthquake with a source at sea off Miyako (Iwate Prefecture). It was accompanied by a large number of aftershocks and a weak tsunami, which was registered by tide gauges on the Sanriku Coast (Table 16, Fig. 34) (Iida, 1956, 1958,

Fig. 33

Record of the tsunami of 19.VII.1935 (Iida, 1956).

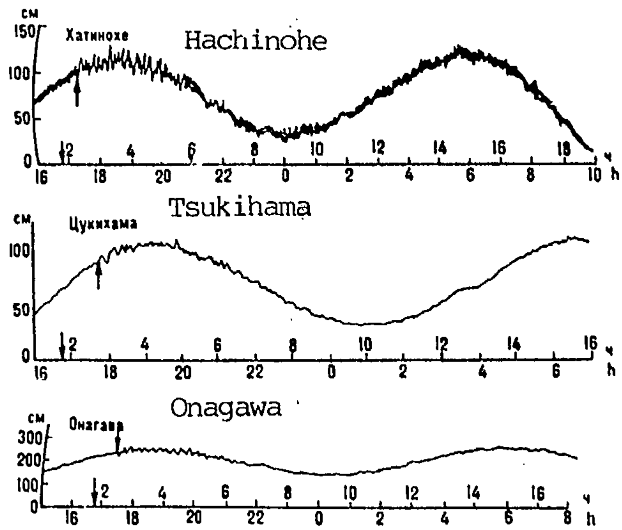


Fig. 34

Records of the tsunami of 13.X.1935 (Iida, 1956).

1963 a,b, 1970; Hatori, 1963 b, 1966, 1970 b; Watanabe, 1964, 1968; Ponyavin, 1965; Katsumata, 1966; Iida _et al._, 1967; Hatori, Koyama, 1971).

Iida _et al._ (1967): 12.X; 16^h45^m; 40° N., 143.6° E.; 40 km; M=7.2, m=-2.

1935, October 18, 9:12. There was an earthquake with source at sea off the coast of Iwate Prefecture. It caused a weak tsunami, which was registered by the tide gauge at Hachinohe (where it had a height of

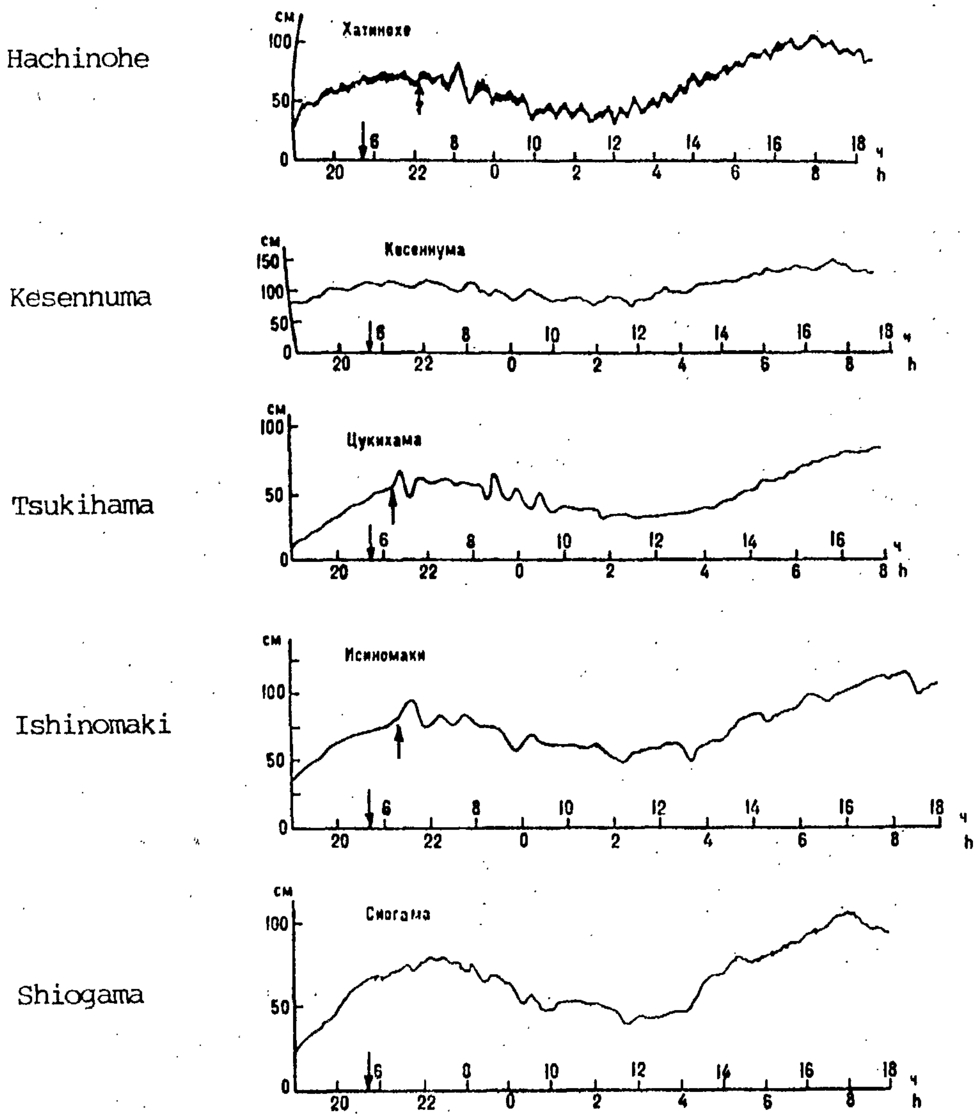


Fig. 35

Records of the tsunami of 3.XI.1936 (Miyabe, 1937).

20 cm) approximately 50 minutes after the earthquake, and by the tide gauge at Miyako about 32 minutes after the earthquake (Iida, 1958, 1963 a,b, 1970; Hatori, 1963 b, 1970 b; Watanabe, 1964, 1968; Katsumata, 1966; Iida et al., 1967).

Iida et al. (1967): 18.X; 0^h12^m; 40.3° N., 144.2° E.; 20-40 km; M=7.1, m=-2.

1936, November 3, 5:46. There was an earthquake with source off Kinkazan Island (Miyagi Prefecture). It was felt rather strongly on the Pacific coast of northeastern Japan, where the walls of warehouses cracked, window panes rattled, and in some places embankments settled in the prefectures of Fukushima, Miyagi and Iwate. It was accompanied by a few aftershocks. /85

Several tens of minutes after the earthquake, a rise in sea level was observed in Shiogama Bay. Here and there at other places, the lower terraces were partly flooded. The tsunami was registered by tide gauges on the northeastern coast of Japan, beginning as a rule with a flood tide (Fig. 35, Table 17).

The predominant periods on all the tide gauges, according to Japanese specialists, was 20-40 minutes (Miyabe, 1937; Takayama, 1937; Iida, 1956, 1958, 1963 a,b,c,d, 1970; Hatori, 1963 b; Watanabe, 1964, 1968; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Hatori, Koyama, 1971).

Iida et al. (1967): 2.XI; 20^h46^m; 38.2° N., 142.2° E.; 50-60 km; M=7.7, m=-1.6.

1938, May 23, 16:18. There was a rather strong earthquake with source off Shioyasaki*, which caused light destruction in Fukushima Prefecture. It was accompanied by a series of aftershocks and tsunami waves, which were registered on the coast of Hokkaido Island, the Sanriku area, and Fukushima and Chiba Prefectures (Fig. 36, Table 18).

The predominant period of oscillations was about 20 minutes at each station (Iida, 1956, 1958, 1963 a,b,c,d, 1970; Hatori, 1963 b, 1966, 1970 b; Watanabe, 1964; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Hatori, Koyama, 1971). /86

Iida et al. (1967): 23.V; 7^h18^m; 36.7° N., 141.4° E.; 70 km; M=7.1, m=-1.3.

1938, May 29, 1:42. There was an earthquake near Kuttyaro Lake on Hokkaido Island. There was much destruction on the western coast of the lake. One person died. A tsunami [seiches?] up to 90 cm high was observed in the lake (Watanabe, 1968, 1969).

Watanabe (1968): 28.V; 16^h42^m; 43.6° N., 144.3° E.; 20 km; M=6, m=-1.

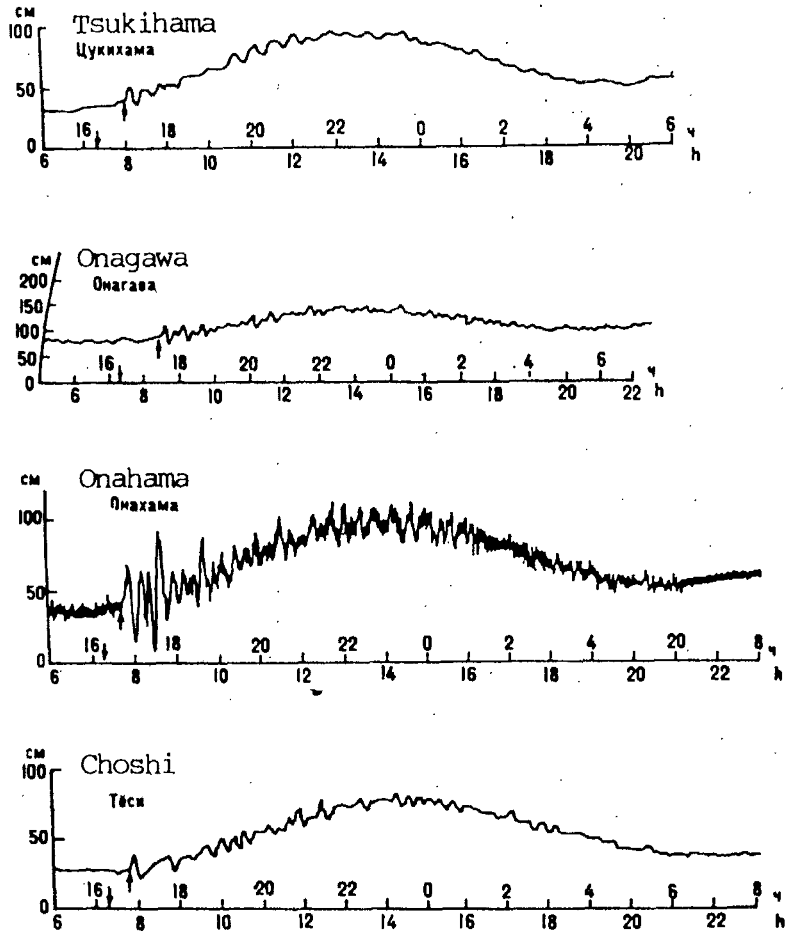


Fig. 36
Records of the tsunami of 23.V.1938 (Iida, 1956).

1938, November 5, 17:43. There was a very strong earthquake with source off the coast of Fukushima Prefecture. It was felt along the Pacific coast from the Kanto region to northeastern Japan. It caused a series of aftershocks. It was accompanied by a tsunami, which was regis- /88
tered on the coast of the Sanriku area, Fukushima and Chiba Prefectures and Hokkaido Island (Table 19, Fig. 37).

The predominant period of oscillations on the tide gauge records is 15 to 30 minutes (Kato, 1939; Otuka, 1939; Anon. (R), 1940 a; Sagisaka, Ito, 1940; Imamura, 1949; Iida, 1956, 1958, 1963 a,b,c,d, 1970; Hatori, 1963 b, 1966, 1970 b; Matuzawa, 1964; Watanabe, 1964, 1968, 1970; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Hatori, Koyama, 1971).

Iida et al. (1967): 5.XI; 8^h43^m; 37.1° N., 141.7° E.; 20 km; M=7.7, m=-0.6.

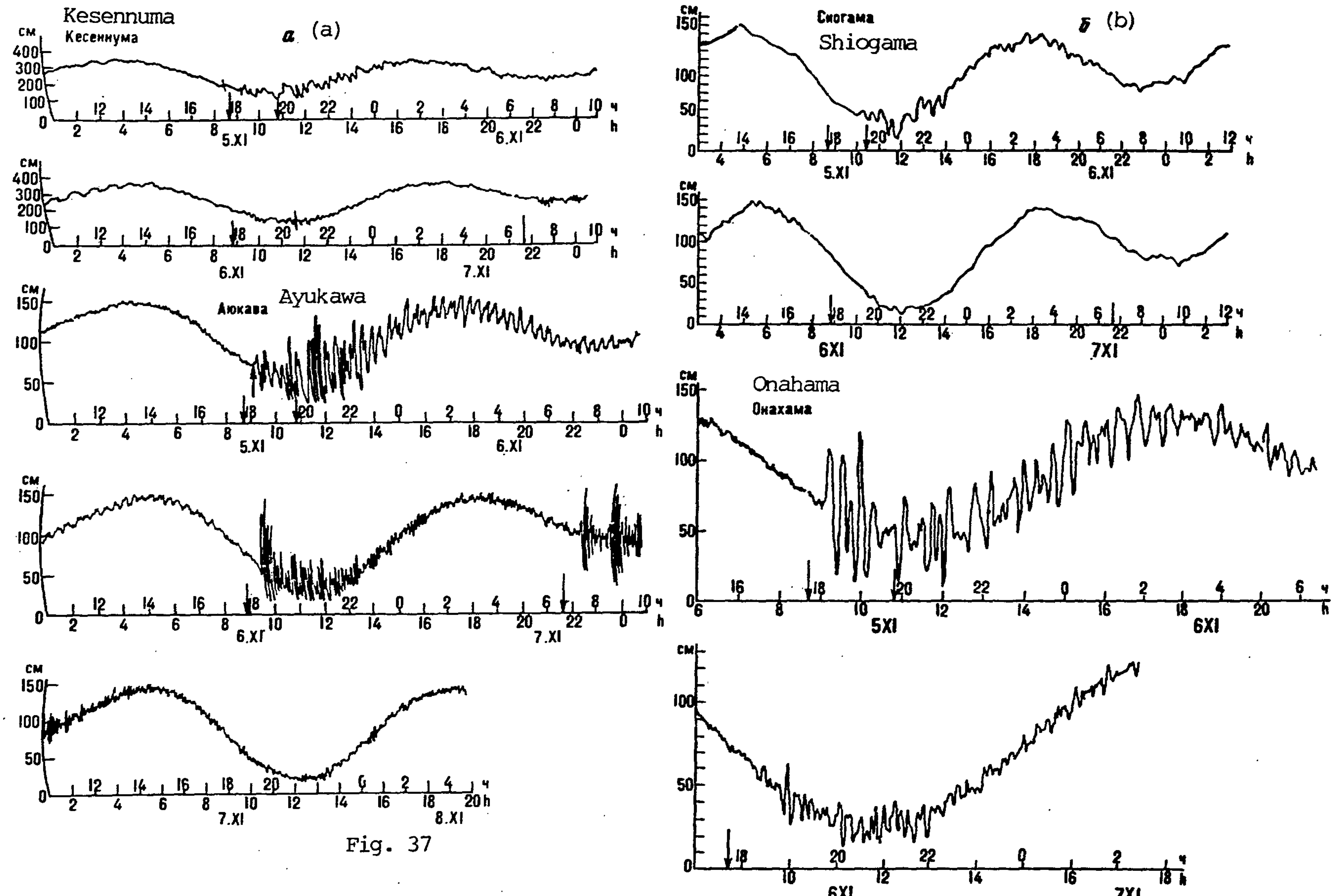


Fig. 37

Records of the tsunamis of 5, 6, and 7.XI.1938 at Kesennuma and Ayukawa (a) and at Shiogama and Onahama (b) (Otuka, 1939).

1938, November 5, 19:50. An earthquake occurred in almost the same place and had almost the same intensity as the preceding one. This aftershock caused a weak tsunami, which was also registered on the Sanriku coast and the coast of Fukushima and Chiba Prefectures and Hokkaido Island (Table 20, Fig. 37).

The predominant period of oscillations on the tide gauge records /89
is almost the same as in the preceding case, that is, 15-30 minutes (Kato, 1939; Otuka, 1939; Anon. (R), 1940 a; Sagisaka, Ito, 1940; Iida, 1956, 1958, 1963 a,b, 1970; Watanabe, 1964, 1968, 1970; Hatori, 1966, 1970 b; Iida *et al.*, 1967; Hatori, Koyama, 1971).

Iida *et al.* (1967): 5.XI; 10^h50^m; 37.15° N., 141.7° E.; 15 km; M=7.6, m=-0.8

1938, November 6, 17:54. There was an aftershock of the earthquake of November 5. The epicenter was situated somewhat northeast of the epicenter of the main shock. In intensity, the shock was almost the same as the preceding one. It caused a weak tsunami, which was registered on the coast of the Sanriku area and the coast of Fukushima and Chiba Prefectures and Hokkaido Island (Table 21, see Fig. 37).

The predominant period of oscillations on all tide gauge records /90
was close to 10 minutes (Iida, 1956, 1958, 1963 a,b, 1970; Watanabe, 1964, 1968, 1970; Hatori, 1966, 1970 b; Katsumata, 1966; Iida *et al.*, 1967; Hatori, Koyama, 1971; Otuka, 1939).

Iida *et al.* (1967): 6.XI; 8^h54^m; 37.5° N., 141.8° E.; 0 km; M=7.5, m=-0.6.

1938, November 7, 6:39. There was an aftershock of the earthquake of November 5. It occurred on the northeast of the Sanriku area and caused a mild tsunami which was registered on the coast of the Sanriku area, Fukushima and Chiba Prefectures (Table 22, see Fig. 37).

The predominant period on all tide gauge records was close to 10 /91
minutes (Otuka, 1939; Iida, 1956, 1958, 1963 a,b,c,d, 1970; Hatori, 1966, 1970 b; Katsumata, 1966; Iida *et al.*, 1967; Watanabe, 1964, 1968, 1970).

Iida *et al.* (1967): 6.XI; 21^h39^m; 37° N., 141.1° E.; 0 km; M=7.1, m=-0.7.

1938, November 14, 7:31. There was a rather weak aftershock of the earthquake of November 5. The epicenter was situated southwest of the epicenter of the main earthquake, off the coast of Fukushima Prefecture. The weak tsunami which it caused was registered on the coast
of Fukushima and Chiba Prefectures (Table 23, Fig. 38). The predominant /92
period of oscillations on all the tide gauge records is 10-15 minutes (Iida, 1956, 1958, 1963 a,b,c,d, 1970; Watanabe, 1964, 1968, 1970; Hatori, 1966, 1970 b; Katsumata, 1966; Iida *et al.*, 1967; Hatori, Koyama, 1971).

Kesennuma

Onagawa

Onahama

Choshi

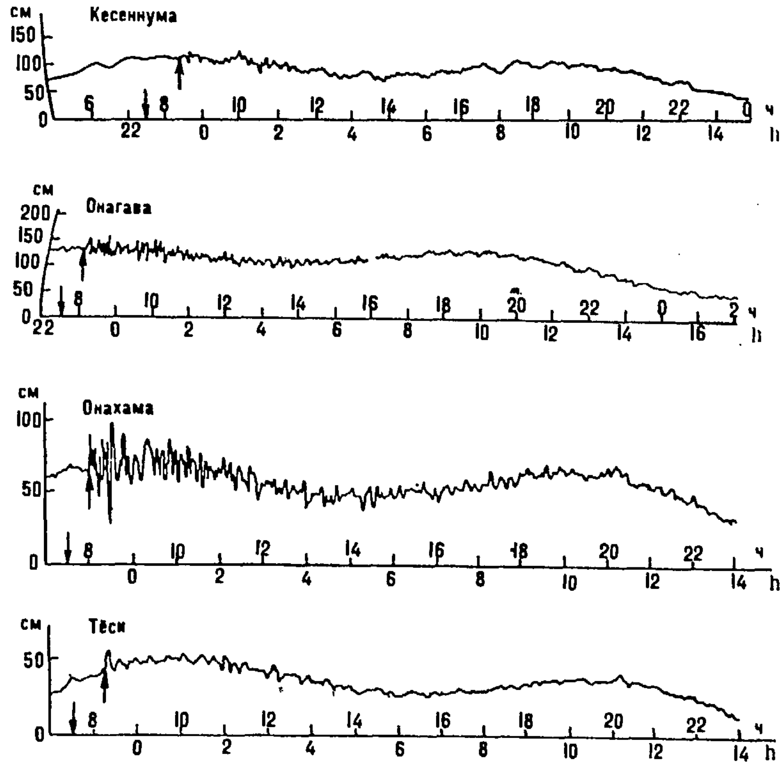


Fig. 38

Records of the tsunami of 14.XI.1938 (Iida, 1956).

Onagawa

Onahama

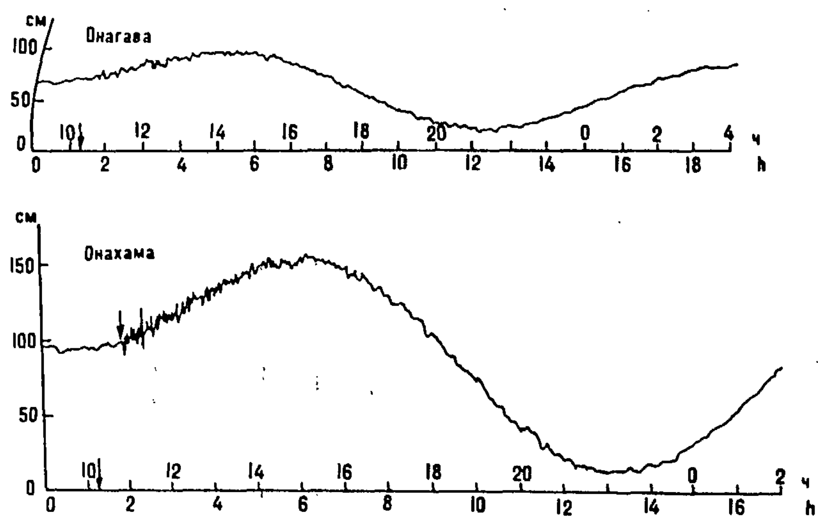


Fig. 39

Records of the tsunami of 22.XI.1938 (Iida, 1956).

Iida et al. (1967): 13.XI; 22^h31^m; 37° N., 141.5° E.; 60 km; M=6, m=-1.5.

1938, November 22, 10:14. There was an aftershock of the earth- /93
quake of November 5. The epicenter was located somewhat southeast of the epicenter of the main shock. A weak tsunami was registered on the coast of Fukushima and Chiba Prefectures (Table 24, Fig. 39).

The predominating period of oscillations on all tide gauge records is 5-10 minutes (Iida, 1956, 1958, 1963 a,b,c,d, 1970; Watanabe, 1964, 1968, 1970, Hatori, 1966, 1970 b; Katsumata, 1966; Iida et al., 1967).

Iida et al. (1967): 22.XI; 1^h15^m; 37° N., 141.8° E.; 10 km; M=6.7, m -2.

1938, November 30, 11:30. There was an aftershock of the earthquake of November 5. It occurred in almost the same place as the shock of November 22.

A weak tsunami was recorded on the coast of the Sanriku area and Hokkaido Island (Table 25, Fig. 40).

The predominant period of oscillations on all the tide gauge records is 10-20 minutes (Iida, 1956, 1958, 1963 a,b, 1970; Watanabe, 1964, 1968, 1970; Katsumata, 1966; Iida et al., 1967; Hatori, 1970 b).

Iida et al. (1967): 30.XI; 2^h30^m; 37° N., 141.8° E.; 5 km; M=7, m=-2.

1939, March 20, 12:22. There was an earthquake with source off the coast of Miyazaki Prefecture. It was felt with a force of 6 degrees (IV JMA) in the prefectures of Miyazaki, Kumamoto, and Oita. It caused a weak tsunami. A wave 80 cm high was observed at Muroto, 12 cm at Tosashimizu, 16 cm at Aburatsu. The assumed travel time of the tsunami to /94
Tosashimizu and Aburatsu was 30 minutes. The energy of the tsunami, according to Hatori's estimates, was 7 X 10^{18} ergs (Iida, 1956, 1958, 1963 a,b, 1970; Hakoda, 1962; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968; Hatori, 1970 b, 1971 b; Hatori, Koyama, 1971).

Iida et al. (1967): 20.III; 3^h22^m; 32.3° N., 131.7° E.; 10 km; M=6.6, m=-0.3.

1941, November 19, 1:46. There was a strong earthquake with source in Hyuga-Nada, about 40 km northeast of Miyazaki. It was felt in a vast zone, including the greater part of Kyushu and Shikoku Islands and the center of Honshu Island. The tremors were especially intensive (IV-V degrees JMA) on Kyushu Island and in the southwestern part of Shikoku Island. The street lights were destroyed or damaged at several places, and the telephone lines were cut in the prefectures of Miyazaki, Oita and Kagoshima, which are close to the source; the residents ran to the streets in panic.

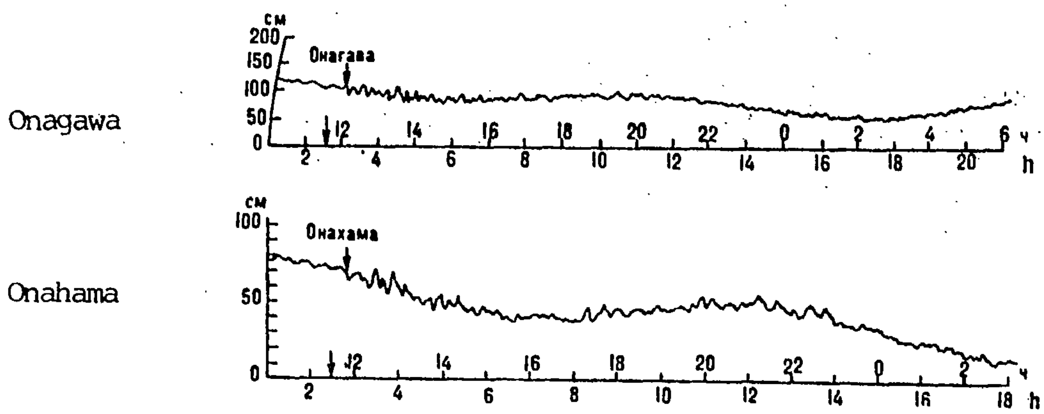


Fig. 40
Records of the tsunami of 30.XI.1938 (Iida, 1956).

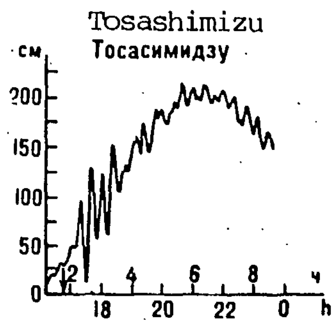


Fig. 41
Record of the tsunami of 19.XI.1941 at Tosashimizu (Hatori, 1969a).

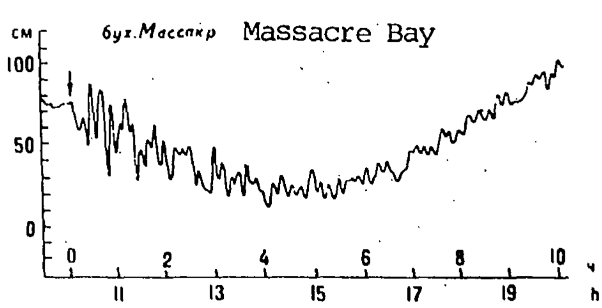


Fig. 42
Record of the tsunami of 7.XII.1944 on Attu Island, Aleutian Islands (Bodle, 1946).

A tsunami 1 m high was observed along the eastern coast of Kyushu Island and the south coast of Shikoku Island. Boats were damaged and there was some destruction. It was registered by tide gauges (Fig. 41) with maximal heights (in cm); 40 at Kushimoto, 110 at Muroto (visual observations), 110 at Tosashimizu, 60 at Sukumo (visual observations), 30 at Uwajima, 35 at Tsukumi, 10 at Saeki, 100 at Hosojima (visual observations), and 100 at Aburatsu (visual observations). The travel times of the tsunami were: 21 minutes to Tosashimizu, 30? minutes to Aburatsu and 50 minutes to Kushimoto. The energy of the tsunami, in Hatori's estimate, was 3 X 10^{19} ergs (Imamura, 1949; Iida, 1956, 1958, 1963 a,b, 1970; Takahasi, Hatori, 1961; Hatori, 1963 b, 1970 b, 1971 b; Takahasi, Aida, 1963; Sagisaka, 1964; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968, 1970; Hatori, Koyama, 1971).

Iida et al. (1967): 18.XI; 16^h46^m; 32.6° N., 132.1° E.; 0-20 km; M=7.4, m=0. /95

1943, June 13, 14:12. There was an earthquake in the southern part of Hokkaido Island, which produced a weak tsunami. At Hachinohe, a wave 0.6 m high was observed. The assumed travel time of the tsunami was 40 minutes to Hachinohe and 60 minutes to Miyako (Iida, 1958, 1963 a,b, 1970; Hatori, 1963 b, 1970 b; Watanabe, 1964, 1968; Katsumata, 1966; Iida et al., 1967; Hatori, Koyama, 1971).

Iida et al. (1967): 13.VI; 5^h12^m; 41.1° N., 142.7° E.; 20 km; M=7.1, m=0.

1944, December 7, 13:35. There was an earthquake in the south of Japan in the Tonankai area, with source off the southeastern coast of the Kii Peninsula, at Kumano-Nada. The earthquake and resulting tsunami caused great destruction and loss of life. Some 998 people died and 2,135 were seriously injured; 26,135 homes were totally destroyed and 46,950 homes were half destroyed; 3,059 homes were washed away and 11 burned down.

The force of the earthquake diminished comparatively quickly with distance from the source. Thus, there was much destruction at Shingu, Temma and vicinity, on the eastern coast of the Kii Peninsula. On the south of the Kii Peninsula, west of Kushimoto, only stone barriers and clay walls were destroyed; the roofs fell from some homes. No cases of even partial destruction of homes were recorded on the western coast of the peninsula at Tanabe.

The southeastern coast of the Kii Peninsula dropped several tens of centimetres during the earthquake.

The tsunami was strongest on this same coast, which is the closest to the source. It reached here in about 10 minutes and had a height of 2 to 6 m (Table 26). A weak tsunami was registered along the entire coast of Japan from the Izu Peninsula to Kyushu Island.

In the region of Nachi-Hamanomiya-Temma, a wave approaching from the east washed away homes, and 30-40 people died. The wave ran 200 m up the Nachi River. At Temma, according to visual estimates, the wave had a height of 5 m; it reached the foot of the mountain and flowed across a new road in the southern part of Temma.

The station master at Nachi related the following about the tsunami. Immediately after the strong shocks, the train from Nachikatsu'ura arrived. Ten minutes later, when the train was to have left, tsunami warning shouts were heard. The passengers were immediately transferred to safe places, and by 13:50 the station was already flooded all around with water. The railway line to Nachikatsu'ura and the station were partially washed away.

No ebb tide was observed in Temma Bay before the arrival of the tidal wave. Between flood tides, the floor of the bay dried up for a considerable distance, at Meshima* Island, for example, 500 m.

The wave which entered Nachikatsu'ura Bay was not high. The western coast of the bay was flooded, but the homes were not washed away. During ebb tides, the floor of the bay dried up for a distance of 20 m. At the top of the bay, at Hachiman*, the wave had a height of 2.5 m.

At Taiji and Shimosato, the height of the waves reached 3-4 m in /97 places. At Urakami, the road leading to the school was completely washed out. However, the children were evacuated to safe places and there were no victims. The wave reached a height of 5 m at the top of the bay. The wave approached Kushimoto 7 minutes after the earthquake and had a height of about 2 m. Nothing was flooded.

At Shinjo, on the western coast of the Kii Peninsula, three waves approximately 1 m high were observed. In the opinion of an eyewitness, who was situated on the beach at Mikonohama at the time, the wave arrived approximately 20-30 minutes after the shock. East of the source, some intensification of the flooding was noted on the south of the Izu Peninsula.

According to a schoolteacher, at Shimoda, the tsunami began at 14:05 with an ebb tide. Seven tidal waves were recorded by 14:41. A wave reached a height of 2.4 m at the top of Shimoda Bay, and its average height on the coast of the bay was about 2.2 m.

At Matsuzaki City, on the west coast of the Izu Peninsula, according to a policeman, three tsunami waves were observed 10 minutes after the shock. Then approximately 5 minutes later, another four large waves were observed. The height of rise of the water was about 1.5 m in the mouth of the river.

At Shimizu (western coast of Suruga Bay), a rather strong ebb tide was observed 20 minutes after the shock. The bottom of the bay was exposed. Then the water level rose about 1-2 m (above the normal mark). Outside Japan, the tsunami was registered by tide gauges on the coast of the Hawaiian and Aleutian Islands (Fig. 42) and North America (Table 27) (Anon. 1945; Bodle, 1946; Heck, 1947; Imamura, 1949; Takahasi, 1951; Yamaguti, 1954; Iida, 1956, 1958, 1963 a,b; Hakoda, 1962; Hatori, 1963 b, 1964, 1966, 1970 b; Iida, Ohta, 1961, 1963; Takahasi, Aida, 1963; Matuzawa, 1964; Sagisaka, 1964; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968; Hatori, Koyama, 1971).

Iida et al. (1967): 7.XII; 4^h35^m; 33.7° N., 136° E.; 0-30 km; M=8, m=3.

1945, January 13, 3:38. There was an earthquake with source on the south of Aichi Prefecture. In Atsumi Bay, 5,539 homes were completely destroyed and 11,706 were partly destroyed as the result of the earthquake; 6,603 non-residential structures were completely destroyed and 9,976 were half destroyed. Some 1,961 people died and 896 were injured. The large number of vicitims is explained by the fact that during the war, the workers in the military plants lived in crowded conditions, in hostels. The earthquake caused a weak tsunami. At Gamagori and Sengen (Aichi Prefecture), waves 1 m and 0.6 m high respectively were observed (Takahasi, 1951; Iida, 1956, 1958, 1963 a,b, 1970; Hatori, 1963 b, 1970 b; Sagisaka, 1964; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968). /98

Iida et al. (1967): 12.I; 18^h38^m; 34.7° N., 137° E.; 0 km; M=7.1, m=-0.7.

1945, February 10, 13:58. There was an earthquake with source off the coast of Aomori Prefecture, which caused a weak tsunami. A wave 35 cm high was registered at Hachinohe about 30 minutes after the earthquake (Iida, 1958, 1963 a,b,c,d, 1970; Hatori, 1963 b, 1970 b; Watanabe, 1964; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968; Hatori, Koyama, 1971).

Iida et al. (1967): 10.II; 4^h58^m; 40.9° N., 142.1° E.; 30 km; M=7.3, m=-1.5.

1946, December 21, 4:19. There was a catastrophic earthquake on the southwest of Japan in the Nankai area (Fig. 43). It was felt almost everywhere in the central and western parts of the country. The number of homes destroyed directly by the earthquake was 2,598; 1,443 people died. In addition, 1,451 homes were washed away by the ensuing tsunami waves.

The earthquake caused great changes in relief. According to repeated geodetic surveys and other data, the southern prominences of Shikoku Island and the Kii Peninsula (Capes Ashizuri, Muroto, Shionomisaki), rose 1/2 to 1 m, while the bulk of Shikoku Island and the Kii Peninsula, including the bays on the Pacific coast, dropped several tens of centimetres. In addition, Shikoku Island and the Kii Peninsula shifted seaward 1/2 to 2 m (Fig. 43). Slow vertical movements of opposite sign had been observed for several decades before the earthquake. After the earthquake, they revived and had great speed, but gradually

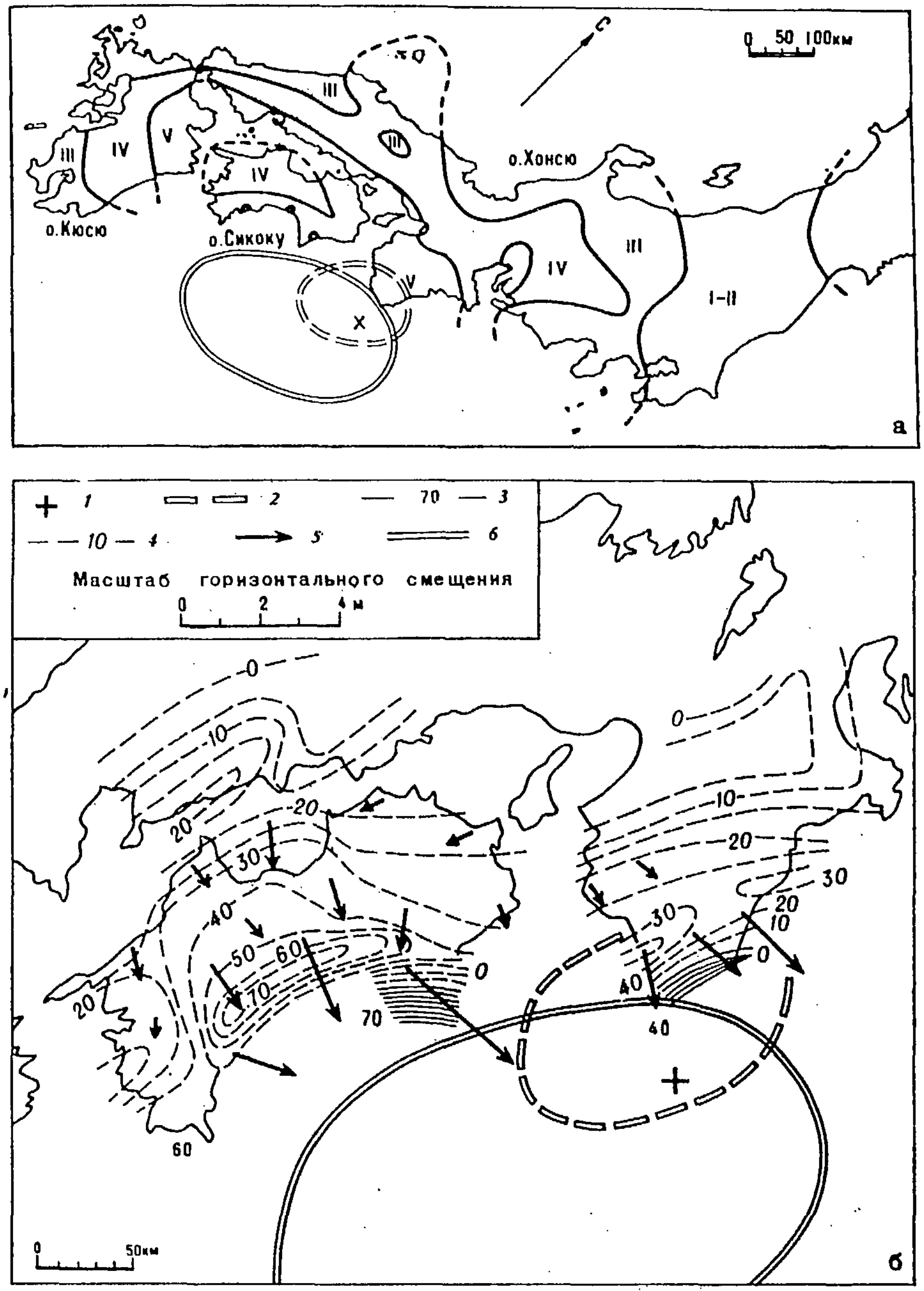


Fig. 43

The earthquake of 21.XII.1946.

(a) force of tremors on JMA scale (Hakoda, 1962)

(b) data on tectonic movements

1 - epicenter of earthquakes

2 - zone of epicenters of aftershocks on the day after the earthquake

3 - isolines and amount of residual elevation (in cm)

4 - isolines and amount of residual subsidence (in cm)

5 - direction and magnitude of horizontal displacements

6 - source of tsunami according to Hatori; plotted from data in general study by Fitch and Scholz (1971)

X - scale of horizontal displacement.

slowed down to the previous rate.

One of the nodal planes of the mechanism of the focus of the earthquake was almost vertical and parallel to the coast, the other was almost horizontal. It is assumed that the earthquake could have been caused by a gently sloping overthrust of the insular flank onto the oceanic flank.

The earthquake was accompanied by a series of aftershocks, but there were not very many. The zone of the epicenters of the aftershocks, and possibly the source of the earthquake in general, were smaller than the source of the tsunami and the zone of noticeable change in relief, which had a length of 300 km. The causes of this discrepancy have so far not been elucidated.

A sizeable tsunami rolled onto the coast of the Kii Peninsula and Shikoku Island (Table 28). The tsunami was strongest on the east coast of Kii Strait, from Fukuro to Mio, where the rise of water was 6 m. The rise was slightly less on the western coast of the strait, and increased from south to north (from 2-3 to 4.5-5 m). In Tosa Bay, the maximal rise of water was observed in the Susaki region, where it also reached 5 m, but the impact of the tsunami was considerably weaker here than in the Kii Strait.

According to visual observations, the first wave was the highest at Sinjo and Kanno'ura, while the second wave was the highest at most other points, and the third was highest far into Susaki Gulf. The wave periods were estimated visually as follows (in minutes): Cape Muroto, 3-4; Shiina, 5-6; Tosashimoda and Cape Ashizuri, 20; Komatsushima, Akaishi, Kanno'ura, 20-30; Sukumo, 40-45; Uwajima, 50-60, Usa, 60. The records for the tide gauges situated on the eastern shore of the Kii Strait, showed that the tsunami began here with an ebb, which was followed by a large rise in the water level.

The following is known about the effects of the tsunami at individual points. On both shores of the entrance to Yura Bay (at Katakui, Okui, Kashiwa and west of Kamiya), the rise of water was 2.7-2.8 m. According to residents, the tsunami advanced slowly here, and the water rose gradually; at Katakui, the sea bottom was exposed. East of the Kashiwa-Itoya line, the rise of water increased markedly, reaching 3.9 m at Yura and Fukui, and 4-4.2 m at the head of the bay. /102

At Tokushima, the water rose only 1.5 m and the incursion did no damage. The rise of water increased towards the head of Akaishi Bay, which constricts in a southwestern direction. At Komatsushima, it was only 1.7-1.9 m (possibly due to the protection of the breakwater) and at Yokosu, the water did not cross a dike 2 m high, but between Kanaiso and Akaishi, it even flowed across a dike 3 m high. At Akaishi, the water rose 2.8-2.9 m. The tsunami approached Akaishi in the form of a step, and the run-up was rather strong. No little damage was done: dikes were destroyed, homes were flooded, and different objects were carried away.

At Shishikui, partly screened from the south by a rocky cape, the rise of water on shore was 3.3 m. Protective tree stands, planted along the coast, somewhat weakened the thrust of the water, and for the most part it overflowed along the mouth of the Shishikui River. The broken surf rose up river. On the south side of this cape, the rise of water was 4.4 m. At Kanno'ura, situated somewhat to the west, the rise of water was rather high, but the coast did not suffer, except for the top of a little bay which constricts to the north. The ships in the harbor did not run aground which indicates the low speed of currents at the steep and deep shore.

At Kanno'ura and at Cape Muroto, according to accounts, the movement of the water began with an ebb tide. Muroto Port dried up as far as the breakwater. At Cape Muroto, both the rise of water and the wave periods were less than on other sections of the coast. At Kochi, a large area of the subsided shore was flooded with water, but the tsunami itself was very weak. The tsunami practically did not enter Urado Bay which has a narrow, long and very shallow entrance.

The rise of water was 4 m at Usa settlement, situated on the north shore of the entrance to the long, narrow, winding and shallow (average depth 1.5 m) Uranouchi Bay, which extends from east to west, and the rise of water was 1.2-1.7 m in the bay itself. We surmise that the direct wave and the wave reflected from the bay came together near Usa. The second and third tidal waves observed at Usa came in the form of steps on the water surface. The rate of advance of the water on land was about the pace of a pedestrian. Far into Uranouchi Bay the water rose very slowly.

At Susaki, a second tidal wave arrived before the first had retreated completely, and was evidently higher on this account. The city was hit by both the advancing and the retreating water, and the rise of water was more than 3 m. The coast at the top of the submeridional Susaki Bay (at Naogo) subsided and was flooded; the sea here first sort of "swelled up" and then a wave surged on shore. Nomi suffered considerably. The rise of water was 5 m here; the water reached the ceiling of the second floor in one of the coastal homes. /103

At Tosashimoda, where the rise of water was no more than 2 m, the tsunami passed up river in the form of a step with surf. At Tosashimizu, according to accounts, the sea floor dried up even beyond the port. The record of the tide gauge at Uwajima shows that the tsunami began here with an ebb tide.

The tsunami was registered far from the source, on the coast of the Hawaiian Islands and North and South America (Table 29, Fig. 44) (Iosida, 1947; Anon., 1946 a, 1947; Heck, 1947; Bodle, Murphy, 1948; Rothé, 1948; Imamura, 1949; Nagata, 1950; Shepard et al., 1950; Savamura, 1951; Takahasi, 1951; Shimozuru, Akita, 1952; Gutenberg, Richter, 1954; Yamaguti, 1954; Iida, 1956, 1958, 1963 a,b,c,d; Iida, Ohta, 1961, 1963; Hakoda, 1962; Takahasi, Aida, 1963; Hatori, 1963 b, 1964, 1966, 1970 b; Sagisaka, 1964; Matuzawa, 1964; Watanabe, 1964, 1968, 1970; Ponyavin,

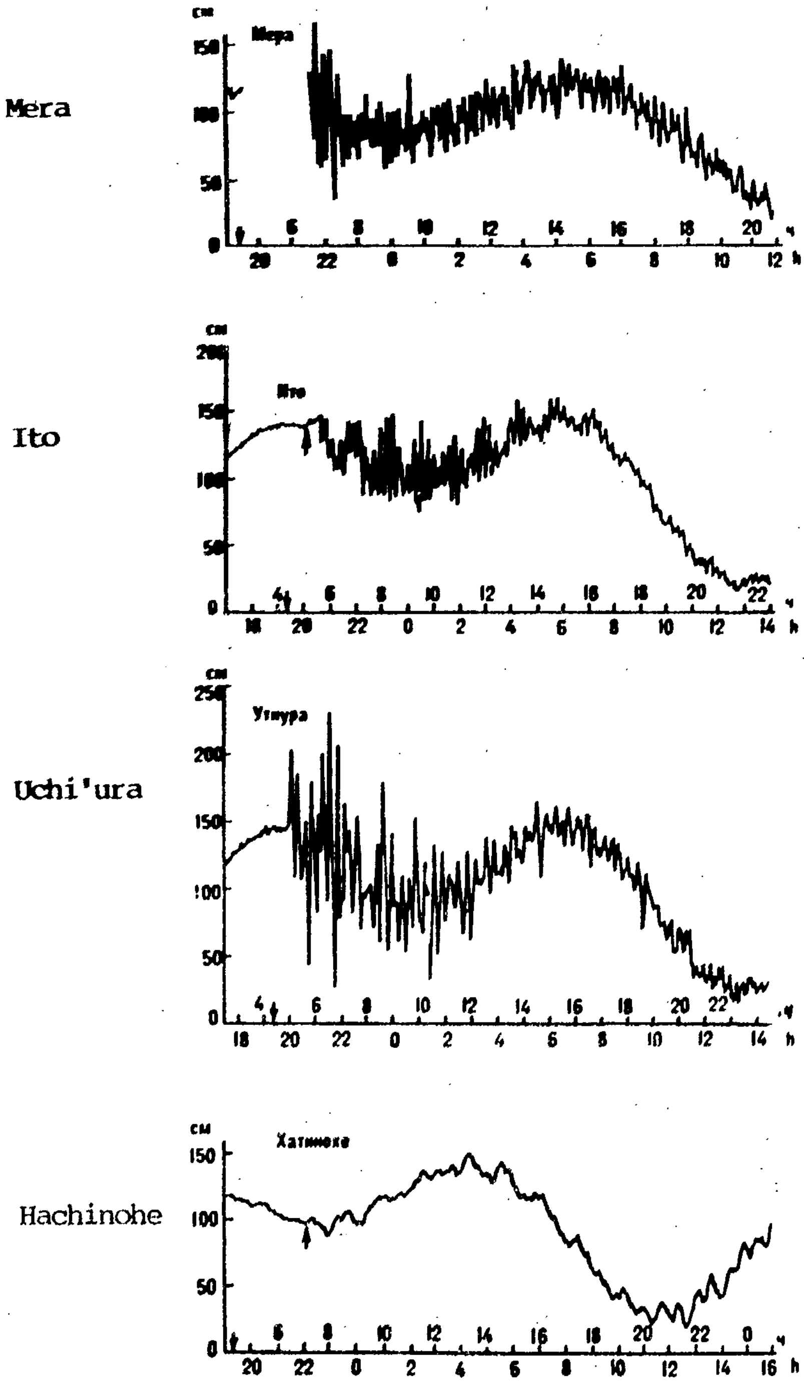


Fig. 44
Records of the tsunami of 21.XII.1946 (Shimozuru, Akita, 1952).

1965; Katsumata, 1966; Iida et al., 1967; Fitsch, Scholz, 1971; Hatori, Koyama, 1971; Kanamori, 1972; Abe, 1973).

Iida et al. (1967): 20.XII; 19^h19^m; 33° N., 135.6° E.; 30 km; M=8.1, m=2.4.

1948, April 18, 1:11. There was an earthquake in the region of the Kii Peninsula. A tsunami 50 cm high was registered at Inami (Wakayama Prefecture). It was 33 cm high at Kushimoto. The assumed travel time of the tsunami was 12 minutes to Kushimoto and 28 minutes to Owase (Iida, 1956, 1958, 1963 a,b, 1970; Ponyavin, 1965; Katsumata, 1966; Hamamatsu, 1966; Iida et al., 1967; Watanabe, 1968; Hatori, 1970 b; Hatori, Koyama, 1971).

Iida et al. (1967): 17.IV; 16^h11^m; 33.1° N., 135.6° E.; 40 km; M=7.2, m=-1.

1952, March 4, 10:23. There was a very strong earthquake on the southeast of Hokkaido Island, accompanied by a tsunami of moderate intensity. The source of the earthquake and the tsunami was situated on the shelf near Cape Erimo and was 100 km long (Fig. 45).

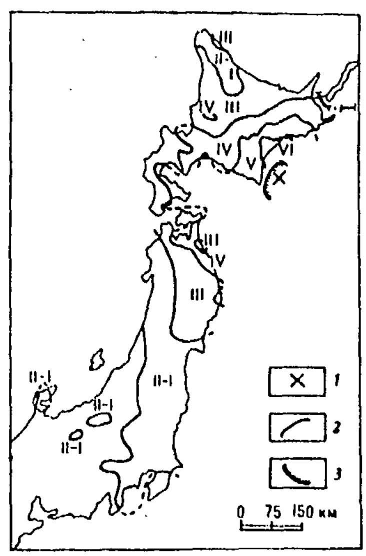


Fig. 45

Source and effects of earthquake and tsunami of 4.III.1952.

1 - epicenter of earthquake

2 - isoseismal lines of earthquake on JMA scale

3 - focus of tsunami

(Anonym, 1953).

The earthquake was felt all over Hokkaido Island and on the northeastern half of Honshu Island, and outside Japan in the Kuril Islands. The tremors reached their maximal intensity (8 degrees) (VI degrees on the JMA scale) in the swampy valley of the lower reaches of the Tokachi River (Map II).

Here, at the settlements of Ikeda, Toyokoro, Urahoro, and Ootsu, 5-15% of the homes were destroyed. Considerable destruction also occurred in the administrative regions of Tokachi, Kushiro and Hidaka, /105
where the intensity of tremors was 6-7 degrees (V degrees on the JMA scale). The oscillations lasted about 5 minutes.

Many aftershocks were registered after the earthquake; 908 were registered before the end of March, including a number of perceptible ones. During the earthquake, the southeastern coast of Hokkaido Island rose several tens of centimetres.

The tsunami was most intensive on the southeastern coast of Hokkaido Island, where the height of rise of water fluctuated mainly from 1 1/2-2 1/2 m with local intensifications to 4-6 1/2 m; on the Sanriku coast the height of rise of water varied from 1-2 m (Table 30). At Kiritappu and other places, the destruction caused by the tsunami was intensified by drift ice picked up by the waves.

The data of both near and distant tide gauges (Table 31, Fig. 46), /108
show that the tsunami began on all coasts with a flood tide, which shows the predominance of elevations of the sea bottom at the source of the tsunami. This conclusion is supported by the results of the determination of the mechanism of the source of the earthquake.

The earthquake and tsunami did major damage in Japan; 815 homes were completely destroyed, 1,324 were half destroyed, 6,395 were slightly damaged, 14 were burned, 91 were washed away, 328 homes and 1,621 non-residential buildings were flooded. Many ships were destroyed, and roads and railway lines were damaged. Twenty-eight people died, 5 people were missing and 287 people were injured.

On the south coast of Japan, west of the Boso Peninsula, the tide gauges did not register the direct tsunami waves, and they registered the marginal waves with difficulty.

The amplitude of oscillations in sea level did not exceed 0.5 m on /110
the Hawaiian and Aleutian Islands and on the coast of North and South America (Anon., 1952 a,b,c, 1953; Yoshida et al., 1952; Kato et al., 1953; Suzuki, Nakamura, 1953; Suzuki et al., 1953; Murphy, Cloud, 1954; Iida, 1956, 1958, 1963 a, 1970; Seismicity in Hokkaido..., 1962; Iida, Ohta, 1963; Matuzawa, 1964; Sagisaka, 1964; Watanabe, 1964, 1968; Katsumata, 1966; Iida et al., 1967; Hatori, 1970 b; Watanabe, 1970).

Iida et al. (1967): 4.III; 1^h23^m; 42.2° N., 143.8° E.; 45 km; M=8.1, m=2.

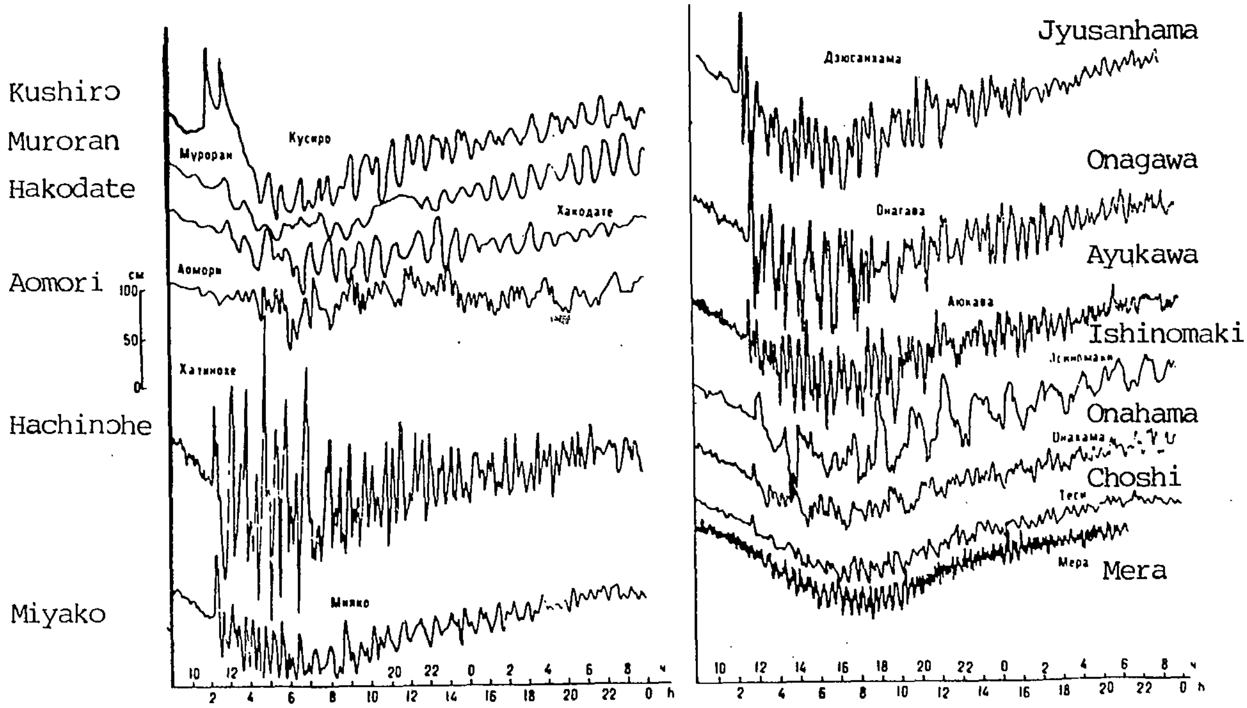


Fig. 46

Records of the tsunami of 4.III.1952 (Anonym, 1953).

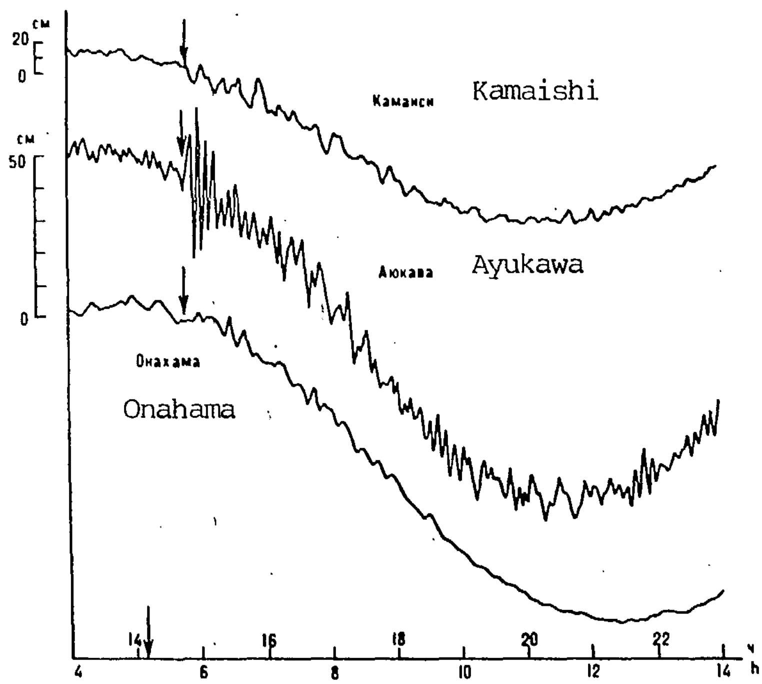


Fig. 47

Records of the tsunami of 22.I.1959 (Hatori, 1969b).

1952, March 10, 2:04. The strongest aftershock of the earthquake of March 4 affected Hokkaido Island and the northern part of Honshu Island. According to newspaper reports, there were 17 injured; 113 homes were destroyed, mainly those which had been damaged by the earthquake of March 4. The telephone line and railway service were cut.

A weak tsunami occurred, which was registered by the tide gauges at Kushiro about 35 minutes after the earthquake, at Hachinohe about 50 minutes after the earthquake and at Miyako. The height of the tsunami was 30 cm at Hachinohe (Anon., 1952 b; Iida, 1958, 1963 a,b, 1970; Watanabe, 1964, 1968; Katsumata, 1966; Hamamatsu, 1966; Iida et al., 1967; Hatori, 1970 b, 1971; Hatori, Koyama, 1971).

Iida et al. (1967): 9.III; 17^h04^m; 41.7° N., 143.5° E.; 0-20 km; M=7, m=-2.5.

1953, November 26, 2:48. There was an earthquake with source southeast of the Boso Peninsula, 60 km long (Map II). Roads were damaged on Oshima and Hachijo Islands. The residents ran to the streets in Tokyo. The earthquake was accompanied by a small tsunami, which was observed visually or registered by instruments on the coast of Sanriku, the Boso Peninsula, the prefectures of Chiba and Shizuoka, Oshima Island, the Kii Peninsula and Shikoku Island (Table 32). There was almost no destruction from the tsunami, but many boats were washed away. The maximal height of rise of water, according to visual estimates, was 3 m at Choshi, although the tide gauge registered a wave only 0.5 m high at this point. The tsunami was registered by tide gauges as far as the Hawaiian and Aleutian Islands.

A wave 0.2 m high was registered on Attu Island (Aleutian Islands) /111
4.2 hours after the earthquake. A wave was registered on Midway Island with a height of 0.1 m and a period of 12 minutes 5.1 hours after the earthquake (Murphy, Cloud, 1955; Rothé, 1955; Iida, 1956, 1958, 1963 a,b,c,d, 1970; Takahasi, Hatori, 1961; Hatori, 1963 b, 1966, 1970 b; Kasumata, 1966; Hamamatsu, 1966; Iida et al., 1967; Watanabe, 1968, 1970; Hatori, Koyama, 1971).

Iida et al. (1967): 25.XI; 17^h48^m; 34.3° N., 141.8° E.; 40-60 km; M=7.5, m=1.6.

1956, August 13, 1:59. There was an earthquake with sourcew off the Izu Peninsula. A very weak tsunami was reported, but these data were not confirmed later (Iida, 1958, 1963 a,b; Iida et al., 1967; Watanabe, 1968, 1969; Hatori, 1970 b).

Iida et al. (1967): 12.VIII; 16^h59^m; 33.8° N., 138.8° E.; 40-60 km; M=6.5, m=-1.

1959, January 22, 14:10. There was an earthquake with source off the coast of Fukushima Prefecture, which was felt in the northern part of Honshu Island. It caused a weak tsunami which was registered by tide gauges (Table 33, Fig. 47) (Eppley, Cloud, 1961; Rothé, 1961 b; Takahasi,

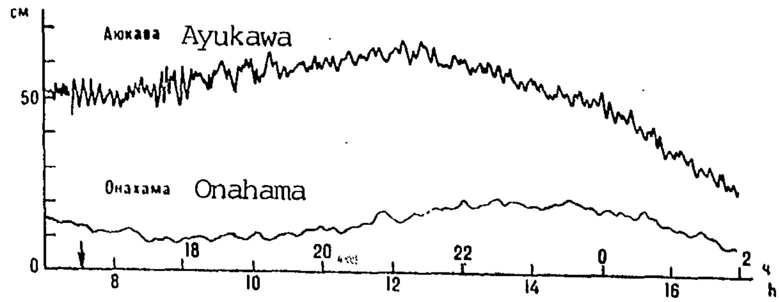


Fig. 48

Records of the tsunami of 26.X.1959 (Hatori, 1969b).

Aida, 1961; Takahasi, 1963; Iida, 1963 a,b, 1970; Hamamatsu, 1966; Iida et al., 1967; Watanabe, 1968; Hatori, 1969 b, 1970 b; Hatori, Koyama, 1971). /112

Iida et al. (1967): 22.I; 5^h10^m; 37.5° N., 142.3° E.; 30 km; M=6.8, m=-3.

1959, October 26, 16:35. An earthquake with source off the coast of Miyagi Prefecture caused a very weak tsunami (Table 34, Fig. 48) which was registered by tide gauges (Iida, 1963 a,b,c,d, 1970; Iida et al., 1967; Watanabe, 1968; Hatori, 1969 b, 1970 b; Hatori, Koyama, 1971).

Iida et al. (1967): 26.X; 7^h35^m; 37.6° N., 143.2° E.; 20 km; M=6.7, m=-3.

1960, March 21, 2:07. An earthquake with source 120 km long off the coast of Iwate Prefecture caused slight destruction. A weak tsunami arose, which was registered by tide gauges (Table 35, Fig. 49) (Takahasi, Aida, 1961; Rothé, 1962; Tally, Cloud, 1962; Iida, 1963 a,b, 1970; Takahasi, 1963; Watanabe, 1964, 1968; Katsumata, 1966; Hamamatsu, 1966; Iida et al., 1967; Hatori, 1969 b, 1970 b; Watanabe, 1970; Hatori, Koyama, 1971). /113

Iida et al. (1967): 20.III; 17^h07^m; 39.8° N., 143.5° E.; 20 km; M=7.5, m=-1.

1960, March 23, 9:30. An aftershock of the preceding earthquake caused a weak tsunami (Table 36, Fig. 50), which was registered by tide gauges (Takahasi, Aida, 1961; Iida, 1963 a,b; Takahasi, 1963; Watanabe, 1964, 1968; Katsumata, 1966; Hamamatsu, 1966; Iida et al., 1967; Hatori, 1969 b, 1970 b; Watanabe, 1970; Hatori, Koyama, 1971).

Iida et al. (1967): 23.III; 0^h23^m; 39.3° N., 143.8° E.; 20

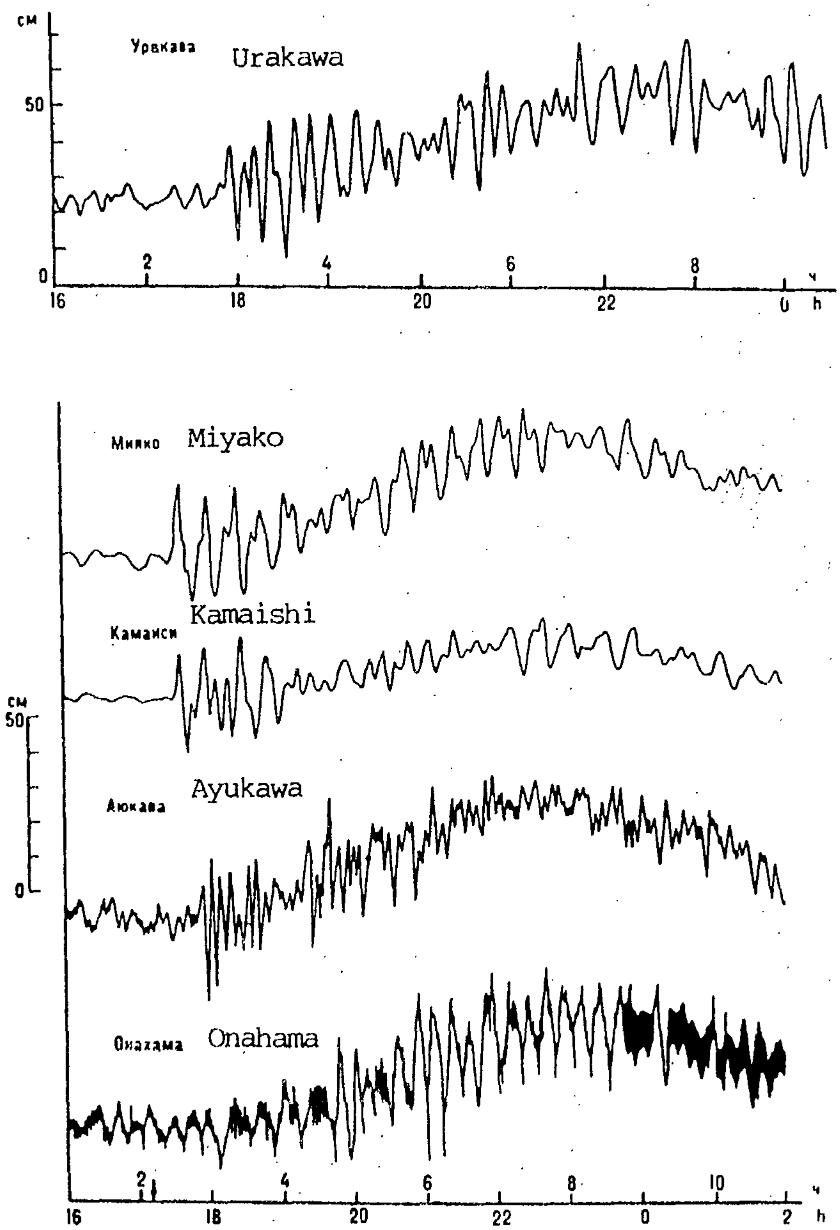


Fig. 49

Records of the tsunami of 21.III.1960 (Hatori, 1969b)

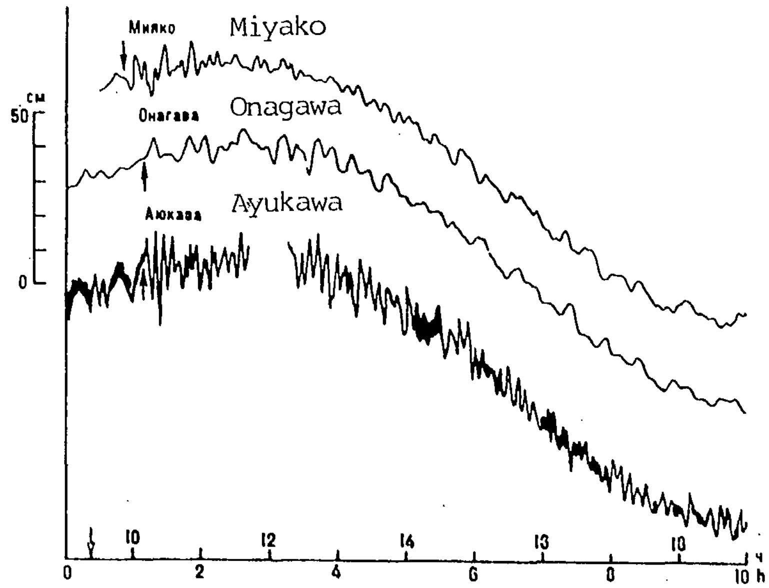


Fig. 50

Records of the tsunami of 23.III.1960 (Hatori, 1969b).

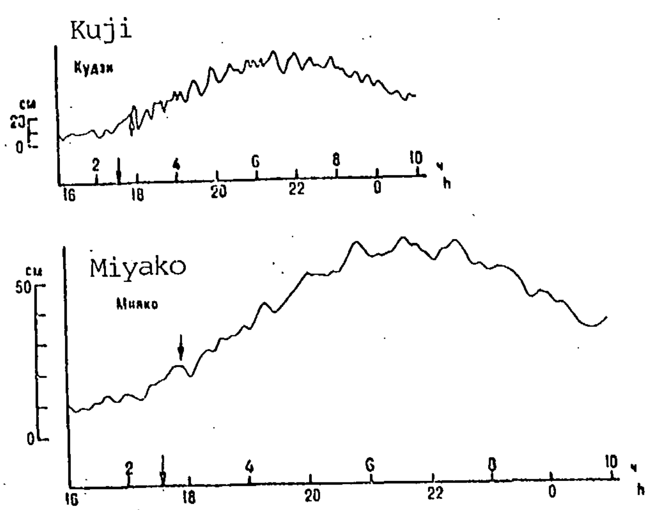


Fig. 51

Records of the tsunami of 30.VII.1960 (Hatori, 1969b).

km; M=6.7, m -3.

1960, July 30, 2:31. An earthquake occurred with source off the coast of Iwate Prefecture, accompanied by a very weak tsunami (Table 37, Fig. 51), which was barely registered by tide gauges (Katsumata, 1966; Hamamatsu, 1966; Watanabe, 1968, 1970; Hatori, 1969 b, 1970 b; Iida, 1970; Hatori, Koyama, 1971). /114

Watanabe (1968): 29.VII; 17^h31^m; 40.2° N., 142.6° E.; 30 km; M=6.7, m=-1.

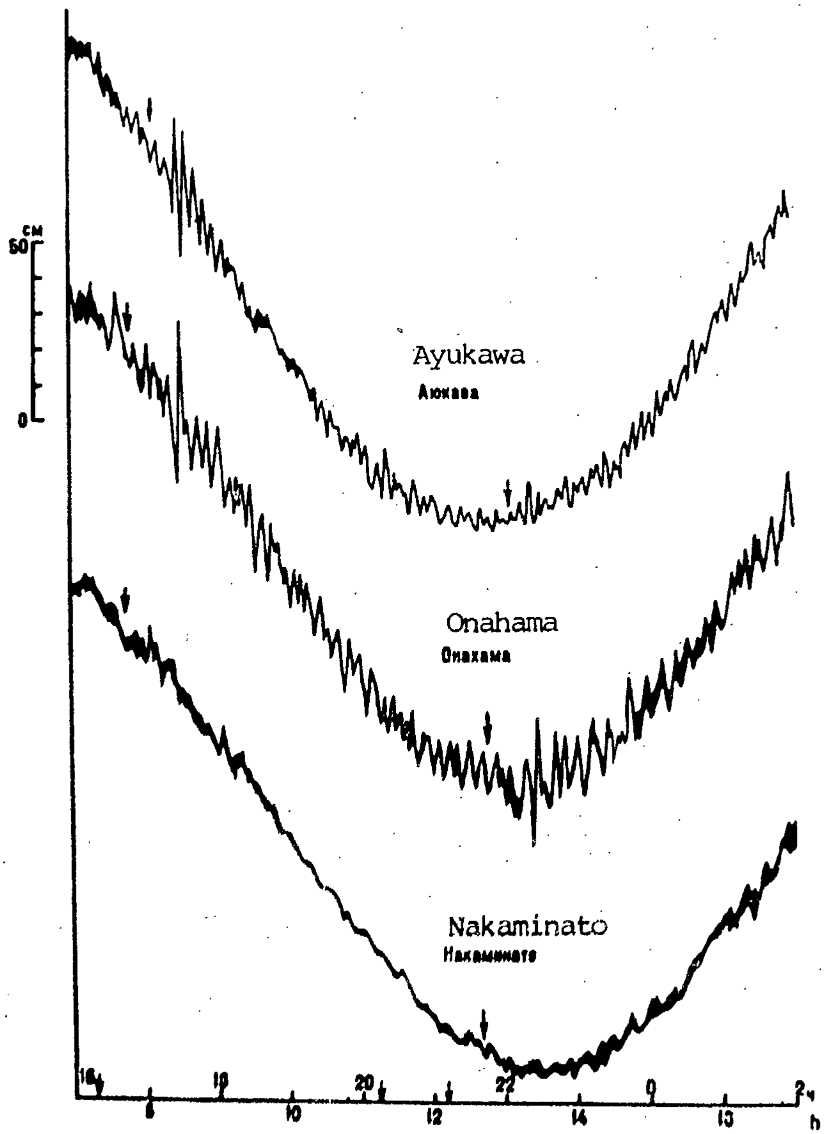


Fig. 52
Records of the tsunami of 16.I.1961 (Hatori, 1969b).

1961, January 16, 16:20. An earthquake with source off the coast of Ibaraki Prefecture was felt on the coast and was accompanied by a weak tsunami (Table 38, Fig. 52), which was registered by tide gauges (Rothé, 1964, Katsumata, 1966; Hamamatsu, 1966; Iida et al., 1967; Watanabe, 1968; Hatori, 1969 b, 1970 b; Iida, 1970; Hatori, Koyama, 1971). /116

Iida et al. (1967): 16.I; 7^h20^m; 36° N., 142.3° E.; 40 km; M=6.8, m=-2.

1961, January 16, 20:19. An aftershock of the preceding earthquake was accompanied by a weak tsunami. The wave was registered at Onahama with a height of 20 cm (Rothé, 1964; Iida et al., 1967; Watanabe, 1968; Iida, 1970).

Iida et al. (1967): 16.I; 11^h19^m; 36.1° N., 142° E.; 20 km; M=6.4, m=-2.

1961, January 16, 21:12. There was an aftershock of the earthquake at 16:20. It was also accompanied by a weak tsunami (Table 39, see Fig. 52), which was registered by tide gauges (Iida et al., 1967; Hatori, 1969 b, 1970 b; Iida, 1970).

Iida et al. (1967): 16.I; 12^h12^m; 36.2° N., 142° E.; 20 km; M=6.5, m=-2.

1961, February 27, 3:11. There was an earthquake with a source 80 km long off the eastern coast of Kyushu Island, at Hyuga-Nada. It was felt with an intensity of 6 degrees (IV JMA) in Miyazaki Prefecture and in the eastern parts of Kumamoto and Kagoshima Prefectures. It caused a tsunami, which was registered by tide gauges from the Ryukyu Islands to the Boso Peninsula and Hachijo Island (Table 40, Fig. 53). /118

The tsunami everywhere began with a flood tide, which shows the predominance of elevations at its source. According to Takahasi and Hatori, the mean period of the tsunami was 22 minutes. The energy of the tsunami, according to Hatori, was 3 X 10^{19} ergs (Takahasi, Hatori, 1961; Hatori, 1963 b, 1966, 1970 b, 1971 b; Iida, 1963 c,d, 1970; Lander, Cloud, 1963; Katsumata, 1966; Hamamatsu, 1966; Iida et al., 1967; Watanabe, 1968, 1970; Hatori, Koyama, 1971).

Iida et al. (1967): 26.II; 18^h10^m; 31.6° N., 131.8° E.; 40 km; M=7, m=-3/4.

1961, August 12, 0:51. An earthquake with source off the southeastern shore of Hokkaido Island was accompanied by a weak tsunami (Table 41, Fig. 54), which was registered by tide gauges (Katsumata, 1966; Hamamatsu, 1966; Iida et al., 1967; Watanabe, 1968; Hatori, 1969 b, 1970 b, 1971 a; Iida, 1970; Hatori, Koyama, 1971).

Iida et al. (1967): 11.VIII; 15^h51^m; 42.8° N., 145.6° E.; 80 km; M=7.3, m -3.

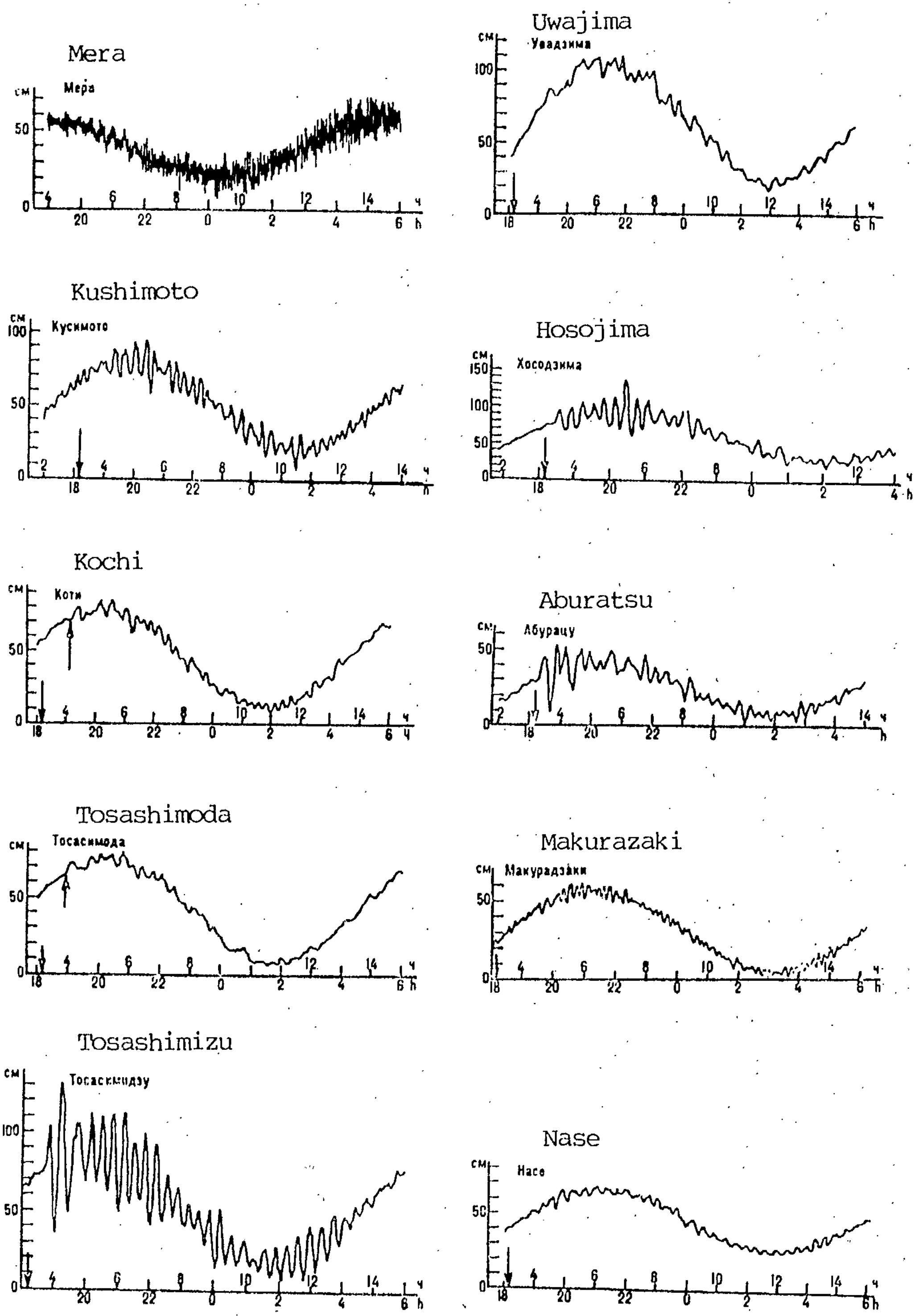


Fig. 53

Records of the tsunami of 27.II.1961 (Takahasi, Hatori, 1961).

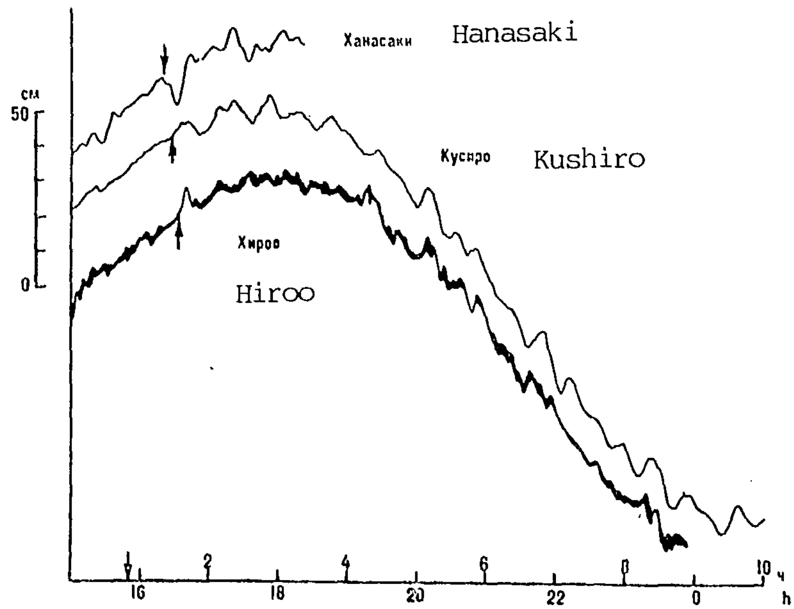


Fig. 54
Records of the tsunami of 12.VIII.1961 (Hatori, 1969b).

Fig. 55
Records of the tsunami of 15.XI.1961 (Hatori, 1969b).

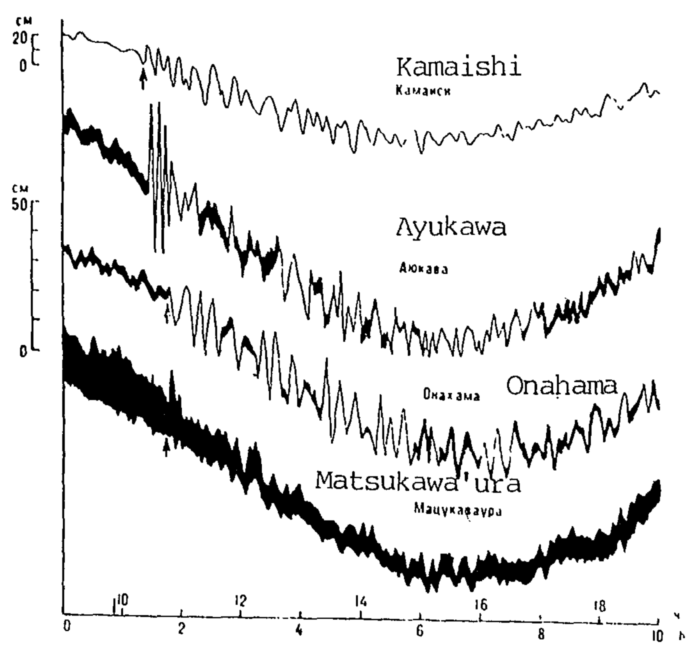


Fig. 56
Records of the tsunami of 12.IV.1962 (Hatori, 1969b).

1961, November 15, 16:17. An earthquake with source off the south-eastern coast of Hokkaido Island was accompanied by a very weak tsunami (Table 42, Fig. 55), which was barely registered by tide gauges (Iida et al., 1967; Watanabe, 1968; Hatori, 1969 b, 1970 b, 1971 a; Iida, 1970; Hatori, Koyama, 1971). /121

Iida et al. (1967): 15.XI; 7^h17^m; 42.8° N., 145.7° E.; 60 km; M=6.9, m -3.

1962, April 12, 9:52. An earthquake with source off the coast of Miyagi Prefecture was accompanied by a weak tsunami (Table 43, Fig. 56), which was registered by tide gauges (Katsumata, 1966; Hamamatsu, 1966; Iida et al., 1967; Watanabe, 1968; Hatori, 1969 b, 1970 b; Iida, 1970; Hatori, Koyama, 1971).

Iida et al. (1967): 12.IV; 0^h53^m; 38° N., 142.8° E.; 40 km; M=6.8.

1962, April 23, 14:58. There was an earthquake with source off the southeastern coast of Hokkaido Island. It was accompanied by a very weak tsunami (Table 44, Fig. 57), which was barely registered by tide gauges (Hatori, 1969 b, 1970 b, 1971 a; Iida, 1970; Hatori, Koyama, 1971). /122

[23.IV; $5^h58^m12^s$; 42.1° N., 143.5° E.; 60 km; M=6.9.]

1965, April 20, 8:42. There was an earthquake, which did light damage to buildings at Shimizu, Shizuoka Prefecture. One person died and four were injured in Aichi Prefecture. It was felt strongly at Yokohama and more northern regions. It shifted rails. Pits appeared in the highway. Soon afterwards, the tide gauges at Tagono'ura and Uchi'ura

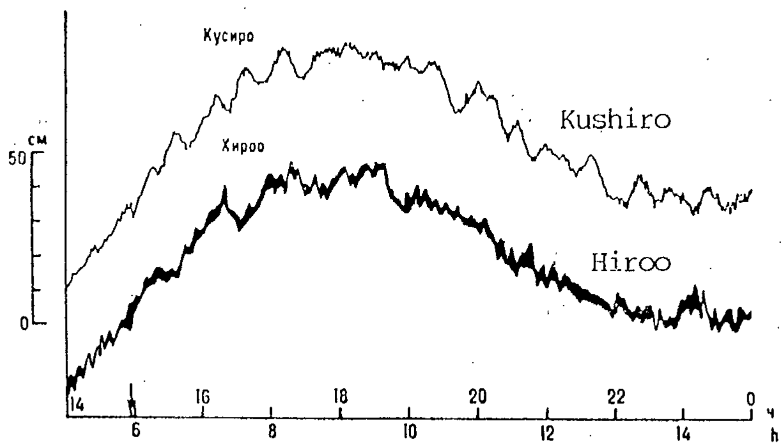


Fig. 57
Records of the tsunami of 23.IV.1962 (Hatori, 1969b).

registered oscillations in level with a height of up to 10 cm and a period of 5 ± minutes. Apparently, these were seiches of seismic origin, and not a tsunami (Hatori, 1965 b; Hake, Cloud, 1967) [19.IV; 23^h42^m; 34.9° N., 139° E.; 36 km; M=6].

1968, April 1, 9:42. There was a strong earthquake with a sublatitudinal source 60 km long between Kyushu and and Shikoku Islands. It was felt with a force of up to 6-7 degrees (V degrees on the JMA scale) in the western part of Shikoku Island and in the eastern part of Kyushu Island and caused some destruction. One person died and 22 were injured.

A tsunami of moderate intensity occurred. It reached the nearest coasts of the islands of Shikoku and Kyushu approximately 20 minutes after the earthquake. On the average, the range of the oscillations in sea level on these coasts was 2-2.5 m. The greatest rise of water, 3 m or somewhat more, was registered on Shikoku Island at Urashiri and Komame; here the water flooded across the protective dikes and caused destruction. At most points, however, the oscillations in level did not exceed the regular flood and ebb oscillations. The tsunami, on the basis of visual observations, began with a flood tide almost everywhere. The first or the second wave was the highest. As a rule, the water level rose quietly, and strong currents arose only in narrow straits. The mean period of oscillations was close to 20 minutes.

The tsunami was registered clearly by the tide gauges on the southern coast of Japan (Table 45, Fig. 58). The tsunami begins with a flood tide on all the tide gauge records. However, on the records of the instruments set up on Shikoku Island, the height of the first trough is approximately twice as great as the height of the first crest. For this reason, it has been surmised that there were subsidences of the floor in the southern part of the source of the tsunami, while elevations of the floor predominated on the whole at the source. According to Hatori, the vertical displacements of the sea bottom at the source of the tsunami /123
were about 20 cm, and the energy of the tsunami was 1.3 X 10^{20} ergs. According to Aida, a comparatively uniform elevation of the bottom by 30-35 cm took place at the source, and the energy of the tsunami was (1.4-2.2) X 10^{19} ergs. It is conjectured that the earthquake was a consequence of a gently sloping overthrust in a west to east direction.

The tsunami crossed the Bungo Strait to Setonaikai (Inner Sea of Japan), but with great losses of intensity. Thus, the maximal range of oscillations was 22 cm at Oita, 8 cm at Tokuyama.

The following is known about the particular effects of the tsunami at the points closest to the source.

Kochi Prefecture. Tosashimizu. The tsunami began 21 minutes after the earthquake with a flood tide. The first crest was maximal, and surpassed the level of the maximal diurnal flood tide by only 30 cm. The water did not flow over the wall of the moorage, but the cables snapped on the fishing ships and boats moored at the fish receiving point. The

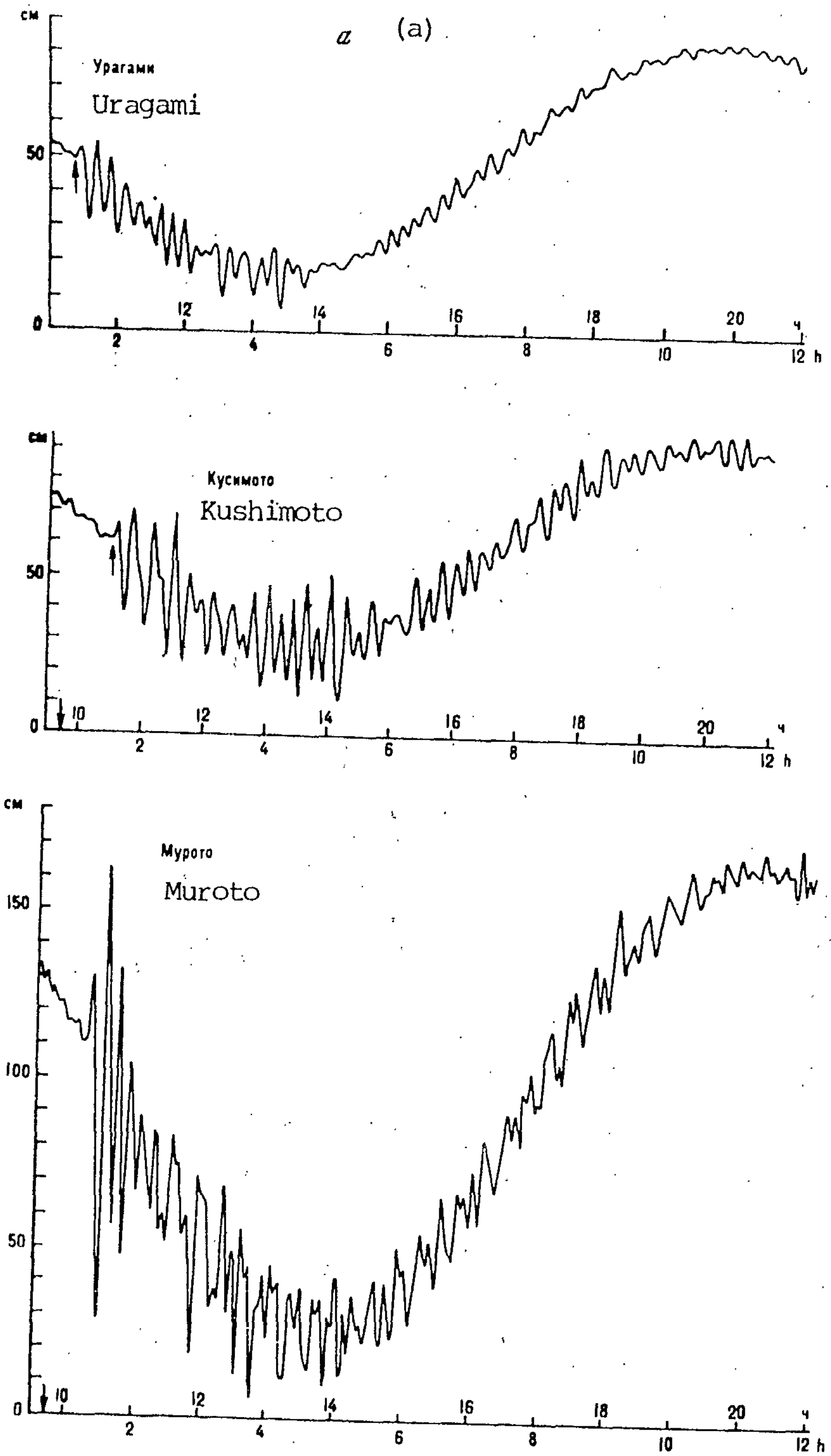


Fig. 58

Records of the tsunami of 1.IV.1968 on tide gauges on the Kii Peninsula and the east of Shikoku Island (a), on the west of Shikoku Island (b), and on Kyushu Island (c) (Kajiura et al, 1968a).

(b)

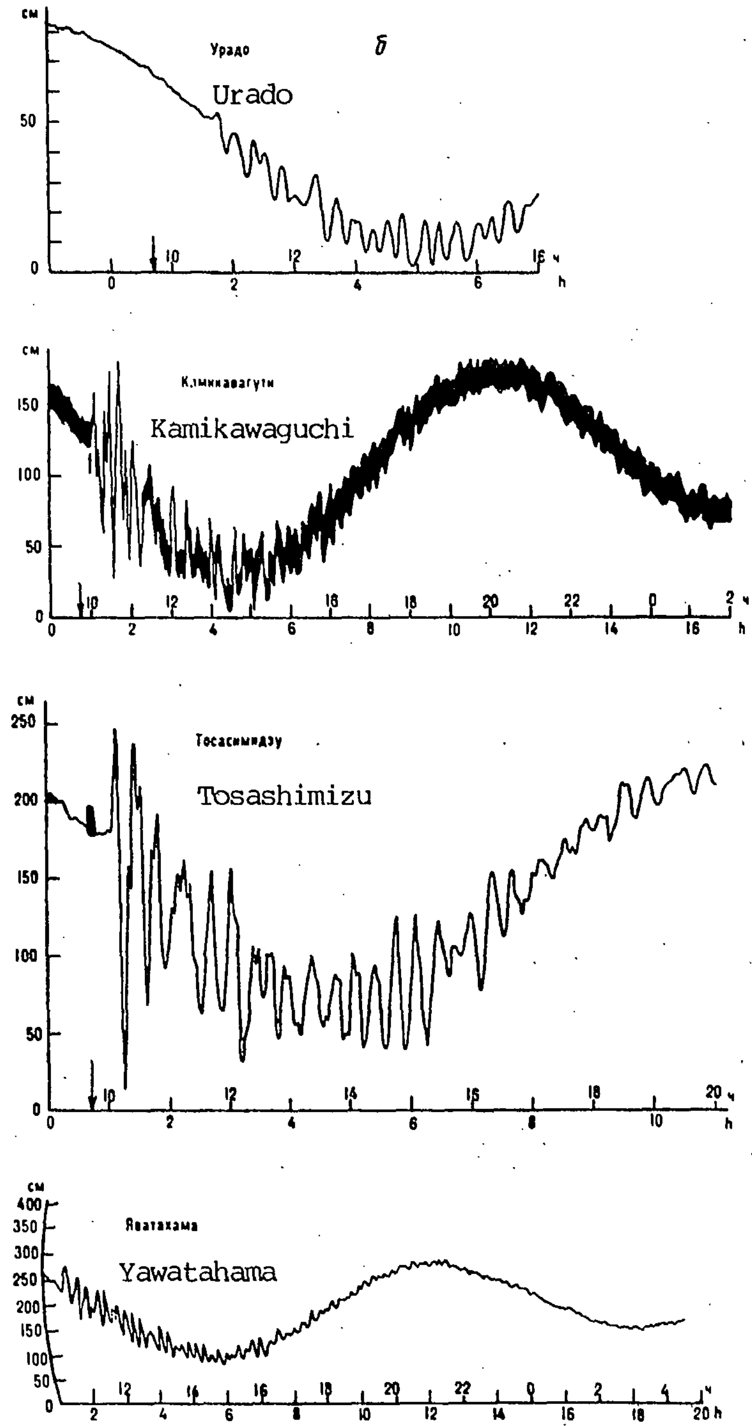


Fig. 58 (continued)

(c)

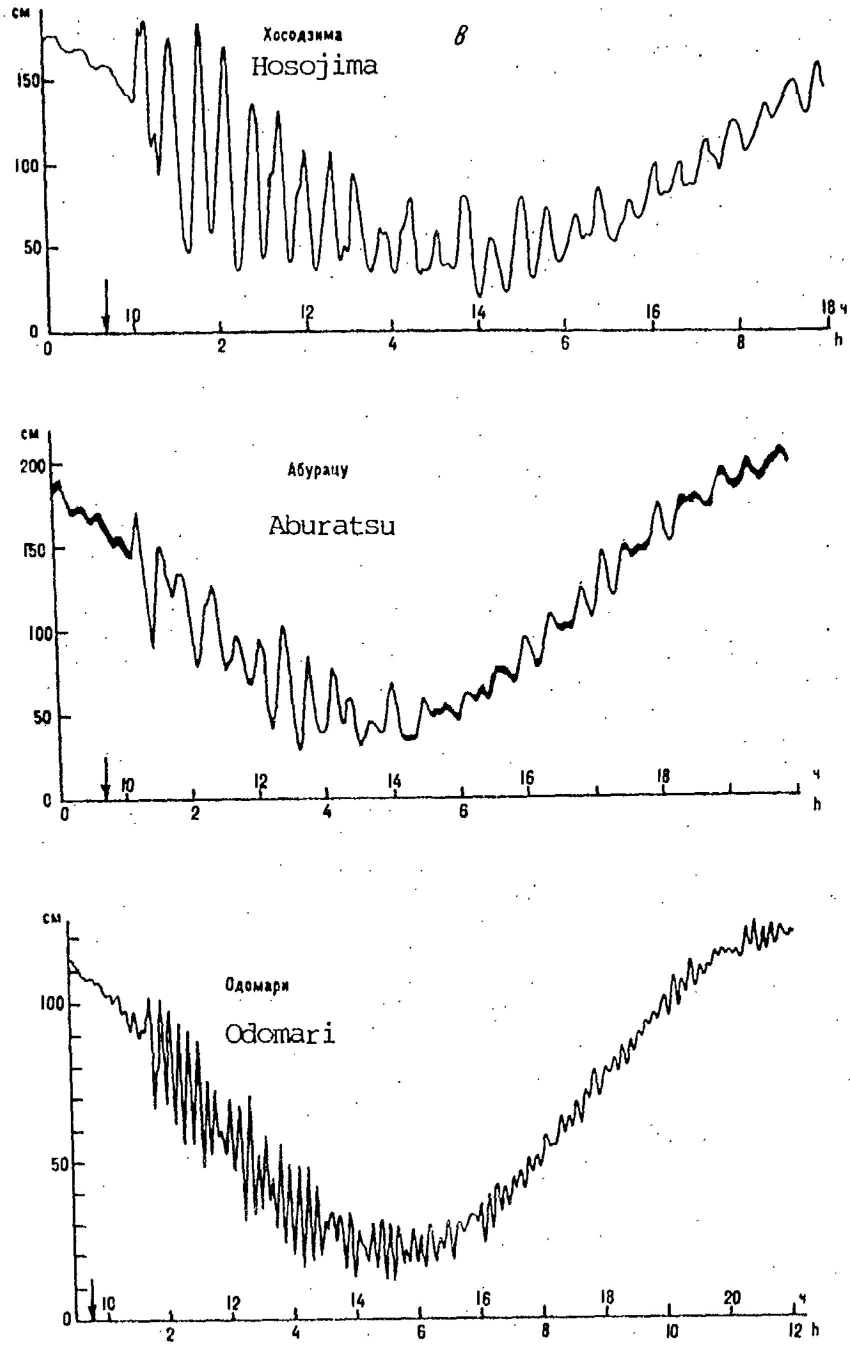


Fig. 58 (concluded)

boats were carried away by the wave, but they were able to return. During the ebb tide, the bottom of the port dried up, and a ship resting on props, whose bottom was being cleaned, fell on its side, and the metal props were bent. Outside the port, the coast dried up and one could collect flounder and squids.

Komame and Urashiri. At the fish receiving point at Komame, a /124
small fishing vessel ran aground. About 20 homes along the protective dike were flooded.

At Urashiri, situated at the top of Komame Bay, about 25 homes and 100 hectares of fields were flooded. A building standing at the mouth of the river was damaged. Many boats ran aground. At the same time, there was no destruction from abrupt impacts of waves, since the tsunami advanced gradually.

At Kasiwajima, situated next to Komame, the height of the wave surpassed the level of the maximal flood tide by 15 cm.

Ehime Prefecture. Fuka'ura and Iwamizu. At Fuka'ura, the first tidal wave appeared about 10:20. The second was the highest and surpassed the level of the maximal flood tide by 30 cm. The numerous
fishing ships in the port almost capsized during the ebb. The height of /128
rise of water in the heart of the port was 1.7 m.

At Iwamizu, some water poured over the dike, but the homes were not damaged. The height of the flood was 1.6-1.7 m, that is, it was about the same height as at Fuka'ura.

Oita Prefecture. Takeno'ura. As a result of the earthquake, the protective dike was damaged. The first wave arrived quietly at about 10:12 and was the greatest. The height of rise of water was 1 1/4 m, and the maximal range of oscillations was 2.5 m.

Kamae. According to inexact data, the water level first dropped 50 cm and then, at about 10:10, the maximal wave arrived. The water rose to the 50 cm mark on the protective dike. The residents of Yakata* Island, situated in front of Kamae, did not notice a tsunami.

In Nagoya Bay, many pearl fishing rafts were washed away. Judging by the distribution of the destroyed rafts, the tsunami approached the bay from the south.

Miyazaki Prefecture. Totoro. In Nobeoka district, an unusual flood tide was noticed at about 9:50, and visual observations were initiated at all ports. As it appeared to observers, a step formed first on the surface of the sea at the entrance to Totoro Port, and then the water flooded the shore. During the ebb, the current was very strong. The maximum rise of water was observed at 10:19 and surpassed the mean water level in the port by 2.2 m.

Hosojima. Visual tsunami observations were conducted at the old mercantile port of the city from 10:35. The maximal rise of water at 10:45 surpassed the mean level in the port by 2.3 m (Kajiura et al., 1968 a; Hatori, 1969 a, 1970 b, 1971 b; Earthquakes..., 1970; Coffman, Cloud, 1970; Iida, 1970; Hatori, Koyama, 1971; Aida, 1972).

[1.IV; $0^h42^m04^s$; 32.6° N., 132.2° E.; 40 km; M=7.7.]

1968, May 16, 9:49. There was a strong earthquake in the regions of Tokachi, Hidaka, Iburi, Oshima, Hokkaido Island and in the region of Tohoku, Honshu Island (Fig. 59). The epicenter was situated 130 km to the southeast of Cape Erimo. It was felt right up to the central part of Japan. The force of tremors reached 7 degrees (IV JMA) on Hokkaido Island and at Tohoku. Aomori Prefecture suffered most of all. Much destruction was done there. On the south of Hokkaido Island and in Iwate Prefecture, collapses on mountain sides occurred in places. A multitude of aftershocks was observed, whose epicenters were concentrated mainly along the northeastern and southeastern boundaries of the source of the earthquake.

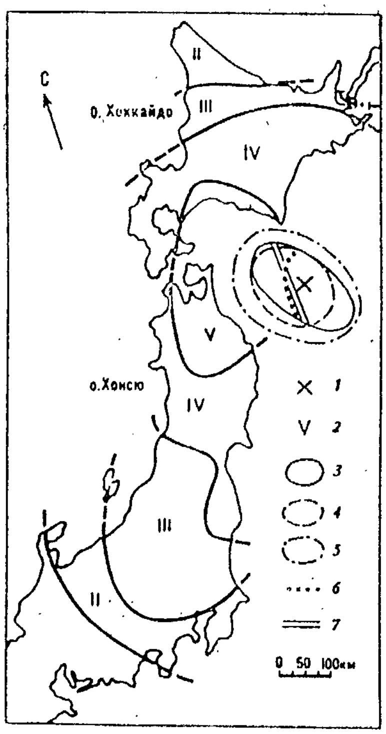


Fig. 59

Data on the main earthquake and tsunami of 16.V.1968.

1 - epicenter

2 - force of tremors (in degrees JMA scale)

3 - source of tsunami, according to Kajiura et al.

4 - the same according to Suzuki

5 - the same, according to Watanabe

6 - boundary dividing zone of subsidence and zone elevation of the sea bottom, based on seismic data, according to Kanamori

7 - the same, based on tide gauge data, according to Aida.

A tsunami (Table 46), which did not do very great damage, was observed on the coast of Hokkaido Island and the Sanriku coast after the earthquake. The limited damage is partly explained by the fact that the tsunami coincided with the ebb tide phase. The protective works built after the Chilean tsunami of 1960 also played a large role. The waves had a height of 1-2 m on the south coast of Hokkaido Island, and 2-5 m in the regions of Tokachi and Hidaka. The tsunami also reached a height of 5 m in places on the Sanriku coast. /129

As a result of the earthquake and tsunami, 52 people died and 329 people were injured; 676 homes were completely destroyed and 2,994 homes were half destroyed; 13 homes burned down and 529 homes were flooded; 97 ships were washed away and 30 were sunk. In addition, roads, bridges and protective dikes were destroyed. The total damage was estimated at least at 130 million dollars.

The tsunami was registered by tide gauges in Japan and outside of Japan (Table 47, 48, Fig. 60). The source of the tsunami, located by various authors by the method of inverse fronts, is shown in Fig. 59. It extends in a northwestern direction parallel to the coast of Honshu Island and on the whole coincides with the zone of the epicenters of the aftershocks. The source appears to be shifted to the east relative to the zone of maximal tremors. /131

An intensive flood tide first approached tide gauges which were relatively remote from the source, but an ebb tide spread first to the northwest of the source (the ebb was registered from Cape Erimo to Hachinohe). This means that in the northwestern part of the source (which made up about 22% of the total area of the source) the bottom subsided and the sea level followed, while in the central and southeastern part of the source, the bottom and the sea level rose. Aida found the approximate location of the boundary, separating the zone of subsidence and elevation of level (see Fig. 59), by analyzing different models of the source of the tsunami and comparing calculated tide gauge records with actual ones. This boundary coincides with the boundary between subsidences and elevations of the floor, determined from the observations of the network of seismic stations. /132

One of the two nodal planes of the mechanism of the source of the earthquake is vertical and coincides with the minor axis of the source (with the direction of the Hokkaido-Kuril arc), while the other plane is almost horizontal. Either a gently sloping overthrust (and a left-sided shift) of the island flank, or a steep upthrust of the oceanic flank occurred at the source. /133

The mean displacement of the surface of the sea at the source has been estimated by Abe at +82 cm in the zone of elevations, and -20 cm in the zone of subsidences. Aida estimated the maximal initial rise of water at 5 m, the drop at 2 m, and the energy of the tsunami at 4×10^{20} ergs. The maximum radiation of the tsunami, according to his calculations, was directed along the minor axis of the source, while more long-period oscillations radiated out along the major axis (Kajiura et

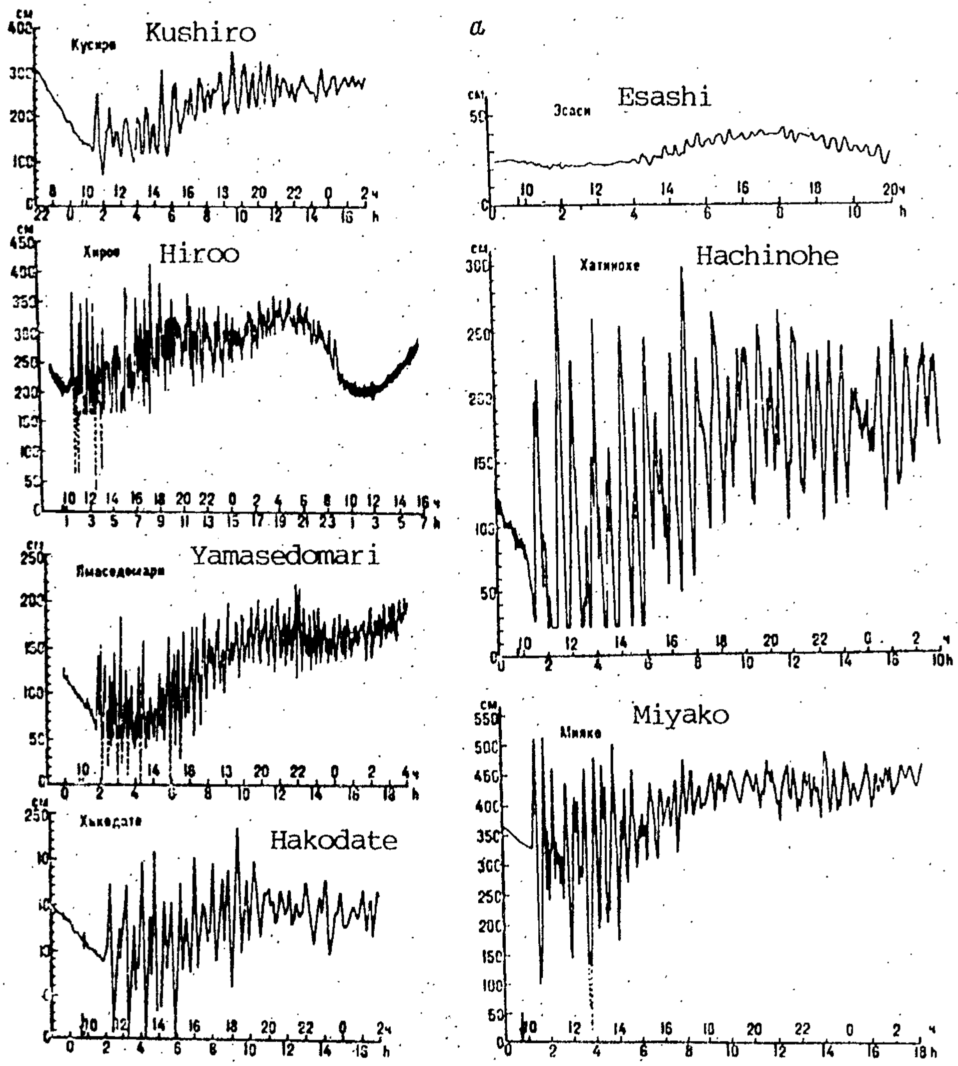


Fig. 60

Records of the tsunami of 16.V.1968 on regular tide gauges situated north and west of the source (a) and south of the source (b) and a Takahasi ERI-IV tide gauge (c) (Report ...., 1969).

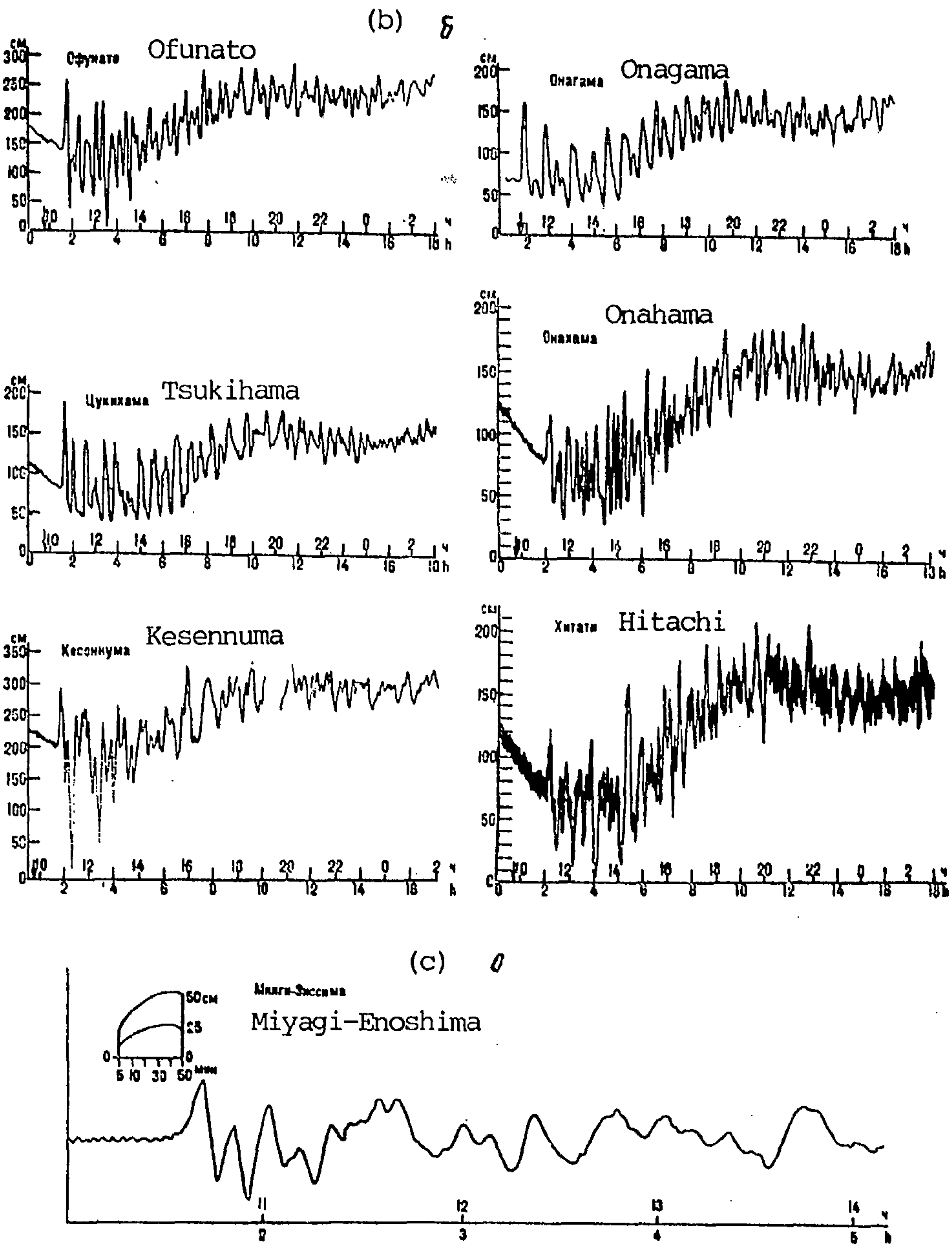


Fig. 60 (continued)

al., 1968 b; Report..., 1968, 1969; Aida, 1969; Hatori, 1969 b, 1970; Nagamune, 1969, 1971; Coffman, Cloud, 1970, Iida, 1970; Itikawa, 1970; Suzuki, 1970; Watanabe, 1970; General Report..., 1971; Hatori, Koyama, 1971; Kanamori, 1971 b; Abe, 1973). /134

[V.16; $0^h48^m54^s$; 40.9° N., 143.5° E.; M=8.2.]

1968, May 16, 19:39. The strongest aftershock of the preceding earthquake (Fig. 61) produced a weak tsunami. It was felt with a force of 7 degrees (V JMA) at Urakawa and Hiroo. Since the shock occurred 10 hours after the main earthquake, it is difficult to estimate the extent /135

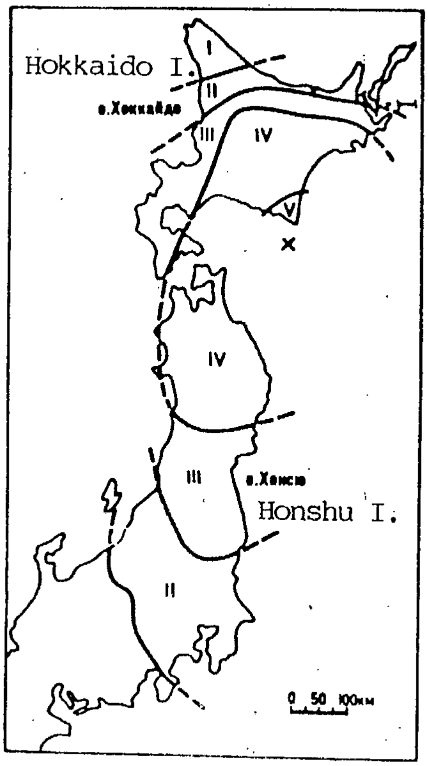


Fig. 61
Epicenter and isoseismal lines (on JMA scale) of the recurrent earthquake of 16.V.1968 (Report ....., 1969).

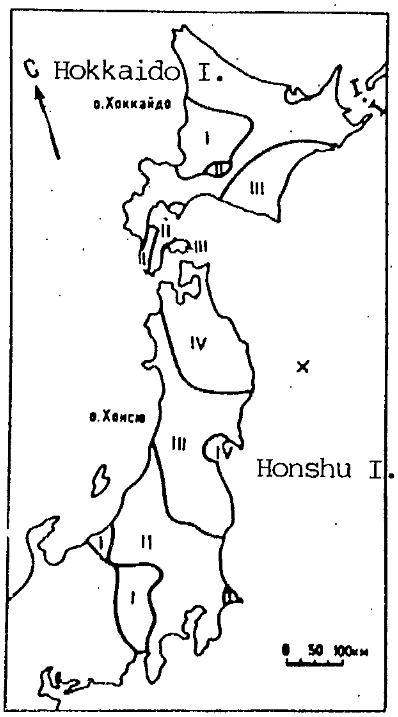


Fig. 62
Epicenter and isoseismal lines (on JMA scale) of the earthquake of 12.VI.1968 (Report ....., 1969).

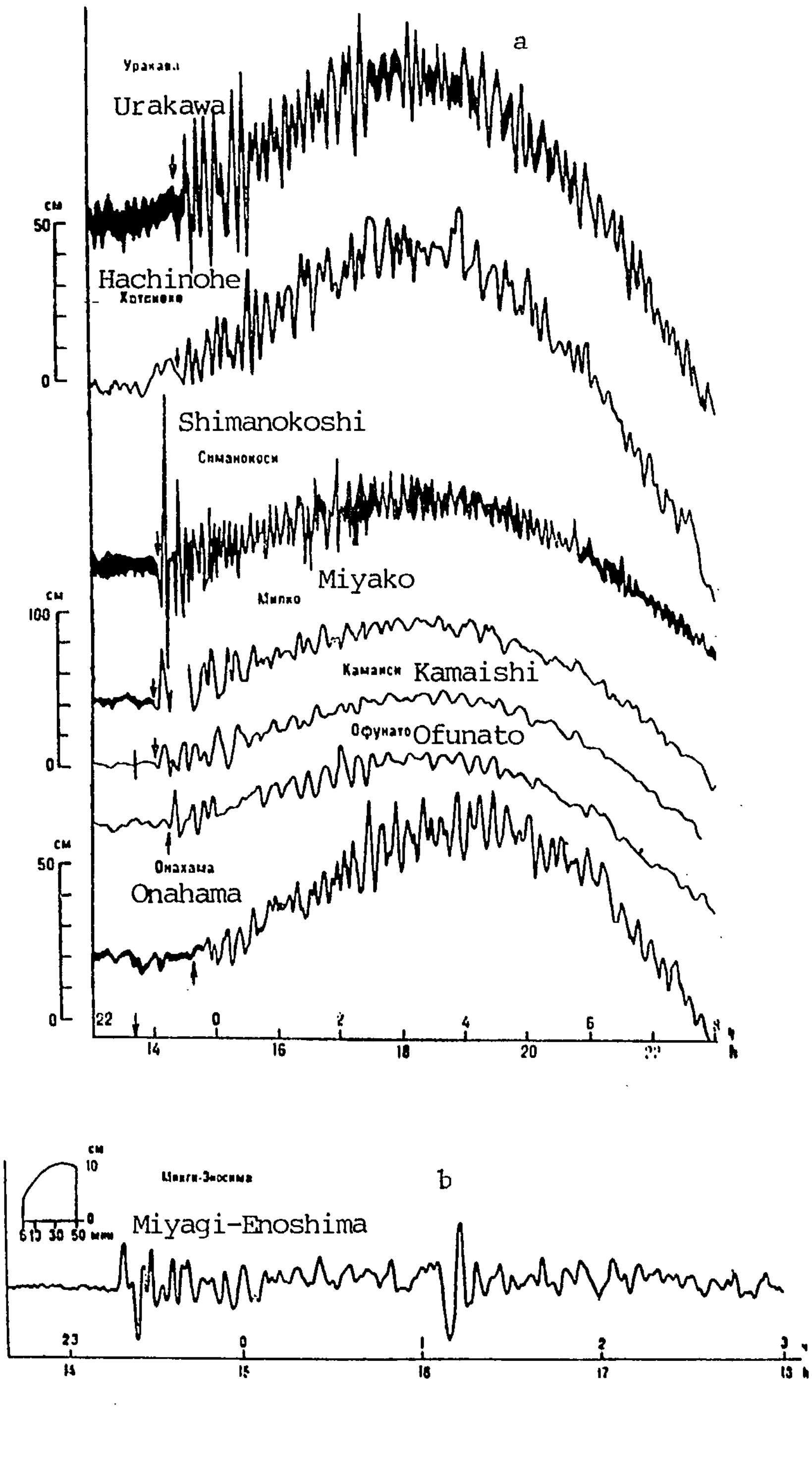


Fig. 63

Records of the tsunami of 12.VI.1968 on regular tide gauges (a) and a Takahasi ERI-IV tide gauge (b) (Hatori, 1969b).

of the destruction which it caused. The tsunami was superimposed on the preceding one. Near Cape Shiriya and on the Sanriku coast, the tsunami had a height of 50-60 cm (Table 49). The source of the earthquake and tsunami evidently extended along the coast of Hokkaido Island. The tectonic shifts at the source were opposite in direction to the movements at the source of the main earthquake (Report..., 1968, 1969; Hatori, 1969 b, 1970 b; Iida, 1970; Watanabe, 1970; General Report..., 1971; Hatori, Koyama, 1971).

[16.V; $10^h39^m00^s$; 41.6° N., 142.9° E.; 40 km; M=7.5.]

1968, June 12, 22:41. An aftershock of the earthquake of May 16 (Fig. 62), or an independent earthquake, was felt in the region of Tohoku with a force of 6 degrees (IV JMA), and was accompanied by aftershocks. The source extended along Honshu Island. The mechanism of the source was the same as in the earthquake of May 16. The tsunami which arose was observed on the Sanriku coast and was registered by many tide gauges (Table 50, Fig. 63) (NL 1968, Vol. 1, No. 2; Report..., 1968, 1969; Hatori, 1969 b, 1970 b; Iida, 1970; Watanabe, 1970; General Report..., 1971; Hatori, Koyama, 1971).

[12.VI; $13^h41^m57^s$; 39.5° N., 142.8° E.; M=7.2.]

1968, August 5. There was an earthquake near Shikoku Island. A weak tsunami of 6 cm height was registered on Wake Island (Coffman, Cloud, 1970). /137

[5.VIII; $16^h17^m05^s$; 33.3° N., 132.2° E.; 43 km; M=6.5.]

COAST OF THE SEA OF JAPAN AND THE SEA OF OKHOTSK

701, May 12. There was an earthquake in the Tango district (Map II). There was a sizeable tsunami in the western part of Wakasa Gulf and on Kamuri Island. Kamuri Island (at that time, its length was 4 km along the meridian, 2.4 km along the parallel) was almost submerged and only the mountain peak was left. The village on the island was completely submerged under water (Imamura, 1949; Musya, 1951; Iida, 1956; Iida et al., 1967; Watanabe, 1968).

Iida et al. (1967): 35.6° N., 135.4° E.; M=7, m=2.5.

850, November 27. There was a strong earthquake in the Shonai* locality (Yamagata Prefecture). A tsunami was observed on the coast of the Sea of Japan. Its source was presumably located to the northwest of Sakata near the coast and south of the source of the earthquake of 1804 (Anon., 1899 a,b; Honda et al., 1908 a,b; Omori, 1913, 1919; Heck, 1934, 1947; Takahasi, 1951; Iida, 1956; Sagisaka, 1964; Ponyavin, 1965; Iida et al., 1967; Watanabe, 1968).

Iida (1956): 39° N., 139.5° E.; M=7, m=1.

Iida et al. (1967): 39.1° N., 140° E.; M=7.9, m=1.

887, August 2, at night. There was an earthquake on the south coast of Niigata Prefecture. A weak shock was felt at Kyoto (Anon., 1899). A tsunami was observed on the coast of the prefecture after the earthquake. The water flooded a vast area on shore. Thousands of residents drowned (Honda et al., 1908 a,b; Musya, 1951; Takahasi, 1951; Katsumata, 1966; Iida et al., 1967; Kawasumi, 1968; Watanabe, 1968).

Iida et al. (1967): 37.5° N., 138.1° E.; M=6.5, m=1.

1614, November 26 (incorrectly 28). There was a strong earthquake /138
in Niigata Prefecture. Takata suffered damage, and there were many victims there. The earthquake was felt rather strongly at Odawara, and also at Kyoto. A tsunami was observed on the coast of Niigata Prefecture. There were victims (Anon. (J), 1899 a,b; Honda et al., 1908 a,b; Milne, 1912 b; Omori, 1913, 1919; Imamura, 1942, 1949; Heck, 1934, 1947; Musya, 1951; Takahasi, 1951; Iida, 1956; Matuzawa, 1964; Sagisaka, 1964; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Kawasumi, 1968; Watanabe, 1968).

Iida et al. (1967): 26.XI; 37.5° N., 138° E.; M=7.7, m=1.

1644, October 18. There was a strong earthquake in Akita Prefecture, in the region of the modern city of Honjo. A castle in the city was damaged, homes collapsed and residents died; fires broke out in the city. The earthquake had similar effects at Isizawa village 10 km southeast of the city. At Innai village, situated 20 km south-southwest of the city, according to historical records, sand and water spurted from cracks in the ground. There is a not quite authentic legend that 117 people drowned in tsunami waves at Kisakata.

Parameters of the earthquake: 39.4° N., 140.1° E.; M=6.9 (Kawasumi, 1968).

1650, December 13 (mistakenly October 31). A tsunami was observed on the coast of Fukui Prefecture. In Imamura's opinion, the waves were of storm origin (Imamura, 1942, 1949; Musya, 1951; Iida, 1956; Iida et al., 1967).

Iida (1956): m=1.

1687, July 26. A tsunami was observed on the coast of Wakasa Bay. There are no detailed data. There are no reports of an earthquake. Musya assumes that the waves were of storm origin (Musya, 1951; Iida et al., 1967).

1741, August 29/30. The volcano on Oshima Island began to erupt on August 23 (26 or 28). The Matsumae Peninsula, right up to Esasi, was plunged into darkness because of the ashfall. A second eruption occurred on August 29. There was evidently no earthquake. A tsunami probably appeared at 20:00-22:00 on the 29th. A tsunami arrived at the coast on August 30 at 5:00 and did great damage in the region of Kumaishi and Matsumae. The height of waves was more than 9 m.

On the 120 km stretch from Nebuta to Kumaishi, 1,467 people died, 729 homes were washed away and 33 homes were destroyed. Two warehouses were washed away and 25 were destroyed. There were 1,521 boats damaged.

In Aomori Prefecture, 8 people died, 82 homes and 53 boats were washed away.

Damage was done along the entire coast of the Sea of Japan; Sado Island suffered especially badly. The mechanism of the generation of the tsunami was presumably similar to the mechanism which produced the tsunami during the Komagatake eruption in 1640 (Imamura, 1921, 1942, 1949; Gondo, 1932; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Kuno, 1962; Seismicity in Hokkaido..., 1962; Sagisaka, 1964; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968).

Iida et al. (1967): 41.5° N., 139.4° E.; M=6.9, m=3.

1762, October 31, about 14:00-15:00. There was a strong earthquake on Sado Island. Stone walls collapsed, but wooden homes did not suffer. At Aikawa and vicinity, several people died in rock falls. Many cracks and sand gryphons appeared in loose ground. Strong tidal waves were observed at Ushima village, on the northeastern coast of the Island. Twenty-six homes were washed away. However, there is no certainty that this was a tsunami, since a strong easterly wind was blowing on that same day (Omori, 1913; Imamura, 1942, 1949; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Matuzawa, 1964; Sagisaka, 1964;

Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Kawasumi, 1968; Watanabe, 1968).

Iida et al. (1967): 38.1° N., 138.7° E.; M=6.6, m=1.

1792, June 13, about 16:00. A strong earthquake, accompanied by a rumble, occurred at sea near the Shakotan Peninsula. A tsunami was then observed on the western shore of Hokkaido Island.

Losses were registered only from the tsunami. Points on the eastern side of the Shakotan Peninsula that suffered included Oshoro, Takashima, Okamui*, Shakotan, Furuhira, and Bikuni. At Oshoro, a moorage was destroyed, several fishing boats were carried off, and five people died. Several people died at Bikuni (Imamura, 1942, 1949; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Seismicity in Hokkaido..., 1962; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968). /139

Iida et al. (1967): 43.6° N., 140.3° E.; M=6.9, m=1.

1793, February 8, 12:00. There was a very strong earthquake on the west of Aomori Prefecture. The source was apparently situated in the coastal region of Odose, and possibly also under the floor of the sea (Fig. 64). The earthquake destroyed 164 homes and caused a small tsunami. Twelve people died in the earthquake and tsunami.

According to chronicles, some more or less marked changes in the relief of the earth's surface occurred in the area of the source before the earthquake. In the morning, it was noted that the sea had begun to retreat, and the ground was bulging in places. The residents of Ajigasawa took this as a sign of a tsunami and began to take to less dangerous places (in the hills). However, the mountains and cliffs

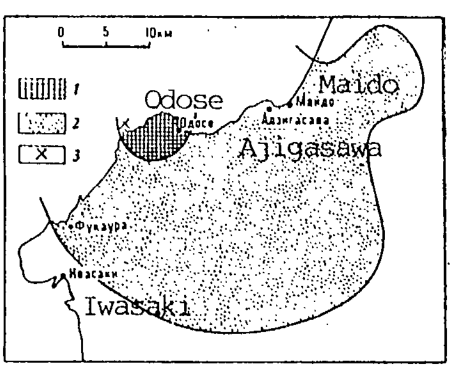


Fig. 64

Surface effect of the earthquake of 8.II.1793 (Imamura, 1921).

1 - zone of tectonic elevations

2 - approximate zone of strong tremors

3 - macroseismic epicenter.

collapsed as a result of the shock. In panic, people fled from the landslides and rolling stones to the seaside. At that time, a tsunami wave approached the coast; there were victims. It is possible, however, that all this is exaggerated. According to a later account of the effects of this earthquake, there were no victims of the earthquake at Ajigasawa.

Nanatsuishi* (eastern part of the city of Ajigasawa) suffered comparatively heavily. A wave flooded and washed away homes and fishing boats. The settlement of Maido suffered still more greatly from the tsunami. There were victims here; the bridge spanning the river fell. The sea retreated from shore on the coast of Nishitsugaru* district; children went onto the dried up part and drowned in the subsequent crest. In addition, the tsunami was strong at Kanaishawa*. The water reached the foot a large tree (age about 400 years), growing at a height of 3.6 m above sea level. The depth of the flood reached 1.5-1.8 m here (Imamura, 1921, 1942, 1949; Heck, 1934, 1947; Imamura, 1937; Takahasi, 1951; Iida, 1956; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968).

Iida et al. (1967): 40.7° N., 140° E.; M=6.9, m=1.

1799, June 29. There was a rather strong earthquake in the Kanazawa region (Isikawa Prefecture). Structures were damaged or destroyed in places. The earthquake caused a tsunami which was observed at Kanaiwa. There were many victims (Honda et al., 1908 a,b; Omori, 1913, 1919; Heck, 1934, 1947; Iida et al., 1967).

Iida et al. (1967): 36.6° N., 136.6° E.; M=6.4, m=1.

1802, December 9 (mistakenly 28), about 10:00. There was an earthquake on the southwest of Sado Island. It was accompanied by an elevation of the coast of the island on a stretch of 25 km from Cape Sawasaki in the west to Akadomari in the east. The greatest rise, equal to 2-2 1/2 m, was apparently registered at Ogi. Inside Ogi Port, the water retreated from shore and the bottom was exposed for a distance of about 100 m. The residents, frightened by the ebb tide, feared a tsunami. However, damage from a tsunami is nowhere mentioned. Apparently, /140
there were no tsunami waves, at least no strong ones, and only an elevation of the island took place, accompanied by buckling.

A very strong earthquake occurred at 14:00. It caused great destruction to homes and monuments. Ogi suffered most of all. Of 453 homes here, 328 homes were destroyed or burned; four people died in the earthquake and 14 people died in the fire. There was also destruction at Aikawa. The total damage on Sado Island, excluding Ogi, numbered as follows: 732 destroyed homes, 1,423 damaged homes (Anon. (J), 1899 a,b; Milne, 1912 b; Omori, 1913, 1919; Imamura, 1921, 1937; Heck, 1934, 1947; Sagisaka, 1964; Ponyavin, 1965; Iida et al., 1967; Kawasumi, 1968).

Iida et al. (1967): 37.8° N., 138.4° E.; M=6.6.

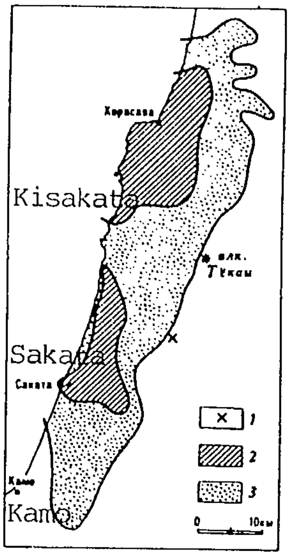


Fig. 65

Surface effect of the earthquake of 10.VII.1804 (Imamura, 1921).

1 - macroseismic epicenter

2 - approximate zone of destruction

3 - approximate zone of strong tremors

1804, July 10, about 22:00. There was a destructive earthquake on the coast of the Sea of Japan between Honjo and Sakata and on Tobi Island. It was strongest at Kisakata, where 65 people died and 423 of 523 homes were destroyed. A few kilometres to the east, southeast of Kisakata, several square kilometers of rice fields subsided 3 m. In the east, the boundary of the pleistoseismic zone included the Chokai volcano (Fig. 65). In the Yuri district (Akita Prefecture) situated to the north of the volcano, 1,200 homes collapsed and 184 people died. In Akumi district (Yamagata Prefecture), situated south of the volcano, 3,400 homes collapsed and 153 people died.

Roads and bridges were damaged, fields were spoiled, and avalanches occurred in the mountains. Three homes collapsed on Tobi Island. In the lower reaches of the Mogami River, near Sakata, the ground cracked and numerous water fountains gushed up to a height of 3 m, as a result of which the lowlands were flooded to a depth of 1 1/2 m. At the Nadicho* temple (55 km from Kisakata), the stone lamps collapsed. There was no damage at Kameda, Kakunodate and on Sado Island. At Odate, the clay walls cracked in the warehouses on the alluvial soils of the Noshiro River. It is possible that the earthquake was felt in the northern part of Chiba Prefecture.

To the north and south of the Chokai volcano, the coast rose. At Kisakata, the rise was more that 2 m. The famous picturesque bay with a diameter of 2 km with "88 gulfs and 99 islands" dried up as a result. At Kono'ura, 6 km to the north of Kisakata, the rise was 1.5 m; as a result, a small island became joined to the mainland.

The tsunami which developed did some damage to the homes near the Mogami River in Sakata. According to other sources, the tsunami waves caused by the earthquake, caused great destruction; there were many victims (Neumann, 1878; Honda et al., 1908 a,b; Omori, 1913, 1919; Imamura, 1921, 1942, 1949; Heck, 1934, 1947; Musya, 1951; Takahasi, 1951; Yamaguti, 1954; Iida, 1956; Sagisaka, 1964; Matuzawa, 1964; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Kawasumi, 1968; Watanabe, 1968).

Iida et al. (1967): 39° N., 140° E.; M=7.1, m=1.

1810, September 25, 14:00. There was a strong earthquake on the Oga Peninsula (Fig. 66). The source was apparently situated in the vicinity of the Kampu volcano, in the eastern half of Oga. The zone of destruction extended for 30 km from Funakoshi to Kurookan. There were 1,804 homes destroyed or seriously damaged, 59 people died. Large avalanches and landslides were observed; there were changes in the level of ground waters and the discharge of springs. According to doubtful data, a tsunami was observed on the coast of the Oga Peninsula (Imamura, 1921; Takahasi, 1951; Iida, 1956; Iida et al., 1967; Kawasumi, 1968; Watanabe, 1968). /141

Iida et al. (1967): 39.9° N., 139.9° E.; M=6.6, m=0.

1828, December 18, 8:00. Milne's catalogue (1912 b) states that an earthquake occurred in Niigata Prefecture and at the same time a tsunami was observed on the coast of Kyushu Island. The data are apparently in error. The Japanese sources do not mention a tsunami, but report only that a strong earthquake was felt that day at Sanjo, Mitsuke, Nagaoka, Yoita and Wakino (Niigata Prefecture). It was preceded by foreshocks. The earthquake was local; nevertheless it left about 1500 victims (Anon. (J), 1899 a,b; Omori, 1919; Sieberg, 1932; Heck, 1934, 1947; Musya, 1951; Kawasumi, 1968).

Kawasumi (1968): 37.6° N., 138.9° E.; M=6.9.

1833, December 7, 15:00-16:00. A strong shock was felt in the area from the southern part of the coast of Akita Prefecture to Sado Island, and a tsunami was observed after the earthquake. Both the earthquake and the tsunami spread to the north to Hokkaido Island, and to the south to Noto Peninsula.

The greatest destruction occurred at Karikawa (Fig. 67). Tsuruoka, Oyama, Makisone, Yosida, Okushinden, and Hironoshinden were half destroyed. At Sakata and Utokawara*, the homes were not destroyed, but some of them were damaged. In the Shonai region, in relation to the total number of structures, the destruction was very small. At Matsugasaki and other villages near Niigata, liquescence of the ground was observed. The zone of destruction and damage adjoined the coast. There was almost no destruction at a distance from the coastal zone, although the ground cracked. The tremors were rather strong on Sado

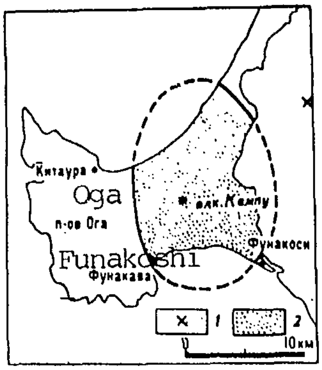


Fig. 66

Effects of the earthquake of 25.IX.1810 (Imamura, 1921).

1 - macroseismic epicenter

2 - approximate zone of destruction

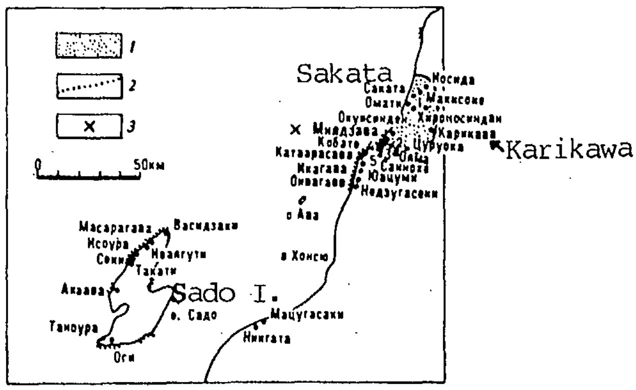


Fig. 67

Effects of the earthquake and tsunami of 7.XII.1833 (Imamura, 1921).

1 - approximate zone of destruction

2 - sections of coast on which tsunami was observed

3 - macroseismic epicenter of earthquake

The numbers denote the following settlements: 1 - Hirata; 2 - Kanazawa; 3 - Imaizumi; 4 - Aburato; 5 - Yura.

Island; homes were destroyed at different points. On Hokkaido Island, the intensity of the earthquake was probably small, since no damage was /142
reported. In all, 540 homes were totally destroyed and 1,790 were partly destroyed as a result of the earthquake. The tsunami, like the earthquake, was strongest between Nezugaseki and Kamo.

The following is known about the effects of the tsunami at particular points.

At Hakodate, during the ebb tide, the sea retreated about 2 km (?). The children began to gather fish, but the water began to rise and flooded the streets. Damage from flooding was recorded in the vicinity of Hakodate.

At Matsumae, half an hour after the shock, a strong flood 1.2 m high was observed, and was followed by an ebb. The oscillations in level lasted about a day.

On the western coast of Aomori Prefecture, it was not so much direct tsunami waves which were observed as secondary (reflected) waves and seiches, caused by the earthquake.

In Akita Prefecture, the tsunami caused destruction in the coastal part of Yuri district. At Kisakata, five people died; a temple was destroyed, sixteen homes were washed away and six homes were damaged (of 523).

In Yamagata Prefecture, in the Shonai* region, the tsunami added to the destruction caused by the earthquake. Rather heavy destruction was observed on the coast at Sakata, Omachi and other points. Fifty homes were completely destroyed at Omachi. There was also considerable destruction at Nakagawakumi*. The tsunami reached Kamo with a height of about 9 m. At Kamo, Imaizumi, Kanazawa, Miyazawa and Aburato, the tsunami did the following damage: 15 people drowned, 70 homes destroyed or damaged, 8 homes and 92 vessels washed away.

South of Sannohe and on the coast of Niigata Prefecture, the destruction from the tsunami was heavy. At Yura, Kobatao, Kataarasawa, Ikagawa, Yuatsumi, Oiwagawa and Nezugaseki, 23 people drowned, 230 homes were destroyed or damaged, 150 homes and 213 boats were washed away.

On Sado Island, the destruction from the tsunami was greater than that from the earthquake itself. The western and southern coasts suffered most, including Tano'ura and Ogi. On the entire island, the tsunami waves washed away or damaged 123 homes and carried away 20 boats. The vicinity of Takachi and Masaragawa suffered especially.

At Wajima, on Noto Peninsula, the tsunami was high enough to move homes from place to place and caused destruction.

In all, as a result of the tsunami, 360 to 600 homes (according to different sources) were washed away and about 50 people died (Anon. (J), 1899 a,b; Honda _et al._ 1908 a,b; Milne, 1912 b; _Omori_, 1913, 1919; Imamura, _1921_, 1942, _1949_; Heck, 1934, 1947; Musya, _1951_; Yamaguti, 1954; Iida, 1956; Seismicity in Hokkaido..., 1962; Matuzawa, 1964; Sagisaka, 1964; Ponyavin, 1965; Katsumata, 1966; Iida _et al._, 1967; Kawasumi, 1968; Watanabe, 1968).

Iida _et al._ (1967): 38.7° N., 139.2° E.; M=7.4, m=2.5.

1834, February 9, about 11:00. There was a strong earthquake in the region of Ishikari Gulf (Hokkaido Island). It caused cracks in buildings and minor damage. There were no human victims (Anon. (J), 1899 a,b; _Omori_, 1913; Sieberg, 1932). A tsunami was observed on the coast of Ishikari Gulf. Two or three waves were registered. About 50 homes were flooded (Honda _et al._, 1908 a,b; Heck, 1934, 1947; Iida, 1956; Ponyavin, 1965; Iida et al., 1967; Watanabe, 1968).

Iida et al. (1967): 43.3° N., 141.4° E.; M=6.4, m=1.

1863, September 20. The sea was rough at Teshio (Hokkaido Island), beginning in the day until 20:00 (Musya, 1951; Yamaguti, 1954; Iida, 1956; Iida et al., 1967).

Iida et al. (1967): M=5.9, m=0.

1872, March 14, 17:20. There was a strong earthquake in Shimane Prefecture, where Nada district suffered especially (Map II). Light damage was recorded in Nima, Ochi, Ano and Mino districts. At Hamada, which was in the pleistoseismic zone (Fig. 68), there were 543 homes damaged, 210 homes half destroyed and 168 homes completely destroyed; 92 homes burned down; 97 people were killed and 200 people were injured. In the Kanoashi district, the tremors were rather strong, but there was no destruction (Anon. (J), 1899 a,b; Omori, 1913, 1919). In all 552 people /143
died in the earthquake; about 5,000 homes collapsed.

The earthquake was preceded by foreshocks. An underground rumbling was heard four or five days before the main shock. On March 14, a rather strong foreshock was felt at about 11:00 and was also accompanied by a rumble. A second strong foreshock occurred at 16:00, another one of less force occurred an hour later, and the main earthquake struck 10 minutes later. It was associated with large changes in the relief of the earth's surface. The main fault apparently crossed Hamada, in a northeast direction. The southeastern flank, made up of Tertiary formations, rose, while the northwestern flank, made up of pre-Tertiary formations, subsided. Corresponding vertical displacements were traced for 20 km on the coast.

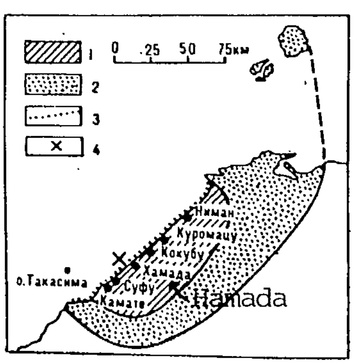


Fig. 68

Effects of the earthquake and tsunami of 14.III.1872 (Imamura, 1913a).

1 - approximate zone of destruction

2 - approximate zone of strong tremors

3 - sections of coast on which tsunami was observed

4 - macroseismic epicenter of earthquake

There are reports that the visible changes in relief and the associated changes in sea level began not long before the main earthquake.

In Hamada Bay, the water began to retreat 10 minutes before the earthquake, and exposed a passage to Tsurushima* Island, 150 m from shore. The usual depth of the sea at Tsurushima* Island is about 30 m. However, about 10 minutes before the earthquake, the depth decreased to 21-24 m. The fishermen rushed to the dried up area and began to collect fish and shellfish, until one of the old men persuaded them to take to the hills because of the danger of a tsunami.

At Aokawaguchi*, in the southern part of Hamada Bay, no change in sea level before the earthquake was recorded. But in the villages of Isotake, Yuzato (Nima District) and in the villages of Nagahama and Kokubu (Naka District), 10 km from Hamada, a reduction in the depth of the sea from 21-24 m to 6-9 m was observed before the shock.

The change in sea level before the earthquake appears to be sufficiently authentic. In particular, it is hardly likely that the fishermen would have dared to collect fish and shellfish after the shock.

After the earthquake, a tsunami was observed on the coast of three districts: Nima, Naka and Mino. It frightened the residents considerably, but did no damage.

At Niman village, the sea withdrew about 50 m. At Kuromatsu village, the sea retreated in an hour to a small island situated 100 m from shore. At Kokubu village, the sea retreated a distance of 100 m and soon returned again.

The water began to rise in Hamada Bay 10 minutes after the earthquake.

At the time of the earthquake, three fishing boats, which had come out from Hamada Bay to fish, were passing through the strait at Setogashima Island. Rocks falling from the steep cliff sank two of the boats, and the surviving boat was carried out to sea by the water leaving the bay. However, after some time, the boat was picked up by a flood tide and once again found itself in the bay.

A flood tide 1 m high was observed at Sufu* village. At Kamate village, soon after the earthquake, the water level increased 75 cm. A similar increase in level by up to 1 m was observed on Takashima Island.

There are reports that changes in sea level of this magnitude were /144
also observed during a strong aftershock of this earthquake (Omori, 1913, 1919; Imamura, 1913 a, 1942; Imamura, 1937; Heck, 1934, 1947; Takahasi, 1951; Iida, 1956; Ponyavin, 1965; Iida *et al*., 1967; Watanabe, 1968, 1969).

Iida *et al*. (1967): 34.8° N., 132° E.; M=7.1, m=1.

1892, December 9, 10:42. There was a strong shock on the northwest of Ishikawa Prefecture. A second shock occurred on December 11 at 1:30 in the southwestern part of the prefecture. During the first shock, cracks appeared in the earth's surface at Takahama. Homes were destroyed at Takahama and Hiuchitani. During the second earthquake, two homes were destroyed and six people died at Horimatsu.

A tsunami was observed on the coast of Isikawa and Toyama Prefectures. The sea retreated for a while, but soon everything was back to normal (Kodaira, 1937; Iida, 1956; Ponyavin, 1965; Iida et al., 1967; Watanabe, 1968).

Iida et al. (1967): 9.XII; 1^h42^m; 36.4° N., 136.3° E.; M=6.5, m=0.

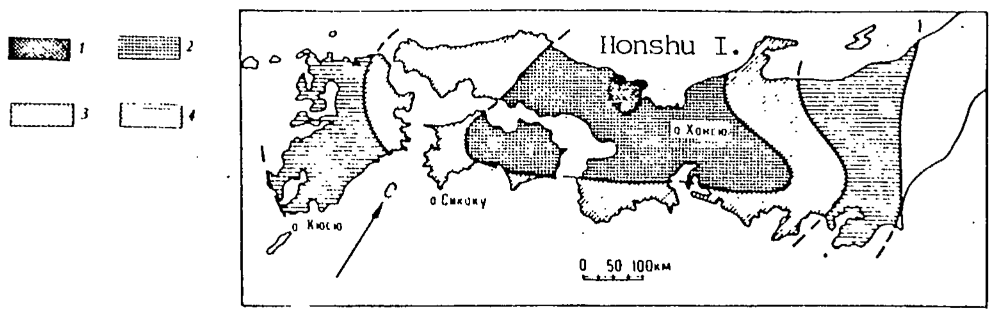


Fig. 69

Surface effect of the earthquake of 7.III.1927 (Imamura, 1928).

Gradation of tremors: 1 - very strong; 2 - strong; 3 - moderate; 4 - weak.

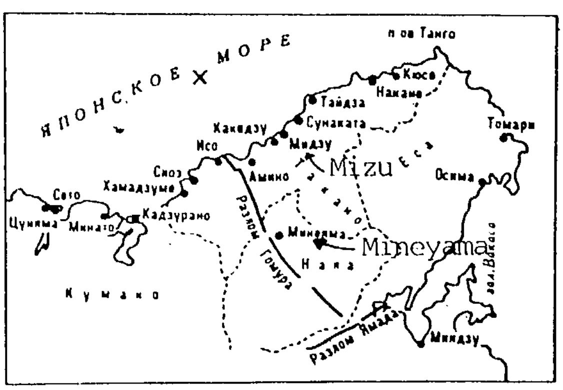


Fig. 70

Revived fractures in the focal zone of the earthquake of 7.III.1927 (Imamura, 1928). The epicenter of the earthquake is shown according to Richter (1963).

1927, March 7, 18:30. There was a catastrophic earthquake in Kyoto Prefecture on Tango Peninsula (Fig. 69). This earthquake was a result of the displacement of the Tango peninsula block to the northeast and the tilting of the block. The faults, bounding the block on the southwest and the southeast, revived (Fig. 70). Along the first of these, the Gomura fault, the relative horizontal displacements of the blocks were 250 cm and the vertical ones were 70 cm; along the second, Yamada fault, the vertical displacements were 470 cm and the horizontal ones were 80 cm. The length of the fresh Yamada fault which was traced on land was 7.5 km, that of the Gomura fault (which represents a series of linked smaller faults) was 18 km. However, the latter, as follows from the results of the echo sounding of coastal waters and the distribution of the focuses of the aftershocks of the earthquakes, undoubtedly continued along the sea floor for another 35 km from shore. It is precisely here, by combined analysis of observations of close and far stations, that the epicenter of the earthquake was established (Fig. 70). The displacements of the flanks of the fault were apparenly greater on the bottom than on land. Ships off the coast felt a strong seaquake. The passengers on a small boat at Shioe felt like they were being tossed up in the air. The Gomura fault was apparently the main fault of the earthquake, and eyewitnesses related that the Yamada fault was formed after the strong tremors had begun in this locality.

The earthquake did great damage in the epicenter zone, which is one of the centres of the silk weaving industry of the country; about 3,000 people died (Table 51). It seems that Mineyama suffered especially. Here, 988 out of 998 homes completely collapsed or burned down; 1,122 people died. Sixteen fires broke out in the city in the first 10 minutes after the earthquake.

According to fishermen, at Mizu (6 1/2 km northeast of the Gomura fault), 2 1/2 hours before the earthquake, the sea level dropped 1.2-1.5 m and the bottom of the harbor was partly exposed. This situation lasted until the earthquake. At Shioe (4 1/2 km southwest of the fault), fishermen noted a small rise of water, about 15 cm, less than 30 minutes before the earthquake. At Tsuiyama, according to a tide gauge record, the sea level was 4-6 cm higher than usual on the day of the earthquake, /146
possibly, however because of a strong northeastern wind.

After the earthquake, different parts of the coast rose and fell in accordance with the general nature of the tectonic movements. West of the Gomura fault, the shore rose 80 to 20 cm on a 9 km stretch while it rose only 10-15 cm east of the fault. At Tsuiyama, the tide gauge record showed that the shore rose 5 cm immediately after the start of the earthquake.

The earthquake apparently caused a small tsunami, which was observed in the region of the Gomura Fault. The data on the occurrence of the tsunami at particular points are presented in Table 52.

The maximal range of the oscillations in sea level, according to accounts, was 2-2.4 m at Taiza. At Mizu, a slow flood tide began after the earthquake and the water gradually reached its usual mark. Two hours after the earthquake, the water rose 0.6 m above its usual mark. The sea returned to its normal level the next morning. At Shioe, after the earthquake, the water rapidly retreated so far from shore that the base of the reefs at the entrance of the harbor was exposed. Then the water gradually returned, but did not reach its previous level.

Ten minutes after the earthquake, the tide gauge at Tsuiyama registered the arrival of a tsunami with an amplitude of 27 cm (Fig. 71). Five "separate tsunamis" were registered, each succeeding one weaker than the preceding. The period of the waves was 12 minutes, which coincides with the period of seiches in Tsuiyama Bay. The oscillations stopped in 3 hours (Imamura, 1928; Heck, 1934, 1947; Davison, 1936; Imamura, 1937; Richter, 1963; Ponyavin, 1965; Iida et al., 1967; Watanabe, 1968; Hatori, 1970 a,b; Iida, 1970)[1].

Iida et al. (1967): 7.III; 9^h27^m; 35.6° N., 135.1° E.; 10 km; M=7.5, m=0.4. /147

Richter (1963): 35.75° N., 134.75° E.

1939, May 1, 14:58. There was a very strong earthquake on the Oga Peninsula (Akita Prefecture). Homes were destroyed on most of the peninsula; 479 homes completely collapsed, 27 people died and 52 were injured. Noticeable deformations of the ground occurred; landslides and avalanches were observed at many places in the mountainous locale. The peninsula rose; the maximal rise (44 cm) was observed on its western coast. This was the strongest earthquake in this region since 1810.

According to the seismic station at Akita, the earthquake consisted of two shocks. The second shock occurred about 1 minute 40 seconds after the first and apparently was somewhat stronger. Both shocks were also clearly registered on the tide gauge record at Tsuchizaki, west of Akita.

After the earthquake, a tsunami was observed on the coast of the Oga Peninsula. Besides the tide gauge at Tsuchizaki, the tsunami was registered at three other stations: Noshiro, Ajigasawa, and Sakata (Fig. 72, Table 53).

The source of the tsunami was sketched from these observations by the method of reverse fronts (Map II). A semicircle, fringing the Oga Peninsula about 2 km from the coast of the peninsula, was obtained.

One can assume, therefore, that the tsunami arose either as a result of the collapse of coastal rocks, or as a result of oscillations

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[1] The Tango earthquake and the Tajime earthquake which preceded it in 1925 were studied in detail by the members of the Seismological Institute of Tokyo University and other organizations. At least 50 papers have been published, a list of which is given in Davison's book (Davison, 1936).

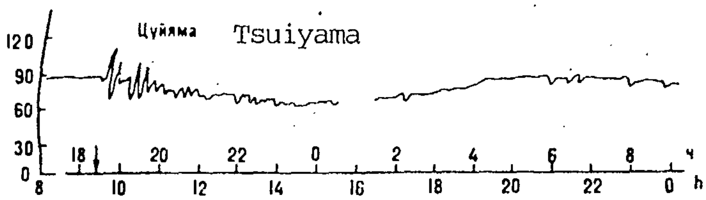

Fig. 71

Record of the tsunami of 7.III. 1927 (Imamura, 1928).

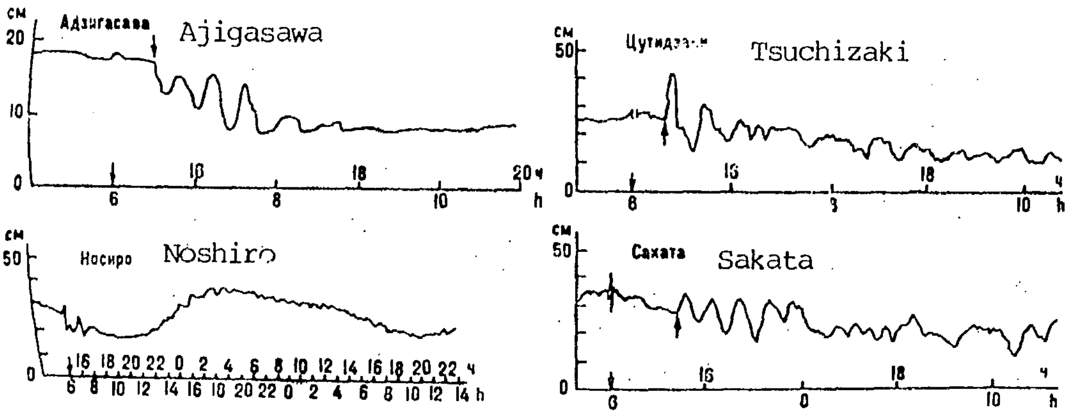

Fig. 72

Records of the tsunami of 1.V.1939 (Kisinoue, Iida, 1939).

of the peninsula as a whole, or as a result of a change in the relief of the sea floor adjoining the peninsula.

The data of visual observations of the tsunami are given below.

At Yasuda, after the shock, the residents watched the sea for a tsunami. However, nothing unusual was noted. /148

At Hamamaguchi, after the shock, the sea first retreated and then rose. About an hour later, the water flooded the shore to a distance of 12-13 m. Oscillations in level were also noticeable on the following day, during the aftershocks.

According to a fisherman from Aikawa, the tsunami appeared in the hour after the earthquake (he did not remember the exact time); when he landed the boat, he noticed that the water had turned white for a distance of 400-500 m, and that the level had fallen about 30 cm; then the boat seemed to rise above the land. In 5-10 minutes, the sea returned to its previous state.

At Kita'ura, during the earthquake, a coastal cliff collapsed; fragments fell into the sea. Water flowed over the protective dike. However, the sea soon returned to its previous condition.

At Yushiri, according to a fisherman, it was noticed soon after the shock that the sea level had fallen 2 $\pm$ m, and after 4-5 minutes it rose 0.9 m. This flood and ebb recurred two or three times. Before the earthquake, the fish catch had been good, but it was very poor after.

At Nishikurosawa, the water retreated about 20-30 m immediately after the first earthquake. The second shock occurred at this time. The returning water again retreated. The sea did not return to normal for a long time. Some said that it calmed down in 2 hours, others said it did not calm down until noon of the next day.

At Usawa, a cliff on shore collapsed during the shock and rocks fell very noisily into the sea. The water began to retreat a bit. A tsunami panic arose.

At Kohama, the water level fell 0.9 m following the shock, and then rises and falls in level recurred. The sea calmed down by morning.

At Hataka, after the first shock, the water retreated noisily about 10 m (in places 3 m), and the sea level fell 0.4-0.6 m. After this, floods and ebbs recurred two or three times, and the sea did not return to its previous condition until evening.

At Toga, during the earthquake, the water retreated 9-10 m, and the level fell 0.4 m. After each aftershock, the water seemed to continually retreat from shore. Although the weather was clear and still, the sea was rough until evening.

At Hamashioya, the water retreated about 1 m from shore immediately after the shock. The sea calmed down by evening of the next day.

At Hamanaka, the water level fell about 1 m after the earthquake. The children climbed up on a cliff, which is usually in the water, without getting their feet wet. The sea returned to normal in a week.

At Shiohama, some time after the shock, the sea retreated a distance of 7-9 m, and the level fell 0.6 m. The oscillations in sea level recurred several times, but the sea calmed down completely by the following day. The water temperature rose in the hot springs near the coast after the earthquake.

At Shiodo, the sea retreated 7 m. After this, oscillations in level recurred in the form of flood and ebb tides.

At Kanagasaki (region of a hot spring), the sea retreated, and the water level dropped 0.3-0.5 m. No change at all was noticed in the temperature of the spring.

At Kamo, the earthquake occurred during an ebb tide. No retreat of the sea was noticed during the first shock. However, during the second shock, the level of the water fell 0.6 m, the sea retreated about 3 m, and oscillations in level were observed after some time. The sea was restless for two or three days.

At Tsubaki, the first shock was weaker than the second. During the first shock, the water level rose 0.9-1.2 m, and then the sea retreated 1.5 m. A tsunami was expected, but no strong tsunami was observed. Slight oscillations in sea level were all that was noticed. /149

At Onagawa, according to a fisherman, the first shock was weaker than the second. During the second shock, the sea retreated about 3 m. After this, no large wave was observed, but only slight oscillations in level.

At Masukawa, the water began to advance noisily during the earthquake. Then the sea retreated. Nothing special was observed after this. However, the people feared a tsunami and spent a night on the mountain.

At Minamihirasawa, 15 minutes after the shock, the water level fell 0.6-0.9 m and the bottom was exposed. After this, the water level rose and fell two or three times. The sea level rose during each aftershock.

At Hadachi, the sea retreated a large distance two or three days before the earthquake. During the earthquake, the bottom dried up once again, but the sea returned to normal after a while.

On Cape Oppa (near Wakimoto), according to some people who were gathering seaweed, at about 15:00 on the day before the earthquake, some sort of sounds were heard, and in the evening, shellfish, octopuses, trepangs, crabs, assorted fishes, eel grass and kelp were washed up on shore by the waves. The next day, two men and three women were on the shore near the cliff during the earthquake. They were gathering kelp. One of the women related that first the sea began to retreat and the bottom was laid bare for a large distance. They had no time to realize that this was a tsunami, when they heard the noise of approaching water. When they began to ascend, they felt the ground oscillating and then the cliff collapsed; one of the women died in the avalanche. It fell dark because of the dust raised. The people felt their way along, and after a while they noticed that they were in the water.

At Wakimoto, octopuses, trepangs, and kelp were washed up on shore on the eve of the earthquake. After the shock, the water retreated 3.5 m, and then it began to rise and left traces for a distance of 30 m from shore. No change in the state of the sea was noticed in the evening (Kisinoue et al., 1939; Kisinoue, Iida, 1939 a,b; Rothé, 1939; Tanaka, 1939, 1940; Sagisaka et al., 1940; Imamura, 1949; Takahasi, 1951; Yamaguti, 1954; Iida, 1956, 1958, 1963 a,b, 1970; Ponyavin, 1965; Hatori,

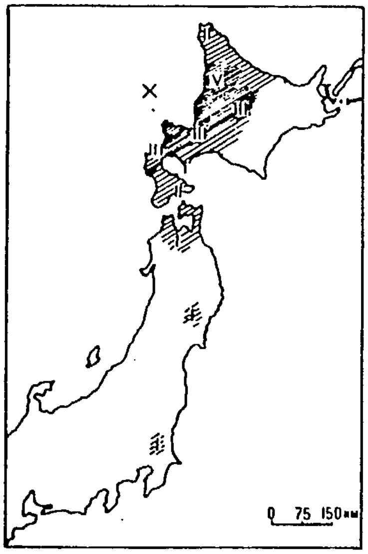

Fig. 73.
Epicenter and perceptibility in Japan (on JMA scale) of the earthquake of 2.VIII.1940 (Anonym, 1940b).

1963 b, 1966, 1970 a,b; Katsumata, 1966; Iida et al., 1967; Kawasumi, 1968; Watanabe, 1968.

Iida et al. (1967): 1.V; 5^h58^m; 39.95° N., 139.8° E.; 0 km; M=7, m=-0.7.

1940, August 2, 00:08. A rather strong earhquake was felt all over the western part of Hokkaido Island and at a number of points on the Soviet Primor'e+ (Fig. 73), and then tsunami waves were observed all along the coast of the Sea of Japan, including the coast of the USSR.

On Hokkaido Island and the north of Honshu Island, the earthquake was strong at Haboro, rather strong at Sapporo, Asahigawa and Sutstsu, moderate at Hokadate and Wakkanai, and weak at Muroran, Aomori, Mizusawa (Iwate Prefecture) and Tsukubasan (Ibaraki Prefecture).

The destruction caused by the earthquake was slight, but the damage done by the tsunami was large. More than a thousand fishing boats were carried off by the waves, timber and other objects were washed away on Hokkaido Island, in Primor'e and on Sakhalin.

The published data about the effects of the earthquake and the tsunami at different places are as follows.

+ Primor'e includes the Maritime Territory and the southern part of Khabarovsk Territory (USSR). - Transl.

On Rishiri and Rebun Islands, the earthquake was quite strong, and the tsunami affected the entire coast of the islands; the tsunami was especially strong on the northern coast of Rishiri Island. Here, at Oshidomari Port, the flood tide reached a height of 2.8-3.0 m. Three more waves followed the maximal wave. West of Oshidomari, on Cape Motodomari, flood tides reached a height of 1.5-1.8 m; while south of Cape Motodomari, where the shore makes a sharp bend at the entrance to the bay, the waves were 2.5 m high. The exact time of the arrival of the tsunami in these regions could not be established. On the south side of Cape Kutsugata, on the western side of the island, the tsunami was observed almost an hour after the earthquake and caused a flood tide 1.0-1.2 m high. In the same region, north of Senhoshi* Village, where the shore forms a straight line, the height of rise of the water was 60 cm. /150

On the southwestern shore, the wave reached its greatest height north of the mouth of the Beutankeushi* River, at the kekurs [conical rocks off the sea coast]. At places where exact measurements could be made, the height of rise of the water was determined at 2.8 m. Here, 30 minutes after the earthquake, a noise like a sudden downpour was heard. Following the noise, the water began to rise gradually. The waves came three times at 5 minute intervals. At Masandomari* Port, the rise of water was 2.2 m on the average. The largest wave, with an amplitude of 2.5 m, was registered on the south side of the port. Here the wave flooded the road at two places. The intensity of the wave gradually abated towards the south. At Motom'ura*, a flood tide 1.7 m high arrived. At Oniwaki and Ratadomari*, where there are bays with a northwestern orientation cut deeply into the shore, the height of rise of the water was 2-2.5 m. To the northeast of these places, the height of rise was no more than 0.7-1.0 m. North of Rutenshira*, the wave was altogether negligible. The losses on the island amounted to 548 of 4,129 boats carried out to sea, 114 smashed, and 75 half destroyed.

On Hokkaido Island at Wakkanai, the tsunami was small and only carried off a few boats. The Teshio-Haboro coast suffered considerably. At Teshio, the greatest damage was done at the mouth of the Teshio River, where small ships and launches and warehouses were damaged, and fishing equipment was washed away. Ten men also drowned here. At 2:00, eight launches, moored at Furaoi, 20 km from the mouth of the river, were torn from their anchors and run far up the Teshio River by a strong wave turning back. Judging by the movement of the ships and other data, the tsunami arrived in the Teshio region from the southwest.

At Shosambetsu, 1 hour and 10 minutes after the earthquake, a strange sound was heard from the sea, and then a large wave arrived. The first crest was 2 m high; 20 minutes later, a second wave of about the same height arrived; the third crest was 1 m high. The changes in level were very considerable by comparison with the usual changes; the rises and falls continued uninterrupted until 16:00. During the first ebb, rocks which are usually submerged by 1.2 m, became visible. Observations of the sea were not conducted until the arrival of the tsunami.

At Haboro, a strong shock was felt at 00:09, and there was a recurrent shock 14 minutes later. At about 1:00, a strange noise was heard from the sea (like that of a multi-ton truck travelling over a bridge). At 01:18, the tsunami arrived, but this, most likely, was the second wave. At 01:30 and at 01:45, there were more waves; their force gradually abated. After the second wave, the water retreated 60 m from shore. At this time, one could see underwater crags, which are usually concealed. The sea water was very turbid and took on a dirty color 300 m from shore. Much seaweed and many sea urchins, inhabitants of the shallows, were washed up on shore. The reinforced concrete wall of the breakwater (about 60 cm thick), which protected the anchorage at Haboro, was torn from its foundation.

Observations of the sea were not made at Tomamae. For this reason, the exact time of the arrival of the tsunami has not been established. The residents who were in their homes, heard the noise of surf 40-50 minutes after the shock. The noise in all probability signaled the approach of the tsunami. After this, typical tsunami noises were heard, and then the wave itself appeared. The height of the flood tide was about 3 m. The wave rolled across the road and encroached 100 m inland. /151

At Onishika, a wave with a crest height of about 2 m arrived; due to the flat coast, the wave encroached more than 100 m inland. At Rumoi, the tsunami arrived at 2:00 with a strange noise; the height of rise of water was 2 m. At Mashike, 30 minutes after the earthquake, two waves arrived, accompanied by a faint noise. The second wave, with a crest height of about 2 m, was somewhat higher than the first. After the first wave, the sea retreated about 100 m. Changes in sea level occurred unitl 16:00.

At Mooi, observations were done on the level from 4:00 to 9:00. The following data were obtained (Table 54).

At Hamamasu, the height of rise of the water was about 1.5 m. At Otaru, as a result of the earthquake, cracks formed in the road embankment, and the escarpments along the road at Shioya also collapsed; 3,600 m^3 of sand and pebble collapsed. The tsunami arrived at Otaru 45 minutes after the earthquake. The rise of water reached its maximal height, 1.5 m at 5:00. The height was 1.2 m at Shioya.

At Yoichi, it has been determined from traces of moisture that the maximal rise of water was 1.2 m. In the mouth of the river, the oscillations in the water surface caused by the tsunami had a period of 20 minutes. At Furuhira, the difference between the flood and the ebb was 2.4 m. A seaboard 15 m wide was flooded. The tsunami arrived at Bikuni 22 minutes after the earthquake. Oscillations in water level, with a maximal tsunami height of 1.5 m, continued at 10 minute intervals until 3:00.

At Irika, the water began to retreat 3 minutes after the earthquake. The water level dropped 2 m in a minute. Soon the water began to rise with a terrible noise, forming large eddies at some places, and rose more than 2 m beyond the usual level. There is no report that such a phenomenon was observed periodically.

At Hitsukase*, the tsunami destroyed part of a reinforced concrete dam; building materials were carried off. At Irika, the height of the flood was 2.7 m. At Yobetsu, the maximal height was about 2.3 m, and the period was 5-10 minutes. At Kamoenai, the height of rise of water was 1.8 m, at Tomari about 1.2 m; here a seaboard 20 m wide was flooded. At Iwanai, the maximal rise of water was 1.7 m at 0:50; the period of oscil- lations was about 20 minutes; three wooden fences were damaged, and two pipes were destroyed.

At Suttsu, the water level rose about 1 m; a coastal strip 6 m wide was flooded; four boats were carried out to sea. At Nishishimamaki, the height of the flood tide was 1.2 m, the width of the flood zone was 8 m; at Setana, these values were 1 and 3 m, respectively, at the Inaho /152
lighthouse (Okushiri Island), 1 and 2 m, respectively, and at Matsumae, 1 and 13 m respectively. A launch and a boat were sunk at Setana.

The wave arrived at Isikawa Prefecture (Honshu Island) at 5:30; the height of the crest was 40 cm, the period of the wave was 20 minutes. At Taizi, Kyoto Prefecture, at about 02:00, the water rose 1-1.5 m above the usual mark. The changes in water level had a period of about 5-6 minutes. On the coast at Saigo (Dogo Island), a small tsunami was observed from 1:00 to 4:00 with a crest height of 40 to 140 cm; 47 homes and a field were flooded. Much timber was washed away.

In Korea at Najin Port, the first wave was observed at 2:00 and the last at 7:00. The ebb was greatest from 5:00 to 7:00. The flood and ebb tides alternated at 30 minute intervals. The flood tide was 1 m above its mean level, while the ebb was 1.2 m below the mean level. A merchant vessel riding in this port capsized in a sudden ebb. However, there was no great destruction from the tsunami.

In the Soviet Primor'e, on Tetyukhe Bay, there were such strong shocks at night that most of the inhabitants woke up and many ran from their homes. Stucco cracked and chimneys collapsed. A weak earthquake was felt in Grossevichi Bay. Many sleepers did not wake up. There was no destruction.

About 40-45 minutes after the earthquake, a loud noise of surf was heard from the sea in Tetyukhe Bay, and the sea level rose 1.5-2.5 m. The wave did not cause destruction. Several minutes later, the water rapidly receded, and the bay was exposed for a distance of at least 50 m. Twenty to thirty minutes after the first flood tide, a second wave arrived; the height of rise of water reached 3.5 m above the level of the tide station. This wave tossed a loaded barge on shore to about 300 m from the flood tide line. A pier was destroyed. The wave hit the floor of the wooden warehouses resting on piles on the seacoast. Some warehouses were lifted up and thrown off their piles. In others, the floor was broken and twisted, and flour and concentrate were washed into the sea. There were three large waves. Following the waves, oscillations in level were observed with gradually abating force for about 20 hours.

The tsunami did considerable damage in Grossevichi Bay. Fishing boats and one longboat were tossed on shore by the wave, a pier was washed out, and fishing gear was carried out to sea.

On the southwestern shore of Sakhalin, in the Nevel'sk region, the tsunami did the following damage: At Yasnormorsk settlement, the

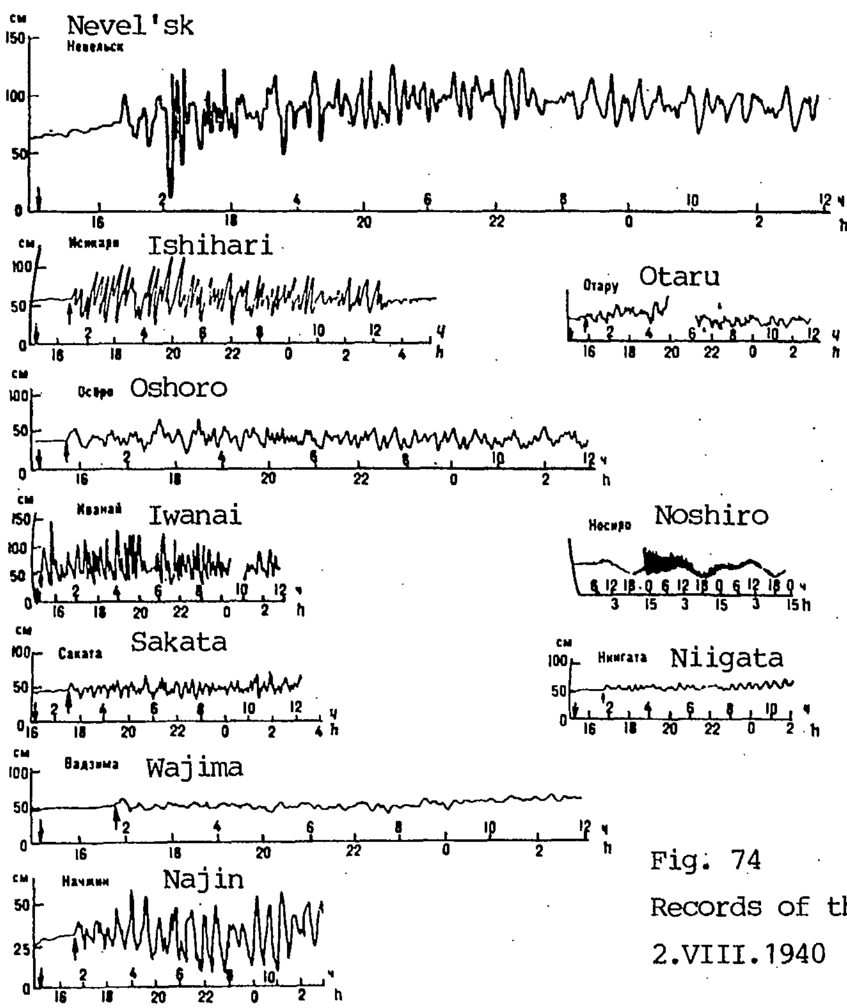

Fig. 74
Records of the tsunami of 2.VIII.1940 (Miyabe, 1941).

basements were flooded in two homes; the pier at the fish cannery was washed out; and three sloops were carried off and damaged. At Zavety Il'icha Settlement, one set of fishing gear and a sloop was carried away. At Gornozavodsk, two sloops and stored logs were carried away. At Koni, the basements were flooded in four homes and two piers and two sets of nets were carried off.

The tsunami was registered by many tide gauges along the entire coast of the Sea of Japan (Fig. 74, Table 55).

The tsunami was not registered at Wonsan, probably because the intake pipe of the gauge was blocked with sand. Apparently, this also partially explains why, at Otaru and other places, the amplitude of the tsunami registered by the tide gauge was much smaller than that observed visually. On all the records obtained, the wave begins with a flood tide; the onset is distinct. This suggests that the cause of the tsunami was elevation of a section of the sea floor at the source of the tsunami. The period of the waves at most observation points was very close to 20 minutes. By the method of inverse fronts, the source of the tsunami was sketched as an ellipse 200-300 km long (Map II), which enclosed the epicenter of the earthquake (Anon. (R), 1940 b; Miyabe, 1940, 1941; Imamura, 1942, 1949; Heck, 1947; Takahasi, 1951; Anon., 1953; Yamaguti, 1954; Iida, 1956, 1958, 1963 a, 1970; Svyatlovskii, 1957; Savarenskii et al., 1958; Soloviev, Ferchev, 1961; Seismicity in Hokkaido..., 1962; Sagisaka, 1964; Ponyavin, 1965; Hatori, 1966, 1969 a, 1970 b; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968; Go et al., 1972).

Iida et al. (1967): 1.VIII; 15^h08^m; 44.1° N., 139.5° E.; 0-20 km; M=7, m=1.8.

1947, November 4, 9:05. At Haboro and Rumoi, there was an earthquake with intensity of 5-6 degrees (IV JMA). Strong shocks were registered at Teshio and on Rishiri Island. /154

A tsunami was observed on the west coast of Hokkaido Island. A wave 2 m high was registered at Wakkanai and on Rishiri Island. It was 0.7 m high at Haboro and several tens of centimetres high at Otaru. There was minor destruction. Boats were damaged (Anon., 1953; Iida, 1956, 1963 a,b, 1970; Seismicity in Hokkaido..., 1962; Hatori, 1963 b, 1970 b; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968).

Iida et al. (1967): 4.XI; 0^h09^m; 43.8° N., 141° E.; 0-30 km; M=7, m=1.

1956, March 6, 8:29. An earthquake occurred in the Abashiri region; there was light damage. The tide gauge at Abashiri registered a tsunami with a height of 0.2 m (Brazee, Cloud, 1958; Iida, 1958, 1963 a,b, 1970; Hamamatsu, 1966; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968; Hatori, 1970 b).

Iida et al. (1967): 5.III; 23^h29^m; 44.3° N., 144.1° E.; 0-20 km; M=5.8, m=-2.

1964, May 7, 16:58. A strong earthquake was felt on the north of Honshu Island and the southwest of Hokkaido Island. Its source was situated approximately 70 km to the northwest of the Oga Peninsula. The destruction was considerable on the recently reclaimed lands of the Hachiro Lake region. Damage was also recorded on the coast in Aomori, Akita and Yamagata Prefectures. The destruction mainly occurred in regions with weak ground and was evidently due in fact to the deformation of the ground. The zone in which the earthquake was felt extended about 1,000 km to the north-northeast (Fig. 75).

The tsunami caused by the earthquake was not strong. Nevertheless it was clearly registered on many tide gauges from Esashi in the north to Naoetsu in the south (Fig. 76), Table 56) [the tide gauges on the coast of the USSR did not register the tsunami]. The record of the waves begins with a flood tide on almost all the tide gauges; the first onsets are distinct. The mean value of the period of the maximal waves was 11 minutes and it varied comparatively little from station to station. The oscillations continued for 12 to 20 hours.

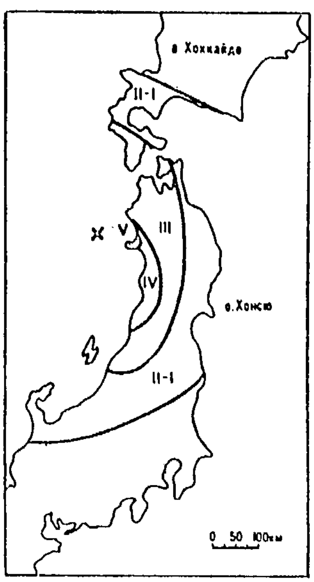

Fig. 75

Epicenter and isoseismals (on JMA scale) of the earthquake of 7.V.1964 (Anonym, 1967).

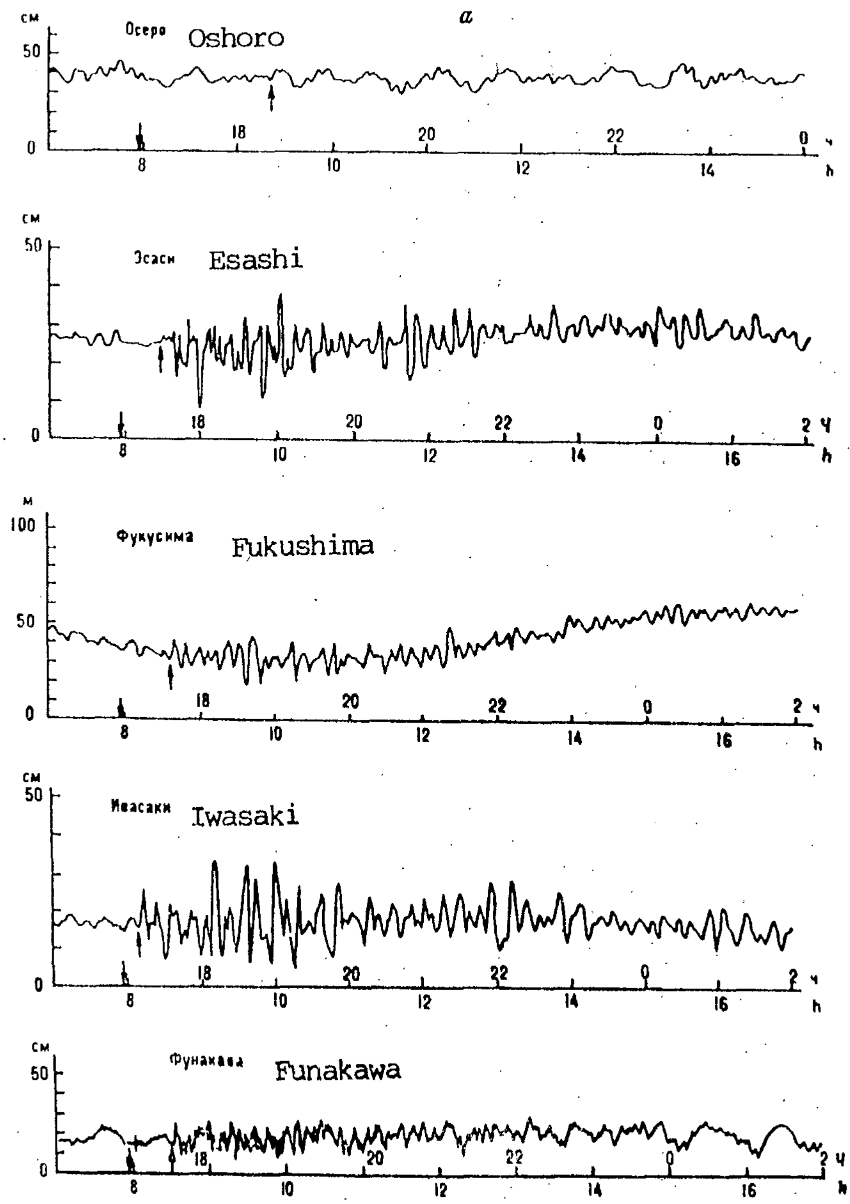

Fig. 76

Records of the tsunami of 7.V.1964 by tide gauges situated north and east (a) and south (b) of the source (Anonym, 1967).

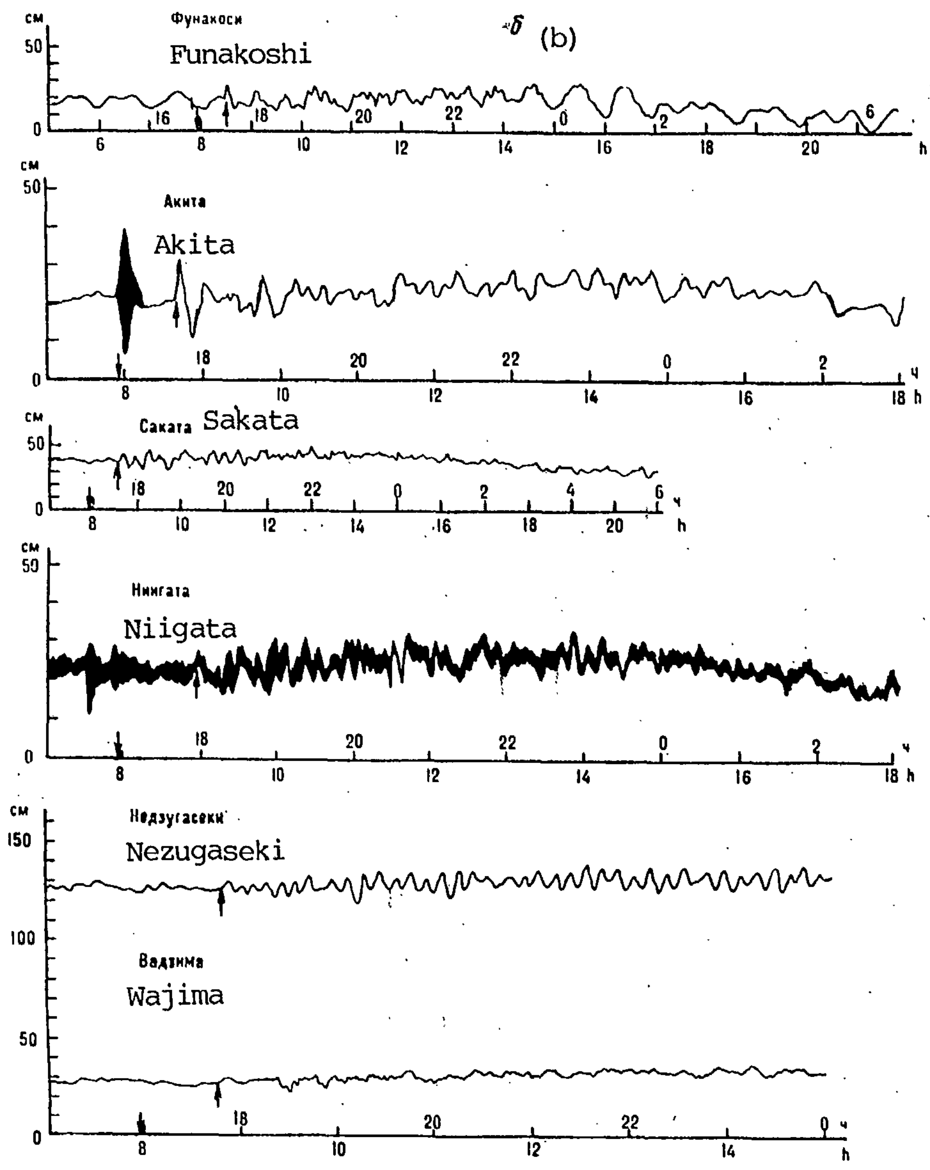

Fig. 76 (continued)

Because of the low intensity of the tsunami, visual observations of the waves were few and unreliable. They amount to the following.

At Matsumae (Hokkaido Island), a rise of water of 0.3 m was registered; it was 0.5 m at Fuka'ura (Aomori Prefecture). According to other sources, the water rose 0.9 m at the moorage wall of the port at Fuka'ura. At Kamaya, a motor boat went out to fish after the earthquake. Having gone 10-15 m, the fishermen saw an advancing water "step" ahead about 200 m away and immediately turned back. The water flooded the coast for about 10 m [horizontally]. An eyewitness standing on the shore found himself up to the waist in water. One can assume that the rise of water was tens of centimetres in this region. It was also reported that north of the Oga Peninsula, in the regions of Hachiryu, Ashisaki and

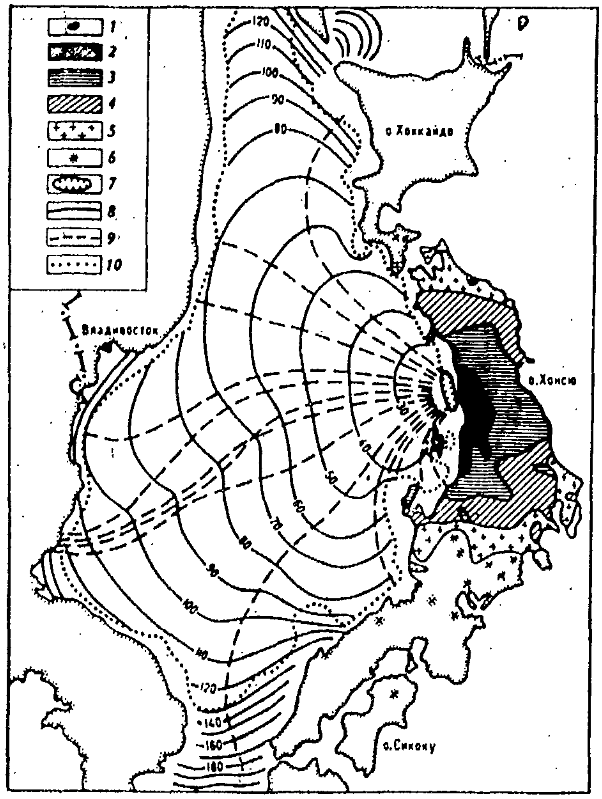

Fig. 77

Surface effect of the earthquake of 16.VI.1964 and diagram of the propagation of the Niigata tsunami in the Sea of Japan (Soloviev, 1968a; Soloviev, Militeev, 1968). 1-6 zones of tremors of different intensity, on JMA scale; 1 - VI (8 degrees), 2 - V (7-8), 3 -IV (6-7), 4 - III (5-6), 5 - II (4), 6 - I (2-3); 7 - source of tsunami; 8 - isochrones of propagation of tsunami (in minutes; according to Hatori); 9 - rays of tsunami; 10 - margin of shelf.

Oyati, the height of the rise of water was 1.3 m, and at Hachimori*, 1.2 m. However, on the coast from Noshiro to the Oga Peninsula, dunes are developed and settlements are situated rather far from shore; in addition they are sparse. For this reason, one cannot rely on the authenticity of these figures.

At Kita'ura, the first wave arrived at about 17:20. According to a /155
mark on the pier wall, the water rose about 60 cm. The first wave was maximal. Fishermen, on lifting a net into the boat, noted that the floats were submerged and took this for the start of a flood tide.

At Monzen, a 30 cm rise of water was noted, and at Tsubaki, women and children escaped from a strong flood tide. At Funakawa, the residents did not notice any change in the level of the sea. At Akita, the first wave arrived at about 17:40; there was no damage.

The focus of the tsunami was mapped by plotting the inverse wave fronts from the tide gauge records (Map II, inset 2). A sublatitudinal ellipse with axis of 80 and 30 km was obtained. The epicenter of the earthquake was approximately at the western focus of the ellipse; the epicenters of the aftershocks fell in the eastern half (Hatori, 1965 b, 1966, 1970 b; Katsumata, 1966; Anon., 1967; Iida et al., 1967; Watanabe, 1968, 1969, 1970; Iida, 1970).

Iida et al. (1967): 6.V; 7^h58^m; 40.3° N., 139° E.; 0 km; M=6.9, m=0.

1964, May 8, 5:13. There was an aftershock of the preceding earthquake, which apparently caused a weak tsunami. The tsunami appears on the records of the tide gauges at Esashi and Tsuchizaki (Anon., 1967).

[7.V; 20^h12^m; 40.4° N., 139° E.; 0 km; M=6.6.]

1964, June 16, 13:02. There was a very strong earthquake and a moderate tsunami with source on the shelf of the Sea of Japan (several tens of kilometers to the north-northeast of Niigata) in the form of an ellipse measuring 90 X 35 km, extending along Honshu Island[1]. The length of the zone of perceptibility was 1000 km (Fig. 77).

The total losses from the earthquake and tsunami (separate figures /156
are not given for each phenomenon) have been estimated at 80 million dollars; 26 people died and about 450 were injured; about 86,400 people suffered material losses.

The bulk of the damage occurred at Niigata. The seismic tremors themselves did slight damage to the city, except that a fire lasting two weeks broke out in the region of the oil tanks.

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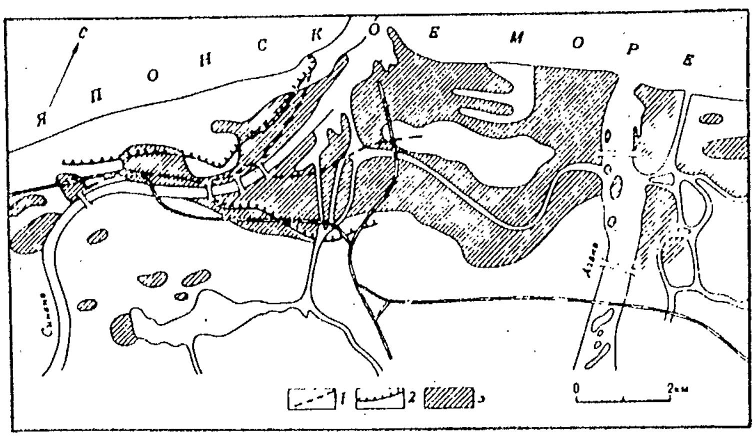
1 The abundant data about these events published in the Japanese scientific literature are condensed here.

However, as the result of the seismic shocks there was an almost instantaneous compaction, with fractures, of the loose delta deposits of the Shinano and Agano Rivers, on which a large part of the city is located (Fig. 78). An abrupt increase in the pressure of ground waters at a depth of about 1 m, caused the appearance of numerous mud volcanoes, which ejected a mixture of sand and water. This, together with other cir- /157
cumstances, led to the flooding of the soil. The upper loose layer liquesced. Multi-storey buildings made of prestressed concrete and other tall structures with weak foundations inclined 5-15° from the vertical, and some lay completely on the ground. Heavy buildings sank into the ground. The ends of long buildings shifted 1-2 m relative to each other.

The cause of the earthquake was the upward dislocation along tectonic fractures of a system of interlocked Neogene - Quaternary anticlinals, including the small rocky Ava Island, and the simultaneous settling of the narrow underwater depression, separating the above mentioned system from Honshu Island (Fig. 79). Thus the dislocations in /160
the earthquake corresponded to the general direction of the most recent tectonic movements in its focal zone. Quantitatively, these dislocations characterized by the following figures. Ava Island rose 1-1.5 m and tilted 1' to the northwest. The maximum elevation occurred on the floor of the sea 15 km south of Ava Island and was 5-6 m. The maximal local



SEA OF JAPAN

Fig. 78.

Effects of the earthquake and tsunami of 16.VI.1964 at Niigata (Soloviev, Militeev, 1967).

1 - areas on which intensive cracking, subsidence and flooding of the ground occurred

2 - areas on which some settling and slight cracking of the ground occurred

3 - areas remaining flooded after passage of tsunami.

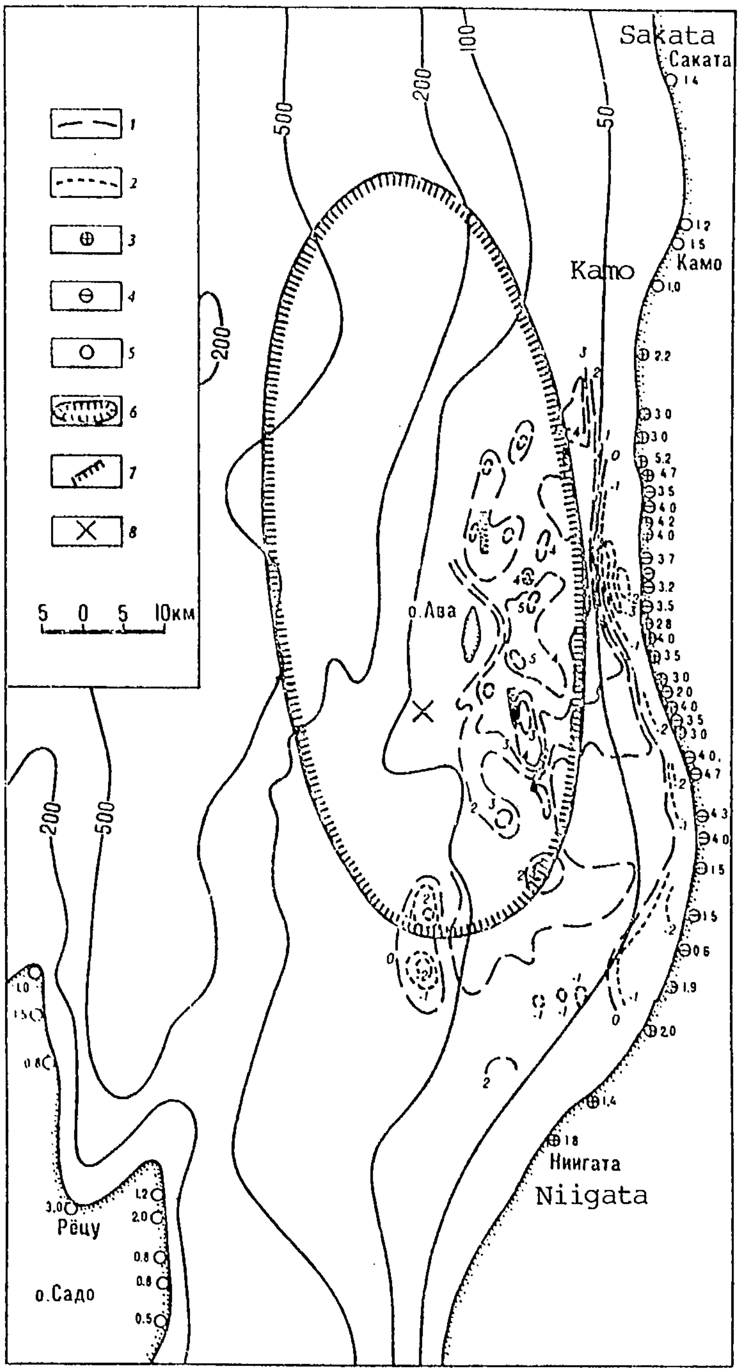


Fig. 79

Source of earthquake and tsunami of 16.VI.1968 (Soloviev, Militeev, 1968).

1 - isolines of tectonic elevation (in m)

2 - isolines of tectonic subsidence (in m)

3 - 5 nature of head wave of tsunami at different places:

3 - flood tide

4 - ebb tide

5 - no data

6 - outline of focus of tsunami on the basis of tide gauge data

7 - fractures on bottom, discovered by geophysical methods and partly confirmed by visual operations

8 - epicenter of earthquake

The figures with signs 3-5 denote the height of rise of water (in m).

subsidence, near Honshu Island, was estimated at 3-4 m. In area, the zone of subsidences was approximately one tenth the area of elevations. These measurements of the floor tie in well with the results of the determination of the mechanism of the source of the earthquake on the basis of instrumental seismic data. The coast of Honshu Island adjoining the zone of subsidences subsided 10-20 cm. According to the tide gauge data, the slow tectonic movements in the focal zone in the four years before the earthquake were directed oppositely to the dislocations, but before and after this period, they had the same direction. On the basis of geomorphological observations, Japanese specialists surmise that about 800 years was required to prepare for the earthquake [this may be exaggerated].

The tsunami was maximal on the coast of Honshu Island closest to the source, which it reached in 10 minutes. Here, on the 40 km stretch between Shioya and Nezugaseki, the maximal rise of water was 4 m with individual splashes up to 6 m. The rise of water was also considerable at Ryotsu, south of the source, on the northern shore of Sado Island, at the top of a bay of triangular shape. The gradual narrowing of the bay caused a rise of water of 3 m at Ryotsu compared with 1-1.5 m at the entrance to the bay.

The rise of water was no more that 1-2 m at other points in Japan. A survey of the effects of the tsunami showed some unusual local intensifications and attenuations of intensity which do not correlate with coastal relief, but were due to the dissipating or concentrating effect of the underwater relief between the source and the coast (see for example on Fig. 77, the convergence of the rays of the tsunami off the coast of North Korea). The assumed profiles of the initial elevation of water at the source of the tsunami (Nekrasov et al., 1972; Hatori, 1965 a) are shown in Fig. 80. The energy of the tsunami is estimated at 2.5 X 10^{20} ergs.

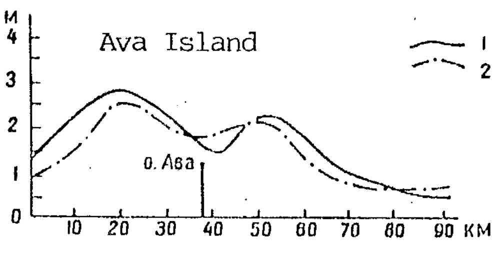


Fig. 80

Profiles of the initial rise of water at the source of the tsunami of 16.VI.1964.

1 - according to Nekrasov et al. (1972)

2 - according to Hatori (1965a).

On Ava Island, that is, directly in the zone of the source, the amplitude of the tsunami was small (from 1/2 to 1 1/2 m according to different estimates). However, as a result of the elevation of the island, most of the moorages were made unusable. Near Ava Island, fish catches, the species make-up and fishing regions changed somewhat after the earthquake and tsunami.

The tsunami was registered by practically all tide gauges on the coast of the Sea of Japan, including in the USSR (Table 57, Fig. 81).

In Primor'e and on the southwest of Sakhalin, the oscillations in sea level had a maximal amplitude of 3 to 22 cm. Further north, along the coast of the Tatar Strait, and in the east, beyond the La Perouse Strait, the intensity of the tsunami fell to the level of irregular background long-period oscillations. The most intensive oscillations in sea level on the coast of the USSR occurred at Nakhodka and Vladivostok.

In accordance with the dislocations of the sea bottom, the tsunami began with an ebb tide on the coast of Honshu Island near the focal zone and with a flood tide at all other places.

Many data have been collected and published on the Niigata tsunami. /161
Given below are some data relating to the effects of the tsunami at different places on the coast of Japan (from north to south).

Akita Prefecture. Tsuchizaki. The destruction from the earthquake and tsunami were considerable. The maximal rise of water was estimated at 65-85 cm and was observed 4 hours and 20 minutes after the earthquake. The period of the waves was about 40 minutes, and the super- /162
position of oscillations with periods of 20-30 minutes was also noticeable.

Michikawa. The fine sandy cover, including pebbles, was washed away in the flood zone. The height of the maximal wave was 15 cm.

Hirisawa. Homes and water pipes were destroyed near the station, but there was no destruction at all in the port region, where the height of waves was under 55 cm.

Kisakata. Several tsunami waves were observed in the old and new basins about an hour after the earthquake. In the old basin, open to the northwest, the waves reached the 1.2 m mark, achieving this maximum about 16:00-17:00. When the water rushed back, the floor of the basin, 1 m deep, was completely laid bare. At the new basin, the waves reached the 1.5 m mark. When the water retreated, its level fell by 1.5 m, and the /163
maximal rise of water was reached at about 14:00-15:00. The sea oscillated all day.

Yamagata Prefecture. Mega. Judging by the mud washed up by the wave, the wave reached the foot of the shore protective dike.

Sakata. According to visual observations, the height of the

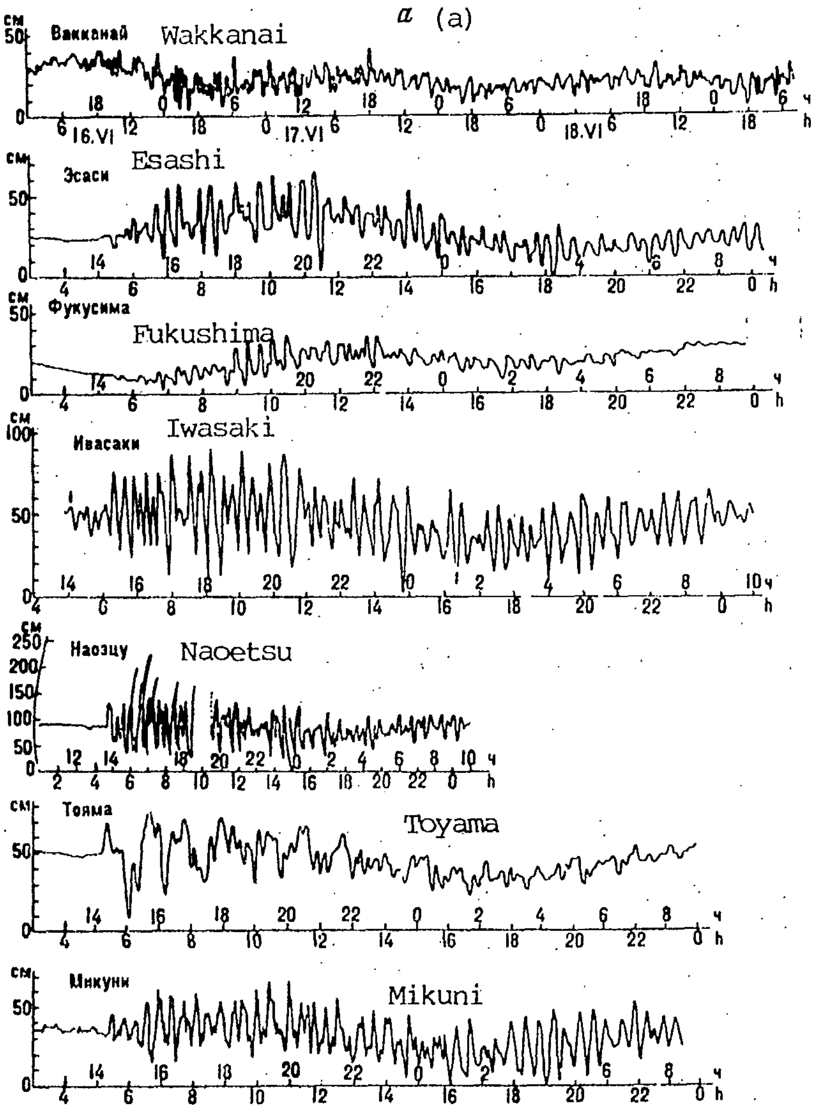


Fig. 81

Records of the tsunami of 16.VI.1964 on tide gauges situated on Hokkaido Island, in the northern and central parts of Honshu Island (a) and in the western part of Honshu Island (b) (Iida, 1968).

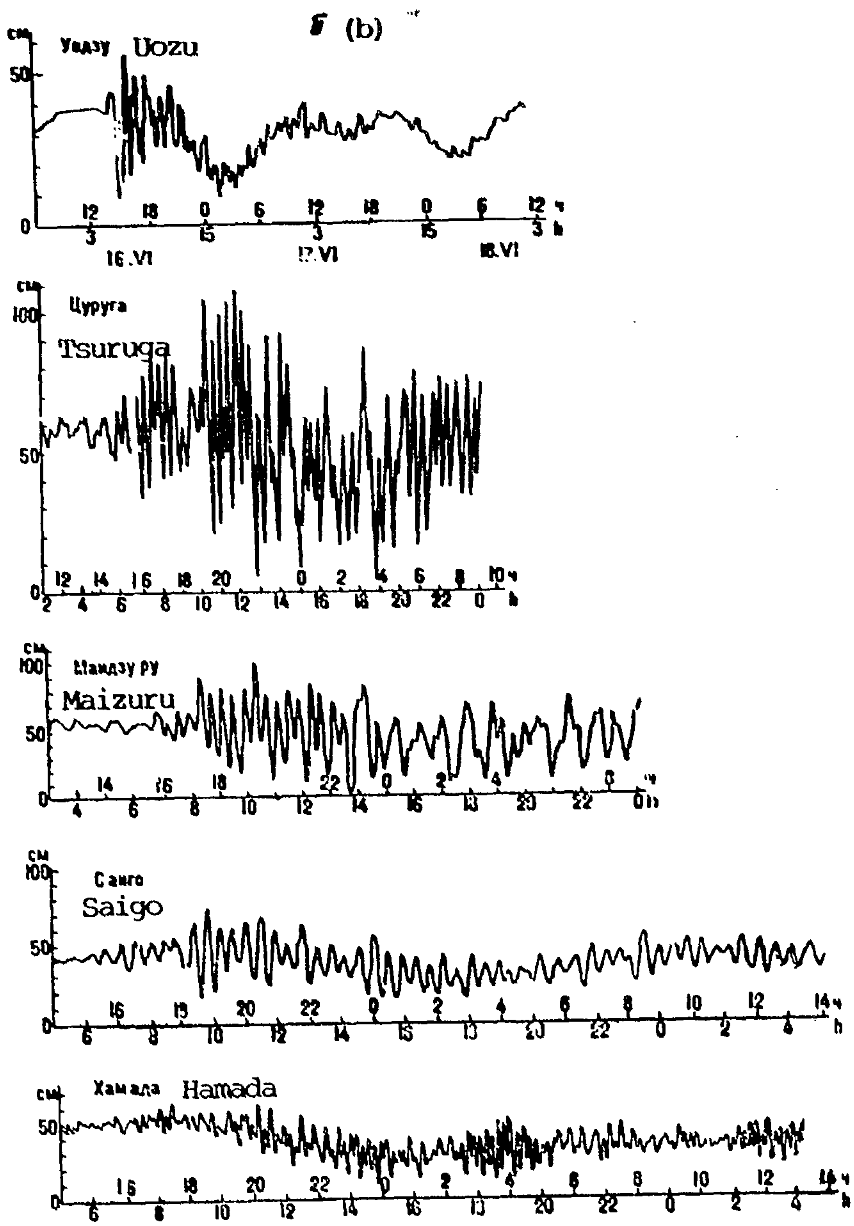


Fig. 81 (continued)

first six crests was 0.9 m, and the height of the first six troughs was 1 m. The height of the next four crests was 1 m, that of the troughs, 1.5 m. The water did not flow across the shore protective dike 1.6 m high (relative to the sea level existing at the time of the earthquake). Several waves were observed before night. Strong currents were formed inside the port upon their retreat. Rough measurements showed some change in depth in the port, which was apparently the result of the /164 tsunami.

Tobi Island. A tsunami 30 cm high was observed; then the sea returned to normal.

Yunohama. In the middle of a sandy shore with a gentle slope, protected by a dike, traces were found of floating objects, apparently washed up by the tsunami wave (rise of water - 1.2 m).

Kamo. The boundary reached by the water lay, as a rule, below the 0.8 m mark, but from traces left in the eastern part of the city, the height of the wave has been estimated at 1.8 m.

Nezugaseki. Some of the moorages of the port were destroyed by the earthquake, but the tsunami did not do any damage. The port is shaped like a "pocket" with a sandy shore, surrounded by a protective dike. Traces of the tsunami remained only on the sandy shore at a height of 1.8 m. In the northern part of the port, in the region of a protective dike 3 m high, the water just barely flowed across the dike.

Niigata Prefecture. Fuya. The highest boundary of traces of the tsunami was found in homes at a height of 6 m. On another section of the coast, the water flowed across the dike, rising to a height of 3.3 to 4.3 m. It flooded a car on shore; the people escaped by swimming.

Katsugi. About 10-20 minutes after the shock, a wave arrived and flowed across the shore dike into a field. A pile of sand apparently transported by the wave was found at a height of 2.7 m.

Neya. A wave reached the 3.9 m mark and flowed across the dike. The first wave arrived at 13:12 as a flood tide.

Wakigawa and Kuwakawa. The water retreated 1.5 ± m from the shore line. About three oscillations in level were observed. First, a small flood tide arrived, and then, about 5 minutes later, the water receded. The first wave was 30 cm higher than the second. The maximal height of the tsunami was estimated at 2.2 m.

Ava Island. At Uchi'ura* on the eastern shore of Ava Island, the water level rose after the earthquake; some time after, the sea returned to normal. Then the level fell and did not return to its previous position. At Kamaya*, situated on the western shore of the island, the water level fell after the shock, and then returned approximately to its previous position. After some time, the level again fell and began to oscillate, without returning to its previous position.

Shonami, Iwafune. The first wave approached 15 minutes after the shock; the height of rise of water was 2.8 m. A ship riding in the port was carried into a little river, where it caught on a bridge and capsized. About 2-3 hours later, the sea quieted down, but another large wave arrived at 17:00. The rise of water was no more than 2.3 m in the centre of the port.

Traces of the wave were found at a height of 6.4 m on the grass cover on the dunes to the north of Iwafune. Apparently, the water reached here as a splash from a heavy impact wave. Still further north, at about 1 km from Iwafune, the water rose to the upper boundary of the dike, at a height of 4.2 m. Measurements of the height of rise of water further to the north from traces on dunes gave values of about 4 m.

Shioya. For 15-20 minutes after the earthquake, the water retreated so far that submarine rocks at a depth of about 1.5 m were exposed. Then the surface of the water began to rise gradually. The water flooded the dunes and the low-lying section of the coast beyond them. The first wave was the largest.

Muramatsuhama. At one point, the rise of water on the dunes was 1.5 m, at another point 1 km to the south, it was 1.9 m.

Niigata. The tsunami arrived at 13:19 and began with a flood tide. The height of the crests was low; the third was maximal, with a height of 1.4 m. However, the tsunami coincided with high water so that a considerable area was flooded (see Fig. 78). The floods took the form of a quiet rise. The rate of the reverse current on the Shinano and Agano Rivers was 7-8 m/second; damage from the tsunami was observed for a distance of 5 km, and traces of the tsunami were observed up to 15 km from /165 the mouth of the rivers.

Filtration of sea water carried by the tsunami and ground waters emerging on the surface was slight, and the part of the city on the flood plain remained flooded for several weeks.

Teradomari. The tsunami began with a flood tide 30 minutes after the earthquake.

Sado Island. Urakawa. The tsunami began 30 minutes after the shock with a flood tide. The water arrived quietly. The third wave was the greatest and reached the foot of the protective dike. During the ebb tide, the level fell 1-1.5 m; the bottom was exposed for a distance of 35 m, and people began to gather fish.

Waki. During the shock, clocks stopped, but nothing fell from shelves. It was established by inquiries that the tsunami began with an ebb tide an hour after the shock. In the maximal ebb, the water retreated 40 m, and then rose very quietly. The period of the waves was about 20 minutes. The water rose to about the middle of the dike, along which runs a road. The road was flooded on a low section of the dike.

Ryotsu. The tsunami began at 13:28. The maximal wave with a crest height of 2.6 m arrived at 14:17 and was the third in succession. The tsunami was especially strong in the inner parts of the port, protected by a dike. Here the height of rise of the water was more than 3 m and many nearby homes were flooded. At Minato near moorage, the flood tide had a height of about 2.8 m. At the entrance to the channel joining Ryotsu Bay with Kamo Lake, the height was 2.5 m. The current in the channel was so strong that the protective dikes on the shores of the channel were washed out. Five spruces with a diameter of more than 30 cm were washed away. Where the water flowed into the lake, the depth of the stream was 3/4 m. The water in the lake oscillated with a period of about 30 minutes; five flood tides were observed.

Yoshizumi*. A flood tide began 20 minutes after the earthquake, and the second crest was the greatest. Five or six flood tides were observed. The water rose to about the middle of the protective dike.

Sumiyoshi. The water level fell short of the top of the protective dike by 1 m.

Shiidomari. A strong ebb was noted about 30 minutes after the shock. The second or third ebb was the strongest. The tsunami arrived very quietly.

Moroo. On the western part of the coast, the water reached the protective dike, and seaweed washed up by the wave remained along the entire coast. In the city, a flood tide appeared about 10 minutes after the shock; 5 minutes later, the flood tide recurred. A boat in a shed on the coast floated up. The third wave was the greatest. In the greatest ebb, the water retreated about 70 m.

Okawa. The tsunami began with a flood tide about 25 minutes after the shock. The period of the waves was 20 minutes. The third ebb was strongest: the water flowed like a river in one direction. The rise of water inside and outside the bay differed by 90 cm.

Suizu. The tsunami was noticed about 13:40. The water oscillated with a period of about 5 minutes. The water level fell about 1 m, so that the shoal was exposed. The second wave was the greatest.

Ogi. The water began to retreat at 13:40. Then the water flooded up to the knees of people standing on the moorage. A fishing vessel ran aground on the pier. Some residents gathered fish during the ebb. The period of the waves was about 10 minutes.

The height of the first crest in the pier region was 0.4 m, that of the second crest 0.8 m, that of the third, 1.3-1.4 m. The waves approached as a regular flood tide. The greatest flood tide, the third, set in about 14:40-14:50.

Kawarada. As a result of the shock, the dune behind the dike dropped 5 cm. A monument standing in this vicinity was overturned.

About two hours after the earthquake, a tsunami surged on shore and reached the base of the protective dike. The bottom was exposed for 50 m. The fifth and sixth waves were the greatest.

Sawane. At about 13:20, the water retreated about 2 m from the shore, and then gradually began to rise. The eighth and ninth waves were the greatest. Ten waves at intervals of about 10 minutes were observed before 17:00. A loaded launch picked up by the tsunami destroyed part of the pier. /166

Aikawa. The water rose slightly; seaweed was washed ashore (Aida et al., 1964; Kagaku Yomiuri, 1964; Mogi et al., 1964; Hatori, 1965 a, 1966, 1970 a,b; Kishinouye, Kobayashi, 1965; Report..., 1965, 1966; Yamaguti, 1965; Hake, Cloud, 1966; Katsumata, 1966; Sugai et al., 1966; Iida et al., 1967; Iida, 1968, 1970; General Report..., 1968; Aida, 1969; Soloviev, Militeev, 1967, 1968; Watanabe, 1968, 1970; Nekrasov et al., 1972).

Iida et al. (1967): 16.VI; $4^h01^m40^s$; 38.3° N., 139.2° E; 40 km; M=7.5, m=2.

1964, December 11, 0:11. There was an earthquake in Akita Prefecture. About 1000 m of protective dike on Hachiro Lake (Oga Peninsula) subsided 20 cm, and cracks appeared in two places in the dike. A sea wave 10 cm high was observed at Fuka'ura (Aomori Prefecture) (Watanabe, 1968; Iida, 1970).

Watanabe (1968): 10.XII; 15^h11^m; 40.4° N., 138.9° E.; 40 km; M=6.3, m=-1.

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RYUKYU-TAIWAN ISLAND ARC

1661 (mistakenly 1660), January 8 or 9. There was a very strong earthquake on Taiwan Island. "All the mountains collapsed." Thirty-one homes collapsed at T'ainan (see Map IV). The thick walls of the Zelandia fort (Anpin) cracked at several places and collapsed here and there. Three ships in the port spun in an unusual way. A flood tide from the sea rose so high that it looked like a mountain. It seemed as if it would flood the island completely. Underground shocks, gradually abating, continued for another six weeks (Schouten, 1708; Montbeillard, 1761; Hoff, 1840; Mallet, 1855; Perrey, 1862 b; Milne, 1912 b; Heck, 1934, 1947; Ponyavin, 1965; Iida *et al.*, 1967; Berninghausen, 1969).

1664. There was an explosion of a submarine volcano in the region of Tori Island (Amami Islands, Map III). A tsunami was observed. Homes were destroyed and there were several victims (Gondo, 1932; Imamura, 1938 c; Iida *et al.*, 1967; Watanabe, 1968).

Iida *et al.* (1967): m=1?

1754, April. There was a tsunami at Tansui (Danshui)* (Hsu, 1971).

1768, July 22, 12:00. A rather strong earthquake was felt at Shyuri (Okinawa Island), and afterwards a tsunami of height 0.6-1.2 m was observed on the coast. The damage was slight. Two or three waves were recorded. Nine villages suffered damage on the coast of the Kerama Islands. Nine homes were destroyed. Both the earthquake and the tsunami were weak (Imamura, 1938 c, 1942, 1949; Musya, 1951; Takahasi, 1951; Iida, 1956; Anon., 1961; Iida *et al.*, 1967; Watanabe, 1968).

Iida *et al.* (1967): 26.2° N., 127.5° E.; m=1.

1771, April 24, about 8:00. A strong shock was felt on all the Ryukyu Islands, though there are no reports about any destruction caused by the earthquake. Its source apparently lay between Ishigaki and Miyako Islands.

Following the shock on the Ryukyu Islands, a tsunami was observed with varying intensity at different places. On the Kume and Kerama Islands, 350 km northeast of the source of the earthquake, the tsunami was weak. On Yonaguni Island, about 180 km southwest of the source, and also on Hateruma and Iriomote Islands, the shores of which are protected by coral reefs, there was no great destruction.

The islands of Ishigaki, Taketomi, Kuroshima, Aragusuku*, Miyako, Irabu, Tarama, and Mizuna situated closest to the source (60-80 km), suffered greatly and there were many victims there.

The damage done by the waves on Ishigaki and Miyako Islands was about the same. However, the quantitative data on the height of the waves on these islands are contradictory. In the Japanese literature, the shaku (30.3 cm) and the jo (3.03 m) are usually used as a unit of measure of length. In all probability, the shaku and the jo were confused in a number of cases in describing the tsunami. Below (Table 58) are given the most likely values of the heights of rise of water (Imamura, 1938 c).

The rise of water on Ishigaki Island can also be judged by the fact that a large stone (750 t) was transported to a height of 15 m. The three waves registered on both islands were observed for 2 hours; therefore one can assume that the period of the waves was about 30-40 minutes.

On Miyako and adjacent islands, 1,054 homes were washed away. A total of 2,548 people died. The villages situated on the Pacific coast of the islands of Miyako and Irabu suffered very heavily. In fact, at Miyakoku, Nissato, Uruka*, and Tomosato homes, stone dikes and trees were washed away, and fields were scoured. On Tarama and Mizuna Islands, closest to the source, absolutely everything was washed away and the villages were levelled. /168

The tsunami approached Ishigaki Island and adjacent islands from the southeast, and the villages of Maezato, Ohama, Miyara, Shiraho, Tozato, Ibaruma and Yasura, on the eastern coast, were completely washed away. More than half of the homes were washed away at the villages of Ishigaki, Shinkawa*, Toyashiro*, and Hirae*, on the south side of the islands.

There was similar destruction on Kuroshima and Aragusuku* Islands; in all, 2,123 homes were washed away and 9,393 people died.

In all the Ryukyu Islands, this tsunami washed away and destroyed 3,137 homes and killed 11,941 people. There was an average of four dead for each home washed away on Ishigaki Island, and 2.5 dead for each home washed away on Miyako Island (Anon., 1899, 1961; Imamura, 1938 c, 1942, 1949; Heck, 1947; Musya, 1951; Takahasi, 1951; Iida, 1956; Ponyavin, 1965; Katsumata, 1966; Iida et al., 1967; Watanabe, 1968).

Iida et al. (1967); 24.IV; 24° N., 124.3° E.; M=7.4; m=4.

1782, May 22 (1682, December ?). An earthquake which affected all of Taiwan Island and caused great destruction, was accompanied by tsunami waves, which ran onto the coast of the island in an east-west direction. "Almost the entire island" was flooded for a distance of more than 120 km (30 leagues). The tremors and tsunami waves lasted 8 hours. The three main cities of the island and 20 villages were first destroyed by the earthquake and then by the tsunami. Retreating, the water left buildings, at best, as piles of debris. "Not a single living soul was left." More than 40,000 residents died. Many ships were smashed or sunk. In place of the capes, jutting into the sea, which were washed out, fresh scarps and gulfs filled with water were formed. Zelandia Fort (Anpin) and Pingkchingi* Fort were washed away together with the hills on which they stood (Perrey, 1862 c; Mallet, 1854; Iida et al., 1967; Cox, 1970).

1791, May 13. A tsunami was observed on the coast of Okinawa Island, although there are no reports of an earthquake. The water level rose 1.5 m on the average, and at Yonabaru Port, on the southeast of the island, it rose up to 11 m due to the funnel shape of the bay. Four harbors were destroyed. According to Imamura, this was a tsunami from a remote earthquake (Imamura, 1938 c, 1942, 1949; Musya, 1951; Takahasi, 1951; Iida, 1956; Iida et al., 1967).

Iida (1956): m=1.

1853, October 3. Tsunami on Okinawa Island (Annotated bibliography..., 1964, N 544).

1853, October 29. There was an underwater eruption off the eastern coast of Taiwan Island. An eyewitness of the event, an officer of an American naval vessel, related: "When we could no long see the volcano, the eruption was still at its height. The volcano disappeared completely north-northeast of us, when we were 20 km away from it. This was at 15:00. No ships were visible on the horizon. Later, when we came near the volcano again, the sea was so agitated and churned so heavily, that the watch and other officers at first assumed that the ship had come into breakers. Then we realized that these effects were due to the vol- /169
canic eruption" (Perrey, 1859 a, 1862 c, 1864 a).

1858, September - 1859, January. There were frequent shocks and unusual tidal waves on the coast of Okinawa Island (Iida et al., 1967).

1865, March 1. A weak tsunami was observed on the coast of Okinawa Island. It was presumably due to an earthquake. The rise in the water level was similar to the tsunami of 13.V.1791 (Imamura, 1938 c, 1942, 1949; Musya, 1951; Takahasi, 1951; Iida, 1956; Ponyavin, 1965; Iida et al., 1967).

[1865, March 1, 9:30. An earthquake was felt at Yokohama (Perrey, 1872 a). It is possible that this is related to the above tsunami.]

1867, December 18, morning. A strong earthquake, lasting about 15 seconds, occurred on the north of Taiwan Island. Chilung (Keelung) was completely destroyed. Many buildings collapsed and there were many victims at T'aipei. In all, it appears that several hundred inhabitants died. Large landslides occurred between Chilung and T'aipei, and several villages were destroyed. Cracks opened and closed in the ground. The mountain side split, and a large gorge was formed, into which flowed a stream from a volanic cavern, saturated with sulphur springs and geysers. The earthquake was felt all over the island. Fifteen shocks were felt during the day at Chilung. Another strong earthquake occurred on the 20th.

After the earthquake, the water left Chilung harbor, exposing the bottom. There were no large ships in the harbor at that time, and all the Chinese junks ran aground. After a moment, these boats were picked up by the returning enormous roller. Some of them were sunk, while the rest were tossed with enormous speed into the city which was also flooded; the few homes surviving the earthquake were thus destroyed. An enormous number of fish was washed ashore and quickly gathered by the population (Holt, 1868; Fuchs, 1869 a; Perrey, 1870 a, 1872 a, 1873; Omori, 1907 a, 1919; Anon., 1914; Sieberg, 1932; Heck, 1947; Musya, 1951; Iida, 1956; Keimatsu, 1963; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969; Hsu, 1971).

[It was not possible to find reports about the appearance of this tsunami in Japan. Perrey (1873) cites reports from London and New York published in the "Times" of February 11 and 12, 1868 that an earthquake which frightened the inhabitants occurred at Shanghai. The date of the earthquake is not mentioned. Another survey (Perrey, 1872 a) mentions that in 1867 (date and month not indicated), an unusual flood tide was observed at Hangchow (China). The level of the Yantzekiang River suddenly dropped 135 cm (4 feet 6 inches) and then rose 165 cm (5 1/2 feet) in 48 hours. It is possible that this was an effect of the Taiwan tsunami.]

Iida et al. (1967): m=2.

1876, October 26. Tsunami on Okinawa Island (Annotated bibliography..., 1924, N 544).

1901, June 24, 16:04. A very weak tsunami was observed on the Ryukyu Islands. At Hosojima (Kyusyu Island), the height of the wave was 20-25 cm. The assumed travel time of the tsunami to Aburatsu was 55 minutes (Iida, 1956, 1963 a,b, 1970; Katsumata, 1966; Iida et al., 1967; Hatori, 1970 b; Hatori, Koyama, 1971).

Iida et al. (1967): 24.VI; 7^h04^m; 28.3° N., 129.3° E.; M=7.9; m=0.

1903, September 7, 23:00. There was an earthquake and tidal waves on Taiwan Island (Rudolph, 1905).

1911, June 15, 23:26. There was a strong earthquake which affected all the Ryukyu Islands and the south of Taiwan Island. The length of the zone in which the earthquake was felt was 1300 km. Kikaigashima Island suffered especially. There, 400 homes were totally destroyed and one person died. Five homes were destroyed and five persons died on Tokunoshima Island. On Ishigaki Island, the destruction was also rather heavy and there were human victims. At Ojima (Kamikoshiki Island), Kagoshima Prefecture, there was minor destruction. In Miyazaki Prefecture, chimneys fell, walls collapsed or cracked, etc. The earthquake was felt strongly in Fukuoka Prefecture.

There are reports that at Chinzei (Kakeroma Island) on the evening /170 of the same day, a tsunami was observed which washed away more than half of the homes. At Agina (Amami-o-shima Island), a fisherman also noted a change in sea level following a strong shock. The assumed travel time of the tsunami to Aburatsu was 65 minutes (Imamura, 1913 b; Watanabe, 1968; Iida, 1970; Hatori, Koyama, 1971).

Gutenberg, Richter (1954): 15.VI; 14^h26^m; 29° N., 129° E.; 160 km; M=8.7.

[The source of this tsunami shown on the map has been tentatively placed in the epicentral zone of the earthquake. It perhaps should be placed at the site of the emergence onto the earth's surface of the focal layer of the seismic foci of the island arc.]

1917, May 6, 21:19. There was an earthquake accompanied by a tsunami on the east coast of Taiwan Island. At Chilung (Keelung), the waves were observed from 2:00 to 16:00. The maximal wave, registered at 3 [5?]:26, had an amplitude of 50 cm (Fig. 82). The predominant period of the waves was 26 minutes (Imamura, Moriya, 1939; Imamura, 1942, 1949; Takahasi, 1951; Iida, 1956, 1963 a,b; Anon., 1961; Ponyavin, 1965; Iida et al., 1967).

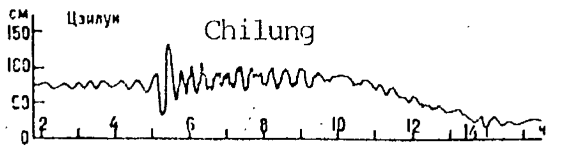

Fig. 82

Record of the tsunami of 6.V.1917 (Imamura, Moriya, 1939).

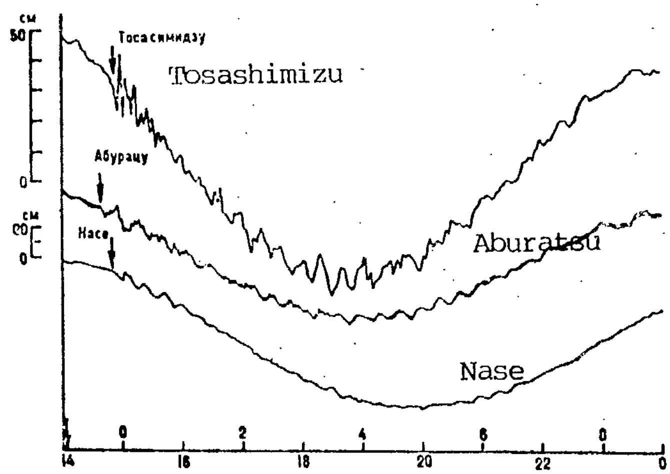

Fig. 83.

Records of the tsunami of 18.VII. 1961 (Hatori, 1969b).

Iida *et al.* (1967): 6.V; 12^h19^m; 23.2° N., 121.6° E.; M=5.8; m=1.

[The times in the text and on the tide gauge record, taken from the primary source, do not coincide. The reason has not been established.]

1938, June 10, 18:53. There was an earthquake in the region of Miyako Island. A tsunami 1 m high was observed on the coast of the island (Iida, 1956, 1963 a,b, 1970; Katsumata, 1966; Iida *et al.*, 1967; Hatori, 1970 b).

Iida *et al.* (1967): 10.VI; 9^h53^m; 25.3° N., 125.2° E.; M=6.7; m=0.

1961, July 18, 23:04. There was an earthquake with source on the north of the Ryukyu Islands. It was accompanied by a weak tsunami, which was registered by tide gauges (Table 59, Fig. 83) on the Ryukyu and Kyushu Islands (Katsumata, 1966; Hamamatsu, 1966; Watanabe, 1968; Hatori, 1969 b, 1970 b; Iida, 1970; Hatori, Koyama, 1971).

Watanabe (1968): 18.VII; 14^h04^m; 30.2° N., 131.9° E.; 20 km; M=6.6, m=-1.

1963, February 13, 16:50. An earthquake on the north of Taiwan /171
excited a tsunami. It was registered at Hualien with a height of 20 cm (Hake, Cloud, 1965; Iida *et al.*, 1967).

[$8^h50^m02^s$; 24.5° N., 122.3° E.; M=7.3.]

1966, March 13. There was a strong earthquake with source between Taiwan and the Ryukyu Islands. Four people died and 11 were injured on Taiwan Island. On Yonaguni Island, the force of tremors was 7 degrees (V - JMA); two people died and minor damage was done. On Ishigaki Island, the earthquake was felt with a force of 6 degrees (IV - JMA). A very weak tsunami was registered on the Ryukyu Islands and the western coast of Kyushu Island (Tokunaga, Katsumata, 1971).

[12.III; $16^h31^m21^s$; 24.2° N., 122.6° E.; 48 km; M=7.5.]

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COAST OF ASIAN CONTINENT

173, June 28 - July 27. In China, there was an earthquake in the region of Poltai Bay (Map IV). A sea flood in Laichou Bay off the Shantung Peninsula was observed in three regions: Huangxian, Yehsian and Chanyi (Keimatsu, 1963; Iida et al., 1967).

Iida et al. (1967): m=1?

1076, October 31. In China, tidal sea waves were recorded on the coast of Chaoang in the province of Kwangtung (South China Sea). Homes were destroyed and people died (according to the history of Zong State). A doubtful tsunami. These were probably waves of storm origin (Keimatsu, 1963; Iida et al., 1967; Cox, 1970).

1407, August 23. There was a tsunami on the coast of Haeju, Korea (Map V). There are no details. No earthquake is mentioned. These were probably waves of storm origin (Musya, 1951; Iida et al., 1967).

1434, August 6. In Korea, there were waves in the region of Inch'on (Chemulpo). Rice fields were ruined. There was no earthquake. According to Imamura, these were storm waves (Imamura, 1949; Musya, 1951; Iida et al., 1967).

1509, June 17 - July 16. There was an earthquake in the region of the mouth of the Yangtzekiang River. Floods of sea water were observed in June on the coast of the Yellow Sea at Chiatung (according to the chronicles of the locality of Chiatung). In the summer, floods of sea water were also recorded on the coast at Nanxiang and Wusong (according to the chronicles of the localities of Nanxiang and Wusong) (Keimatsu, 1963; Iida et al., 1967).

Iida et al. (1967): m=0?

1519, September 24. In Korea, waves were observed on the coast of Ch'ungch'ong Province (north of Kunsan). There are no details available. No earthquake was registered. These were probably waves of storm origin (Musya, 1951; Iida et al., 1967).

1556, October 21?. In Korea, waves were observed on the coast of the Yellow Sea in the provinces of Kyonggi and Ch'ungch'ong, in the regions of Ansan+ and Isan+. There are no detailed data; there was no earthquake. According to Imamura, these were storm waves (Imamura, 1949; Musya, 1951; Iida et al., 1967)

1580, January. There was a tsunami in Korea in the province of Kogen. No details are available. No earthquake was noted. May be a distant tsunami or storm surge (Musya, 1951; Iida et al., 1967).

+ Transliterated: May be Ansong and Yesan. - Transl.

1636, July 31. There were waves in Korea, at Tongnae (near Pusan). There are no details available. No earthquake was recorded. According to Imamura, these were probably waves of storm origin (Imamura, 1949; Musya, 1951; Iida et al., 1967).

1640, September 16. There was an earthquake in the province of Kwangtung in China. A tsunami was observed at Chenghai, Chuogang and Chieyang (according to the chronicles of these localities) (Keimatsu, 1963; Iida et al., 1967; Berninghausen, 1969; Cox, 1970).

Iida et al. (1967): 16.IX; 23° N., 117° E.; m=1?

1643, July 25 (24). There was an earthquake in Korea on the coast of the province of Kyongsan (about 60 km north of Pusan). Tidal waves were observed after the earthquake (Imamura, 1949; Iida et al., 1967).

Iida et al. (1967): m=1.

1649, December 9. In Korea, there was an earthquake in the Wonsan region. A tsunami was observed on the coast of the Yellow Sea in the province of Cholla. Six villages suffered damage (Imamura, 1949; Musya, 1951; Iida et al., 1967).

Iida et al. (1967): m=1.

1668, July 31. There was an earthquake in Korea. It was felt all over the western part of the country. A tsunami was observed on the western coast of P'yongyan, including Ch'olsan. The tsunami flooded the /173
land, people died and homes were destroyed. No other details are available (Musya, 1951; Rustanovich et al., 1961; Iida et al., 1967).

Iida et al. (1967): m=1?

1670, August 19. In China, there was an earthquake in the Shanghai region, which was accompanied by an underground rumble and tsunami waves at Chiating, Nanxiang and Wusong. Many people drowned (according to the chronicle of the Suzhou district) (Keimatsu, 1963; Iida et al., 1967).

Iida et al. (1967): m=1?

1681, June 12. Korea, east coast, Yanyan and Sanchok. There was an earthquake accompanied by a "sea wave vibration," but more likely a seaquake or seiche (Musya, 1951; Iida et al, 1967).

1700, September 12. In Korea, there was an earthquake and tsunami on the coast of the province of P'yongyan, at Naepo*+. There was no destruction (Imamura, 1949; Musya, 1951; Iida et al., 1967).

+Transliterated: Nepo. - Transl.

According to D.N. Rustanovich et al. (1961), an earthquake occurred in the province of Ch'ungch'ong. At Chulgsan, large cracks formed on the surface of the ground. A tsunami occurred.

Iida et al. (1967): m=0?

1765, May, end of the month. There were waves 9 m high (?) near Kwangchow (China). The sea suddenly rose and washed away 10,000 people. There was no earthquake. This was probably a wave of meteorological origin (Mallet, 1854; Iida et al., 1967; Berninghausen, 1969).

1767, November 22, 21:50. A letter sent from Aomen (Macao) to London on November 23, 1767, mentions that on the previous night at 9:50, the residents were struck by a terrible earthquake, which lasted about a minute and took the form of strong rocking. The author of the letter could hardly stay on his feet. The home rocked so severely that it appeared that it would be swallowed up by the earth at any minute, but there were no accidents. The earthquake was accompanied by terrifying sounds. At first the residents thought that these were cannons firing or thunder rumbling in the distance. At 23:05, another shock was felt, but it was not as strong. Still another, rather strong shock was felt at 3:00. In all, five shocks were felt, of which the first was the strongest. Even the oldest residents could not remember such strong and prolonged earthquakes.

A ship in the bay was shaken and spun in all directions, and it seemed to those on board that a hurricane had sprung up. But the wind was light (De Visme, 1809; Berninghausen, 1969; Cox, 1970).

[In Berninghausen's opinion, which is shared by Cox, this and the preceding description relate to the same incident.]

1882. There is a mistaken reference by Berninghausen (1969) to a possible tsunami in China. The matter evidently concerns an overflow of a river (the Huanghe?) in Kansu Province (Cox, 1970).

1917, January 25. There was a strong earthquake in China on the coast of Taiwan Strait. In the Tungan region of the province of Fukien, there was an unusual ebb tide, followed by a flood tide. Many fishing boats were damaged (according to the chronicle of the Tong'an region) (Keimatsu, 1963; Iida et al., 1967; Berninghausen, 1969).

Iida et al. (1967): m=1?

1923, August. There was a tsunami in Korea. There were enormous losses (Montandon, 1924 a). [Apparently, these were waves of meteorological origin or the facts are muddled.]

1926, July. A tsunami devastated the south of Korea; many hundreds of inhabitants were lost (Montandon, 1927 a,b). [Apparently, these were waves of meteorological origin.]

NAMPO, MARIANA, CAROLINE AND MARSHALL ISLANDS

1606, January 23. There was a volcanic eruption on Hachijo Island (Map VI), accompanied by tidal waves (Gondo, 1932; Iida et al., 1967).

1747?, March?. Fishing boats were washed away on Hachijo Island; no earthquake is reported; the tsunami evidently came from a remote source or the waves were of storm origin (Imamura, 1949; Iida et al., 1967).

1819. Mariana Islands. There was a strong explosion of a volcano on Asuncion Island. There was a tsunami. There are no details (Sapper, 1927; Sieberg, 1932; Heck, 1947; Ponyavin, 1965; Iida et al., 1967).

Iida et al. (1967): m=1?

1826, January. There was a very strong earthquake, accompanied by a tsunami, on Chichizima Island (Peel Island). In Futami Bay (Port Lloyd), which is of crater origin, according to two eyewitnesses (English sailors left on the island), the water rose 6 m (20 feet) above the level of the highest high tides. A schooner being built in the bay was smashed, and the freight removed from the preceding vessel, which had been wrecked, and floating in the bay, was washed ashore. Several barrels were left at a height of 3 1/2 m (12 feet) above the usual water level. The frightened sailors took to the hills to escape the flood (Beechy, 1831; Perrey, 1862 c).

1837, October. As a result of a strong storm, the sea flooded several areas of the coast of Guam Island, causing collapses here and there and considerable losses. During this storm in the Caroline Islands, four low lying islands disappeared under water: Elato, Satawal, Lamonia*, and Gulay*. Subsequently, two of these partially reappeared on the surface, while the other two became banks (Dumoulin, 1840).

1849, January 24 (or 25), 14:30 (or 14:56). There was a destructive earthquake on the Mariana Islands. All stone structures on Guam Island were left in ruins: a church, a church townhouse, the seminary at Agaña, churches at Umatac, Pago and Agat and many homes. Enormous cracks opened up in the ground at many places. A tsunami occurred.

The earthquake was followed by an enormous number of recurrent shocks. No less than 128 were counted before March 11. The strongest were the shocks of January 27 at 8:00 and February 27 at 8:37. The aftershocks caused new victims and panic among the inhabitants, who feared that their island would be swallowed up by the sea.

One of the eyewitnesses, who was on board a ship riding in the bay, gave the following account of the effects of the main earthquake and the tsunami in Umatac Bay: "I had never before experienced anything like it. The tremor lasted about a minute and continued at night with seven shocks, much less strong. The last of them occurred at dawn on January 25.

"The first, main earthquake began with an exceptional trembling of the water, which was then transmitted to the land. The displacements of the ground were so large that all stone and brick buildings suffered to some extent, and many completely collapsed.

"One of my boats was taking on a supply of water in the mouth of the river. It was caught by the flood tide, and almost tossed onto the trees. Barrels and other objects were carried 1/2 km (1/4 mile) or more from shore to open sea. When the wave rolled back, hundreds of fishes were left on the dried bottom. The shore near the river dropped about 3 1/2 m (12 feet). The wave entrained the ship with such force, that it could not hold to its anchors. The water ran up onto the island in an /175
east-west direction. A mild northeasterly wind was blowing."

In the Inarajan region, a woman was caught up by the wave near the Talofofo River, and never reappeared.

People arriving from Satawal Island (Caroline Islands) related that this island was flooded by a wave (Perrey, 1851, 1854, 1855 a, 1866, 1872 a; Anon., 1900; Maso, 1910 a; Krümmel, 1911; Sieberg, 1932; Repetti, 1939 a; Iida *et al*., 1967).

Iida *et al*. (1967): m=1?

1850 (no month or date). The American naval vessel "Mary" travelling from the Hawaiian Islands to Hong Kong and situated at 20° 36' N., 134° 45' E., apparently witnessed an underwater eruption. A moderate easterly wind was blowing and the sea was calm. Suddenly, the wind fell, and the sea got rough; the air temperature rose and some smelled sulphur. Several gusts of wind came from different directions, but they were not able to raise the sails before the wind fell. All this continued for about 25 minutes, after which the easterly wind resumed (Perrey, 1859 a, 1862 c).

1854, January 15. There was an underwater eruption at 20° 56' N., 134° 45' E.; the air was scorching and the sea was rough; there was a sulphur smell (Sapper, 1927). [An inexact re-telling of the preceding incident].

1872. Bonin Islands. In Cholmondley's book (1915), there is the following record of a tsunami observed in 1872 at Futami, Chichizima Island (Bonin Islands), which the author was visiting to collect material for a book.

"I must give a brief account of a tidal wave or 'borras,' to use the local name, which was observed on the island in the fall of 1872 and in which I almost lost all my documents. This occurred on Sunday about midnight and was preceded by a strong earthquake. The sea was calm at that time. The people had just recovered from the shock and had begun to lie down again to sleep, when...they noticed a rapid advance of the water through the forest which lies between the seaside and the residential structures.... It seems that there were six or seven waves of different intensity, one after another. The middle one was the strongest. The people scrambled up the steep slopes behind the homes and came down between floods to save what they could. The documents were in a steamer trunk and I was able to save it, but the bulky diary and the books resting on a table by the wall, unfortunately, were washed away and lost" (Tanakadate, 1940). [Apparently, the tsunami was recorded on the Hawaiian Islands.]

1892, May 16, 21:10. There was a strong earthquake on Guam Island. It began with sudden vertical shocks, which made all the inhabitants run to the street. Then, horizontal north-south and east-west oscillations began. The tremors lasted about a minute. The tiles flew off all the stone buildings and many buildings cracked. Two pits opened up in the ground about 5 km from Agaña.

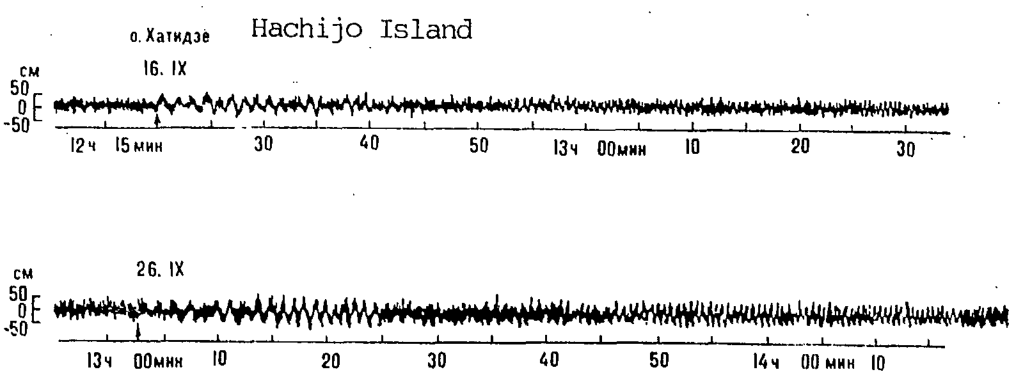

Fig. 84

Records of the tsunamis of 16. and 26.IX.1953 (Unoki, Nakano, 1953a).

The sea retreated from shore right up to the reefs, but due to the fact that the return movement was slow, it did not advance beyond the shore in the centre of the city, though it did in the San Antonio quarter. Another three very strong shocks were felt at night (Maso, 1902, 1910 a; Repetti, 1939 a).

1903, beginning of February. There was a series of underground shocks on Guam Island. The level [of the sea?] rose 15 cm (6 inches) (Montessus de Ballore, 1903).

1906, July 1. There was a tsunami in the Marshall Islands (Heck, 1934, 1947; Ponyavin, 1965). The primary source, to which Heck refers, gives no data on the tsunami. A very doubtful case (Iida et al., 1967).

1912, November 1, about 2:00. An earthquake with an intensity of 3 degrees (Rossi-Forel) lasting 5 seconds, was felt on Yap Island. It was reported that a few moments after the shock, an unusual noise of sea surf was heard, although the weather was completely still (Maso, 1912 a).

Gutenberg, Richter (1954): 31.X; $17^h24.1^m$; 7° N., 138° E.; M=7.

1912, December 6, 15:11. On Yap Island, there were undulating /176 tremors of an intensity of 3 degrees (R-F), lasting 4 seconds; they were accompanied by an underground rumble. Two weak recurrent shocks were felt at night. Immediately after the earthquake, a wave was observed at sea (Maso, 1912 b). [The earthquake was apparently not registered by the East Asian seismic stations: Manila and others.]

1925, December 22, 16:00. The western part of the Caroline Islands was devastated by a terrible tsunami. Yap Island suffered especially. There, an enormous number of homes were washed away and there were many victims. The underwater cable between Guam and Yap Island was cut (Montandon, 1927 a, b; ISS for 1925). [There were waves of meteorological origin.]

1952, September 16 - 1953, March 25. There was a multiple eruption of the Miyejin submarine volcano (31° 56.7' N., 140° 0.5' E.) 130 km south of Hachijo Island. The augite-hypersthene-dacite composition of the lavas determined the explosive nature of the eruptions. All the explosions were well recorded by the hydrophones of the American SOFAR[+] system, including those on the coast of California. Some of the eruptions were observed visually from ships and airplanes by Japanese specialists. Thus, during the weak eruption of September 23 at 13^h 40^m, a water dome, with protuberances 600-800 m high and 2 km in diameter, arose over the volcano. No seaquake was felt, but waves 50 m long and 2 m high spread over the sea surface. During the stronger eruptions, /177 weak tsunamis were generated, 52 of which were registered by the tide gauge on Hachijo Island (Table 60; Fig. 84). The strongest of these

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[+] Sound fixing and ranging system - Transl.

waves were also registered by tide gauges on Jogashima* Island and Cape Omae on the south coast of Japan. The travel time of the waves to Hachijo Island was about 30 minutes, the period 1.5 minutes, the height 10-90 cm. In the nature of dispersion and other parameters, the waves corresponded to theoretical Cauchy-Poisson waves from an initial impulse with a source diameter of 2 ± km. Some waves were like pulses. This was apparently due to the interference of waves bending around both sides of Aoga-shima Island, midway between the volcano and Hachijo Island.

The tsunami of September 26 was recorded in Hilo, in the Hawaiian Islands with an amplitude of less than 0.1 m.

The ship "Kiyo Maru No 5" of the Japanese hydrographic service, which had come out to study the eruption, was lost in the eruption of September 24 (Anon., 1953; Dietz, Sheehy, 1954; Unoki, Nakano, 1953 a, b, b; Miyoshi, Akita, 1954, 1956; Nakano *et al.*, 1954; Miyoshi, 1955; Brekhovskikh, 1956; Iida *et al.*, 1967; Pararas-Carayannis, 1969; Iida, 1970).

THE PHILIPPINE ARCHIPELAGO

1627, September (August). During a layover at Bangui (Map VII) of the Spanish Fleet, which was trying to drive the Dutch from Taiwan Island, there was an earthquake. Fourteen shocks were felt on the ships in one day. Several monasteries in Cagayan province were destroyed. The sea flooded the land for 4 km (1 league) and the waves uprooted trees (Montbeillard, 1761; Perrey, 1860 b; Maso, 1926; Repetti, 1946; Iida et al., 1967; Berninghausen, 1969; Cox, 1970). Brief information on the earthquake, with no mention of the tsunami, is given in a number of other publications (Mallet, 1855; Maso, 1910 a).

1638. According to Repetti and others (Repetti, 1946; Iida et al., 1967; Cox, 1970), this is an erroneous date for the tsunami of 1627 on Luzon Island, which is mentioned in a footnote in Perrey's compendium (Perrey, 1860 b).

1645, November 30, 20:00. There was an earthquake, more catastrophic than any previous on the Philippine Islands. "No stone was left on stone" from Manila to the north coast of Luzon Island. In the capital, only two of twelve churches remained standing, while the rest were left in ruins. Other stone buildings, built in abundance in Manila for half a century, also collapsed. The number of dead surpassed 600 and there were 2,500 injured.

From the provinces of Cagayan and Northern Ilocos, situated on the extreme north, changes in relief were reported: the course of rivers changed, loose ground settled, sand was ejected from cracks or gryphons, and new springs appeared. One could not remain standing.

The earthquake was also destructive on Mindoro Island, Marinduque Island and some other islands to the south of Luzon Island. The provinces of Camarines and Albay in the southeastern part of Luzon Island did not suffer or suffered very little.

Numerous subsequent shocks were felt until the end of 1646; the strongest of them occurred on 5.XII at 23:00 (Maso, 1910 a, 1926). During the earthquake (or the strongest aftershock), "the succession and movement of waves on the river at Manila was so enormous that it seemed the water would submerge all the land. The fury of the waves made the river leave its banks, and its water was thrown over the top of the bridge" (Repetti, 1946). [The hypothesis by Iida, Cox and others (Iida et al., 1967; Cox, 1970), that this agitation was caused not by a tsunami but by seiches in Manila Bay is plausible.]

1653, between June 26 and July 23. According to one source, not confirmed by others, the "San Francisco Xavier" en route to Manila, passing through the San Bernardino Strait and casting anchor on Mindoro Island, felt an earthquake which caused storm waves at sea. The ship was torn from its anchors and damaged (Repetti, 1946; Iida et al., 1967; Cox, 1970). [It is difficult to interpret the report; the possibility of a tsunami is not excluded.]

1675, March (February). There was an earthquake stronger than usual on Luzon and Mindoro Islands. A depression formed on Mindoro Island near the small city of Pola at the foot of one of the mountains. The sea penetrated along it onto the land and flooded a vast and very fertile plain, making it unsuitable for cultivation and habitation (Perrey, 1860 b; Maso, 1910 a, 1926; Sieberg, 1932; Repetti, 1946; Iida et al., 1967; Berninghausen, 1969; Cox, 1970). [The possibility of a tsunami is not excluded, although there are no direct indications.]

1677, December 7, 19:30. There was a prolonged earthquake in the /179
central and southern parts of Luzon Island. Beams cracked in buildings, tiles fell, walls made out of stone were weakened. One or two people died. Subsequent shocks lasted all night and there were at least 40 of them. Cracks formed in the ground at Bauang and Gapan.

Sea waves were observed at a number of places and it was reported that boats at sea almost sank (Maso, 1926; Repetti, 1946; Heck, 1934, 1947; Iida et al., 1967; Berninghausen, 1969). [The possibility of a tsunami is not excluded.]

1735, February (December) 27, 2:00. There was a strong earthquake at Baler, after which the sea very quickly began to rise and soon flooded the entire settlement. It was completely destroyed and many residents died. A few escaped by swimming, and also on the roof of the church, which remained above water. According to another source, some of the land at Baler subsided and became a lagoon. There was no such flood tide at other settlements on the Pacific coast of Luzon Island (Casiguran, Dipaculao*, Humirey) (Maso, 1895, 1926).

1744. In the northern part of Luzon Island, there were earthquakes which affected a vast area and lasted several months. The sea entered the river with great force (Repetti, 1946; Berninghausen, 1969).

1747. The bishop of Naga (Nueva Caseras*), in the southeastern part of Luzon Island, in a letter dated 8.II.1748, reported that the residents here "experienced every calamity: earthquakes, typhoons, eruptions and floods." These events presumably occurred in the second half of 1747 (Repetti, 1946).

1770, December [no date], 21:00. A strong shock was felt at Manila. Several homes were destroyed. The earthquake began with a sharp southern wind, which caused a rough sea (Perrey, 1860 b; Maso, 1926; Repetti, 1946; Berninghausen, 1969; Cox, 1970).

1824, October 26. There was an earthquake in Manila and surrounding provinces. Several churches, a bridge and many homes were destroyed and the barracks collapsed in the capital. Near the Pasig River, about 7 km upstream from the city, the "ground split" with a deafening noise. A crack 7 km long was formed. Schools of dead fish floated on the river. The churches were destroyed at Cavinti (Laguna Province) and Lucban; the church at Antipolo was damaged. Many residents of Manila, frightened by the continuing shocks, left the city and lived in temporary huts and tents.

The earthquake was accompanied by a hurricane, which tore the roofs off the huts and ran six ships onshore (according to other sources, sank) in Manila Harbor. In one of the sources, the shipwrecks are not associated with the hurricane, but only with the earthquake (Perrey, 1860 b; Maso, 1910 a, 1926; Repetti, 1946).

1828, November 9, 18:30. There was an earthquake at Manila in the form of long-period regular oscillations, lasting 2 or 3 minutes, which appeared to come from the south. The damage was not extensive: the arches in two churches collapsed, the buttress collapsed in still another church, many homes cracked, and the jail was damaged lightly. There were no victims.

After the earthquake, the water in the Pasig River rose to a level reached only in the rainy season, and inundated the floodplains near shore. The next day, the water level fell below its usual mark as far as it had risen above the norm on the previous night (Perrey, 1860 b; Maso, 1895, 1910 a, 1926; Repetti, 1946; Iida et al., 1967; Berninghausen, 1969; Cox, 1970). [Iida et al. express doubt that this phenomenon was a tsunami.]

1830, January 18, 17:15. There was an earthquake at Manila and the surrounding provinces. A resident of the capital was standing at a window before the earthquake. The oscillations were slight at first, then quickly intensified, and the eyewitness, frightened, went downstairs to the garden, which led to the river; it was very difficult to move. Reaching the river bank, he was obliged to run back, since the water was rapidly surging on shore, rising a metre (several feet). However, the water just as rapidly receded, but surged onto the opposite shore with a noise like peals of thunder, and then gradually retreated. All this /180
lasted no more than a minute.

Returning home, the eyewitness found that pieces of stucco had fallen from the ceiling, and the walls had cracked. At least 22 cracks were counted in the walls of one room alone. However, there was no serious damage in the city and only one person died.

The earthquake was stronger in the provinces. Heavy damage was done, and in particular, the church at Mauban (Tayabas Province) was heavily damaged (Perrey, 1860 b; Maso, 1895, 1910 a, 1926; Repetti, 1946; Iida et al., 1967; Berninghausen, 1969; Cox, 1970). [Most likely, these were seiches in Manila Bay.]

1830, September 16. There were several strong shocks at Manila during a colla or a typhoon. The river left its banks and some of the suburbs of the capital were flooded (Perrey, 1860 b; Maso, 1926; Repetti, 1946).

1840, March 22, morning. There was an earthquake in Sorsogon Province on Luzon Island. The church at Sorsogon was destroyed, injuring many people. Many homes were also destroyed; 17 people died and about 200 were injured. Churches were destroyed at Legaspi (Albay) and Casiguran. There was destruction at Masbate. The shore of Sorsogon Bay subsided 1 1/2 m (5 feet). The bottom of the bay also subsided, and where proas used to run aground, ships with a large draught now began to cast anchor. The sea inundated a large area of the coast and the homes nearest to the shore line. According to some sources, 35 people drowned (Maso, 1910 a, 1926; Sieberg, 1932; Repetti, 1946; Iida et al., 1967; Berninghausen, 1969; Cox, 1970). [There is no direct information about a tsunami, but the possibility of a tsunami is not excluded.]

1852, September 16, 18:30. There was a destructive earthquake in the central part of Luzon Island.

The destruction was greatest in the provinces of Bataan, Cavite and Batangas. Here, not only did many buildings collapse, but the ground cracked and collapses and slumps occurred. Extensive damage was done in the province of Mindoro.

The zone of the greatest tremors apparently stretched from the Zambales Mts. to the coasts of the Province of Batangas and the northern part of Mindoro Island. The mountainous small island of Ivliva* crumbled and disappeared under water in Subic Bay. The earthquake lasted about 3 minutes at Manila. Many buildings were destroyed or damaged.

Strong tremors were observed in the provinces of Rizal, Laguna, Tayabas, Zambales, Pampanga, and Bulacan. The bells rang by themselves in Nueva-Ecija Province. The tremors were felt onboard a ship at 17° 30' N., 118° 50' E.

At Manila, the sea rose considerably with a slight wind of variable direction, and the water phosphoresced. The report of the governor general notes that, fortunately, it was ebb tide; had it not been for this, the water of the river would have flooded the floodplain around the city and caused much trouble (Perrey, 186 b; Maso, 1910 a; Repetti, 1946).

1862, March 4, about 17:30. There was an earthquake in the southern part of Luzon Island and on Mindoro Island.

There was a strong vibration, lasting about half a minute, at Manila. Cracks formed in some buildings. The barracks, the telegraph office and the king's palace were damaged at Cavite. There were moderate, prolonged oscillations at Gapan and San Isidro (Maso, 1910 a; Repetti, 1946).

Perrey (1864 b) mentions, without indicating the exact cause, that "several boats were lost."

1863, June 3, 19:20. There was a catastrophic earthquake in Manila and adjacent provinces. It was comparable in force only with the earthquake of 1645. In half a minute, all the churches in the capital except one, the palace of the governor general, the barracks, the hospitals, homes, etc., in all 1,172 structures collapsed. The others were heavily damaged.

The earthquake left marked traces in the provinces of Rizal and Bulacan. It was less strong in the provinces of Cavite, Pampanga, Laguna and beyond them. It was not felt in the north, in Pangasinan Province. In all, about 400 people died and 2,000 were injured in the country, mainly in the capital. /181

The extent and force of the earthquake can be judged by the fact that churches, which were the most numerous stone buildings of that time, collapsed or were very heavily damaged at Manila and in the nearest settlements of Pasig, Taguig, Cainta, San Mateo, Bocaue, and also in the cities of Las Piñas, Bacoor, Maragondon, Polo, Santa Maria, Bulacan, Malolos, San Rafael, Angat, San Isidro, Euiginto*, Lubao, Cabugao*, San Pedro, Tunasan, Tanay, and Pililla (provinces of Cavite, Bulacan, Pampanga, and Laguna).

There was also extensive destruction at the cities of Binondo*, Santa Cruz, Lipa, Tondo, San Miguel, Tambobo*, and Navotas. In some places, cracks formed in the ground; large avalanches and collapses occurred in the mountains at Angat.

The water in Manila Bay retreated from the capital to Cavite, and then returned, moving in the opposite direction. The captains of two English frigates, riding in the bay, related that at about 19:30, a wave surged onto the ships from the southeast. It hit the ships and rolled over the decks, completely submerging them. The frigates shook and trembled as if they were being hit on the bottom. The water around churned and was covered with foam. A boat [or one of the frigates?] supposedly touched bottom at a depth of 18 m (10 fathoms). It was also said that the steamship "Esperanza" disappeared with all its crew.

The sources note that after the earthquake the coast was constantly visited by storms, which almost paralyzed navigation. The sea inflicted heavy losses (<u>Perrey</u>, 1865 a; Dutton, 1904; Maso, 1910 a, 1926; Milne, 1912 b; Krümmel, <u>1911</u>; Sieberg, 1932; Heck, 1934, 1947; <u>Repetti</u>, 1946; Ponyavin, 1965; Iida <u>et al</u>., 1967; Berninghausen, 1969).

<u>1865, October 19 (13), 22:00</u>. There was a considerable earthquake in the provinces of Albay and Camarines.

A stone post broke at Cajo* Port (Tiwi Region). Three corners fell out and the embrasure of the city hall, constructed of limestone and brick, collapsed; the rest of the building cracked. Some 209 homes were left unfit for habitation.

At Luban*, a bridge 136 m long and 11 m wide cracked; one of its spans partly collapsed. A bell tower crumbled, and the church itself cracked. The monastery building tilted, the balconies and one of the walls collapsed.

At Tabaco, the earthquake bagan with a terrifying rumble; the city hall cracked and several beams shifted. The entire plain, as far as Malinao, subsided. Enormous cracks and pits formed in the ground, particularly at San Vicente. At Masarag*, on the road from Sabluyan* to Ligao, the river went underground for a distance of 120 km (30 leagues) [?].

At Malilipot, the city hall cracked; a large bridge across the Bulanan* River was put out of commission. Two walls of a school fell at Bacacay. At Legaspi (Albay), some of the merchant stalls collapsed. A church cracked. Some beams jumped out of their grooves, and a wall moved away on the administrative building.

Fourteen homes collapsed in the Iraya* region, at Libon, Polangui and Oas; the church and the vicarage cracked. At Ligao, new seams appeared in the building of the church and old cracks reappeared. An immense avalanche occurred in the Guinobatan region which blocked the road. Churches and municipal buildings suffered considerably in the Rinconada* district. Bell towers collapsed at Iriga and Nabia. Several homes on swampy grounds collapsed. The earthquake lasted 15 seconds at Naga (Nueva Caseres). Only minor damage was done to the city. Oscillations of great intensity were felt all over Burias Island. There were many recurrent shocks after the earthquake. More than 150 were counted in five days.

During the earthquake, the sea was also extremely rough [in the Tabaco region?]. The residents had never seen such flood tides (Perrey, 1867; Repetti, 1946).

1869, August 16, 15:00. There was a strong earthquake in the south- /182
east of Luzon Island and the east of the Visayan Sea, lasting about 15 minutes [?]. It was the strongest earthquake in living memory on Masbate Island. All the residents ran from their homes in fear. The animals and birds milled about in terror. Various objects shifted. The few brick structures on the island suffered considerable damage or tilted. Large trees fell. Large cracks opened up in the ground on the south of the island. Landslides came down from the hills and the steep bluffs on shore. The arch of a church was damaged at Albay. A more or less strong earthquake was felt on Burias Island, at Naga, Catbalogan, and Tacloban. More than 100 recurrent shocks were felt in two weeks at Masbate.

The sea was rough off the coast of Masbate Island. To the north of Ticao Island, one of the little islands supposedly disappeared (Repetti, 1946; Berninghausen, 1969; Cox, 1970).

1871, February 21. On Camiguin Island (Fig. 85), there was a destructive earthquake, which devastated the extreme northern part of the island and which was felt on the islands of Mindanao, Bohol, Cebu and others. Many wooden homes were destroyed and massive stone walls collapsed at Mambajao and Catarman; many avalanches occurred in the

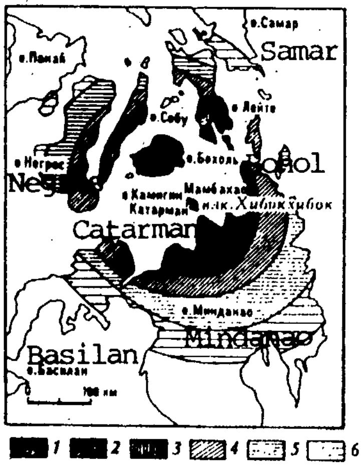

Fig. 85

Surface effect of the earthquake of 21.II.1871 (Maso, 1895).

Symbols for figures 85, 86, 88, 89: gradation of tremors:
1 - destructive
2 - very strong
3 - strong
4 - moderate
5 - weak
6 - very weak

mountains. Many more shocks were registered almost daily until April 30 (Table 61). Four of these were strong, and were felt almost the same as the main earthquake (Maso, 1910 a).

On April 30, the Hibokhibok Volcano (Camiguin Island), which had been considered extinct, exploded and a new crater was formed at its foot. Maso (1911 b), describes the events as follows.

On April 30, at 7:00, a new volcano exploded with a terrifying roar on the north-northeast tip of the island. A column of steam, stones and ash rose into the air; the ash fell for a distance of up to 200 km from the volcano. Everything was destroyed in a radius of 2-3 km from the new crater. There were no victims, since the residents of the nearest settlement, Catarman, frightened by the earthquakes, had left their homes before the eruption. The underground shocks stopped almost completely for several days after the eruption.

Fuchs (1872) describes the eruption somewhat differently.

On April 30 (or May 1), the plain at Catarman settlement began to subside gradually, so that the roofs of the homes were soon at ground level. While many residents were observing this phenomenon, suddenly, at 17:00, a terrible roar pealed out, cracks appeared in the ground, and an eruption began from the small crater which had newly appeared in place of the village. A large cloud of smoke rose into the air. Flows of lava and water issued. The explosions, like shots from a large cannon, continued uninterrupted for several hours. Then a brief pause ensued, after which the explosions began again and new subsidences occurred, and lava again flowed from the crater, flooding the huts in its path and falling with a terrible hiss into the sea. A dense cloud of ash hung over the island. Shafts of flame from the volcano burst through the dark ash. The eruption lasted a long time. /183

The population of 26,000 people fled the island; it was inundated by a wave from the sea.

Perrey (1875) gives a fuller description of the eruption, but says nothing about a tsunami.

1872, January 26, 19:30. There was a strong earthquake on the coast at Zambales Range, near Agno. It was followed by 10 or 12 recurrent shocks, and they were all accompanied by a loud underground rumble. The area of damage was very small. An unusual wave was observed soon after the earthquake on the coast and in the river at Agno. The city was partly flooded (Maso, 1910 a, 1924 a; Heck, 1934, 1947; Ponyavin, 1965; Iida *et al.*, 1967; Berninghausen, 1969).

1880, July 18, 12:40. There was a destructive earthquake with source near the Pacific coast of the central part of Luzon Island. It was preceded by a destructive foreshock on July 15 and was accompanied by numerous aftershocks, the strongest of which occurred on July 20 and caused fresh destruction as far as Manila.

Fig. 86 shows two published diagrams of the isoseismals of the earthquake. The intensity of the tremors (in degrees) at different places has also been estimated as follows: 7 degrees (VIII Rossi-Forel) in Tayabas Province, in particular, the Infanta region, 8-9 (IX-X) degrees on the water divide between Tayabas Province and Rizal and Bulacan Provinces, 7-8 (VIII-IX) degrees in Nueva Ecija and Rizal Provinces, 7 (VIII) degrees in Bulacan Province, 6-7 (VII-VIII) in the provinces of Tarlac, Pampanga and Bataan, on the coast of Bai Lake, up to 6 (VII) degrees in Zambales Province, 5-6 (VI-VII) degrees in Cavite Province and on Polillo Island, from 7 (VIII) to 5 (VI) degrees from southeast to northwest in Pangasinan Province, from 6 (VII) to 4 (V) degrees from the southeast to northwest in La Union Province, 5 (VI) degrees at Lucban, on the western coast of Bai Lake and in Batangas Province, from 4-5 (V-VI) to 3-4 (III-IV) from south to north in Ilocos Province. The earthquake was felt, but without material damage, in the provinces, of Isabela and Cagayan. /184

The tremors were destructive almost exclusively on soggy loose grounds: along coasts and river valleys, including along the banks of the Big and Little Pampanga*, Pasig and Agno Rivers. Bacolor suffered most of all. At Manila, many buildings were destroyed, mainly in the flood plain of the Pasig River, but not one of them collapsed.

There were huge avalanches in the pleistoseismic area, on the slopes of the Sierra Madre, including at Bongabon. Numerous cracks of different sizes opened up in the ground in the eastern part of the

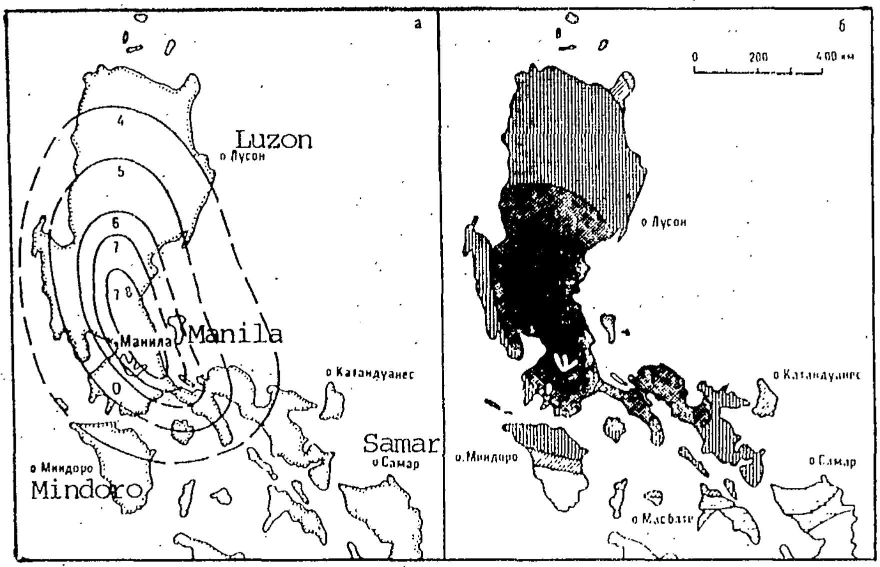

Fig. 86

Surface effect of the earthquake of 18.VII.1880. Symbols for "b", See Fig.85. a - according to Centeno y Garcia (1883); b - according to Maso (1895).

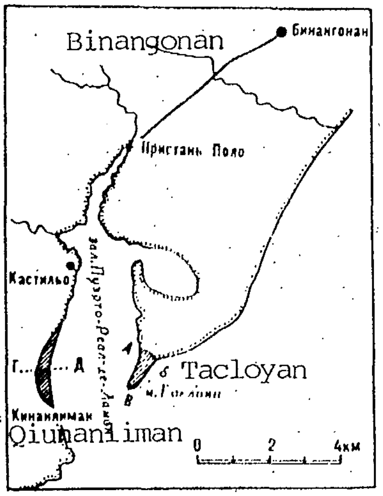

Fig. 87

Areas of the coast of Puerto Real de Lamon Bay (hatched) which subsided under water in the earthquake of 18.VII.1880 (Centeno y Garcia, 1883).

Fig. 88

Surface effect of the earthquake of 2.II.1887 (Maso, 1895).

Symbols, see Fig. 85.

central plain of the island.

The tremors were very strong in the region of Infanta at Binangonan (Fig. 87). All three stone structures, the church, the bell tower and the monastery, collapsed completely. The governor's homes, the court and the barracks, built of wood and palm leaves, were so heavily damaged that they had to be abandoned. More than 200 homes of wood and leaves collapsed; only the vertical props in their shattered earth pockets remained of some of them.

Large landslides and settling of the ground occurred along the banks of Puerto Real de Lamon Bay: at Cape Tacloyan and at the settlement of Quinanliman (see Fig. 87). At the first site, the amount of settling increased from the line AB to the point C. Five months after the earthquake, the depth of the water at point C was 6 m, and only the tops of dead trees appeared above the water, while before the earthquake, the ground had been situated several tens of centimeters above the water /185 level. Near the line AB, the water only flooded the roots of trees slightly.

At the second site, a crescent-shaped area of the shore subsided. The subsidence was greatest along the line D-E and was equal to 4 m. North and south of this line, the amount of settling gradually decreased. A settlement was situated on the flooded area. The residents abandoned it in a hurry and there were no victims.

Several small boats, situated in the estuary near Polo Pier, were tossed by surging water into mango groves on shore and were left there after the water had returned to its usual mark.

In Manila, rumors (possibly exaggerated) circulated from residents of the Pacific coast about an enormous number of boats tossed onshore to a great height and the death of hundreds of people (Centeno y Garcia, 1883; Berninghausen, 1969; Cox, 1970).

Other sources mention that eight homes built out of light materials sank to one side at Baler during this earthquake. Cracks formed in the walls of stone buildings. An old abandoned tower collapsed. The ground cracked. Water and sand was ejected from the cracks, spoiling the crops. Landslides took place in the mountains. There were many recurrent shocks.

The water in the rivers became dirty and continually agitated, and this lasted at least a day (Fuchs, 1881; Maso, 1910 a; Repetti, 1946).

1887, February 2, 23:00. There was a strong earthquake on Panay Island (Fig. 88). It is included in Heck's list (Heck, 1947; Berninghausen, 1969) of tsunamigenic earthquakes with a reference to Milne (1912 b). However, as Iida correctly notes (Iida et al., 1967; Cox, 1970), neither this catalogue nor Maso's catalogues (Maso, 1895, 1910 a) or Repetti's catalogue (Repetti, 1946) make any mention of a tsunami.

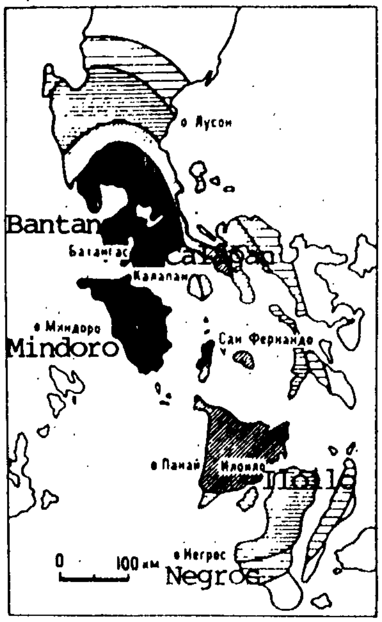

Fig. 89

Surface effect of the earthquake of 26.V.1889 (Maso, 1895).

Symbols, see Fig. 85.

1887, September 23. There is an erroneous reference in the papers by Sapper (1927), Heck (1947) and Ponyavin (1965) to a tsunami on the Philippine Islands, the Tiburon Peninsula and at Jeremie.

In fact, the tsunami occurred not on the Philippine Islands, but in the Caribbean Sea; Tiburon and Jeremie are situated on the south coast of Haiti Island (Iida et al., 1967).

1889, May 26, 2:23. There was a destructive earthquake in Batangas Province and on the north of Mindoro Island (Fig. 89).

At Batangas, the buildings of the church, the court, the jail and many homes were damaged. The front of the governor's home collapsed. /186
Cracks formed in the ground at many places in the province. The church was damaged at Bauan. At Resting*, the masonry of the bay of the observatory tower cracked. The piles cracked in homes at Calapan (Mindoro Island). A bell tower was damaged.

There was a "terrible" earthquake at Iloilo. There were strong tremors at Cañacao*, Punta Santiago, Taal, Cavite, on Corregidor Island, at Moron, Montolban, Balanga, Bacolor, San Fernando, and Cabanatuan. There were moderate tremors at Calamba, Tayabas, Mariquina, Malolos (Bulacan), and Dagupan.

The tide gauge which had recently been installed at Manila observatory registered waves in the well of the instrument with an amplitude of 10 cm and a somewhat smaller rise in water level (Maso, 1895, 1910 a; Repetti, 1946; Iida et al., 1967; Cox, 1970).

1897, September 21, 3:13. There was an earthquake, which was felt with a force of 7 degrees (VIII Rossi-Forel) in the northeastern part of the Sulu archipelago, and with a force of 6 degrees (VII) on the islands of Mindanao and Jolo. The size of the area of perceptibility was 600 x 500 km. Numerous aftershocks occurred.

There was confused data about the occurrence of a tsunami. A report from Dapitan about the subsequent catastrophic earthquake, which occurred 10 hours later and was accompanied by a tsunami which was the strongest yet known on the Philippine Islands [see below - Transl.] mentions that after each of these two earthquakes the water rose 2 m and the people living on the coast were forced to leave their homes (Maso, 1908 b, 1909 b).

Richter (1963): 20.IX; 19^h06^m; 6° N., 122° E., M=8.6.

1897, September 21, 13:15. There was a destructive earthquake on the southwest of the Philippine Islands, with a maximal intensity of 8 degrees (IX Rossi-Forel). It affected Mindanao Island, the Sulu archipelago and the islands to the south of the Visayan Sea. The dimensions of the area of perceptibility were 800 x 800 km. The earthquake was accompanied by an enormous number of aftershocks which were registered for 18 months.

At Zamboanga, the church, the priest's house and the majority of other stone structures collapsed. There was similar destruction at Ayala, Tetuan, Mercedes, and Bolong. The banks of the Tetuan River collapsed. A large crevice travelling from the sea inland, and many other fissures appeared in the surface of the ground at Magay. Near Bolong, a crack 50 m long and 1 m wide formed in the ground and ejected water and sand. At Isabela, all structures suffered heavy damage. At Maybung, the soil cracked. Buildings suffered damage at Porto Santa Maria.

The steamship "Brutus," situated near Zamboanga, felt a strong seaquake. "Waves arose, moving to the east and breaking on shore near Zamboanga about 10 minutes later."

At Dapitan, the earthquake lasted almost a minute, but did not cause damage. Moderate oscillations were registered in the province of Iloilo and Capis (at Passi, San Joaquin and other places), on Negros and /187
Cebu Islands, in the valley of the Agusan River, and at Vernela. A weak earthquake was registered at Puerto Princesa on Palawan Island, Kudat and other places on the northern coast of Calimantan Island. The

oscillations were not felt on Labuan Island* (Sabah, Malaysia).

Some sources indicate that there was an eruption of the volcano on Jolo Island (Neumann van Padang, 1953).

At Zamboanga, about 15:00, an earthquake recurred with the same force as the preceding one. Then a phenomenon occurred which caused great panic. The sea level fell 5 m, and then rose and fell with great speed. After several such oscillations in level, sea waves began to flood the city, although they did not advance further than the first few homes. The water picked up proas riding off shore and left them high and dry. According to eyewitnesses, the greatest oscillations in level were observed from 15:00 to 16:00, and at 16:00, the second of the strongest waves arrived. The ebb tide was especially large. The phenomenon lasted a little less than 2 hours.

At Isabela, about half an hour after the earthquake, water burst with a roar into the northeastern passage leading to the port. The enormous waves moving from the west washed away everything on shore; the sea level rose at least 7 m above the usual mark. The sea rose and fell more than 30 times, and one of the waves was considerably larger than the others. The waves broke on shore with such force that they easily rolled building timber 6 m long and pieces of masonry. A grocery store was washed away, 25 homes were destroyed, and the gunboat "General Laso" was imperilled.

There were victims on the farms of the Moro tribe: at Panigayan*, two injured; at Balauan*, five dead, six injured; at Labotan*, three dead, six injured; at Matiban*, five dead, homes destroyed; eight homes were washed away at Tagu*.

An eyewitness on a boat riding at anchor in Sibuguey Bay, related that the water raised the boat together with its two anchors several times and the ship was in great danger.

At Dapitan Port, the sea rose 2 m at the head of the bay.

At Negros Island, at noon a boat was crossing the bay; its movements were almost totally paralyzed by the waves.

On Jolo Island, 15 minutes after the earthquake, the sea began to rise and fall at 15 minute intervals, retreating 200-250 m from shore. The maximal height of rise of water was 1 m. The ebb tides were stronger than the floods, and their amplitude gradually increased. The rough sea calmed by 21:30.

On Siau Island (Sangihe Islands, Indonesia), the first drop in level was observed 1 1/2 hours after the earthquake. In 1/2 hour, the water retreated far beyond the ebb tide mark. Then it returned, reaching the flood tide mark in a few minutes. Regularly alternating rises and falls in level occurred for more than an hour.

Tsunami reports also came from the north coast of Calimantan Island (Kudat region) and from the eastern shore of Sumatra Island.

Between Labuan* Island and the coast of Calimantan Island, where the depth of the water had been 6 m, a new little island quietly rose out of the water after 13:00 on the 21st. The island was made up of clay and pebbles and was 200 m long, 150 m wide, and 20 m high. Its surface gave off hot gases and there was a strong petroleum smell. It is possible that the island was built up by the tsunami waves; on the other hand, the island could also have been the result of an underwater mud eruption (Figee, 1898 b; Coronas, 1899; Montessus de Ballore, 1906; Maso, 1908 b, 1909 b, 1910 a, 1918 b; Milne, 1912 b; Sapper, 1927; Sieberg, 1932; Heck, 1934, 1947; Repetti, 1946; Anon., 1961; Ponyavin, 1965; Iida *et al.*, 1967; Berninghausen, 1969).

Richter (1963): 21.IX; 5^h12^m; 6° N., 122° E.; M=8.7.

1897, October. The bibliography on tsunamis (Annotated bibliography..., 1964, No. 816) makes a reference to the following description. "A telegram from Manila on November 2nd, 1897, received at Victoria (Hong Kong) says that a tsunami fell on the coast of the Philippine Islands. A strong wave crossed the San Juanico Strait. The water overflowed and /188
damaged Tacloban. There were victims. Dams were destroyed at Granborengal*. The source was apparently situated at open sea" (Anon., 1897 a).

[One can assume that this tsunami was formed as the result of the earthquake of 19.X at 8:00 (Richter, 1963; 18.X, 23^h48^m; 12° N., 126° E.; M=8.1), which reached 9 degrees (X Rossi-Forel) on the eastern part of Samar Island. It caused considerable destruction at Sulat, Palapag, Catubig, Oras, Gandara, and Laoang, and caused numerous cracks in the ground. Strong tremors were felt at Catbalogan, on Biliran Island, at Tacloban and moderate or strong oscillations were felt in the region of Albay Bay, at Sorsogon, Tabaco, Daet, Ginaiangan*, Seber*, and Iloilo. The area of the tremors, which included the southeast of Luzon Island, the Visayan Sea and the north of Mindanao Island, measured 800 x 600 km. Numerous recurrent shocks were registered including one 15 minutes after the main earthquake with a maximal intensity of 8 degrees (Maso, 1908 c, 1910 a; Repetti, 1946).

In other words, the earthquake had many of the usual signs of tsunamigenicity. There were no other strong earthquakes in the Tacloban region in 1897. However, Coronas (1899) directly states that the flooding at Tacloban was caused by the very strong hurricane of 12.X which fell on the Philippines.]

1901, September (or October) 10, 8:30. There was a strong earthquake in the eastern part of Tayabas Province, which was accompanied by an underground rumble. The church at Calauag was damaged and structures were damaged in the cities on the eastern shore of Lamon Bay, in the northeastern part of which the source was presumably located. Yawning cracks were formed on the coast, and the water became very turbid; dead fish were also found. The dimensions of the area of perceptibility were 300 x 180 km. The earthquake was preceded by a four degree foreshock at 7:40 with an area of perceptibility of 200 x 120 km and was accompanied by several weak aftershocks (Maso, 1908 b, 1910 a). [A possible cause of the water becoming turbid may be a tsunami; there are no direct indications of the appearance of waves.]

1902, August 21, 19:17. There was an earthquake with a maximal intensity of 9 degrees (X Rossi-Forel) on the south of Mindanao Island, in the provinces of Lañao and Cotabato. Its source was situated in the northern part of Illana Bay. Heavy losses were inflicted on all the buildings in the cities, to the fortresses as well as the settlements of the Moro tribe, situated in the pleistoseismic zone. Unusual effects were observed on land as well as in the bay. In particular, the underwater telegraph cable in the bay was cut and washed out. There were rather reliable reports about numerous victims at the fortifications of the Moro tribe, but the exact number is unknown. The zone of perceptibility included the islands in the Visayan Sea and measured 700 x 680 km. An underground rumble was heard for an enormous distance. There were so many recurrent shocks that about 400 were counted in only the first eight days after the catastrophe, and 10-12 of them reached 5-6 degrees (VI-VII). The main earthquake was registered by European seismic stations (Maso, 1908 a, 1910 a).

[Sieberg (Sieberg, 1932; Iida et al., 1967; Cox, 1970), in relating this information, adds that a tsunami occurred. There is thus no reliable information about a tsunmmi, although one cannot entirely eliminate the possibility.]

1905, December 8, 16:22. There was an earthquake with source in the region of the Visayan Sea. At Tuburan, it lasted 1/2 minute and was accompanied by a strong rumble; the ground cracked; stone walls collapsed. Strong tremors were felt at other places on Cebu Island, at Ilaya and in Aclan Province; they lasted about a minute. The tremors were moderate in Iloilo Province, at Bacolod and Tagbilaran; they were weak but accompanied by a rumble in Capis Province. The earthquake was felt all over Bohol Island, at Ormoc, Tacloban and Maasin, and weakly at Bais and Balingasag.

Eyewitnesses in a boat at Tagbilaran did not feel the shocks, but /189
noticed unusual irregular waves, which suddenly appeared off the coast (Algué, 1905).

[It is difficult to interpret the account: this was certainly not a seaquake, and at the same time, it is not quite like a tsunami or seiches.]

1910, December 30, 8:49. There was an earthquake with pleistoseismic zone in the valley of the Agusan River. It was felt with a force of 6 degrees (VII Rossi-Forel) at Butuan, 5 degrees (VI) at Talacogon, 4-5 degrees (V) at Surigao, 4 degrees at Davao, 3 degrees on the Cebu, Samar, and Leyte Islands, and near Lañao Lake, at Cotabato. It was registered by seismographs in Europe.

At Butuan, the earthquake lasted about a minute. The movements were mild for the first 10 seconds, and vertical and horizontal shocks of enormous force were felt the rest of the time. As a result, light partitions fell, brickwork cracked, and bells rang by themselves. Large waves arose in the river and capsized a raft (Maso, 1910 b). [Seiches in the river?]

[30.XII; 0^h45^m; 9° N., 125.5° E.; 60 km; M=6.2.]

1911, July 12, 12:08. There was an earthquake with pleistoseismic zone in the valley of the Agusan River, where its force reached 7-8 degrees (VIII-IX Rossi-Forel).

At Talacogon, the tremors lasted 3 minutes and were preceded by weaker oscillations. According to accounts, high waves formed in one of the lakes, flooded the shore and travelled far inland [seiches?].

At Butuan, the earthquake lasted 2 minutes, and began with very weak movements. Almost all the homes, both pile as well as brick, were damaged. Trees were ripped from the ground. Cracks appeared in the ground. People bathing in the river, related that the water first rushed from the western shore to the eastern, and then back again. The movement of the water was so strong, that an enormous beam, secured with a thick reed, was ripped off and carried away [seiches on the river]. The earthquake was followed by a large number of aftershocks (Maso, 1911 a).

Gutenberg, Richter (1954): 12.VII; $4^h07.6^m$; 9° N., 126° E.; 50 km; M=7.75.

1915, November 19. There was an earthquake on the northwest of Luzon Island, which affected the provinces of Nueva Ecija, Tarlac, Zambales, Pangasinan, La Union, Mountain, Nueva-Vizcaya, Isabela, Cagayan, and Northern and Southern Ilocos. The tremors had a force of 4 degrees (V and IV Rossi-Forel) at Aparri and Vigan.

The earthquake had the greatest intensity, reaching 6 degrees (VII) at Laoag, where cracks appeared in large brick buildings, the wooden frames cracked in buildings of mixed materials and belongings were smashed.

Cracks appeared 6 km from the city on the sandy coast near the mouth of the Laoag River. Large waves were observed (Maso, 1915). [The information is insufficient to interpret the report; the possibility of a tsunami is not totally excluded.]

[18.XI; $20^h19^m18^s$; 18° N., 119.5° E.; M=6.4.]

1917, January 31, 11:38. There was an earthquake with source to the south of Mindanao Island, near Sarangani Bay. It was felt all over Mindanao Island and in the eastern part of the Sulu archipelago. The tremors were strongest, 7-8 degrees (VIII-IX Rossi-Forel) to the east and southeast of Sarangani Bay, in particular at Glan.

According to a report of the police station at Glan, the tremors lasted about a minute. Eighteen buildings collapsed, including the school, a new warehouse and so on. The public pier was completely put out of commission and required major repairs. All the buildings of the police station at Glan were destroyed, except for one new annex; two people were injured by falling beams. Seven people died under a large landslide at Tuyan (a suburb of Glan). A mass of cracks up to 1/2 m wide appeared in the ground. At many places, water and mud spurted up several metres. Recurrent shocks were felt all day and all night, and seven strong earthquakes and many weak ones were registered in Glan in February. A tidal wave 1-1 1/2 m high (4 feet) high appeared at Glan /190
several minutes after the earthquake of January 31 (Maso, 1917).

[31.I; $3^h39^m55^s$; 6° N., 125° E.; M=6.4.]

1918, August 15, 20:18. There were strong tremors of very great duration all over Mindanao Island. They were accompanied by an enormous number of aftershocks. The station at Butuan, 450 km to the north-northeast of the epicenter, equipped with a Wiechert seismograph, registered 600 shocks before the end of August; 250 of these registered on the 15th and 16th.

The earthquake did great damage on the coast of the Celebes Sea between Cotabato and Davao Bay and was accompanied by colossal sea waves, which washed away everything on the coast between Lebac and Glan Ports. Details about these events were received only from the above-mentioned points.

At Glan, the earthquake lasted more than 3 minutes and destroyed all the homes on the coast of Sarangani Bay. Forty-six people died. A landslide occurred on the slopes of one of the large mountains adjoining the bay.

The tsunmai reached a height of 7 m (24 feet) at some places, and it reached a height of 5 1/2 m (18 feet) at the police station at Glan. It destroyed all that remained of the buildings after the earthquake, swamped people, cattle, horses and other domestic animals, washed away stocks of food, and ruined the harvest in low-lying places. All boats were smashed or washed out to sea. Large rivers disappeared completely and reappeared.

At Lebac Port, near the sawmill, the tsunami had a height of 2-2 1/2 m (from 6 to 8 feet). Six people died. Much sawwood was tossed a large distance inland. South of Lebac, according to reports, the tsunami reached a height of 6-7 m (20-25 feet).

On the north of Sulawesi and Halmahera Islands, at Bocat*, Paleleh, Gorontalo, Manado and Tobelo, the earthquake took the form of rather strong regular oscillations lasting 1-5 minutes. There was slight

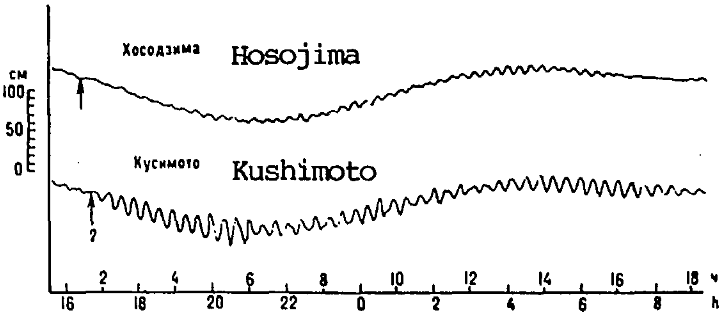

Fig. 90

Records of the tsunami of 15.VIII. 1918 in Japan (Imamura, Moriya, 1939).

damage to a stone bridge at Paleleh. Doors and various hanging objects swayed at Manado.

The tsunami was observed on the north coast of Sulawesi Island: at Paleleh and Bocat* at 21:00, at Manado at 21:15 and also at Buol. Several unusual rises and falls in sea level to a height of about 1 m occurred in 15-30 minutes at Manado. At Buol, the oscillations in level were much stronger and did material damage. The majority of reports mentioned three waves.

The tsunami was registered in Japan by at least two tide gauges (Fig. 90); the parameters of the record are taken from Imamura, Moriya and Hatori (Table 62).

The waves were also registered by the tide gauge at Honolulu with a period of 17 minutes and a height of less than 10 cm (Maso, 1918 a,b; Anon., 1919 b; Visser, 1921 a, 1949; Sieberg, 1932; Heck, 1934, 1947; Imamura, Moriya, 1939; Gutenberg, Richter, 1949, 1954; Imamura, 1949; Shepard et al., 1950; Iida, 1956; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969; Hatori, 1969 c; Cox, 1970).

Gutenberg, Richter (1954): 15.VIII; $12^h18.2^m$; 5.5° N., 123° E.; M=8.25.

1921, November 12, 2:38. On November 7, at 0:02, there was an earthquake with source off the southeastern coast of Mindanao Island in the form of sudden vertical shocks. The coast from 8° N. to Cape San Agustin, with centre at Caraga, suffered most. The 6-degree (VII Rossi-Forel) isoseismal included an area of land 200 km long along the coast and almost 100 km wide inland. The 3-degree isoseismal was almost 400 km to the west of Caraga, and 600 km to the north, reaching the southeastern tip of Luzon Island and the Visayan Sea.

Many recurrent shocks occurred; their frequency markedly decreased by the 10th but began to increase again on the 11th. The main earthquake struck at night on the 12th, and was accompanied by a large number of aftershocks.

In the Caraga region, the force of the earthquake was 7 degrees /191
(VIII). It did only slight damage to the few light structures there. The collapse of the roof of the church at Manay was reported. The church was a wooden building with a corrugated iron roof, which was in a very bad state of repair. Several pile huts were damaged, while other huts settled into cracked ground. Many cracks developed and collapses occurred on the step and abraded limestone cliffs and on the hillsides. The earthquake was felt as far as Manado (Sulawesi Island) where it was estimated at 4 degrees (V).

After the main earthquake, a tsunami arose, which inundated the low-lying coasts of several bays, for example, at Manay, and did some damage to structures and plantations there. The tsunami was also observed at Manganitu (Fig. 92) on Sangihe Island (Maso, 1921; Visser, 1922 b; Repetti, 1931; Berninghausen, 1969; Cox, 1970).

Gutenberg, Richter (1954): 11.XI; $18^h36^m08^s$; 8° N., 127° E.; M=7.5.

1922, February 28, 4:41. There was an earthquake on Cebu Island. It was the strongest (or one of the strongest) since the island had been discovered by Europeans. It began suddenly, without perceptible preliminary shocks. It was accompanied by a "noisy roar" which, according to eyewitnesses, was like the roar of heavily loaded moving trucks or of a hundred horses galloping over a large wooden stage.

The intensity was 6-7 degrees (VII-VIII Rossi-Forel). The zone of damage extended 40 km to the north-north-east direction and included Mactan Island, Cebu City and the central part of Cebu Island to the north of Cebu. On Mactan Island and north of Cebu, cracks appeared in the alluvial soils and on the steep calcareous shores and hillsides, and also in the cement floors of the buildings here. The cracking of the ground frightened the population, who feared an explosion of the volcano. The tile roofs which are widely used on Cebu Island were damaged; three of them partially collapsed, including the very old, steep roof of a monastery. /192
Damage was also recorded where drainage pipes, wooden and cement staircases met walls and the ground. Hairline cracks appeared in the walls themselves of buildings; only old homes, as a rule built of coral limestone blocks, were damaged. In addition, at Cebu, two very old walls standing alone fell on the huts, made of leaves, sheltered by the walls, killing five people. None of the concrete buildings, made out of good lime mortar, suffered any damage. Old, but well repaired houses, were also unharmed. No collapses or slumps were recorded in the coal mine

near Cebu.

The earthquake was strong on the Camotes Islands and on the western coast of Leyte Island. It was felt on the islands of Leyte, Samar, Bohol, Negros, and on the east of Panay Island. The tremors were barely noticeable on Burias Island. The large axis of the area of perceptibility extended to the north-north-east and had a length of about 400 km. The earthquake was accompanied by recurrent shocks, the force of which occasionally reached 4-5 degrees.

Unusual movements of the sea were noticed after the earthquake in the passage between Cebu and Mactan Islands and around the northern tip of Cebu Island. The underwater cable, running from the northern tip of Cebu Island to Masbate Island, as well as the cable connecting Masbate and Burias Islands, was cut on the same day. The exact time of the breakage of the cables is unknown (Maso, 1922 a; Repetti, 1931; Sieberg, 1932; Iida *et al.*, 1967; Berninghausen, 1969; Cox, 1970).

[27.II; $20^h39^m50^s$; 10.2° N., 124.1° E.; M=6.25.]

1922, March (mistakenly September) 1, 17:10. There was an earthquake on the southeast of Negros Island, reaching an intensity of 6-7 degrees (VII-VIII Rossi-Forel) on the coast from Siaton to Bacong*. It damaged buildings, including churches and monasteries. Avalanches occurred and the ground cracked in the region of Samboangita and other places. At Siaton, the facade of a monastery collapsed, but there were no victims. At the church at Bacong*, according to the priest, up to seven visible oscillations of the walls were observed, the pulpit "danced," and people shouted and ran outside; the trees rocked heavily. The number of landslides, cracks in the ground and other effects of the earthquake decreased markedly with distance from Samboangita to the north, into the hills of volcanic origin.

At Dumaguete, the shocks barely exceeded 5-6 degrees (VI Rossi-Forel). On Siguijor Island, the earthquake had an intensity of about 4-5 degrees. It was felt at Tuburan on Cebu Island. At the same time, no reports of an earthquake were received from other places on Negros Island, except for those mentioned, or from the northern shore of Mindanao Island.

A monk was sitting on the shore at Bacong* at the time of the earthquake. Suddenly the sea rushed towards him, and he took fright, but looking around and seeing the swaying of the trees, he realized that an earthquake was taking place (Maso, 1922 b; Repetti, 1931; Berninghausen, 1960; Cox, 1970).

[$9^h10^m23^s$; 9° N., 123.25° E.; M=6.]

1923, March 3 (mistakenly February 23), 0:49. There was a strong earthquake in the province of Cotabato, especially on its southern and southwestern shores. The intensity was about 5 degrees (VI Rossi-Forel) all over Mindanao Island. It was felt on the south of the islands of

Cebu, Bohol and Negros.

Unusual sea waves were noticed on the southern and southwestern shores of the province of Cotabato and in the Mindanao River (Rio Grande) at Cotabato (Maso, 1923 a; Repetti, 1931; Berninghausen, 1969; Cox, 1970).

Gutenberg, Richter (1954): 2.III; $16^h48^m52^s$; 6.5° N., 124° E.; M=7.2.

1923, July 18, 10:42. There was an earthquake of intensity 3 degrees at Butuan and on Camiguin Island. It was reported, that several minutes later, during the ebb tide, enormous waves coming from the Surigao Strait were observed at Mambajao. The coast was inundated. The water rose higher than during the greatest flood tides. The rough sea lasted about an hour. No similar reports of rough sea were received from any other places (Maso, 1923 b; Repetti, 1931; Berninghausen, 1969; Cox, /193
1970).

Repetti (1931): 18.VII; $2^h42^m19^s$; 9.3° N., 125° E.

1924, April 15, 0:20. There was a destructive earthquake with source to the southeast of Mindanao Island. On the Pacific coast, approximately between 8° north and Davao Bay, the loose soil cover cracked, numerous landslides descended from the steep slopes, and rocks fell from cliffs. At Mati, at the top of Pujada Bay, a broad area of the coast subsided 1/2 m. Several bamboo huts collapsed. At other homes, various objects fell and broke, and partitions were damaged. The earthquake was felt rather strongly in the valley of the Agusan River. The isoseismals of the earthquake extended north and north-west; the 4-5 degree (V-VI Rossi-Forel) isoseismal was 400 km from the epicenter in this direction. The 3 degree isoseismal was 1000 km away and included all Mindanao Island and the islands in the Visayan Sea. The magnitude was 4 degrees on Sangihe and Talaud Islands. The earthquake was felt very weakly at Manila and on the northeast of Kalimantan Island at Bengalon*. Numerous recurrent shocks were felt after the earthquake (as far as the Talaud Islands) and were registered.

A strong seaquake was felt on board a steamship riding at anchor in Caraga Bay. The sea suddenly became very stormy. The steamship was jerked so strongly that they feared that the anchor chain would snap. At the same time, one could see enormous waves smashing against the cliffs on the northern coast of the bay. Binuangan* was inundated. There were no victims. The tsunami may have been observed at Mati (Algue, 1924; Visser, 1925; Repetti, 1931; Sieberg, 1932; Anon., 1961; Iida et al., 1967; Berninghausen, 1969; Cox, 1970).

Gutenberg, Richter (1954): 14.IV; $16^h20^m23^s$; 6.5° N., 126.5° E.; M=8.3.

1924, May 7, 0:10. There was an earthquake with epicenter near 16° N., 118° E. It was felt with a force of 4 degrees (V Rossi-Forel) at Agno, and also at Bolinao and some other settlements in the provinces of

Zambales, Pangasinan, Northern and Southern Ilocos and Benuet, as far as the central regions of Luzon Island. It was preceded by a foreshock on May 3 at 15:15:02, which was felt at Agno with a magnitude of 4 degrees. Some of the residents thought that they saw lights flickering over the sea during the main earthquake.

Agno was the only sizeable settlement near the source of the earthquake. It is situated on the northern shore of the Agno River (Balincagin), 3 km from the mouth. The sea coast on this area, which is made up of river deposits, is low-lying, unlike the high abraded shores lying to the north and south.

Soon after the earthquake, four large sea waves surged onto Agno. The waves inundated the lower regions of the city and terrified the residents. However, no one was injured and material damage was minor (Maso, 1924 a; Repetti, 1931; Anon., 1961; Berninghausen, 1969; Cox, 1970).

[6.V; $16^h09^m20^s$; 16° N., 119° E.; M=6.9.]

1924, June 2. A mistaken date (SN, 1924, vol. 14, No. 2; Iida et al., 1967) for the earthquake and tsunami of 7.V.1924.

1924, August 30, 11:07. There was an earthquake which was felt from the southeastern regions of Luzon Island as far as the Talaud Islands (2 degrees at Beo) and from the coast of the Pacific as far as Zamboanga. It reached its greatest intensity, about 6-7 degrees (VII Rossi-Forel), on the northeast of Mindanao Island, in the provinces of Surigao and Agusan, on an area of about 8000 km^2. On the Pacific coast and along the river banks in the valley of the Agusan River (Butuan and other regions), numerous cracks appeared in the ground and many avalanches and landslides occurred, but all this was observed only in very young, very loose alluvial ground.

Considerable material damage was done here. However, the predominant types of structures in this locality were wooden or bamboo pile huts, which easily withstood the underground shocks. Some of the huts sank /194
completely into the cracked ground. A reinforced concrete building built on loose ground, suffered damage.

Recurrent shocks of different force occurred very frequently during the first eight days after the earthquake (SN, 1924, vol. 14, No. 3; Maso, 1924 b; Visser, 1925). A tsunami was observed at Bislig and Hinatuan (Repetti, 1931; Berninghausen, 1969; Cox, 1970).

Gutenberg, Richter (1954): 30.VIII; $3^h04^m57^s$; 8.5° N., 126.5° E.; M=7.3.

1925, May 5, 18:07. There was a strong earthquake on the Dumaguete Peninsula (southeast of Negros Island). The settlements of Tolong, Siaton, Tanhay, Bais and others, situated on filled-in ground or on the swampy Quaternary and Tertiary terraces, fringing the steep slopes of the ancient Tigas volcano which makes up the peninsula, suffered most of all. It was mainly poorly built structures and those which had long needed repairs which were damaged: the sugar factories at Bais and Isabela, the school, the church, the monastery and the town hall at Siaton, the monastery and town hall at Tanhay. Some of these were pile structures with weak supports (of rotted beams) and heavy roofs. Brick chimneys of old sugar mills collapsed and the weak parts of the old churches and monasteries fell everywhere at a distance of up to 125 km from the source of Negros Island.

On the neighboring islands, Cebu, Siquijor, and Mindanao, at the same distance from the epicenter, the earthquake was less strong. Many collapses, landslides and mudslides occurred along the valleys of the channels on the steep slopes of the Dumaguete Peninsula; 17 people died as a result. Recurrent shocks were registered almost constantly in the epicentral zone during the first few days and sporadically for several months.

The south coast of Negros Island (and only this coast) was inundated by waves caused by the earthquake (Maso, 1925 b; Repetti, 1931).

Gutenberg, Richter (1954): 5.V; $10^h06^m06^s$; 9.5° N., 123° E.; M=6.75.

1925, May 25, 11:44. There was a "vast" earthquake, which was felt with a force of 5-6 degrees (VI-VII Rossi-Forel) on Tablas Island and 4-5 degrees (V-VI) on the islands of Sibuyan and Romblon and nearby little islands up to 200 km from the source. A seaquake was felt distinctly on a steamship to the southwest of Romblon Island. The small tsunami which resulted flooded Tugdan and several low-lying villages on the southeastern coast of Tablas Island (Maso, 1925 a; Repetti, 1931; Berninghausen, 1969; Cox, 1970).

Gutenberg, Richter (1954): 25.V; $3^h43^m06^s$; 12.5° N., 122.5° E.; M=6.25.

1925, November 13 (mistakenly 25), 20:16. There was a strong earthquake with source to the northeast of Samar Island. The islands of Batag and Laoang suffered most. Here the ground cracked and many homes were destroyed. On Batag Island, the new concrete lighthouse building cracked and its optical mechanical equipment was damaged. On the coast of Samar Island, considerable damage was done not only to the local homes, but also to more solid structures. Here, the force of tremors reached 7-8 degrees (VIII-IX) Rossi-Forel).

The 4-5 degree (V-VI) isoseismal was 300 km from the source and included the southeast of Luzon Island, Masbate, and Leyte Islands, and the north of Cebu Island. The boundary of the area of perceptibility was 600 km from the focus and included the south of Luzon Island, the islands of the Visayan Sea, and the northeast of Mindanao Island.

At Manila, only a few people, who were at rest, noticed the earthquake. However, water splashed out of two large reservoirs 20-25 m in diameter, possibly because of the resonance oscillations which developed. The earthquake was accompanied by numerous recurrent shocks.

Off the low-lying coast of Batag Island, the sea retreated, and then surged in strongly; several fishermen drowned and many fishing boats were sunk (Maso, 1925 c; Repetti, 1931; Berninghausen, 1969; Cox, 1970).

Gutenberg, Richter (1954): 13.XI; 12h14m45s; 13° N., 125° E.; M=7.3.

1928, June 15, 14:13. There was a destructive earthquake off the southwestern tip of Mindoro Island. The force of tremors reached 6-7 degrees (VII-VIII Rossi-Forel) for a distance of 20 km along the coast. The main destruction occurred in the region of the spit, screening Mangarin Bay. Here ran a railway which connected Mangarin Port with a sugar factory, and stood houses of workers and fishermen. As a result of strong tremors and cracking of the ground, houses collapsed completely, and a concrete warehouse and the coastal part of the road were heavily damaged. The loose soil cover apparently slid into the sea; fresh exposures appeared at the line of collapse; the port shallowed; the shore rose in places and subsided at other places. /195

The force of tremors rapidly abated inland. The radius of the 5 degree (VI) isoseismal was estimated at 160 km; the radius of the boundary of perceptibility was 300 km. Many recurrent shocks occurred, which were registered mainly before the 22nd.

Immediately after the main shocks, the sea surged on land, partly washed out the railway, and inundated the subsided areas of the shore (Maso, 1928).

Gutenberg, Richter (1954): 15.VI; 6h12m36s; 12.5° N., 121.5° E.; M=7.

1928, December 19 (mistakenly 28), 19:37. There was a strong earthquake which affected all Mindanao Island. Many homes collapsed at Cotabato. Zamboanga and Davao did not suffer, although the tremors were very strong.

A tsunami was observed in Illana Bay. A wave rose up the Mindanao River to Cotabato, where it did damage. Four people died and 102 were injured (SN, 1928, vol. 18, No. 4; Heck, Bodle, 1930; Sieberg, 1932; Iida et al., 1967; Berninghausen, 1969; Cox, 1970).

Gutenberg, Richter (1954): 19.XII; 11h37m10s; 7° N., 124° E.; M=7.3.

1929, June 13, 17:24. There was a strong earthquake with source off the eastern shore of Mindanao Island. At Hinatuan and Ebra, situated on weak loose soils, the force of tremors was estimated at 9 degrees (X Rossi-Forel). At Hinatuan, the earthquake began with abrupt vertical shocks; then regular horizontal oscillations were observed. People remained standing with difficulty. Many old homes were destroyed. Almost all of those that remained standing tilted to one side. The concrete cupolas of the church were not damaged. Numerous landslides occurred in the mountains between Hinatuan and Cape Lamon.

Homes sank to one side at Ebra. Ground waves could be seen. Many landslides and cave-ins of the ground were observed near the city. The water in the river began to move and inundated the subsided areas of the flood plain. At Lianga and Bislig, situated near Hinatuan, but located on bedrocks, the tremors were considerably weaker. At Talacogon, the tremors, estimated at 7 degrees (VIII), lasted 50 seconds. The banks of the river collapsed. At Butuan (6 degrees), the earthquake was preceded by an underground rumble. People were thrown to the ground. Several old walls and staircases collapsed. The water in the river surged onto the eastern shore. The tremors were also estimated at 6 degrees (VII) at Cantilan, Veruela, Calava*, 5 degrees (VI) at Surigao and Malaybalay, 4-5 degrees at Guiuan, Davao and Malita, 4 degrees at Catbalogan, Borongan, Ormoc, Mambajao, and 3 degrees at Iloilo, Cebu, Carmen, Cagayan, Canassi*, and Cotabato. Recurrent shocks were felt almost continuously for a month at Hinatuan. Up to 70 were counted on some days.

After the earthquake, a small tsunami entered Hinatuan Bay. An eyewitness, who sailed on the following day from Liang to Hinatuan, noted that the entire shore from Cape Lamon to Hinatuan, as well as the surface of the sea, were strewn with dead fish. A resident, who was in a boat on the Agusan River, 2 km upstream from Butuan, noted that after the earthquake, the river flowed backwards (Repetti, 1930, 1931; Heck, 1934, 1947; Ponyavin, 1965; Iida _et al._, 1967; Berninghausen, 1969).

Gutenberg, Richter (1954): 13.VI; $9^h24^m34^s$; 8.5° N., 127° E.; M=7.2.

1933, December 25. According to newspaper reports, the Bulusan Volcano (southeast of Luzon Island) erupted strongly. The strong tidal wave which accompanied the eruption did great damage. Nine people died (Anon., 1934; Neumann van Padang, 1953). This information is reproduced in some compendia with no indication of the site (Neumann, 1935; Iida _et al._, 1967; Cox, 1970). /196

1934, February 14, 12:00. There was a strong earthquake in the South China Sea, off the western coast of Luzon Island. It was felt all over Luzon Island except for its peninsulas, on the south of Taiwan Island and at Victoria (Hong Kong). The area of tremors was almost 1,900,000 km^2. The tremors were felt for 90-120 seconds in the coastal cities closest to the source, and for 60 seconds at Manila. The earthquake greatly frightened the residents, but the damage was slight. At Manila, the wall of a school cracked and a floor settled several centimetres at one place. However, this was due to the poor quality of the materials and the structures themselves.

The earthquake was accompanied by a small tsunami, which was observed at San Estaban. According to reports, the sea first retreated so markedly that the residents rushed to the dry strip of bottom to collect fish. Some of them almost drowned when the reflux was succeeded by a tidal wave.

Almost immediately during the earthquake (at 12:01), the Manila - Shanghai cable was cut. A ship sent from Shanghai to fix it found breaks at the following points: 17° 26' 24" N., 119° 16' 50" E., and 17° 25' 45" N., 119° 16' 50" E. The cable was repaired on February 23-25, but broke again on March 2 about in the middle between these two points, but this time the seismic stations did not register any earthquake. The bottom in the region of the break previously had an average depth of 2,465 m. Measurements of the bottom during repairs showed that the depth of the sea had diminished to 2,366 m 4 km south of the break, and had increased to 2,563 another 2 km further south.

The distinctive feature of the earthquake was the presence of very intensive long-period (20-30 sec.) waves between P and S onsets on the records of the stations at Hong Kong, Fulyan, Tsi Ka Vei (China) and others. The earthquake was accompanied by numerous recurrent shocks (Repetti, 1934; Neumann, 1936; Heck, 1947; Ponyavin, 1965; Iida *et al.*, 1967; Berninghausen, 1969).

Gutenberg, Richter (1954): 14.II; $3^h59^m34^s$; 17.5° N., 119° E., M=7.6.

1937, August 20. There was a strong earthquake with source apparently near Alabat Island. On this island the force of tremors was 7-8 degrees (VIII-IX Rossi-Forel). Almost all the homes tilted or suffered light damage. Thirty-seven people were injured.

The earthquake caused damage to various structures at Polillo, Mauban (the shore dike was damaged), Atimonan, Gumaca, Lucban, Tayabas, Lusena, Santa Cruz, Paete, Siniloan, Cavinti, Pililla, Tanay, Taytay, Pasig, Manila, Antipolo, Caloocan, Cavite, San Miguel and Naga. Hundreds of people were injured. At Manila, the tremors continued for 4 minutes, and the strongest ones lasted 40 seconds. The earthquake was noticeable as far as Laoag, Iloilo, and according to dubious sources, the north of Mindanao Island. It was accompanied by numerous recurrent shocks.

The earthquake affected the sea. There were reports of a rise in water level at Quezon, on the south of Alabat Island and at the top of Calauag Bay. At Calauag, the level rose from the ebb tide mark to the flood tide mark in 10 minutes. Some rafts, on which several people were travelling up the Calauag River, were picked up by a strong flood current (Repetti, 1937).

Gutenberg, Richter (1954): 20.VIII; $11^h59^m16^s$; 14.5° N., 121.5° E.; M=7.5.

1939, May 7, 1:00. There was an earthquake with source in the Verde Passage. There were strong tremors on the north coast of Mindoro

Island and the south coast of Luzon Island. At Batangas, the earthquake had a force of 4-5 degrees (V Rossi-Forel) and was accompanied by a muffled rumble. At Ambulong Island, Atimonan, Lusena, Boac, Daet, Santa Cruz, and Manila, the intensity was 4 degrees (IV). The radius of perceptibility of the earthquake was 200 km. There was a weak aftershock 9 minutes later and a strong one another 12 minutes later. Then followed a series of weak shocks (Repetti, 1939 b). /197

According to a chronicle (SN, 1939, vol. 29, No. 3), as a result of these shocks, the water in the wells became unusually warm, rocks rolled down from the hills and the ground cracked on Verde Island. Part of the island, beginning on 18.V [?] settled 1 m. Rothé's compendium (1941), adds that the island was flooded by the sea and the residents had to be evacuated.

Gutenberg, Richter (1954): 6.V; $17^h00^m07^s$; 13.5° N., 121.25° E.; 110 km; M=6.5.

1948, January 25, 1:47. There was a destructive earthquake on Panay Island. It was especially strong at Iloilo and Jaro. Twenty people died. Cracks more than 100 m long appeared in the ground. Large landslides came down from the hillsides, low-lying plantations subsided and the principal water mains burst. The banks where fish were caught were washed out by the sea (SN, 1948, vol. 38, No. 2; BCIS; ISS; Hamamatsu, 1966). Two people drowned in tsunami waves at Iloilo (Murphy, Ulrich, 1951 a; Iida et al., 1967; Berninghausen, 1969; Cox, 1970).

Gutenberg, Richter (1954): 24.I; $17^h46^m40^s$; 10.5° N., 122° E.; M=8.2.

1949, September 5, 10:54. There was an earthquake with source on the north of Luzon Island. It was felt with a force of 4-5 degrees (V Rossi-Forel) at Tuguegarao, 4 degrees (IV) at Manila, with oscillations lasting 30 seconds, 3 degrees at Aparri and 2 degrees at Bagio and Vigan. Two aftershocks were felt (Minoza et al., no date).

There is an unclear record from the tide gauge at Manila, which can be interpreted as a tsunami or seiches with a height of 10 cm and a period of 17 min. (Iida et al., 1967). [Undoubtedly seiches.]

[5.IX; $2^h54^m01^s$; 17° N., 121.5° E.; 80 km; M=6.4.]

1949, December 29, 11:05. The strongest earthquake since the Second World War occurred on the northeast of Luzon Island. It was felt all over the island (Fig. 91). The force of tremors at the largest settlements was: 6 degrees (VII) at Tuguegarao, 5 degrees (VI) at Cabanatuan, Aparri, Baler, Manila, 4 degrees (V) at Bagio, Laoag, Lusena, Casiguran, Quezon City, Vigan, 3 degrees at Daet, Ambulong Island and Iba, and 2-3 degrees at Basco. In the pleistoseismic zone, the ground cracked and sand and water smelling of hydrogen sulfide was ejected from the cracks. It was mainly the old churches, which had been built in the 17th and 18th centuries, which had been damaged during the war, which

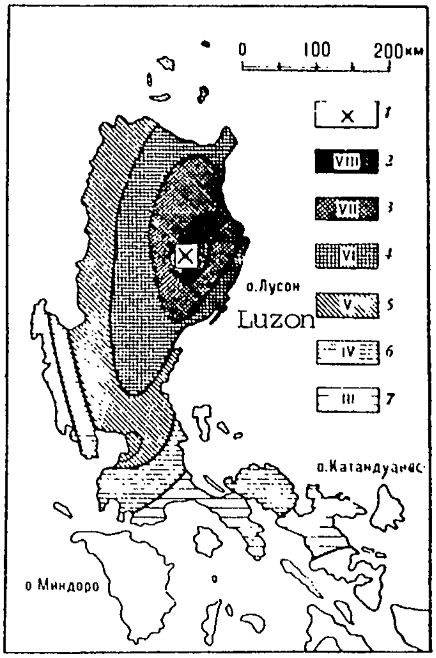

Fig. 91
Surface effect of the earthquake of 29.XII.1949.
1 - epicenter
2-7 force of tremors on Rossi-Forel Scale
(Minoza et al., no date).

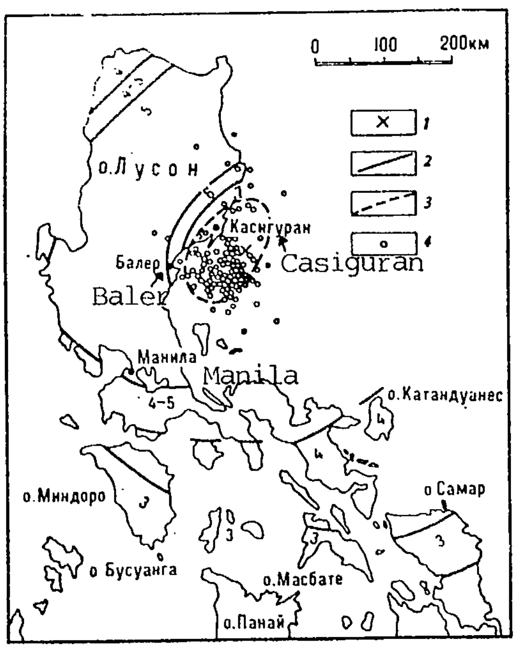

Fig. 92
Effects of the earthquake of 2.VIII.1968
(Omote et al., 1969).
1 - epicenter of main earthquake
2 - isoseismal lines
3 - approximate source of earthquake
4 - epicenters of aftershocks.

suffered. The wooden homes on concrete foundations which had been built after the war did not suffer any damage. Fifteen people died, the majority because several boats were sunk on the Cagayan River, and the rest were buried under the collapses of the steep shores of the river. About 50 aftershocks were felt for a week in the epicentral zone (Minoza et al., no date).

Near Mersedes*, one person died in the tsunami waves (Murphy, Ulrich, 1951 b; Hamamatsu, 1966; Iida et al., 1967; Berninghausen, 1969; Cox, 1970).

Gutenberg, Richter (1954): 29.XII; $3^h03^m54^s$; 18° N., 121° E.; /198
M=7.2.

1952, March 19, 18:59. There was an earthquake with source to the east of Mindanao Island. The force of tremors was: 5 degrees (VI) at Butuan, 4-5 degrees (V) at Surigao, 4 degrees at Tacloban, Cebu, Cagayan, Dipolog, Davao, 3 degrees at Catbalogan, Dadiangas, Virac, Hunatuan*, Borongan and 2 degrees at Iloilo and Malaybalay. The only damage was the cracking of the wall of the city church at Butuan and the falling out of a piece of wall 2-3 m in size, which broke several pews (Minoza et al., no date).

A tsunami arose, which was registered as a wave 7 1/2 cm high (1/4 foot) on Yap Island and on Guam, in Apra Harbor and at Tarague*. The tide gauge on Angaur Island, in the Palau Islands, registered oscillations in level with a maximal range of 66 cm (2.2 feet) (Murphy, Cloud, 1954; Iida et al., 1967; Cox, 1970).

Gutenberg, Richter (1954): 19.III; $10^h57^m12^s$; 9.5° N., 127.25° E.; M=7.75.

1968, August 2, 4:20. There was a destructive earthquake with source off the east coast of Luzon Island. It was preceded by at least four shocks which were felt at Casiguran during the 24 hours before the earthquake.

The force of tremors (in degrees) was estimated as follows (Fig. 92):

Casiguran	7 (VIII)	Tarlac	
Palanan	6 (VII)	Ambulong Island	4-5 (V)
Baler		Infanta	
Tuguegarao		Jomalig Island	
Aparri		Laoag	
Bagio		Lusena	
Dagupan	5 (VI)	Calapan	4
Iba		Aurora	
Manila		Catarman	
Cabanatuan		Virac	
Alabat Island		Romblon	3
Quezon City	4-5 (V)	Vigan	

The radius of perceptibility was more than 600 km. At Casiguran, loose ground settled 1-2 m. The channel which connects the Casiguran and Casalogan Rivers dried up. Numerous cracks 10-500 m long and 0.3-1.0 m wide appeared in the ground, here and there ejecting water, sand and mud. In the city, several buildings made of wood and concrete suffered damage. A bridge shifted. The people ran from their homes in panic. Posts and various subjects fell.

Near Dinadyavan, numerous avalanches and landslides occurred along the coast of Casiguran Sound and in the valley of the Jagdauan* River. At Baler, the damage was slight: a bridge shifted out of place near the city. In the middle reaches of the Casiguran River, near Manglad and Maddela, large mudflows and landslides descended. In the upper reaches of the Manglad* River, a part of the river bed 2.5 m wide and 0.5 m deep dried up. At Quezon City, according to the accelerograph record, the acceleration of the ground was estimated at 50 ± gal. /200

At Manila, homes situated at the mouth of the Pasig River on

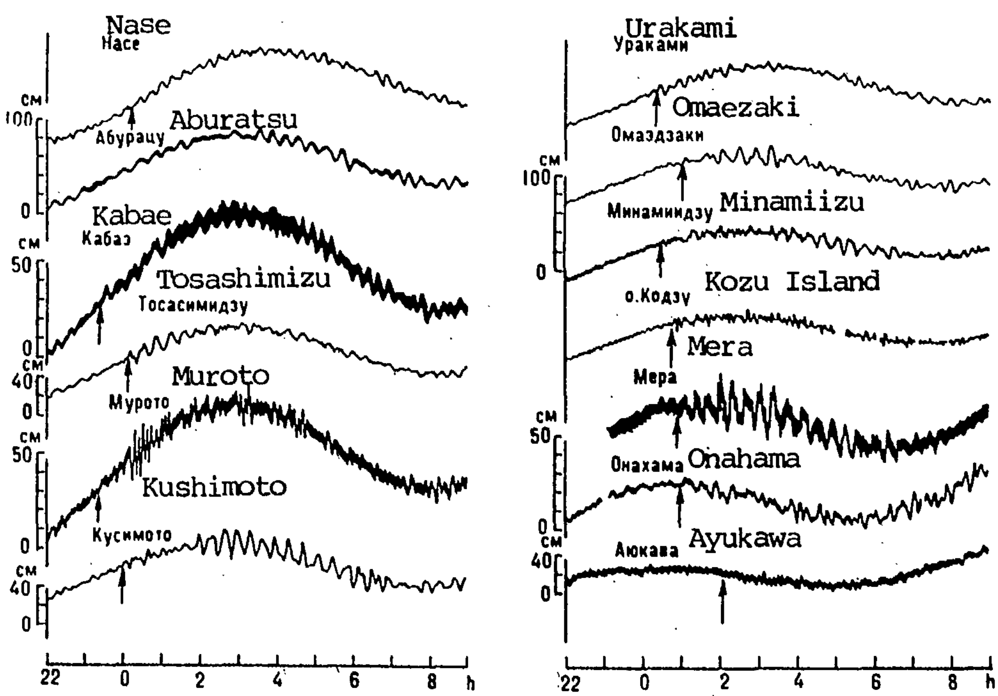

Fig. 93

Records of the tsunami of 2.VIII.1968 in Japan (Hatori, 1969a).

young alluvium more than 20 m thick suffered heavy damage. The "Ruby," a six-story reinforced concrete building, completely collapsed, as a result of which 268 people died and 260 people were injured. Up to another 10 such buildings almost collapsed and had to be demolished. Non-structural damage to buildings occured in many, though hardly all, regions of the city.

In addition to the above-mentioned victims, another two dead and one injured were registered in the country. The material losses have been estimated at at least 8 million dollars. Many recurrent shocks were registered. Their epicenters approximately outline the source of the main earthquake (see Fig. 92) (Omote et al., 1969).

The earthquake caused a tsunami, which was registered by the tide gauges on the Ryukyu Islands and the Japanese Islands with a mean height of 10 ± cm (and a maximal height of 30 cm off the capes on the south coast of Japan, which intensified the oscillations; Fig. 93, Table 63).

The records of the special automatic registers on the islands of Enoshima (Miyagi Prefecture) and Oshima (off the Izu Peninsula), barely show the tsunami. At Ishigaki and Naha (Ryukyu Islands), the height of the tsunami was under 15 cm. The envelope of the oscillations has a spindle shape. The front of the tsunami is traced with difficulty. The time of onset of the most intensive oscillations presumably corresponds to the approach of the marginal (shelf) waves (Hatori, 1969 c).

A weak tsunami was registered by the tide gauges of the U.S. Coast and Geodetic Survey on Guam Island with a height of 3 cm, Wake Island (9 cm), at Honolulu (3 cm), Nawiliwili, and on Attu Island (9 cm) (NL, 1969, vol. 11, No. 2; Coffman, Cloud, 1970).

USCGS: 1.VIII; $20^h 19^m 22^s$; 16.5° N., 122.2° E.; 36 km; [M=7.7].

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INDONESIAN ARCHIPELAGO

416. The Javanese "Book of kings" ("Rustaka radja"), which is a chronicle of the island, contains the following account of the eruption of Mount Kapi*. In 338 Saka (that is, 416), a thunderous roar was heard from the bowels of Mount Batuwara* (also called Pulosari, an extinct volcano in the Banten region, the closest to the Sunda strait). This roar was answered by an identical roar from the bowels of Mount Kapi*, which is situated west of the modern [region?] of Banten. An enormous blinding flame, which reached the heavens, exploded from Kapi* Mountain. The whole world shook. Thunder pealed out, a storm burst, and it began to rain. However, the eruption of flame from Mount Kapi* not only did not diminish with the rain, but even increased. The roar was terrifying. In the end, Mount Kapi* exploded into pieces with a terrific noise and descended into the depths of the earth.

A sea wave arose and inundated the land. The locality from Batuwara* Mountain east to Gede Mountain (Kamula) and west to Radjabasa Mountain [the most southern volcano on Sumatra Island, situated in the vicinity of Lampung, see Map VIII] was inundated by the sea. The residents of the northern part of Sunda district, as far as Mount Radjabasa were drowned and washed away together with all their belongings.

After the water receded, Mount Kapi* and its locality were left on the sea bottom, while Java Island split into two parts...Thus the islands of Sumatra and Java were separated (Judd, 1889; Wichmann, 1918; Heck, 1934, 1947; Ponyavin, 1965; Iida *et al.*, 1967; Berninghausen, 1969; Cox, 1970).

[The events are very similar to the famous eruption of Krakatau in 1883. It is possible that Mount Kapi* is in fact the Krakatau Volcano.]

1608, July. The Dutch fleet, which had just conquered Makian Island (Map IX), was riding at anchor in front on the fort on the island. For several days, the sea had been unusually quiet. Suddenly, the sea became so rough, and there was such a strong run-up on shore, that the ships could not be kept under sail. On July 1, the ships "Valkiria" and "China" were run aground on the reefs, moreover, as is mentioned in a Dutch letter dated 3.VIII.1608, not by a storm, but by a large tidal wave. There were victims on the "China." Only some of the freight could be saved from the ships. After this, the explosive activity of the Tidore Volcano supposedly intensified. On August 3, having made repairs, the Dutch fleet left for Banten (Perrey, 1859 b; Wichmann, 1918).

1629, August 1, 21:30. The Banda Islands (Fig. 94) felt a strong earthquake; the ground cracked. Half an hour later, a high mountain of water appeared in the strait between Lonthor and Neira Islands. The tidal wave rolled directly onto Fort Nassau and the coastal settlement of

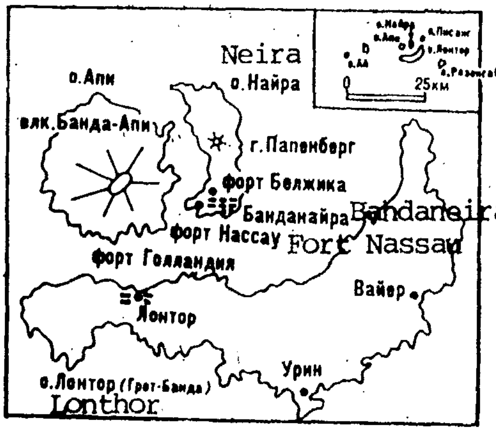

Fig. 94

General map of the Banda Islands, based on a Dutch XVII Century Map.

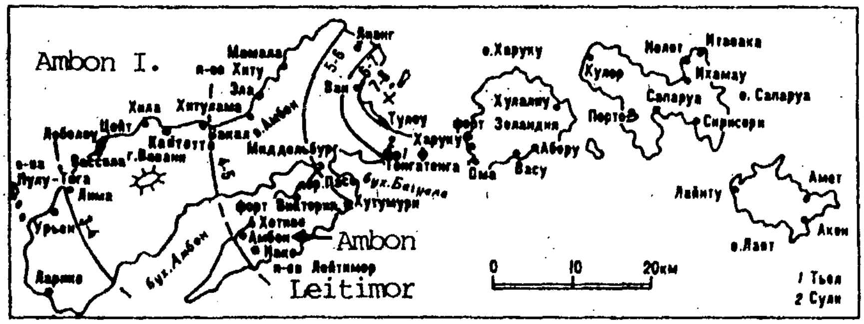

Fig. 95

General map of the islands of Ambon, Haruku, Saparua, and Laot. Epicenter and isoseismal lines of the earthquake of 9.IX.1932 are taken from Visser

Bandaneira on Neira Island. The water rose 16 m (9 fathoms) above the spring flood tide mark (according to Perrey, the water inundated Fort Nassau by 3 m [9 feet]). The stone breakwater in front of the fortress was washed away. The water invaded the fort with such force that a cannon weighing 1 1/2 tons was dragged 11 m. Several homes on the shore were washed away, and others were destroyed. The wave rose three times and spun the "Brill," which was riding at anchor in the roadstead, though the ship was not damaged. Many fish were tossed up on shore.

In the eastern direction, the tidal waves surged onto the coast of Lonthor Island, where a stone breakwater was also washed away. The rise of water was 4 m (13 feet) here, and a proa, situated at Cape

Mandjangi* was dragged inland past the guard post. The fishermen at open sea did not observe any signs of a tidal wave. The earthquake was apparently felt at Ambon (Perrey, 1858; Wichmann, 1918; Berninghausen, 1969; Cox, 1970). /202

1630 or 1631. A date for the tsunami of 1.VIII.1629 (Montbeillard, 1761; Hoff, 1840; Mallet, 1855; Perrey, 1858; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

1648, February 29 (mistakenly 2). At Ambon, in the region of Fort Victoria, there was a considerable earthquake with a strong roar like the pounding of distant surf, but there was no appreciable damage (Wichmann, 1918). [This reference to surf led to the mistaken assumption of flooding in Ambon Bay in Wichmann and Cox's compendia (Wichmann, 1918; Cox, 1970).]

1657 (or 1659), December. There was an earthquake on the islands of Buru and Ambon and in many other places. Mountains collapsed. Ships riding at anchor at a depth of 55-70 m (30-40 fathoms) spun so that it was feared that they would run aground on the shore, the reefs or the shoals (Montbeillard, 1761; Perrey, 1857 a; Wichmann, 1918; Cox, 1970).

1659, November 11. Teun Island. Strong earthquakes on the 9th, accompanied by a rumble, forced the local residents to flee to Nila and Damar Islands. A strong eruption of Teun Volcano (Funuweri) followed on the 11th. The rumble which it caused, like a cannonade, was heard at Ambon and on the Banda Islands. A tidal wave was observed in Ambon Bay and reached a height of 1-1 1/2 m (3-4 feet) (Wichmann, 1918; Cox, 1970).

1673, May 20. An additional date (Mallet, 1855; Wichmann, 1918; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969; Cox, 1970) for the tsunami of August 12, 1673.

1673, July 12. There was a strong earthquake at Ambon; the ground cracked; avalanches buried the villages; there was a tsunami and many aftershocks (Sieberg, 1932; Iida et al., 1967; Cox, 1970). Perrey (1857 a) notes that there was a terrible hurricane on the morning of the same day and ships at open sea suffered damage. Wichmann (1918) reports strong shocks at Ambon on the 12th at 18:00, but makes no reference to a tsunami. [The fact of the tsunami is dubious.]

1673, August 12, between 22:00 and 22:30. Such a strong earthquake occurred on Ternate Island that no one could remember the like. The southern slope of Ternate Volcano split from top to bottom. Avalanches and rock falls occurred. The houses of the King of Ternate, standing at the foot of the volcano, made of stone and covered with tiles, collapsed completely.

The sea "swelled up" so much that all the ships in the roadstead almost went to the bottom. Fish were tossed up on the beach in enormous amounts. This destructive phenomenon continued for at least another two months (Perrey, 1859 b; Wichmann, 1918; Heck, 1934, 1947; Ponyavin, 1965;

Iida et al., 1967; Berninghausen, 1969; Cox, 1970).

1674, February 17, between 19:30 and 20:00. There was a very strong earthquake, which affected all Ambon Island and adjacent islands and left human victims. The shocks which continued all night and on the next day almost without interruption were accompanied by a roar like cannon shots. The first shock was the strongest. At Ambon (Fig. 95), the Chinese district was completely flattened. All the stone houses and the church cracked so much that they became unusable. Seventy-nine Chinese /203 and seven Europeans died under the debris of the buildings; 35 people were injured (fractures of the arms and legs). Seven homes collapsed completely at Nako. The roof of the redoubt was cast down at Hitulama. The Middleburg redoubt collapsed.

On the Leitimor and Hitu Peninsulas, the ground cracked at many places and there were numerous avalanches, which were especially strong in the Wawani and Manuzau* Mountains. Some streams, especially on the western shore, were blocked. The ground water level oscillated with an amplitude of up to 1-2 m. The water rose up so quickly from deep wells that it could be scooped up in the hands, and then fell back just as quickly. East of the Wai Tomo* River, water mixed with blue clay splashed to a height of 5 1/2-6 m out of a crack which had appeared. A very similar gryphon was formed on the south coast of the Leitimor Peninsula at Hutumuri. Flashes of light like "columns" were observed on the western coast of the island before the earthquake.

Immediately after the earthquake, a tsunami occurred on the entire coast of Ambon Island. The northwestern shore of Hitu Peninsula suffered most of all, especially the region of Ceyt, between Lima (Negrilima) and Hila. Here the water rose 80-100 m (40-50 toises), that is, to the top of the coastal hills. The trees, including those in the clove plantations, which covered the calcareous coastal slopes at Mamala, Ela, Sinalo*, Kaitetto, Ceyt, Loboleu, almost as far as Lima, were uprooted. Only the higher-lying plantations at Nausihola*, Wakal and Hitulama escaped destruction.

Everything was so "jumbled" onshore that it was unrecognizable. In the region of Loboleu, a coastal strip with the width of a musket shot subsided. The shore became very precipitous. Between Ceyt and Hila and at Hila itself, part of the coast also collapsed into the water, carrying with it the settlements of Nukuali*, Ehalaa*, and Wawani*. In all, 2,243 people died on Ambon Island as a result of the tsunami.

According to eyewitness accounts, the water rose up like a mountain. First it inundated Loboleu, and then it split into three streams. One of them spread along the coast to the west to Lima and Urien, another to the east to Hila, and the third went out to sea, in the direction to Cape Ryst on Ceram Island, carrying with it trees, houses, domestic livestock and people. The movements of the water were accompanied by a very loud noise. The moving water was black, very dirty and evil smelling; its surface phosphoresced.

According to the eyewitnesses, the surface of the sea in the strait between Ceram and Ambon Islands was calm, and it was agitated and made a deafening noise only off shore, to the distance of a musket shot. People in a boat not far from shore did not notice anything unusual in the state of the sea; the oscillations in its surface were just as weak and small as usual. On the coast, all the proas and other boats were smashed or carried away by the water. Many fish were tossed up on land. /204
The following is known about the effects of the tsunami at particular places.

At Larike at the Dutch redoubt, the water rose 1/2 m (2 feet). The damage from the flood tide was slight, although it recurred three times.

On Nussatelo Island* (Pulu Tiga Islands), the water first rose instantaneously, and then fell so far back to the east, that the bottom was exposed as far as the horizon and the former shore line could be discerned only with difficulty. The water immediately returned and inundated the low-lying parts of the island from one shore to the other, picking up and entraining in whirlpools and currents houses and everything that got in its way. This happened three times.

At Urien and other places, the water rose and then retreated a considerable distance from the shore opposite Nussatelo Island*. These unusual movements of the water washed away fences and small houses.

Near Lima, on the road to Boboleu, at the walls of the redoubt, water mixed with silt and sand rose up and carried away enormous stones, such as two or three soldiers could hardly carry. One woman was dragged 350 m from the redoubt, where she grabbed hold of a tree and saved herself. The soldiers took refuge on the roofs of buildings and in trees; two of 12 men died, six were seriously injured and only four remained unharmed. Part of Binau* settlement was washed away and 86 people died. Thirty-nine people, on their way to Hila, also drowned.

At Ceyt, the water rose to the loopholes of the redoubt with such force that it tossed up the mortar. The garrison suffered heavy losses. The water knocked down all the homes at the adjacent settlements of Ceyt, Loboleu and Wassela; 619 people died at Layn. There were no victims at higher-lying Hahntuna, except for those residents who went after the earthquake to pray at the mosques in lower-lying settlements, and drowned.

At Hila, after the earthquake, the Dutch garrison of Fort "Amsterdam" collected on the main square of the fort. Suddenly the water rose and flooded the structures to the roofs. The entire garrison of 31 people drowned. The walls of the fort, 2.5 m thick and 3 m high, were sheared away to the foundation. All the surrounding structures, except for two shacks, suffered the same fate; 1,461 people died.

The plantations at Sinola* to the east of the fort were inundated at least three times. The water advanced so quickly that the eye could hardly follow it. The first flood and ebb were rather calm. The second wave ripped up trees and bushes and scattered them about. The third wave carried off everything, leaving in its wake such a bare flat expanse, that one could not make out where the homes of the village and its plantations used to be.

At Wakal, one resident died, and some homes were destroyed.

At Hitulama, the water rose 3 m (10 feet) above its usual level; 35 residents and one soldier died.

At Mamala (near the northern tip of the Hitu Peninsula), about 40 homes were destroyed but no one died.

On the northeastern tip of the Hitu Peninsula, at Liang, Wai, Tuleu, Thiel and as far as Suli (not far from the Paso Isthmus), the tsunami also did damage, but considerably less. Although the water rose above the usual level, homes did not suffer, and only fences were washed out. Only at Pasir-Kutet (eastern tip of the Hitu Peninsula) did the waves carry off one house.

The Paso Isthmus (Baguala) was not inundated. The water reached only the first structures at the Middleburg redoubt.

On the island of Haruku, Saparua and Laot, the shocks were also strong and were felt all night. At Oma, two coastal hills collapsed into the water and the road cracked. The walls of homes cracked. A tidal wave was observed on the coast of the islands. It reached a height 1 1/2-2 m (6 feet) above the usual sea level.

After the earthquake and tsunami, the small island of Itelam*, situated near Ambon, supposedly disappeared. In its place, depths of 110 m (60 fathoms) were formed.

On Ceram Island, an earthquake and tsunami occurred mainly in the /205
southwest part of the island, on the Huwamunal Peninsula (Fig. 96). Here Cape Ryst, which had never before been covered with water was inundated; great damage was done. A sandy shoal appeared on the western shore of the bay, and Cape Wai (on the east) subsided. The small settlement of Loki at Fort Overberg* was inundated with water rising 5 1/2 m (3 fathoms) above the usual level; all structures and boats were smashed, but no one died. All the trees were washed off the plain on Cape Kaula*, while the homes there of the employees of the East India Company, were carried into a neighboring forest. Half of the settlement and the church were inundated in Tanuno Bay; however, no one died.

The earthquake was felt on Buru, Ambelau, Manipa, Kelang, and Boano Islands. On Manipa Island, the water suddenly rose and reached the moat of the redoubt, carrying with it about 50 fish. On Kelang Island, the water rose about 5 m (16 feet) at the guardhouse of the East India Company.

Only a weak earthquake was felt on the Banda Islands; the tidal wave was also slight (Seyfart, 1756; Perrey, 1857 a; Wichmann, 1918; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

1674, May 6, 4:30. There was a shock of moderate strength (one of the numerous recurrent shocks of the earthquake of 17.II.1674), which was accompanied by a booming rumble from the mountains on the Hitu Peninsula.

There was a weak tidal wave in Ambon Bay, advancing and retreating three times (Wichmann, 1918; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

1690, no date. There are erroneous references in some sources to a tsunami on the Banda Islands.

1708, November 28, between 22:00 and 23:00. A tidal wave burst into Ambon Bay with a loud noise and inundated the region as far as the homes on the slopes of Mount Batu Mera*, east of the city. Streams flowed backwards, and bridges were smashed. Then the water again surged back in a strong current and retreated so far that it was scarcely visible. Both the flood and ebbs lasted so long that one could count to 100-150 during a single flood or ebb. The process lasted until 3:00 on the following day, after which these waves were not observed. A similar phenomenon occurred at midnight in Baguala Bay. No such phenomena were observed on other areas of the coast (Perrey, 1857 a; Wichmann, 1918; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

1710, five weeks before April 10 (March 6?). There was a "large and terrible" earthquake at Bandaneira. The surface of the earth did not repose for a month. Most of the homes were substantially damaged. The sea repeatedly surged on to land as far as Fort Nassau and left fish in front of the water gates (Wichmann, 1918; Sieberg, 1932; Iida et al., 1967; Cox, 1970).

1711, September 5, between 22:00 and 23:00. Ambon. There were tidal waves, like the waves of 28.XI.1708, which lasted till 8:30. On September 6, the water in the bay rose and fell three times at half hour intervals. The rise of water occurred very quickly and was 1.2 m (4 feet). Two homes were destroyed. Two children drowned on the road at Hotiwa. The tsunami occurred mainly on the eastern coast of the island. In Baguala Bay, a tidal wave was observed which advanced and retreated 13-14 times, but it was not noticed at Poka*. At Kampung-Mardjika*, the water left a well [the result of an earthquake?].

On the islands of Haruku, Saparua, Laot and Banda, a strong earthquake occurred at the same time as a tidal wave appeared in Ambon Bay; 13-14 shocks were recorded (Perrey, 1857 a; Wichmann, 1918; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

1722, October, no date, 8:00. Djakarta (Batavia). There was a strong earthquake. In addition, the water was tossed up in the roadstead as in a "boiling saltern" (Wichmann, 1918) [A seaquake?].

1754, August 18, immediately after 15:30. There was an earthquake on the islands of Ambon, Haruku, Saparua, and Laot. It began with undulating movements, followed immediately by a strong shock. At Ambon, a bazaar, resting on 60 stone pillars, collapsed; several other buildings were also destroyed; four people died in the debris. The other homes cracked. Cracks two fingers or more across appeared in the ground at many places. A mud flow burst from Mount Batu Mera* east of the city. /206

The walls of buildings were damaged at Hila as well as at Hitulama, on the north coast.

At Hutumuri, on the eastern coast of the island, a tidal wave followed a strong earthquake.

On Haruku Island, water gushed up at many places and some walls of buildings collapsed. The earthquake was followed by a tsunami, which however, soon stopped.

On Saparua Island, the earthquake did not do substantial damage to structures. A tidal wave was also noticed here. An earthquake was felt on Manipa Island (Perrey, 1857 a; Wichmann, 1918; Sieberg, 1932; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969; Cox, 1970).

1754, September 7, between 12:00 and 12:30. On Haruku Island, there was an earthquake almost as strong as the one on August 18. It was accompanied by a tidal wave (Wichmann, 1918; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969; Cox, 1970).

1757, August 24, about 2:00. At Djakarta (Batavia), there was a strong undulating tremor lasting 5 minutes. At 2:05, during the strongest shock, a wind blew in from the northeast. The water in the Liwung River, which flows into the sea at Djakarta, rose to a height of 1/2 m (2 feet) above the usual level and fell by the same amount (Wichmann, 1918; Cox, 1970).

1763, September 12 (1), about 17:00. There was a strong earthquake, lasting 4 minutes, on the Banda Islands. The rumble was like cannon shots. In the evening and at night, another 16 weaker shocks were felt. Three quarters of the homes at Bandaneira were left in ruins. Enormous chunks collapsed from Panenberg Mountain. On Lonthor Island, the earthquake was especially strong at the settlement of Waier on the eastern coast and at Urin. It was also strong on Ai Island. The earthquake was felt to a lesser extent on Pisang and Rozengain Islands.

During the first shocks, the sea level fell 9 m (30 feet) and then quickly rose (in less than 3 minutes). A large area of land was flooded. Seven people died (Mallet, 1854; Perrey, 1858; Wichmann, 1918; Sieberg, 1932; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969; Cox, 1970).

1770, no date. In the Bengkulu district (Sumatra Island), there was a very strong earthquake. A settlement was destroyed. The ground cracked. One of the cracks had a length of 500 m, a width of 3 1/2 m and a depth of 8 m, and from it oozed a bituminous substance. At the same time, a section of coast near the mouth of the Padang Gutongi River, which flows in the Mana district, dried up. Finally, a tidal wave occurred simultaneously with the earthquake.

As Wichmann notes, the year given is tentative. The event could have coincided with the earthquake experienced at Bengkulu by Ch. Miller, who says: "One earthquake, in particular, after my arrival here was very strong and did much damage in the country. The Dempo Volcano, visible from Fort Malboro at Bengkulu and smoking almost constantly, ejected flames during the earthquake" (Wichmann, 1918).

1771, November 9, 10 and 11. A heavy rumble issued from the depths of the Ternate Volcano. A strong northwestern wind blew up heavy waves off the reefs, such as no one could remember. The water was tossed up on shore, where great damage was done. One sailor drowned (Perrey, 1859 b). [Taking everything into account, this was not a tsunami.]

1773. In a very dubious letter, the captain of a Spanish ship /207 reports an underwater eruption, accompanied by agitation at sea near Kalimantan Island, on the route from the Sunda Strait to the Philippines, which he supposedly observed in this year (Wichmann, 1918; Cox, 1970).

1775, April 19, about 1:00. At Ambon, there were strong undulating oscillations, which were accompanied by a dull underground rumble and lasted 5 minutes. The wall of the rice storehouse cracked and a small pavilion collapsed. The water in the bay oscillated greatly. A moored ship was pulled forcefully backwards and forwards (Mallet, 1854; Perrey, 1857 a; Wichmann, 1918; Iida et al., 1967; Berninghausen, 1969; Cox, 1970).

1797, February 10, about 22:00. There was an earthquake on the west coast of Sumatra Island. It occurred at latitude 2° north to 2° south of the equator. It was apparently rather strong also on the east of Sumatra. The first tremor lasted about a minute. At Padang, cracks up to 10 cm wide appeared in the ground. These, however, closed up in the subsequent tremors. The walls cracked in most of the homes. The earth was restless during the entire night and the next day, and strong shocks occured at 15-20 minute intervals. They were still being felt for a week, but the intervals gradually increased. A tidal wave followed the earthquake. It burst into the river at Padang with great force and inundated the city. After this, the water retreated so far that even the river bed dried up. This process recurred three times. The settlement of Ajermanis on the coast was flooded and many huts were washed away. About 300 people died. One ship was carried 5 1/2 km (3 miles) inland.

The tsunami was considerable on the Batu Islands as well (Mallet, 1853; Wichmann, 1918; Sieberg, 1932; Heck, 1934, 1947; Ponyavin, 1965; Berninghausen, 1966).

1799, no date. Sumatra Island. There was an earthquake and tsunami, about which the following reports are available. During the earthquake, a tidal wave rose along the coast, and reached a height of 15 m (50 feet) above the usual water level. A new reef was also formed, which became a danger for navigation. It was discovered by the ship "Bergen" on 11.XI.1799. The earthquake did considerable damage at Palembang (Wichmann, 1918; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967).

[Apparently, the date is not accurate and the description relates to the earthquake and tsunami of 10.II.1797.]

1802, August. Ambon. A letter dated August 25 reports a strong earthquake which affected Ambon Island and other islands on the east of Indonesia. The water at sea rose very high and did great damage on the coast of the islands (Mallet, 1853; Perrey, 1857 a; Wichmann, 1918; Sieberg, 1932; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

1814, no date. At Kupang (Timor Island), there was an earthquake which immediately generated a tidal wave, which burst into Kupang Bay. There was also an eruption of a mud volcano, as a result of which the Pulu Burung* Bank off the north shore of the bay turned into a small island. A destructive earthquake apparently occurred simultaneously on Kissar Island (Wichmann, 1918; Sieberg, 1932; Iida et al., 1967; Cox, 1970).

1815, April 10 (mistakenly 4). There was an explosion of the Tambora Volcano on Sumbawa Island which was thought to be extinct. It was the strongest explosion in historial times in Indonesia. It was accompanied by considerable oscillations in sea level. The eruption began on April 1. At 22:00 at Banjuwangi (Java Island), a cannonade boomed out like peals of distant thunder. It was repeated from time to time, and this continued until 9:00 on the 2nd. On the morning of the 3rd, a light fall of ashes began; on the 5th, explosions began to be heard at 1/4 hour intervals.

The eruption reached its peak on the evening of the 10th, when a colossal pillar of smoke rose above the volcano and the entire mountain seemed to eject flame. Soon the volcano and all that occurred there were hidden in a dense cloud of smoke.

The sound of a shot was so loud that it was heard for an enormous /208
distance: from Bengkulu and Banka Island in the west to Ternate Island in the east. At Surabaja, the air wave uprooted trees, destroyed the walls of homes, and bowled over people and animals. The tremors were felt more or less strongly at Banjuwangi, Sumenep, Surakarta, Rembang, apparently on the southeast of Kalimantan Island, at Makassar and on Flores Island.

Scorching hot slag and ashes covered all of Sumbawa Island and a sizeable water area. Buildings collapsed under this load. The previously picturesque island was turned into a desolate desert. Of 12,000 residents, only 26 survived. On neighboring Lombok Island, the depth of the layer of ashes was 1/2 m. A similar layer of ashes was floating at sea west of Sumbawa Island on the 12th. On Java Island, the ashfall was so dense that complete darkness set in. The ashes fell on Java at a distance of 550 km from the volcano; it also fell on Sulawesi Island and at Ambon. From this one can conclude that the ash was ejected to a very great height, as otherwise it would have been carried by the trade winds only to the west.

On the 10th, with still weather, the sea off the coast of Sumbawa Island suddenly rose to a height of 1/2 to 3 1/2 m (from 2 to 12 feet). Large waves burst into the estuaries of the rivers and immediately surged back. Here and there homes and trees were washed away. At Bima, the water submerged the floors of homes by 0.3 m (1 foot). All the proas and boats were torn from their anchors and tossed on shore. The coast at the Tambora volcano subsided so that water 5-6 m (18 feet) deep appeared in place of the land.

Short-period (duration no more than 3 minutes) oscillations in level were noted on Sulawesi and Java Islands. At Sumenep, on the 11th at 19:00 during an ebb tide, a flood tide of water from the bay made the river rise 1-1 1/2 m (4 feet); then the level fell for 4 minutes.

The explosions of the volcano, which were accompanied by strong tremors, lasted several more days. The eruption finally came to an end only on July 15 (Raffles, 1817; Lyell, 1868; Fuchs, 1875 b; Wichmann, 1918; Sapper, 1927; Sieberg, 1932; Heck, 1934, 1947; Neumann van Padang, 1951; Ponyavin, 1965; Iida *et al.*, 1967; Berninghausen, 1969; Cox, 1970).

1815, April 11 or 12. There was a strong earthquake at Ambon. Cracks opened and closed in the ground. At Haruku, on Haruku Island, the fort and houses were completely destroyed; the ground cracked. Shocks were felt on the Banda Islands.

On the next day, the sea in the vicinity of Ambon became very rough. In two minutes, its level rose to the high high tide mark and fell with the same speed to the low tide mark (Wichmann, 1918; Sieberg, 1932; Heck, 1947; Ponyavin, 1965; Iida *et al.*, 1967).

[These oscillations in sea level on the east of Indonesia may have been caused by the passage of the air wave, which arose during the eruption of the Tambora volcano, as occurred during the Krakatau eruption in 1883. The tremors of buildings may also have been caused by the air wave, at least partly.]

1815, November 22, 22:00-23:00. There was an exceptionally strong earthquake at Buleleng on the north coast of Bali Island. The tremors lasted almost an hour and were accompanied by a deafening rumble, which seemed to come from the coastal mountains. The earthquake was strong on Lombok Island and at Surabaja, where it lasted 30 seconds, and it was also apparently felt at Bima.

The coastal mountains "crumbled" with a monstrous roar and partly collapsed into the water; 10,253 people were buried under a mudflow. A sea wave arose, which flooded the land for a large distance, as a result of which another 1,200 people died.

The fracture which formed during the earthquake crossed Danau-Tamblingan Lake, situated between Buleleng and Tabanan. The lake partially flowed out, which aggravated the flooding (Wichmann, 1918; Sieberg, 1932; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

1816, April 29, about 2:40. On Penang Island and the Malacca Peninsula, there was a very strong shock especially in the northern and central parts of the island. The direction was northwest to southeast, the duration was 15-20 seconds. Pieces of stucco collapsed from the ceiling in the rooms of some homes. /209

On the night of the 31st [one should probably read the 30th] and during the next two nights, shocks were felt on board the brig "Helen." There was a rough sea together with the earthquakes (Wichmann, 1918). [It is difficult to say whether this concerns a seaquake or a tsunami.]

1818, March 18. There was an earthquake at Bengkulu. The ships "Northumberland" and "Sandbury" were shaken so strongly that the sailors were tossed from their berths.

The tremors were felt by Raffles, who was onboard a ship 350 km (200 miles) from the coast of Sumatra. At Fort Malboro, a very strong shock occurred at night. One of the eyewitnesses who described the earthquake was thrown from his bed, and the wall of the home partly collapsed. At dawn, it was found that the sea had retreated far from shore and that all the ships riding in the roadstead had sat on the bottom. Soon thereafter the sea returned, surging in with great force and washing away everything in its path. The water advanced so far inland that a bridge was inundated.

At Bengkulu, the shocks lasted at least until April 8, the post-date on the letter (Mallet, 1853; Wichmann, 1918; Sieberg, 1932; Heck, 1934, 1947; Ponyavin, 1965; Berninghausen, 1966).

1818, November 8. Java Island. There was an earthquake, which spread over the entire island and was especially strong in its eastern part (at Banjuwangi and Pasuruan). A seaquake was registered in Bali Strait. A strong shock was felt in the vicinity of Pasuruan at about 23:15; it was followed by six or seven weaker shocks. The duration was almost 4 minutes. A shock was also felt at Malang. In addition, an eruption of the Lamongan volcano occurred at night (Wichmann, 1918). In the same year (date unknown), large earthquake lasting 3 minutes occurred at Bima (Sumbawa Island). The shocks were so strong that people could not stand, and all stone structures crumbled. In the bay, the sea level rose 3 1/2 m (2 fathoms), and a tidal wave fell on the city (Wichmann, 1918; Cox, 1970). According to Sieberg (1932), both reports relate to the same event.

1820 (incorrectly 1821), December 29, 10:00. There was a strong earthquake lasting 2 1/2 minutes at Makassar. It was also felt at other places on the southwest of Sulawesi Island.

The earthquake was followed by a tidal wave, which was then repeated. The tsunami was strongest on the coast from Bonthain on the west to Bulukumba on the east; here many coastal settlements were destroyed and many people died.

There is a detailed description of these events at Bulukumba. The earthquake began with weak, but gradually intensifying tremors. The house of the fort commander rocked in every direction. The guns on the bastion jumped from their carriages. The earthquake lasted 4-5 minutes, when, it seemed, a cannon shot pealed out from the west. A sloop sent to reconnoiter had not had time to return with the report that there were no ships on the horizon, when a water wall 20-25 m (60-80 feet) high arrived with a whistling and at the same time thunderous roar and inundated everything. Surging 300-400 m (400-500 paces) inland, the water destroyed the barracks of the fort and the villages of Nipanipa and Terangterang. Four to five hundred people drowned, including three Europeans. Ships off the coast were tossed into the rice fields. The oscillations in level recurred several times, and the water retreated several kilometres (miles) from shore during the ebbs.

A strong earthquake lasting 2 minutes, accompanied by a loud rumble, was felt at Bima. It was followed by a tsunami which tossed ships riding at anchor in the harbor far inland; some ships were even tossed over rooftops by the waves.

The earthquake was also felt on Palu Island in the Flores Sea.

A strong earthquake lasting 1 minute was felt at Sumenep. A rather strong tsunami was also observed here at 15:00 (Mallet, 1853; Wichmann, 1918; Sieberg, 1932; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969; Cox, 1970). /210

1823, September 9, about 8:00. At Bogor (Buitenzorg), and also in the Cheribon district, an earthquake occurred, which was felt especially strongly in Cheribon city, where it was accompanied by a rumble. At the same time, the sea rose about 0.3 m (1 foot) (Wichmann, 1918; Cox, 1970).

1828, December 29. A repeated date in some sources (Mallet, 1853; Milne, 1912 b; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969) for the earthquake and tsunami of 29.XII.1820.

1833, November (January) 24, about 20:30. There was a strong earthquake on Sumatra Island, which was also felt at Singapore and on Java Island. The barrier on the slope of the Kaba volcano which holds back the lake burst. The lake flowed out, and the resulting flood inundated and destroyed seven villages. A strong seaquake was felt by the "Mercurius" at the latitude of the Pagai Islands off the west coast of Sumatra. At Palembang, as a result of the earthquake, buildings cracked and several huts collapsed.

The earthquake lasted 5 minutes at Bengkulu. Buildings were damaged and some collapsed. A tidal wave surging onto the coast destroyed a breakwater and the homes situated near to it. Two schooners and several small ships were run aground.

At Padang, strong tremors lasted 3 minutes. The shocks recurred for several days and were accompanied by a rumble. Buildings were damaged. The ground cracked, and water and mud flowed from the cracks. A surging tidal wave caused considerable losses.

There were strong tremors at Indrapura and Pulu Tjinko*. The losses from the tidal wave were considerable; there were victims.

There were exceptionally strong shocks at Pariaman. Cracks 1/2 m or more wide formed in the ground. The tremors lasted many days. The water retreated and returned with force in an enormous tidal wave. All the ships were torn from their anchors (Wichmann, 1918; Sieberg, 1932; Heck, 1934, 1947; Ponyavin, 1965; Berninghausen, 1966).

1836, March 5. Bima. There was a strong earthquake accompanied by a tidal wave, which inundated the locality (Wichmann, 1918).

1836, November 28, 10:30. There was a strong earthquake at Bima. It lasted several minutes and did heavy damage to structures. Rock masses collapsed into the valley from the mountain spurs south of Soromandi* Mountain. The tremors, which continued with lesser force until 18:00, then again intensified and were accompanied by a tidal wave (Wichmann, 1918; Cox, 1970).

1837, end of September, no date. Penang Island and the northwestern coast of Sumatra. "Penang. The earthquake which occurred here two weeks ago was felt at the same time, with very great force, at Atjeh [and] along the entire coast of Pidie. In fact, a skipper, arriving on Wednesday, October 4th, brought stories about several eruptions [this refers to the eruptions of Peuetsagu Volcano] and earthquakes, occurring at Lhokseumawe and other places, especially at Banda Atjeh, where, according to the stories, an earthquake lasted seven days and did considerable damage" (apparently at the end of September). There was a strong tidal wave at Singapore (Wichmann, 1918).

1840, January 4, about 13:15. There was an earthquake in the middle of Java Island. It was strong in the districts of Semarang, Djapara, Jogjakarta, Madiun, Pekalongan, Kediri, and in the eastern part of Banyumas district. It was felt in the western part of Banjumas district, [and] in Kedu district. There were no tremors in Besuki district.

In Semarang district and especially in Bagelen* district, the earthquake was destructive. At Semarang, cracks formed in the walls of the citadel and one of the homes. Part of the road near Kendal collapsed. Several homes collapsed in the Bagelen* district at Purworedjo, while the rest suffered light damage; a stone bridge cracked. An indigo factory near Purworedjo was heavily damaged. Buildings were heavily damaged at Wonosobo and Sapuran. The walls of homes cracked at Patjitan; the earthquake was accompanied by a tidal wave (Wichmann, 1918). /211

1840, February 14. There was an eruption of the volcano on Ternate Island on February 2. The eruption was not accompanied by any underground shocks. In the afternoon of the 14th, a terrifying rumble was heard and lasted 5-10 minutes. During a terrible downpour, following two light oscillations, a strong shock occurred which knocked over most of the residences. The ground cracked in many places. Water rushed inland and this added to the destruction (Perrey, 1859 b).

1841, November 26, 6:00 (according to other sources, at 6:30). At Bandaneira, there was a weak horizontal shock. It lasted more than 1 minute (according to other sources, from 2 to 3 minutes). Fifteen minutes later, a tidal wave surged with great force onto the south coast of Neira Island. It reached a height of 2 1/2-3 m (8-9 feet), or, according to other sources, 2 m (6 feet) above the level of the maximal flood tides, so that the water came up to the gates of Fort Nassau. The flood and ebb continued for more than 45 minutes. This phenomenon occurred during an ebb (Perrey, 1858; Wichmann, 1918; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

1841, December 16. There was an earthquake and tsunami on the islands of Ambon, Buru and Ambelau. At Ambon, at about 2:00, a not particularly strong shock was felt. It was followed in about 15 minutes by a tidal wave, which reached a height of 1 1/2 m (4-5 feet) above the high water level and repeatedly rolled onto the coast of Ambon Bay. At Galala*, west of Ambon, several huts of local residents were washed away. On Buru Island, and also on Ambelau Island, a considerably stronger earthquake occurred between 1:00 and 2:00. It was accompanied on Ambelau Island by a large tidal wave, which washed away many huts and mosques in the coastal villages. The tremors continued on December 17 to 21 (Wichmann, 1918; Sieberg, 1932; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

1843, January 5, 23:30-24:00. There was a destructive earthquake on Nias Island and adjacent areas of the coast of Sumatra Island. The oscillations, weak at first, rapidly intensified and lasted 9 minutes. Recurrent shocks continued almost without interruption until 4:30 on the 6th. Less frequent shocks were felt for many days. The fortifications and other stone structures on the hill near Gunungsitoli were almost completely destroyed. Trees were ripped up and broken; the ground cracked and mud flowed from the crevices. The earthquake apparently spread to Singapore and Penang Island.

Before the earthquake, the sea off Nias Island was absolutely calm. Suddenly, at 0:30, a terrible wave advanced from the southeast with a terrifying noise. It affected the entire coast of the island and destroyed everything in its path. The large settlement of Kampong de Mego* 2 km (1 mile) from Gunungsitoli, was completely washed away. The proas on the river were tossed on land 30-50 m (100-160 feet) from their moorage.

At about the same time, a somewhat less terrible wave, with a noise like a hurricane, advanced on Barus from the southwest. Three ships were later found on land 600 m (1900 feet) from their anchorage (Perrey, 1859 a; Montessus de Ballore, 1906; Milne, 1912 b; Wichmann, 1918; Sieberg, 1932; Heck, 1934, 1947; Ponyavin, 1965; Berninghausen, 1966).

1843, February 7. At night, an unusually strong swell was observed on the south coast of Genteng Island, opposite the southeastern shore of Madura Island. The swell was such as might have been caused by an underwater earthquake. Then two new rocks were noticed, rising 0.3 m (1 foot) above the high water level (Wichmann, 1918).

1845, February 8, 15:30. A strong earthquake occurred suddenly. It affected the eastern tip of Minahassa Peninsula (Sulawesi Island).

The tremors lasted 50-60 seconds at Manado and were so strong that it was impossible to stand. Gaping cracks formed in the walls of Fort Amsterdam. One home collapsed in the European quarter. Many homes /212
collapsed in the Chinese quarter and in the settlements of Tikala, Lota, Kakazkazen, Tondano, Tanawanko, Kawankoan, Romoon, Tombasian, and Zonder.

In the Tomoon district, settlements were more than half destroyed. At Amurang, the walls of an old fort collapsed, and a church and buildings suffered damage. At Wuwuh village, a church and 125 homes collapsed, and the remaining homes were left unsuitable for habitation. Many cracks occurred in the ground, and there were avalanches. Springs dried up.

Strong shocks were felt at Kema and Likupang. On the other hand, Tompazo, Ratahan, Pazan, and Belang suffered only slightly. A total of 118 people were killed or injured. Avalanches occurred in the mountains at Lokon, Kakazkazen and other places. Many subsequent shocks were registered.

On the roadstead at Kema, the water twice inundated the shore and three times retreated to the end of the breakwater, so that it was possible to collect the fish left on the dried bottom before the sea returned to its previous state (Perrey, 1847, 1859 a; Wichmann, 1918; Sieberg, 1932; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

1846, January 25, 9:00. There was an earthquake on Ternate Island. It was not strong, but prolonged. An unusually high water level was observed in the wells. An underground noise was heard in the southern part of the island. A shock was felt onboard the English ship "Rochester," which was situated 90 km (50 miles) to the northeast of Morotai Island.

On Ternate Island, the first shock, which lasted about 1 1/2 minutes, was followed by a tidal wave which reached a height of about 1.2 m (4 feet). Floods and ebbs recurred (sometimes 10 times an hour each) until 16:00. The tsunami was noticed not only on the coast of adjacent islands, but even near Manado (Perrey, 1859 a,b; Milne, 1912 b; Wichmann, 1918; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

1851, May 4, 9:00. At Telukbetung, in Lampung Bay on the south coast of Sumatra Island, with still weather, there was a tidal wave which rose 1 1/2 m (5 feet) above the flood tide level observed in the preceding days. On the same day, at about 13:30, light underground shocks were felt at Djakarta (Batavia) (Perrey, 1859 a; Wichmann, 1918).

1852, January 9, soon after 18:00. There was an earthquake, which spread from the western part of Java to the southern part of Sumatra. At Djakarta (Batavia), two rather strong and several weak shocks were felt. One of them, at 18:09, stopped the astronomical clock. At Bogor (Buitenzorg), there were three strong tremors at 18:25. At Djaringin, there were three very strong shocks and about four weak ones, in rapid succession, accompanied by an underground rumble; they lasted 2 minutes. There was a rather strong shock at Serang.

At 18:25, there were strong horizontal shocks at Telukbetung. They recurred twice, at short intervals; the duration was 3 minutes. At 20:00, there was an unexpected rise and then a fall in sea level, which recurred several times. However, the height of the flood did not surpass the height of the highest high tides (Perrey, 1856, 1859 a; Wichmann, 1918).

1852, November 11, 7:00. There was an earthquake on the west coast of Sumatra Island, at Singkel and Sibolga and on Nias Island. It affected an area of 600 km^2 (180 square miles), and the waters on all this area were disturbed. A shock was felt at sea 6 km (3 miles) from Gunungsitoli. An earthquake was felt at Padang. At 8:30, there was a weak shock on Penang Island (Perrey, 1856, 1859 a, 1862 a; Wichmann, 1918). [It is difficult to judge whether this refers to a seaquake or a tsunami.]

1852, November 19 (10). At Ambon, there were shocks supposedly accompanied by strong "movements" of the sea (Perrey, 1855 b; Wichmann, 1918).

1852, November 26 (16, 23), 6:42. At Surabaja, there were light shocks, which were also felt at Semarang and Pasuruan. There was a weak shock at Sumenep. The earthquakes were accompanied by movements of the water from north to south in Grati Lake (Pasuruan District) (Perrey, 1855 b, 1856; Wichmann, 1918). [Apparently, these data relate to the /213 earthquake described below.]

1852, November 26, 7:40. On Neira Island, there were strong vertical shocks, which rapidly became undulating oscillations of growing force, which lasted 5 minutes. All the residents ran to the streets. It was impossible to stand without holding onto something. Most of the residences on the island were left in piles of ruins, and the homes which remained standing became unsuitable for habitation because of the numerous cracks. The part of Papenberg Mountain on which the signal station was situated collapsed. Numerous cracks appeared in the ground on the coast.

The earthquake did similar destruction on Lonthor Island as well. It was accompanied by a roar like cannon shots. After the earthquake, there were many recurrent shocks, including some rather strong ones. The effects of the earthquake were also serious on the islands of Rozengain and Ai.

At Ambon, strong undulating tremors lasted 5 minutes with no destruction. The earthquake was similar in its effects at Hila and Larike. On Haruku Island, the walls of the church at Aboru and the walls of Fort Zelandia cracked. Many buildings were damaged on Saparua Island. The earthquake was felt on the islands of Laot, Buru, Ceram, and possibly on the islands of Batjan and Ternate. The flagstaff and trees swayed strongly at Labuha on Batjan Island.

At Bandaneira, 1/4 hour after the earthquake, the sea rose and the frightened residents took to the hills. The bay alternately dried up quickly, then filled with water. A ship riding at anchor at a depth of 9 m (5 fathoms) sat on the bottom twice. The water rose to the roofs of the storehouses and homes and smashed all the doors, inundated Fort Nassau and reached the foot of the hill on which Fort Belgica was situated, tossing a fair amount of fish on land. The strong oscillations in level had ceased by 13:00.

According to the account of the captain of the brig "Hai," before the earthquake, the ship was riding at anchor at a depth of 11 m (6 fathoms) between the islands of Neira and Lonthor; the length of the anchor chain was 65 m (35 fathoms). The seaquake was very strong. Then at 8:10, the sea which had risen quickly, surged off to the southeast with unbelievable speed. During the strongest ebb, the depth of water fell to 7 m (3 3/4 fathoms). All the reefs around dried up. After this, at still greater speed than it retreated, the water rose and ran 65 proas aground which a few minutes prior had been left on dried bottom. Between the start of the ebb tide and the maximal flood tide, when the depth of water was 13 m (7 1/4 fathoms), 20 minutes elapsed. Then the water once again surged back with terrible speed, destroying and carrying away everything. The ship dropped once again, quickly and very dangerously. Twenty minutes later, the water rose again; the depth of the water was 14 1/2 m (8 fathoms). This time the wave was as much stronger and more fearsome as it was higher. It inundated the breakwater and the embankment, where most of the crews of the proas had taken refuge, and carried them off. Sixty people died. Many proas, small and large, were tossed onto the embankment and destroyed. Buildings standing on the embankment were washed away. After this the water fell 8 m (26 feet). Waves just as terrible recurred another four times, with the same period. At 10:30, the oscillations in level began to abate.

No considerable oscillations in sea level were observed on the north coast of Neira Island or on the south coast of Lonthor Island.

On Ai Island, the sea level was a metre (a few feet) higher than the usual flood tide level.

At Ambon, soon after the earthquake, a rise of water began in the bay. It was followed by a rapid ebb. This process occurred a good 20 times before 14:00. The water level oscillated at a 74 cm range, surpassing the usual flood tide level by approximately 20 cm. The tsunami was also observed at Hila and Larike.

On Saparua Island, a tidal wave advanced 4 times between 8:30 and 11:00. The second and fourth waves reached a height of 3 m (10 feet) above the level of the highest flood tides. In the vicinity of the settlements of Saparua and Tidjau*, the water encroached 120 m (400 feet) /214
inland. After 11:00, the floods and ebbs began to diminish gradually, but continued until late evening. At other settlements on the island, Hatuana* on the northeast coast, Kulor on the north coast, Porto on the west coast, and Sirisori in Saparua Bay, only a weak tsunami was observed.

The tsunami was noticed on Haruku Island at the coastal settlements of Hulaliu and Wassu, on Laot Island at the settlements of Ameth, Akon, Laintu, and on Buru Island. On Ceram Island at the settlements of Amahai and Wahai [?], the water flooded homes near the beach; many proas were washed away. The tsunami was not noticed on Batjan Island.

In 1853, great physiographic changes were discovered between Kai Island and the two islands of Pulu Pisang*, which belong to the same group. These changes were ascribed to the earthquake and tsunami of 26.XI.1852. The surface of these islands was still soft and had a yellow golden color. Three new small islands were discovered between the islands of Tayandu (Trando) and Kaimer (Kauer). These islands were composed of fragments of corals and yellow sand. As was related, one of them was later washed away, while the other two were covered over with shrubs. In 1854, a new island was discovered between the islands of Pulu Ergodan* and Pulu Hodin* (according to other sources, it was situated in the region of Yut* Island, at 5° 35' S. and 133° E.). The island was round, 250 m in diameter, and protruded above a bank with depths of no more than 2 m (1 fathom). It was made up of clay and was covered with fresh shrubbery (Perrey, 1854, 1856, 1857 a; Rudolph, 1887; Dutton, 1904; Krümmel, 1911; Milne, 1912 b; Wichmann, 1918; Heck, 1934, 1947; Ponyavin, 1965; Iida *et al.*, 1967; Berninghausen, 1969).

The report of the Chilean tsunami (Anon., 1961) mentions that the tsunami of 1852 was observed in the Caroline Islands.

1852, December 24, 14:30. At Bandaneira (?), there were two recurrent shocks of the earthquake of November 26. Several homes which had withstood the preceding earthquakes collapsed. Two spice plantations which had not been affected previously were reduced to complete disorder.

A large number of proas in the roadstead and off the coast of Ceram Island, and also floating villages off Gorong Island were inundated and smashed on shore with the inhabitants. There were victims. About 400 proas were wrecked.

The effects were similar on the islands of Tioor, Ambon, Saparua, and Haruku (at Hulaliu, Oma, Wassu) and also at the settlements of Ameth, Akon, and Laintu on Laot Island (Perrey, 1854, 1857 a).

1854, January 4. Rather strong shocks, accompanied by a loud underground rumble, were felt on the shores of the strait between the islands of Haruku and Saparua on the 2nd, 3rd, 4th and 5th. The direction of the shocks was from the southwest to the northeast. After the first shock on January 4, strong oscillations of sea level began. The sea flooded the beach on the coast of the strait. The shocks did not do any damage and were not felt on Ambon Island (Perrey, 1856, 1857 a; Wichmann, 1918).

1854, September 27, evening. On Ternate Island, there was an earthquake and tidal wave, which did not do any damage (Perrey, 1856; Wichmann, 1918).

1855, April 14, 21:00. A tidal wave arose in still weather at Nangaramo, Mangarai* District, on the southwestern shore of Flores Island. The impact of the flood tide was so strong, that a schooner riding in the bay sprang a leak. In the second ebb tide, the schooner snapped its anchor chain and the vessel ran aground in the shallows, where it was smashed by subsequent waves (Wichmann, 1918).

1856, March 2, between 19:00 and 20:00. On Sangihe Island, after a sudden "unbearable" roar, the Awu Volcano began to erupt (see Fig. 97). Incandescent lava rushed down the slopes of the mountain with irresistible force, destroying everything in its path. Where the lava reached the shore, the sea water began to boil. Strong hot springs gushed up and the abundant surging boiling water destroyed and carried away everything that the fire had spared.

The sea surged onto the shore cliffs as during an underwater earthquake, and with a terrifying noise, it flooded the coast and "snatched its victims from the fire."

An hour later, thunderous blows were heard, shaking the earth. A black column of ash and stones was ejected from the peak of the mountain. The column rose to the "heavens" and fell in a rain of fire on the slopes /215
of the volcano, which were lit up by the red hot lava. Total darkness fell, in which one could not make out the closest objects; it was interrupted from time to time by outbreaks of light. Large bombs fell to the

earth. The settlements and fields not destroyed by the lava were buried under a layer of ash and rocks. The flows rushed down from the mountain, and, encountering obstacles, spread out in lakes, which then became a new source of destruction.

All this took several hours. By midnight, all had quieted down, although the eruption began with new force the next noon. The ashfall continued all day and was so intensive that no light could penetrate, and almost total darkness set in.

A hurricane southeastern wind blew since the beginning of the eruption, and the ashes were carried as far as Mindanao Island. Later the wind blew from the north.

On March 17, there was a new eruption, in which fields and trees on the coast at Tabukan (Fig. 97) were destroyed. After this, the volcano quieted down, except that steam continuously rose from the numerous cracks and fractures. However, the lava flows were still so hot that one could not approach them. According to residents, the top of the volcano did not change noticeably in appearance.

At the main village of the island, Tahuna, several people were injured and homes were destroyed during the fall of ash and stones. Obstacles in the form of hills made the lava flow deviate from the village and turn to the sea in another place.

Along the flat slope between Tahuna and Kandhar, seven large lava flows descended to the sea, devastating this agricultural region. One of the flows passed through Kalongan village; only a few burned posts were left. Between Kalongan and Kandhar, a large area of the coast subsided below sea level. The mountain side had previously sloped gently to the very water line; after the eruption, it broke off as a steep wall about 60 m (200 feet) high.

The settlement of Kandhar, protected by this "rib," suffered little: it was affected only by the fall of ashes and stones and the streams of hot water. In addition, before the eruption, the residents, fearing pirates, had hidden with their belongings in the thickets above the settlement, and did not suffer from the flooding.

The devastation was even greater on the coast from Kandhar to the northern tip of the island. Two tongues of lava thrust far into the sea to previous bottom marks of several metres (fathoms).

The number of victims was considerable: at Tahuna 722, at Kandhar 22, at Tabukan 2,039; total 2,806. For the most part, the people died in the gardens where they sought relief from the heat. Those who attempted to run, were overtaken by flows of lava and water, perished under collapsing trees, were suffocated or were burned in the ashfall and the fires. At Kalongan and Tariang, the residents who took refuge in their houses died in the debris. Finally, those who took to the sea shore "fell prey to vicious waves" (Perrey, 1857 b; Wichmann, 1918;

Sapper, 1927; Heck, 1934, 1947; Neumann van Padang, 1951; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

1856, July 25, no date. At Labuantereng, on the west of Lombok Island, there was an earthquake. At the same time, a strong surf was noticed on the beach at the locality of Ampenen, situated about 20 km to the north (Wichmann, 1918).

1857, May 13, about 10:30. There was a strong earthquake on Timor Island. The tremor lasted at least 15 seconds at Dilhi. People were thrown to the ground. The walls of the fort partially collapsed. The ground cracked on the coast. At Gera, situated 20 km (12 miles) east of Dilhi, there was an even stronger earthquake; the ground settled at many places; mud flowed out of cracks.

On Kambing Island, there was an exceptionally strong earthquake. The hill on which the settlement of Makadade is situated (on the southern shore of the island) subsided. Twenty-three men, thirteen women and many children died.

The tremors were no less strong at the villages of Lautem, Laklo, Laleya and Batugade. Collapses occurred along the road to Vimor* and in the valley of the Wikeke* River. At the same time, the Bibiluto mud vol- /216
cano erupted and the village of the leader (queen) of Wikeke* district was partly destroyed.

Weak shocks were registered at Atapupu and Kupang. At least another 15 shocks were felt in the next three days.

In Dilhi Bay, the water rose and fell 3 m (10 feet) four times. At Likisa*, a tidal wave surged onto the land and completely inundated the village. At about 11:30, strong oscillations in sea level were observed at Ambon (Perrey, 1858, 1860 a; Wichmann, 1918; Sieberg, 1932; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

1857, November 17, 4:00-4:30. There were shocks at Manado, Kema and on Ternate Island. Very high tidal waves appeared at the latter two points and carried away many huts and trees. The old men could not remember such large floods (Perrey, 1859 b; Wichmann, 1918; Cox, 1970).

1857, November 18, 6:00 and 9:00. There were more underground shocks at Manado and Kema. Strong movements of the water continued at Kema (Perrey, 1859 b; Wichmann, 1918; Cox, 1970).

1858, December (November) 13, 16:00. There was a strong prolonged earthquake all over the Minahassa Peninsula. It began with several light vertical shocks and ended with "terrifying" horizontal oscillations. Nevertheless, the destruction was not very large, except for villages on the plateau in the Tondano district, where 15 homes collapsed. Avalanches and landslides occurred at many places. There were many recurrent shocks after the earthquake.

There was a rather strong earthquake on Ternate Island. It lasted almost 1 1/2 minutes and was accompanied by an underground rumble. An old wall collapsed in the Chinese quarter. The earthquake was felt at Manado and weakly at Gorontalo.

Forty-five km to the north of Ternate Island, in Djailolo Bay, the ship "Ester Elena" and 17 km to the west of Ternate Island, the ship "Surinam" felt a strong seaquake.

The reports of the captains of the ships indicates that the entire eastern coast of Sulawesi Island from the Bangai archipelago in the south to the Sangihe Island in the north were hit by a destructive tsunami. Villages were destroyed (Perrey, 1862 b, 1864 a, 1873; Wichmann, 1922; Sieberg, 1932; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969; Cox, 1970).

1859, June 28, after 20:00. There was a strong earthquake at Kema. It recurred at midnight and was accompanied by such strong movements of the sea that one of the government ships riding at anchor at a depth of 4 1/2 m (2 1/2 fathoms), was run aground. These two earthquakes were followed by still others of lesser force. Weak shocks were felt at Rurukan.

There was a rather strong and prolonged earthquake on Ternate Island. It was preceded by a loud underground rumble, like distant peals of thunder, and was accompanied by oscillations in sea level. Two proas ran aground, but were washed out again by the subsequent wave.

At Sidangoli, on the western coast of Halmahera Island, the tsunami reached a height of 10 m (30 feet) (Perrey, 1862 b, 1864 a,b; Wichmann, 1922; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

1859, July 20, about 20:00. On the west coast of Lonthor Island, there was an underground shock and rumble, like a cannon shot. At first it was thought that the battery at Bandaneira was shooting, but this was a mistake, since after some time, more shots were heard and the sea began to rise slowly above its usual level. Then it fell, and rose again about twice and then returned to the level which existed before the small tsunami.

Nothing unusual was noticed on the coast of Neira Island and the other islands of the Banda archipelago (Perrey, 1862 b, 1866; Wichmann, 1922; Cox, 1970).

1859, July 29, 13:30. There was a strong earthquake at Manado. It lasted 5 minutes and threatened to overturn everything. The shocks were felt almost without interruption until 16:30. Later, in the evening and at night, they returned, but there were now intervals between them.

During the earthquake the sea at Kema was very agitated. The huts and goods which were on the beach were washed off. The earthquake was /217 strong at Gorontalo, Boalemo and Mondono. On Bangai Island, a strong tsunami washed off homes which were situated on a low terrace, and also a herd of goats and sheep.

On the same day at 15:15, there was a strong and prolonged earthquake on Ternate Island (apparently, it was the same earthquake as the one on Sulawesi Island). Cracks opened up at many places in the ground. Although they closed up at once, traces remained on the surface, as if someone had been digging in the ground. Despite its magnitude, the earthquake did not cause considerable damage. There were many recurrent shocks.

The earthquake was accompanied by oscillations of the sea, which rose 1 m (3 feet) above the high watermark, although it was ebb tide. The ship "Freundschap," riding in the roadstead, found itself on dry bottom when the water retreated. The rigging shook on board the naval vessels "Surinam" and "Bali." The earthquake was felt and was accompanied by similar oscillations in sea level on the islands of Tidore and Makian (Perrey, 1862 b, 1864 b; Krümmel, 1911; Milne, 1912 b; Wichmann, 1922; Sieberg, 1932; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

1859, September 25, evening. There was such a strong shock on the islands of Lonthor and Neira that "it made the impression of an irresistible force, preparing to destroy the archipelago." The sea "rushed" onto the southern shore of the island with enormous force, then retreated and gradually calmed (Perrey, 1864 b; Wichmann, 1922; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

1859, October 20, about 17:30. There was a strong underground shock, accompanied by a tsunami, at Patjitan (Java Island). The wave arrived precisely when the "Ottolina," which was riding in the roadstead, was getting ready to cast anchor. A sloop, loaded with anchor and chain, sank; of the crew of thirteen, 11 were saved (Wichmann, 1922; Heck, 1934, 1947; Ponyavin, 1965; Berninghausen, 1966).

1859, December 17, 20:00. There was a shock at Manado. It was also felt at many other places on the Minahassa Peninsula. The earthquake was accompanied by a light tsunami at Belang in the region of the prison (Perrey, 1862 b, 1864 b; Wichmann, 1922).

1859, December (October) on the night of the 25th to the 26th and early in the morning of the 26th. There was a strong tidal wave at Kema. It reached the roof of coal shed No. 3 and even reached shed No. 2 further from shore. Some of the front gardens at the new moorage were washed off (Wichmann, 1922; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

1860, August, no date. There were numerous light earthquakes and abundant rains, accompanied by strong winds and floods, on the Minahassa Peninsula (Perrey, 1864).

1860, October 6, after midnight. An earthquake was felt on the south coast of the Halmahera Island. A tidal wave fell on a proa at the southern tip of the island, but did not do any damage. After this phenomenon had been repeated 10-12 times, the surface of the sea became like a mirror (Wichmann, 1922; Cox, 1970).

1861, February 16, about 19:00. There was an earthquake of exceptional strength and great duration, accompanied by a tsunami, on the entire western coast of Sumatra.

At Padang and vicinity, strong tremors were felt for two minutes. The residents fled their homes in panic fearing that they would collapse, but there was no destruction. Cases of sea sickness were noted. There was a stronger earthquake at Pariaman than at Padang. It apparently lasted 4-5 minutes. The earthquake was so strong on the Padang Plateau that it was difficult to remain standing. The earthquake was very strong at Ajerbangis and was preceded by an underground rumble. It was catastrophic on the Batu Islands. At Pulu Tello, Talu, Rau and Natal, the shocks were very strong and lasted 2-4 minutes. A large number of homes /218 collapsed in the districts of Mandeling (vicinity of Pendjabungan) and Angkola; fields were made havoc of; colossal avalanches buried villages; Sialang was so buried that not a trace remained of it.

At Sibolga and Barus, yawning crevices opened up in the ground at many places and fountains of water gushed up. Eyewitnesses related that these cracks opened and closed. At Singkel, most of the homes, in particular the barracks, were left unsuitable for further use; the ground cracked.

On Nias Island, the earthquake was even stronger than everywhere else. At Fort Laundi, the soldiers were bowled over. The same occurred at Gunungsitoli.

On the north, the earthquake spread to Atjeh, where it caused considerable destruction and human victims. No less damage was done by the earthquake at Batak. The earthquake was felt apparently without damage at Bengkulu, in the region of Siak, on the Riau archipelago, and at Japara and Kuningan (Java Island). A seaquake was felt by the American ship "Humboldt" at the latitude of Simeulue Island and by the Dutch ship "Vesta" at the latitude of the Pagai Islands. At Singapore, the oscillations lasted 2 minutes; cases of sea sickness were observed. The earthquake was still rather strong on the Malacca Peninsula and on Penang Island. It was felt at Dacca and caused seiches in ponds on the east of India. An unusual trembling of level, ascribed by A. Wagner to this earthquake, was noted at the Pulkovo astronomical observatory during observations of 16.II.1861.

The earthquake was accompanied by an enormous number of aftershocks.

At Ajerbangis, the sea became agitated during the earthquake. From time to time, the river dried up completely, and then the sea "rushed" on shore, advancing with great force. These oscillations in the level of the river repeated until noon on the 17th; the duration of one oscillation was 15 minutes.

On Pandjang Island, opposite Airbangis, thousands of dead fish were found after the tsunami.

At Pulu Tello, where the governor's residence was situated, the sea rushed on land with "irresistible force" approximately an hour after the first underground shock. Soon all the coastal trees were inundated and were completely hidden under water. On the night of the 16th-17th, the island was totally inundated four times by churning waves, which destroyed everything in their path. Seven hundred residents drowned. On the island there remained not a trace of the abundant luxuriant vegetation which used to cover it, but only furrowed land.

The other Batu islands, for example Simuk Island, where 80 homes were destroyed, also suffered badly.

At Natal, the river left its banks. At Sibolga, somewhat after the first shock, strong oscillations in water level began in Tapanuli Bay. The water retreated twice with such force that ships riding in the roadstead were left on dry bottom. Then the water quickly returned, and rushing on shore, covered the road running along the coast.

At Barus, the sea also inundated the shore, but the water did not rise more than 1/2-1 m (2-3 feet) above the mean level and fell back almost immediately.

At Singkel, the most northern point from which reports could be received, the water rose while the soldiers were erecting temporary tents for the night, and the settlement was completely inundated. At the highest places, the water reached people's chests. The water surged back, then returned and carried off everything in its path. About 20 people died. The shore was heavily washed out, and water began to cover the place where the fort and warehouses had been situated.

At Fort Laundi, on the south coast of Nias Island, a wave approached from the southeast 4 hours after the earthquake and in 45 minutes most of the buildings were washed away. According to many accounts, the water rose 7 m. A ship riding at anchor in the roadstead, was entrained by the water and ran aground. The water continued to advance and retreat and in the end returned to its usual boundaries. About 50 people died.

At Gunungsitoli on the northeastern shore of Nias Island, the sea retreated 32 m, and then surged in "with enormous speed" and destroyed a considerable number of coastal villages. Many local residents died. One schooner ran aground at Damula* on the eastern shore of Nias Island. /219

Lapau Island, to the north of Nias Island, was almost completely destroyed. New reefs appeared and a number of existing reefs disappeared along the western shore of the island. At some places the shore subsided, while at others it rose. Hundreds of residents died.

At Bengkulu, on the 17th at 4:00 the water rose 1 m (3 feet). A road running along the beach was destroyed on a stretch 500 m (280 fathoms) long and 55 m (30 fathoms) wide. The mouth of the river in Pulu Bay broadened by about 60 metres. The road from this bay to Bengkulu was covered with water to a depth of 2 1/2-4 1/2 m (from 1 1/4 to 2 1/4 toise).

On the evening of the 17th at Krawang (Java Island), the water in the Tarum River suddenly rose 1 1/2 m (5 feet) and formed a stream which carried with it a ship riding at anchor in the bay.

On the coast of Atjeh, the water rose 1 1/2 m. According to other sources, the entire coast of Atjeh was devastated as a result of a sudden invasion of the sea, which penetrated inland, uprooted trees, destroyed crops and homes, and in retreating, carried off a multitude of residents. In Analaboo port alone, 135 people drowned (Perrey, 1864 a, 1865 a, 1872 b; Guillemin, 1886; Milne, 1912 b; Wichmann, 1922; Sieberg, 1932; Heck, 1934, 1947; Ponyavin, 1965; Berninghausen, 1966).

1861, February 21. There is an incorrect reference by Perrey (1865 a) to oscillations in sea level at Wanaidjas, accompanying an earthquake. In fact, strong seiches occurred in a large lake as a result of the earthquake: the water rose 1 m, and then fell 3 m (Wichmann, 1922).

1861, early March. It is reported that there was supposedly an unusual flood tide at Ambon; the bridge was torn down; the water rose to a height of 1.8 m (6 feet) in many homes (Perrey, 1865 a).

1861, March (June) 9, 22:00. Apparently, the strongest aftershock of the earthquake of February 16 occurred.

On the Batu Islands, it was preceded and accompanied by an underground roar and caused more serious effects than the main earthquake. The shock was rather strong at Airbangis and very perceptible at Padang.

The earthquake was accompanied by a tsunami, which reached its greatest intensity on Simuk Island, that is, on the western tip of the archipelago. Here the residents suddenly espied an enormous wave, which rose at sea and passed 300 m (1000 feet) to the interior of the island from its northern side, so rapidly that most did not have time to escape. The flooding, according to accounts, lasted about an hour.

Before the catastrophe, there were 120 homes on this island in the villages and temporary settlements, and about 1000 people lived there. Ninety-six homes were destroyed by the earthquake and tsunami; about 3/4 of the population perished. The previous villages were left as waste strewn with stones or as piles of ruins.

The western and northwestern shore of Pulu Tello Island also suffered very heavily, while other areas of the coast of this island did not suffer damage.

The sea level oscillated considerably off the adjacent islands of Babanirege and Lakao*, where many residents also died.

According to the account of a surviving resident of Babanirege Island, an enormous wave covered the residents who were fleeing on foot and carried off 200 of the 280 people who used to live here. The others escaped to the jungles, counting on the vegetation for protection. Two waves collided near where they were hiding, wreaking enormous destruction. Colossal stone chunks were carried inland 30-60 m (100-200 feet) by the waves (Perrey, 1864 a, 1865 a; Wichmann, 1922; Heck, 1934, 1947).

1861, April 26, 6:00. There was a strong earthquake lasting 2-3 minutes at Pariaman. It lasted 1 1/2 minutes at Singkel. At Padang and Ajerbangis horizontal undulating movements about 2 minutes in duration were observed. Light shocks were felt at Fort de Kok. /220

At Singkel, the sea level rose so high, that the floor in the commander's home was covered with a layer of water 25 cm deep. In the next two days, the water rose more than once to the same height, though no new underground shocks were felt (Perrey, 1865 a; Wichmann, 1922).

1861, June 5, about 8:00. On the coast off Pakis (Java Island), in the mouth of the Tarum River, a tidal wave fell with force, causing oscillations of the water level in the river. Several bamboo huts were more or less damaged (Perrey, 1865 a; Milne, 1912 b; Wichmann, 1922; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

1861, June 17, before 10:00. At Ajerbangis, there were long-period undulating tremors for about 1 minute. A little after this earthquake, the water rose and fell three times, as happens during tsunamis (Perrey, 1865 a).

1861, September 25, 13:30. At Padang and Pariaman, there was a strong undulating earthquake. It was also felt on the plateau at Solok, Lolo and at Fort de Kok for several seconds.

At Indrapura, the earthquake was accompanied by a tsunami. The sea was rough, and the water rose so high that it did damage on the coast. Several boats and huts were washed off. A second branch formed at the mouth of the river (Perrey, 1865 a; Milne, 1912 b; Wichmann, 1922; Heck, 1934, 1947; Ponyavin, 1965; Berninghausen, 1966).

1862, April 8. There is an erroneous reference in a number of compendia (Heck, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969) to a tsunami on Java Island with a reference to Wichmann. In fact Wichmann (Wichmann, 1922; Cox, 1970) mentions that on April 8 about 19:00, on one stretch of the Lenor* River in the region of Galu* (Cheribon District), the water suddenly became very agitated and the resulting waves flooded the shore by 2 m (6-7 feet).

1863, March 16, about 21:00. There was an earthquake on Java Island. There were rather strong shocks at Lebak, moderate ones at Djakarta (Batavia) and on Kapal* Island in Djakarta Bay, and weak ones at Serang and Tjaringin. At the latter place, immediately before the earthquake itself, a tidal wave rolled on shore with a loud noise (Wichmann, 1922).

1864, February 16. There was a very strong earthquake on the west coast of Sumatra Island, in the districts of Mandeling and Angkola, and at Padang and Penjabungan, on the Batu Islands, which was accompanied by a tsunami (Milne, 1912 b; Heck, 1934, 1947; Ponyavin, 1965; Berninghausen, 1966). [Apparently, an erroneous date for the earthquake and tsunami of 16.II.1861.]

1871, March 3 (2). Tahulandang Island. From about the middle of February the residents of the island began to feel underground shocks. On March 2, chunks of stone began to roll down from the top of Ruang Volcano, standing in the sea 300 m from the island. On the 3rd at about 20:00, an earthquake began suddenly, and at the same time a thunderous rumble "announced" the eruption of the volcano.

A few seconds later, an enormous sea wave surged onto the coast of Tahulandang Island. It penetrated 180 m (100 fathoms) inland, and destroyed all the huts and plantations in its path. At the centre of Tahulandang (Buhias) settlement, a wave rose 25 m (14 fathoms) above the usual sea level, as was determined by an official who investigated the island on March 30-31, from objects which caught on some trees which survived the waves. Two more waves followed the first wave at very short intervals.

Of the flourishing settlement, consisting of 75 homes, there remained only three huts on its northern margin. However, they were all heavily damaged, and only one remained suitable for habitation; in addition, all the outbuildings and utensils kept under the huts were washed off. All the other homes were overturned and smashed or washed away, /221 including a well-built church with stone walls 1/2 m thick. Bits of masonry were scattered around for a distance of up to 100 m, so that only the remaining paved courtyard indicated the previous site of the church. The earth was furrowed with ditches, carved out by the retreating water. The trees were uprooted and strewn helter-skelter with debris of homes and various utensils. A small ship was tossed to the foot of the mountain. The plantations situated on the mountain side remained intact. Out of the 500 residents of the settlement, 277 died.

Other settlements on the western and southwestern shores of the island also suffered destruction (Bohoi*, Tulusan*, Haasi*). In all, about 400 people died on the island.

All the plantations and in general all the vegetation on the slopes of the Ruang Volcano were also destroyed. From 20:00 on March 9 to 14:00 on the 10th, there was a recurrent eruption of the volcano; sand and stones were ejected. Then the eruption resumed on March 14 and continued until 3:00 (Bergsma, 1873; Perrey, 1875; Fuchs, 1885 b; Wichmann, 1922; Sapper, 1927; Sieberg, 1932; Heck, 1934, 1947; Neumann van Padang, 1959; Ponavin, 1965; Iida et al., 1967; Berninghausen, 1969; Cox, 1970).

1871, August 25. There was a seaquake or tsunami at Gorontalo (Perrey, 1875 b).

1874, middle of May. It was reported that there was an eruption of the Ruang Volcano on Manado Island during a strong earthquake. An entire settlement of local residents, numbering 300 people, was snatched by the sea (Fuchs, 1875 a). [Wichmann (1922) does not mention this. The data are very doubtful; more likely, the matter refers to the events of 1871.]

1876, May 28, 12:30. On Buru Island, there was an earthquake accompanied by a tsunami. After eight strong shocks, which lasted, together with a number of weak ones, 3 minutes, recurrent tremors were registered from time to time, which became very perceptible and frequent by 18:00. A seaquake was felt on proas at open sea. At Kajeli, several homes were damaged, and a minaret collapsed at Masarete. A rather strong shock, lasting 50 seconds, was felt at Ambon and Hila and on the northern coast of Ambon Island.

The tsunami entered Kajeli Bay seven times, reaching, however, a height of only 0.3 m (1 foot) above the usual water level (Wichmann, 1922).

1878, August. Tagriland* Island, in the Malaysian archipelago, was completely devastated by the sea; at the same time, an earthquake and volcanic eruption occurred on Burrang* Island; many craters were formed; a new island appeared from under the water and disappeared again (Goll, 1903). [Most likely, this is a distorted account of the events of 2.III.1871; the matter concerns Tahulandang Island and the Ruang Volcano.]

1882, October 10, 23:00. At Bandaneira, there was a rather strong earthquake lasting 5 minutes, followed by oscillations of the sea, lasting until 2:00 (Van der Stok, 1884).

1883, May. The ship "Samarang" came into a heavy swell of the Horn* Islands between 10:00 and 12:00. The swell was spreading from the north-northeast to the northwest. The propeller was left dry several times. The sea was completely calm before and after. The captain surmised that his phenomenon was connected with the Krakatau eruption, but this is obviously incorrect. The record of the tide gauge at Tandjungperiuk* shows no unusual oscillations in level (Verbeek, 1885).

1883, from May 31 to June 1. The bark "Bantang", riding at anchor in the roadstead at Belinju (Banka Island), was rocked in unusually rough water in completely calm clear weather. The rudder hit against the planking of the ship (Verbeek, 1885).

1883, August 27, 10:02. There was a catastrophic eruption of the Krakatau volcano, which was accompanied by an enormous tsunami. The maximal height of rise of water was 30 m on the shores of the Sunda Strait, 4 m on the south coast of Sumatra Island, 2-2 1/2 m on the northern and southern shores of Java Island, 1/2-1 m in the Pacific Ocean as far as South America. In Indonesia, 36,000 people died. The main eruption was preceded by less strong ones on the 26th at 17:07 and 19:00-23:00, the 27th at 1:42, 5:30 and 6:44, which were also accompanied by less /222 intensive tsunamis. We do not give a detailed account of these events here. Some information about the events can be found in a number of papers (Verbeek, 1885; Iida et al., 1967; and others).

1883, October 10, about 22:00. At Tjikawung on the coast of Slamadatang* Bay, a wave was observed which flooded the beach 75 m beyond the usual high high tide line. A dull roar came from Krakatau, and was heard not only at Tjikawung, but also a little to the north at Sumur*. There were no reports about a wave from any other place because the coast devastated by this wave was deserted at night. No unusual events were observed on ships situated in the Sunda Strait (Verbeek, 1885).

1884, February (?). Five months after the Krakatau explosion, a small tsunami arose, caused by a new volcanic eruption (Annotated bibliography..., 1964, No. 1688).

1885, April 30, a few minutes before 13:00. There was an eruption on the Maluku Islands. It was accompanied by numerous aftershocks.

At Kajeli, on Buru Island, shocks lasting 50 seconds were so strong that portable lamps and other objects were overturned. At Ambon, on Haruku Island, and at Wahai, there were rather strong tremors lasting 20-30 seconds. There was an earthquake on Saparua Island. There were tremors lasting 15 seconds on Ternate Island; lamps rocked heavily; windows left ajar opened in some homes. At Bandaneira, there was a strong shock lasting 6 seconds.

Half an hour after the earthquake, the coastal village of Djikomurasa, situated 28 km (15 miles) west of Kajeli, at a height of 0.75 m above sea level, was inundated by the sea three times. The movements of the water were regular with a period of about 20 minutes. The sea retreated about 300 m beyond the lowest low tide mark, and then flooded by 1.2 m a plain 800 m long and 50 m wide, on which was situated a village, right up to the slopes of the coastal mountains. Three out of the 46 homes of the settlement were destroyed, and a large number of proas riding at anchor were tossed onto the foot of the mountains. The residents escaped, but the material losses were considerable. In the rest of Kajeli Bay, the sea supposedly maintained its usual level.

At Wahai, at about 14:00, the sea rose 0.3 m and washed away the boats lying on the shore. The rises in level, gradually abating, continued until 17:00 (Anon., 1887).

1885, July 29, 23:34. At Ajerbangis, there was an earthquake of magnitude 6 degrees (VII Rossi-Forel) lasting 15 seconds. It was preceded and accompanied by an underground rumble, which came from the sea and was like the noise of suddenly intensifying surf. Waves began to break on shore with great force (Figee, Onnen, 1887 a).

1885, August 3/4 and later. Irregular flood and ebb tides were observed on the coast at Boijong and Manado (Figee, Onnen, 1887 a).

1885, December 14, 21:11. There was a short earthquake of magnitude 4-6 degrees (V-VII Rossi-Forel) at Banda Atjeh; there were many aftershocks. On the same day, and also on the 15th, 16th, 17th and 19th, the water in the river was high; on the 21st, the water level fell below usual (Figee, Onnen, 1887 a).

1886, January 31. Starting at 12:45, many underground shocks occurred at Koeta Radja* (Atjeh). The sixth had an intensity of 5 degrees (VI Rossi-Forel), the rest 4-5 degrees (V). The entire plain was inundated (Figee, Onnen, 1887 b).

1887, May 19, 4:34. At Sigli (Atjeh Province), there was a rather strong horizontal shock lasting 3 seconds. It was preceded by a clearly audible noise of sea surf (Figee, Onnen, 1887 c). [Apparently, both this and the next case refer to ordinary underground rumbles.]

1888, March 21, 4:40. On Breueh Island, there were two strong vertical shocks. They were preceded and accompanied by an underground rumble and the roar of sea surf. The entire garrison was awakened (Figee, Onnen, 1890).

1889, August, beginning on the evening of the 16th and on the 17th. /223
At Anjer (Java Island), there was an unusual rise of water at sea; the sea level was the highest observed for a year (Figee, Onnen, 1891).

1889, September 6, after 20:00. There was a strong earthquake and tsunami on the northeast of Indonesia.

On the Minahassa Peninsula, in the region of Manado, there were strong tremors everywhere, predominantly in a horizontal direction, lasting 5 minutes. At Manado, the trees swayed as in a strong wind; the bell of the city clock sounded by itself because of the large angles of the stand. A new house cracked. At Tondano and in the rural locality, several homes collapsed. The water in a spring became turbid. At 21:30 and at 22:00, rather strong, but less prolonged tremors were felt again. Still less strong and prolonged shocks occurred daily afterwards.

On Ternate Island, strong tremors were registered all night long. Cracks appeared in the walls of the well-built home of a resident, an office and the prison. One wall collapsed. There were no vicims. At 21:30, there was another strong earthquake, which lasted 20 seconds. Very perceptible shocks recurred at 22:00, 22:15, 22:30 and 22:45, and then at 2:00 and 4:00 at night and at 9:00 in the morning. The earthquake and recurrent shocks were also felt on Batjan Island. The old residents could not remember another earthquake of such strength since 1872. The volcano on Ternate Island may have ejected a small cloud of smoke.

There was also a strong earthquake on Sangihe Island. It began with mild oscillations, which became strong horizontal tremors. The trees swayed as if someone was shaking them strongly. Half the water poured out of a filled barrel 1/2 m high. The tremors recurred three times, but with lesser force, during the night. Weak shocks were then felt for a whole month.

A tsunami appeared soon after the earthquake. The sea suddenly rose 2 m (1 fathom) at Manado, 3 1/2-4 m (2 fathoms) at Kema; the same occurred at Amurang. Thirty residential blocks (districts) were destroyed at Kema.

At Bentenan, one residential district was flooded 15 times in 2 hours. The water rose 1/2 m (2 feet) in the yard of a home on the coast during the first three waves. The Palemba* River was dammed and swelled heavily on a 700 m stretch, though adjacent areas were not inundated. The tsunami began during an ebb when the sea level fell 2 m below the mean mark, and the shore was inundated to a height of 2 1/2 m above this mark. Thus, the amplitude of oscillations can be estimated at 9 m [2 1/4 m?].

The sea was very restless at Ternate Island, now falling, then slowly rising.

On Sangihe Island at Peta, there was a very great flooding. At Tahuna, there was a rise in water level by about 1 1/2 m. The water rose in about 2 minutes and fell in 3 minutes. The movement of the water, according to an eyewitness, began a minute after the earthquake and was accompanied by a noise like a strong surf. The bridge across the river at Tahuna was lifted by the flood and partially knocked off its piers. The waves recurred throughout the night until morning, at gradually increasing intervals: from 5 minutes to 30 minutes. Most of the residents of Tahuna rushed to the adjacent hills after the earthquake and spent the night there. On the 9th, many dead fish were found on Cape Tahuna. Six proas were loaded full with the fish. It was on this account that the residents thought that the cause of the earthquake was the eruption of an underwater volcano (Banda Wuhu?] in the vicinity of Sangihe Island (Figee, Onnen, 1891; Neumann van Padang, 1951; Berninghausen, 1969; Cox, 1970).

1889 (1899), September 8 and 9. There was an earthquake and a tidal wave. There were dead fish and the Ruang Volcano erupted on the Sangihe Islands (Sapper, 1927; Heck, 1947; Iida et al., 1967; Berninghausen, 1969). [A distorted account of the events of 6.IX.1889.]

1889, November 23, evening. There was an earthquake on Madura /224
Island, at the coastal settlement of Gersikputic. Then an unusually high sea level was observed. The dikes of the ponds were breached, and the

fish being bred there were washed away. On the 25th, the sea level was again normal (Figee, Onnen, 1891).

1891, May 19, 1:09. Sigli (North of Sumatra Island). There was a very brief shock, followed by another, much stronger shock. The tremors, lasting a total of 5 seconds, were preceded by a comparatively strong sea surf (Figee, Onnen, 1893 a). [Most likely not a tsunami.]

1891, June 10, about 21:00. On Batjan Island, the sea surged on shore with force up to seven times; there were no losses (Figee, Onnen, 1893 a).

1891, June 20. There was a tsunami of unknown origin on the east of Indonesia.

At Saparua, waves were observed from 20:00 to 20:30. The sea retreated about 200 m from shore several times and rushed back rapidly a moment later. These movements of the water were also observed at other places in Ambon Department. No earthquake was felt at that time. The flood and ebb movements of the water were not noticed on the government steamship "Havik," which was riding at anchor in front of Saparua Bay. On the next day, from noon to about 16:00, the surf in the bay was stronger than usual and was even so heavy that a sloop launched from the steamship could not approach the moorage, and returned to the steamship.

Weak movements of the water were observed at Bandaneira from 22:00 on the 20th to 2:00 on the 21st. The movements were very noticeable all around Lonthor Island, especially at Lonthor itself. The tidal waves surged onto the coast at Lonthor, but did not go beyond the usual flood tide marks and did not do any harm (Figee, Onnen, 1893 a).

1891, October 5, 20:15. There was an earthquake on Timor and adjacent islands. At Maumere, there were heavy tremors lasting 20 seconds. At Trong, there were rather strong oscillations lasting 70 seconds; there was a mass of aftershocks. At Kupang, there was a very strong undulating movement. There were strong shocks at Babau, Pariti and Amasari, and several shocks at Ende. There was a strong earthquake for 20 seconds at Atapupu; there were many aftershocks. Oscillations in sea level also occurred during the first shock. The water rolled onto the coast of the bay with great force several times and rolled back at 5 minute intervals (Figee, Onnen, 1893 a).

1892, May 17, 20:00. There was an earthquake with source off the coast of Sumatra Island, which affected all of Sumatra Island, the Malacca Peninsula and the western part of Java Island.

The earthquake was strongest - up to 6 degrees (VII Rossi-Forel) - in the Padangsidimpuan - Lake Toba - Tandjungbalai triangle. The tremors lasted from 1 to 5 minutes, according to different estimates.

The strongest shocks and undulating oscillations of the ground were felt at Padangsidimpuan. Three public buildings were heavily damaged, and the jail and the warden's home were so heavily damaged that they were unsuitable for further use. A mass of recurrent shocks were felt at night. According to boatmen from Lake Toba, a large house collapsed on its shore. The telegraph line from Bentan* to Prapat was cut.

At Tandjungbalai, many homes were more or less damaged; some of them tilted to one side; fires broke out at two places; an unfinished home collapsed. One resident jumped out of a window in panic and broke a leg. There were no other victims from the earthquake. At Labuandeli, in the Chinese quarter, all the residents ran to the street in fright.

The earthquake was strong at Tandjungmorawa, Sungeibras*, Bindjai, and in the region of Asahan. A rumble was heard at Qualamintjirim*. At Tandjungpura and Tebingtinggi, the tremors had a force of 5 degrees (VI); some residents felt symptoms of sea sickness; lamps swayed strongly. At Medan, the earthquake began with barely perceptible oscillations; their intensity slowly increased and then diminished again.

Very perceptible, but not destructive, tremors spread to Stabatestat*, Klamberlima*, Berapi* (Natal region), Padang and Mukomuko. The earthquake was felt at Tandjungkalean*, Palembang and Djambi.

On Penang Island, the residents ran out of one home in panic. At /225
Singapore, there was widespread panic, and people crowded onto the street. Tall houses swayed from top to bottom. Wooden bungalows shook, the door posts were warped. The force of tremors first gradually rose, and then gradually decreased.

A very weak earthquake was felt at Djakarta (Batavia) and Indramaju.

A strong surf was observed in the rivers on the eastern coast of Sumatra Island. At Tebingtinggi, the water in the Barau and Hilang Rivers surged onshore several times. At Tandjungpura, the water in the river became unusually agitated. A strong movement of the water in the rivers was observed at Qualamintjirim* and at Klambierlima. At Tandjungbalai, the river was very fast.

At Singapore, the water became agitated, alternately rising and falling (Figee, Onnen, 1893 b).

1892, June 7. There was a powerful eruption of the Awu Volcano on Sangihe Island, which generated, so far as can be judged from the fragmentary data (Figee, Onnen, 1893 b; Wichmann, 1893), joint gravitational oscillations of the atmosphere and the hydrosphere of the same type as the waves from the Krakatau explosion and corresponding oscillations in level [seiche type?] in the internal seas in Indonesia.

The eruption began at 18:10 without any preliminary phenomena. A huge column of smoke rose over the volcano. Lightning flashed. It rained with a mixture of ashes. This soon became a real ash and rock fall.

The explosion of the volcano was not accompanied by noticeable tremors of the island. The eruption reached extraordinary power at about 21:00. After this, the fall of pumice stopped, and the ashfall also diminished by midnight. Soon after the eruption, boiling mud flows saturated with hydrogen sulfide, presumably formed as a result of the emptying of the crater lake, rushed along the crevices which furrowed the slopes of the volcano. As a result of the eruption, 1,532 people died on the island, or 2% of its population, since many huts collapsed under the weight of ejecta, while others were washed away by the streams. The northern part of the island suffered considerably more than the southern. Gardens, kitchen-gardens, and coconut plantations were buried.

The loud noises of the explosions of the volcano were heard on Ternate Island from 18:00 to 22:00 and then at night until 2:00. At Manado, several explosions were heard for half an hour after 18:30, and flames flickered on the horizon to the north. At Tolitoli and Donggala, and also at many parts in the southern and eastern regions of Sulawesi Island and on Kabia Island, including Makassar and Maros and on Timor Island, at 19:30 and later, very faint muffled booms were heard, like distant artillery fire. Similar sounds were heard at 20:30 at Ambon and at night on Flores Island, at Larantuka.

The sound wave was followed by a gravitation wave, which caused perceptible tremors at a number of places. Prolonged faint trembling of the ground was felt in the evening on Ternate Island. At Makassar at 1:57, tremors 3-4 degrees in strength were registered. An eyewitness who was in a hotel, woke up from the regular rocking of the bed. Hanging lamps swayed; bolts, doors, window frames rattled, some bells rang, dogs howled, the pendulum of the clock stopped. The other occupants of the hotel did not wake up. Similar oscillations were registered at Maros and in general in the southern and eastern regions of Sulawesi Island and on Kabia Island. At Bima, on Sumbawa Island, very strong horizontal oscillations were felt from 2:05 to 2:15, and very weak [ground] waves were felt at 5:10 and at 8:10. Several huts collapsed on Flores Island at Reo. At Maumere, horizontal oscillations lasting 2 minutes were felt at 2:30; one hut collapsed. At Ende, strong oscillations were felt at 1:00. At Larantuka, horizontal tremors lasting 2 minutes were felt at 2:30; one residence collapsed. There was a weak shock at Trong at 2:00. On Sumba Island at Waingapu, horizontal tremors lasting 1 minute were felt at 2:10.

At Surabaja at 1:34, the pendulum of the astronomical clock stopped. At Djakarta (Batavia), the magnetograph registered an earthquake at /226
1:17 and then at 1:21 and 6:00.

Oscillations in sea level were noticed at Bonthain, Bulukumba and Salajar; the only consequence was minor damage to one boat in the Tanga Tanga* River at Bonthain.

At Bima, oscillations in level were noticeable at 3:00. The water rose high at the entrance to the bay; this was accompanied by a loud noise, which was even heard in the home of the local superintendant, a 2-hour walk away. This rustling lasted 20 minutes, after which the water began to rise very quickly. The highest rise of water was observed at 5:00, when there should have been an ebb.

A weak tsunami was observed at 7:00 in Ambon Bay. In a few minutes, the water level oscillated from the highest to the lowest level, with a range of more than 1 1/2 m.

To give a fuller account of this phenomenon, we note that the ashes ejected during the explosion settled on a considerable area to the south of Sangihe Island. A ship travelling to Sangihe Island from Ternate Island was covered with ashes; ashes fell on Likupang. At Donggala and Makassar, much ash fell on the 8th from 3:00 until sunset (Figee, Onnen, 1893 b; Wichmann, 1893; Sapper, 1927; Heck, 1947; Neumann van Padang, 1951; Ponyavin, 1965; Iida *et al*., 1967; Berninghausen, 1969).

1892, November 18, after 2:00. At Kajeli, there were strong tremors lasting 7-8 minutes; there was still another light shock in the evening of the following day. There were rather strong shocks at Ambon, Hatusua, Kairatu (Ceram Island), and weak shocks at Tifu and Masarete. An hour after the earthquake, there were slight oscillations in sea level at Kajeli (Figee, Onnen, 1893 b).

1896, October 10, 17:30. There was an earthquake on the southwestern coast of the islands of Sumatra and Java.

There were two heavy tremors at Bengkulu; the roof of one home in the Chinese quarter collapsed. The earthquake also occurred at Lais, Seluma, Mana, Mukomuko, Kauer, and Krui.

There were rather strong and prolonged tremors at Talangpadang and Padangulaktanding (Palembang Province). There were two rather strong tremors in very rapid succession at Muaradua. There was a weak horizontal shock at Lahat. There was an earthquake at Telukbetung.

There was a rather strong and prolonged earthquake at Ardjasari; there was an earthquake at Sinagar*, and there were weak horizontal tremors at Gede, Tjiandur and Mangunradja.

At Rangkasbitung and Malingping, there were horizontal shocks lasting 30 seconds. At Bogor (Buitenzorg), tremors lasted 5-7 minutes. There were very many weak shocks, following each other at 2-3 second intervals. Only the first two were felt distinctly; they caused swaying of lamps. The others could be noticed only from the trembling of reflections in water in a glass. The earthquake was registered intensively by the Milne seismograph and the magnetograph at Djakarta (Batavia); the oscillations lasted at least 10 minutes.

At Natal, three shocks lasting 15, 50 and 10 seconds occurred one after another. There were regular, not strong, oscillations at Singkel.

At Gunungsitoli, there were undulating, not strong, movements. For an hour after, the sea was considerably more restless than during the preceding 6 hours (Figee, 1898 a).

1897, March 15, 6:30. There was a strong earthquake on Kajuadi Island. It was accompanied by a thunderous roar coming from the water. The ground cracked here and there; a crack about the width of a little finger cut across the lowlands on the southeast of the island. Stones of different size flew down from the hills. A weak shock was felt at Salajar. Many recurrent shocks occurred and continued in April, though at 7-10 day intervals.

According to an eyewitness, a half hour after the start of the /227
tremors, a cry went up that the water was rising. Reaching the shore, he saw that a wide roller had arisen far from shore. It soon broke up into three waves. One of them went out to sea; another advanced on Bonelamber settlement, on the western side of the island, but broke on the reefs protruding from the water here. The third wave rolled onto the coast at the settlement and advanced beyond the usual flood tide line, but did not reach the homes. The water was an unusual green color (Figee, 1898 b).

1899, September 30, 1:42. There was a destructive earthquake and tsunami with source off the southern coast of Ceram Island. The areas of the coast which suffered mainly were investigated by the well-known Dutch geologist, Verbeek, who happened to be in the vicinity of the island. The governor of the province of Ambon gathered much information about this natural catastrophe. A number of reports came directly to the observatory at Djakarta (Batavia). It should be mentioned that no information about the earthquake was received from the internal regions of the island because of the lack of residents of European origin there.

According to Verbeek, the earthquake was felt with greatest force at the settlements of Hatusua, Paulohi, Makariki, Tehoro and Wolu and was connected with a shift along the tectonic fault which separates the peninsula in the southwestern part of Ceram Island from the main part of the island (Fig. 96).

In fact, according to the reports of an official, sent to the /228
afflicted region to help the population, three cracks formed in the ground at Waisamu. Sizeable displacements occurred along these cracks, as a result of which one flank of the fault was elevated by 0.3 m relative to the other. At other places, water was ejected from the cracks.

At Amahai, three large cracks appeared on the coast. They reached a width of 1/2 m and a depth of 1 m in places. One of them stretched to the Polapa. Numerous avalanches occurred in the mountains. Avalanches were observed in the region of Paulohi, on the stretch of coast between Kawa and Taniwil and at Boano.

According to some reports, strange glows appeared above the sea in the pleistoseismic zone. The few details about the effects of the earthquake at particular places amount to the following.

At Waisamu, churches were damaged. At Piru, a church was also

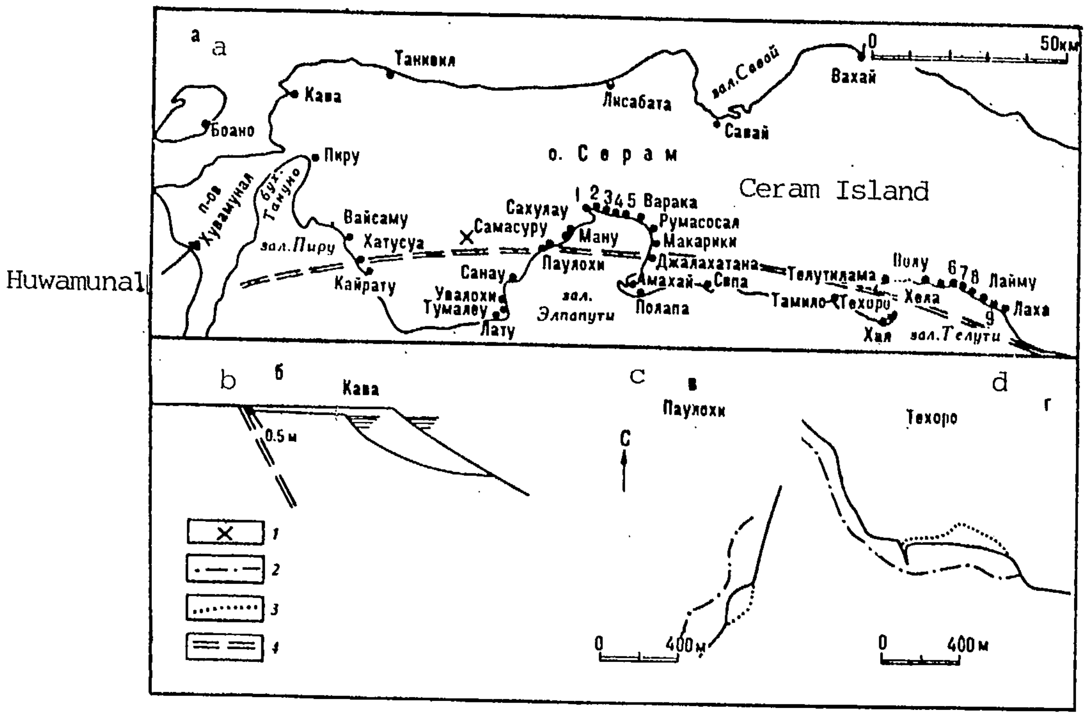

Fig. 96

Data on the earthquake and tsunami of 30.IX.1899 (Verbeek, 1901).

a - settlements on Ceram Island affected by the earthquake or the tsunami of 30.IX.1899; the numbers denote the settlements: 1 - Liang, 2 - Rumalait 3 - Tananau, 4 - Apisano, 5 - Waija, 6 - Namiang, 7 - Latumula, 8 - Tehuwa, 9 - Humusi;

b - diagram of the collapse on the coast of Kawa settlement; shows the old and new profiles of the coast and the plane of the revived fracture;

c,d - collapses in the region of the settlements of Paulohi and Tehoro; 1 - assumed macroseismic epicenter; 2 - boundary of flooding; 3 - old shore line; 4 - assumed tectonic fault.

damaged. The ground cracked everywhere, and the frightened residents decided to transfer the settlement to higher ground.

At Kawa, six huts collapsed, and some others cracked partly because the ground had settled by 0.5 m (see Fig. 96, b).

Six homes also collapsed at Boano-Serani; most of the others cracked. At a kirk, equipment fell, the door posts came away etc., and the church was left unsuitable for use. The stone memorials in the cemetery remained standing.

At Boano-Islam, which made up another part of Boano settlement, a mosque was half destoyed and two stone homes collapsed, as a result of which a little girl died.

On the northwest coast of Ceram Island, in the Taniwil-Lisabata region, all the settlements suffered from the tremors to some extent; at Lisabata, for example, several homes crumbled.

At Laimu, the earthquake was not very strong. On the south coast of Ceram Island, east of Teluti Bay, some damage may have been done only at Afang. At Wahai and Waru and on Geser Island, the earthquake was felt, but no damage was done.

At Saparua, a school, a kirk, and a doctor's home were slightly damaged. Kirks were heavily damaged on the islands of Haruku and Laot. The earthquake was strong on Ambon Island, but did not do any damage there.

More or less strong tremors were felt on the islands of Obi (at Laiwui), Batjan (at Labuha), Ternate, at Gorontalo, where a crack supposedly appeared in a carriage shed, and on the Banda Islands. The earthquake was felt on Boano Island, at Kajeli, the Kai Islands, the Sula Islands (at Sanana), Bangai Island and at Manado; they were felt weakly at Tolitoli, Tondano, and on Halmahera Island. No information was received about the effects of the earthquake on the islands of Leti and Wetar. Thus, the area of perceptible tremors apparently extended in a northwest-southeast direction.

On many areas of the coast of Ceram Island, large massifs of loose materials, mainly Quarternary sandy-clay and rubbly-pebbly alluvial deposits, tumbled into the water. These slumps, together with assumed tectonic dislocations on the bottom of large bays, generated tsunami waves, which reached a height of 9 m (16 m according to the governor of Ambon) in some places. In accordance with the nature of their generation, the height of the waves varied markedly from place to place.

At Paulohi, an area of coast 260 m long and 100-150 m wide (see Fig. 96, c) went under water together with quarters of the districts of Paulohi and Samasuru, which made up the former settlement of Elpaputi. In place of the previous gently sloping shore, a steep cliff 8.8 m high was formed. Around the shore at this place, where the depth of the bottom had been 20 m (11 fathoms), the bottom was more than 75 m (40 fathoms) deep after the earthquake. The tidal wave arising as a result of the slump immediately inundated the remaining part of the shore terrace. The wave reached a height of 9 m (15 m according to other sources), passed 170 m inland from the former shore line and washed away all the structures except for two homes. Only 130 of 1,700 residents were /229 saved (according to other sources, 60 men and 40 women and children were saved).

From Paulohi, the wave spread in every direction, and to a greater or lesser extent, depending on the coastal relief, flooded all the coast of Elpaputi Bay. Makariki and Amahai, situated at the top of a funnel-shaped inlet opening to the northwest, suffered especially. The tsunami arrived here 5-10 minutes after the earthquake and flooded the settlement to a height of 6.4 m. All the homes below this mark were destroyed, except for the more solidly constructed stone kirk; 350 people drowned. A bare expanse remained in place of the northern part of the settlement. An iron flagpost on the coast was ripped from its stone foundation, carried 200 m along the 100° azimuth and crumpled. The chief of the station was picked up by the wave and tossed onto one of the huts, which immediately collapsed; however, he was able to get out of the debris safely. The fortifications were completely inundated and partly destroyed, but the soldiers escaped by climbing onto the rampart; the water stopped only 1/2-1 m short of them.

The water also devastated the southern slope of the cape, which bounds Amahai Bay. It swamped a point situated at a height of 8.3 m above sea level and left bits of coral reef on the tree branches here. Since this stretch was uninhabited there was no damage, but had the wave been only 2 m higher, none of the residents of Amahai would have escaped.

To the southwest of Paulohi, the tsunami did damage at the settlements of Uwalohi and Tumaleu, on the southwestern tip of the bay. Latu suffered to a lesser extent; apparently, Sanau suffered not at all. After the wave receded, a layer of silt remained on the coast of Elpaputi Bay.

Table 64 gives an idea of the effects of the tsunami at different places on the coast of Elpaputi Bay.

There was no damage from the tsunami at the settlements on the /230 south coast of Ceram Island, betwen Elpaputi Bay and Teluti Bay (Polapa, Sepa, Tamilo, Haja).

Table 65 gives a picture of the effects of the tsunami in Teluti Bay.

In Teluti Bay, according to the local village elders (Verbeek could personally investigate only Laimu settlement here), Tehoru was completely destroyed (see Fig. 96, d). There a section of coast together with a settlement tumbled into the water. No reports were received about collapses on other areas of the coast of the bay. According to the governor of Ambon, the wave reached a height of 12 m at Tehoru.

About 10 minutes after the earthquake, the settlement of Laimu was flooded by a wave which came from the west. It encroached 270 m inland and reached a height of 9 m in the western part of the settlement and 7 m in the eastern part. Houses and trees were washed away.

There is no information about the effects of the tsunami to the east of Teluti Bay.

In Piru Bay, the strongest wave was registered at Hatusua. According to a report which reached Ambon, the residents of this settlement were awakened shortly before 2:00 by strong tremors, which intensified for a long time. The frightened residents ran from their huts and heard a loud rumble from the sea, which was rapidly approaching the village. They had not all had time to climb to the nearby hills, when a wave fell on the settlement. It encroached 150-200 m inland and reached a height of 4 m (according to later measurements by Verbeek, the height of the wave was 2 m above the flood tide level or 2.4 m above the ebb tide level). The settlement was almost totally destroyed, and all the homes, which however, were not very sturdy, were "sheared off." An iron flagpost standing on shore was ripped off its stone foundation and tossed 150-200 m along the 93° azimuth. The single public structure in the region, the jail, hardly suffered; only an outside door, the lobby and a barbed wire fence were damaged. Ninety-five people drowned and 65 were injured. The other residents were left destitute. After the water retreated, the shore was covered with a layer of black mud and smelled of hydrogen sulfide.

North of Hatusua, at Waisamu, and south, at Kairatu, the wave did not do any damage, possibly because these places are cut off from Hatusua by small capes. The western shore of Piru Bay did not suffer from the tsunami. According to residents only one large wave was observed in Elpaputi, Teluti and Piru Bays.

At Kawa (northwestern shore of Ceram Island), a stretch of coast about 100 m long and 60 m wide collapsed and went under the water (see Fig. 96, b); nine people died. The collapse caused a small wave, which /231
flooded the land to 45 m beyond the new shore line and reached a height of 1.7 m. There was no damage.

Further to the northeast, at Taniwil, a section of alluvial coast about 50 m wide collapsed into the sea. Two men working there died. The collapse generated a wave which rose to a height of 4.6 m. A large boat riding 80 m from the shore was washed out to the sea, and two others were smashed to smithereens. The homes in the settlement did not suffer, since they were located at a height of about 4.5 m above sea level.

The northeastern and eastern coasts of Ceram Island did not suffer from the tsunami. However, slight oscillations in the sea level were noticed at Wahai. The waves which formed off the south coast of the island, primarily in Elpaputi and Teluti bays, spread rather far to the south. The low-lying settlements of Itawaka, Nolot and Ihamau on the northeast coast of Saparua Island were partially inundated; there were, however, almost no victims. The locality of Hatawanu* on the north coast of Saparua Island, suffered especially. Homes and boats situated on the coast were washed away and smashed. The settlements of Tomaleu* and Hualoi* were completely devastated.

At Saparua, the water invaded homes situated near the shore and ruined furniture and other household belongings. A small Indonesian ship was sunk in the roadstead.

A ship riding at anchor off the east coast of Ambon Island near the Paso isthmus was capsized by the waves and sank as well.

In the roadstead at Ambon, at 2:15, a noise was heard as from a waterfall, and a ship, which was riding with the bow to the southwest, was spun 180°. For five minutes the noise gradually died down, and then the ship turned again to the southwest. The succession of flood and ebb currents, at gradually increasing intervals, stopped at 7:00.

In Ambon Bay, the water began to rise and fall about an hour after the earthquake. The shore was hardly inundated, but in the morning it was discovered that the waves had washed away all the fishing gear there. The movements of the water stopped by 6:30.

The tsunami showed up distinctly on the Banda Islands. About 1/2 hour after the earthquake, the water burst with force into the fairways leading to Bandaneira and Lonthor. By 2:45, the rise of water had reached its highest level, about 1 m above the regular flood tide mark. The movements of the water continued until dawn with gradually diminishing force. Stones of different sizes were tossed by the waves onto the coast of the islands of Neira, Lonthor and Rozengain. In the Kalobi* district, on the north coast of Api Island, the waves penetrated 50 m (28 fathoms) inland and washed away one hut. A strip of shore 5 m wide was washed out. In Kalobi* harbor, 13 Indonesian ships and boats sank. In Bandaneira Bay, ships were run aground; a moorage and a booth near Fort Nassau were shifted. No accidents were reported.

The tsunami was also observed in Kajeli Department (Boano Island), where it did not do any damage (Milne, 1900 b; Anon., 1901; Verbeek, 1901; Rudolph, 1904; Montessus de Ballore, 1906; Sieberg, 1932; Severit, 1933; Heck, 1947; Gutenberg, Richter, 1949, 1954; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

Richter (1963): 29.IX; $17^{h}03^{m}$; 3° S., 128.5° E.; M=7.8.

1900, January 10, 3:15. At Galela (Halmahera Island), there were strong undulating tremors; a seaquake or a tsunami (zeebeving) was observed at the same time (Anon., 1902).

1903, March 30, 11:30. At Tifu, Masarete and Kajeli, there were three horizontal tremors of considerable force lasting 5 minutes. The direction was from the northeast. They were felt at Buru. They were registered by mechanical seismographs at Djakarta (Batavia) at $3^{h}26.7^{m}$.

Immediately after the earthquake, oscillations in sea level, lasting about 45 minutes, were observed at Tifu and Masarete. The water rose to a height of 1 m (Anon., 1905 a; Rudolph, 1905). /232

Milne (1912 a): 30.III; $3^{h}23^{m}$; 3° S., 126° E.

1904, February 2, 17:00. Tolitoli Region. As a result of a tidal wave, various farm plots and the road to Malosong* settlement remained under water for 10 minutes (Anon., 1905 b; Oddone, 1907).

1904, July 5, early morning. The sea was very stormy in Saparua Bay and outside of it, although there had been no storm there before. Part of the pier was smashed and washed off. At 2:00, a tidal wave fell on the coast at Sirisori; one proa, loaded with goods, ran aground and was smashed, but the passengers were saved. On other areas of the coast, as far as is known, nothing similar was observed. The cause of the waves is unclear. The last known earthquake had occurred on the 4th after 13:00 and was felt at Piru, Amahai and Wahai (see Fig. 96) (Anon., 1905 b; Soetadi, 1962; Berninghausen, 1966).

1904, September 7. Ground tremors were felt at Tjilatjap. One eyewitness on the coast of Java Island noticed at noon that the water in the sea had grown white (had become like milk). The phenomenon stopped by 23:00, but resumed 2 hours later (Oddone, 1907).

1907, January 4, 12:20. There was a strong earthquake with source off the western coast of the northern part of Sumatra Island.

At Gunungsitoli, undulating movements of the ground were so strong that it was impossible to stand. Great damage was done to structures everywhere. A crack formed in the cement floor of the customs office. At Barus, there were very strong shocks in rapid succession; wooden buildings creaked; the concrete wall of the abandoned fortifications cracked. Strong tremors were felt at Rundeng, Pariaman, Airbangis, Natal, Siborongborong and Talu, where the wooden parts of the buildings creaked, cupboards were shifted, lamps swayed, and people felt nausea. Rather strong tremors were registered at Balig, Labuhanbilik, Bagansiapiapi, where an eyewitness felt dizzy, and at Tadjungbalai, where the pendulums of clocks stopped, lamps described circles with a radius of 30 cm, and the residents also felt dizzy. Reports about the earthquake came from Kualabeu, Sidikalang, where buildings shook and lamps swayed, and from Lubuksikaping and Shribudolok. Weak tremors were reported from Sibolga, Pajakumbuh and Pulu Pandjang. A rumble was heard at many places (Kualabeu, Barus, Tandjungbalai, Sibolga and others).

Less strong foreshocks were felt at a number of places at 2:00, 9:00 and 12:00.

A tsunami arose and caused great destruction on Simeulue Island. It was observed on the entire coast of Atjeh, in Tapanuli Bay, on the Mentawai Islands, at Gunungsitoli, Pulu Boanga*, Natal, Barus, Meulaboh, Kualabeu, Puluradja and Pulu Tello, and it was also registered by the tide gauge at Padang (at Telukbajur). About 400 people died.

The later recollections (Visser, 1931 a) that at the time when the Hinako Islands were devastated by an earthquake, the sea at Sibolga retreated from shore, and then a tidal wave appeared and flooded huts, apparently relate to these same events (Anon., 1909; Visser, 1922 a; Sieberg, 1932; Heck, 1947; Gutenberg, Richter, 1949, 1954; Ponyavin, 1965; Berninghausen, 1966).

Gutenberg, Richter (1954): 4.I; $5^h19.2^m$; 2° N., 94.5° E.; 50 km; M=7.6. [The instrumental data about the earthquake are in poor agreement with the macroseismic data.]

1907, March 30 and 31. On Karakelong Island (Talaud Islands), there were unusually high waves, which spread approximately from west to east. The water rose to a height of 4 m, so that some cultivated areas 50 m from shore were devastated. On the 30th, at about 5:00, weak underground shocks were felt at Lirung, Tomoon and Donggala (Anon., 1910).

Gutenberg, Richter (1954): 29.III; $20^h46.5^m$; 3° N., 122° E.; /233
500 km; M=7.25.

1908, February 6, 8:00. There was an earthquake with source off the western coast of Sumatra Island.

At Sikakap, there were strong shocks lasting 45 seconds. At Udjung-Sungei-Bramei, shocks lasted 2 minutes, window frames and doors rattled, one pane broke. There were prolonged heavy tremors and an underground roar at Balaiselasa and Mukomuko, strong shocks at Sandaran, Bengkulu and Mana, and rather strong tremors at Tandjungsakti and Bintuhan. There were tremors at Alahanpandjang, Muaratelang* and Tais, where they were preceded by a dull noise. There were weak shocks at Padang, where several clocks stopped, and at Banko, Muarabliti and Palembang, where the furniture vibrated. There was a very faint trembling at Krui. The earthquake was registered by the seismograph at Djakarta (Batavia). It was accompanied by a large number of aftershocks and was preceded by a foreshock on the 3rd at 2:00, which was felt at Sikakap, Udjung-Sungei-Bramei, Padang and Balaiselasa.

The earthquake was accompanied by a tidal wave, which reached the street at Sikakap (Anon., 1910; Milne, 1913 b; Visser, 1922 a; Heck, 1934, 1947; Ponyavin, 1965; Berninghausen, 1966).

Milne (1913 b): 6.II; $1^h27^m\pm$; 5° S., 100° E.

1908, March 23/24. (Soetadi, 1962; Berninghausen, 1969) mention that the strong earthquake of March 24 at Atapupu (Timor Island) was followed by tidal waves. This reference may be mistaken; the original account (Anon., 1910), it seems, mentions only a seaquake and not a tsunami. Here are the relevant data.

On March 23, after 20:00 there was a strong earthquake all over Timor Island. At Atapupu [evidently mistakenly dated March 24], oscillations lasted about 3 minutes. Vials fell from a shelf in an office. Cracks appeared in the walls of the fort, and one piece of wall 5 m long fell down. The wall of one home in the Chinese quarter also collapsed . Narrow cracks up to 25 m long appeared on the coast. Fishermen at sea were rocked heavily for a short time. At Kupang, the earthquake was considerable; according to the elders of one of the nearest villages it was the strongest since 1881. It was felt on the islands of Roti and Sawu. A ship in the passage between the islands of Timor and Alor felt a very strong seaquake. On Alor Island, chairs and walking-sticks standing in the wardroom fell down; hanging objects swayed for 10-12 minutes. At Ende, the anchor chain of a ship knocked against the bottom repeatedly during the earthquake. Weak tremors were registered at Bima, on Selaru Island and at Merauke (Map X).

[23.III; 12h20m; 10° S., 129° E.; M=6.6.]

<u>1909, June 4, 1:41.</u> There was a strong earthquake with source in the vicinity of Kerintji, off the western coast of Sumatra Island.

There was serious destruction and victims in the districts of Kerintji and Redjanglebong, at Ketaun, Sungaipenuh, Tandjung, Pau* and Muti*. Fires broke out as the result of collapses. The telegraph link was cut. Balaiselasa, Muaralabuh, Kambang, where the ground cracked, and Painan felt very strong tremors. At Padang, the walls of many stone buildings cracked and slanted; pillars broke in two but did not collapse; there were no victims. At Solok, panic reigned and everyone ran from the creaking homes; ornaments fell from the walls to the floor. The road between Kubangnandua and Alahanpandjang cracked. The lighthouse at Pulu Pandjang buzzed, the tower clock rang out, and oil spilled out of the reservoir. At Banko, this was the strongest earthquake in living memory. At Ipu, the tremors lasted a minute. Strong shocks were registered at Padangpandjang; at Bua, where the wooden barracks creaked, people were rocked and a lamp on a cord 1 1/2 m long oscillated with the same amplitude; and at Taluk, where homes and trees swayed, and boats in the river felt a strong shaking. Rather strong shocks, accompanied by a roar, were felt at Djambi and Bajunglentjir, where shutters rattled strongly, lamps swayed and furniture vibrated, and at Rengat and Talu. The earthquake was felt at Pajakumbuh, Pakanbaru, Djebus, Tandjungpinang and Palembang. At Singapore, some sleepers were awakened by strong unpleasant vibrations /234
and the creaking of furniture, doors and windows; here and there, residents rushed to the streets in panic and some heard a rumble. A number of considerable aftershocks were felt.

A tidal wave, which may have done damage, occurred near the focal zone (at Tandjung, Pau*, Muti* and other places). Large movements of the water were observed at Kambang (Anon., 1911).

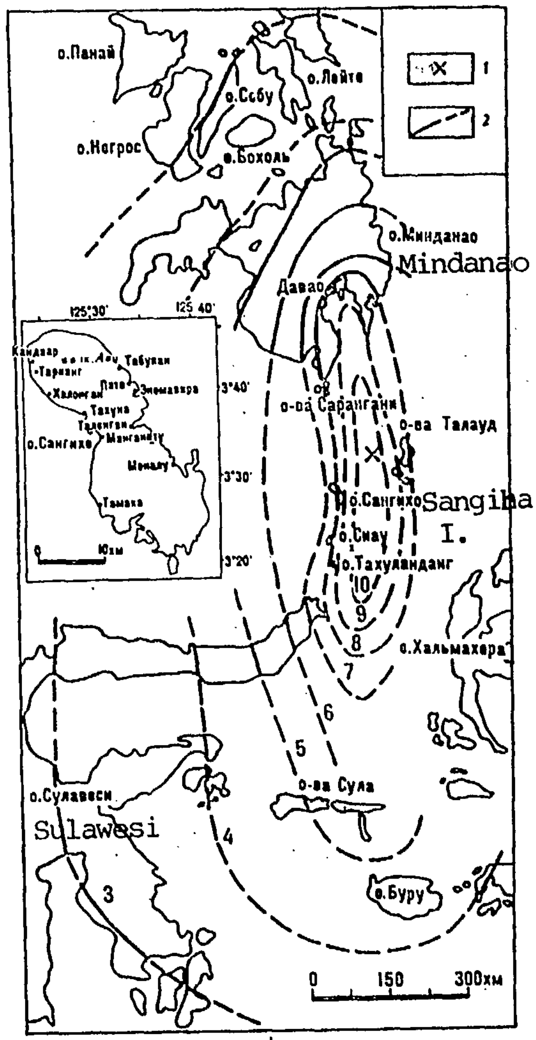

Fig. 97

Epicenter (1) and isoseismal lines (2) of the earthquake of 14.III.1913 (Sieberg, 1932).

Gutenberg, Richter (1954): 3.VI; $18^h40.8^m$; 2° S., 101° E.; M=7.6.

1910, December 18, about 0:00. At Lirung, Talaud Islands, there was a rather strong vibration of the ground for 3-4 seconds; some people felt less strong but prolonged tremors also on the 12th, the 15th, the 16th and the 18th.

Some residents of Moranga*, which is situated at one hour's walk from Lirung, thought that the level of the sea fell somewhat (Anon., 1912).

[18.XII; 2^h42^m; 4° N., 127° E.; M=6.7.]

1913 (mistakenly 1914), March 14, 16:45. There was a very strong earthquake with source near Sangihe Island. A number of studies (Visser, 1921 a; Sieberg, 1932; Severit, 1933; Heck, 1947; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969) mention that the earthquake was accompanied by tsunami waves. This is apparently mistaken. In fact, flooding of an altogether different nature was taken for a tsunami. The original accounts (Maso, 1913; Anon., 1915; Komorowicz, 1916) mention the following.

The earthquake was felt most strongly on the southeast of Sangihe Island (Fig. 97). It lasted 4 ± 2 minutes and was accompanied by a loud rumble. At Menalu, situated on swampy ground, the piles of homes were ripped out of the ground and the homes sank to one side or collapsed altogether. People were thrown to the ground. Various structures collapsed at Enemawira, Peta and Tabukan.

At Tamako, the school and some homes and shops were destroyed. The same occurred at Manganitu, but there was no serious destruction at Kandhar. Twenty people died. Numerous collapses and rock falls occurred along the entire rocky coast of the island, including the Kandhar region. In Menalu Bay, a chunk 1000 m^3 in volume collapsed into the water from a height of 80 m. To the west of Menalu, a mud flow, which travelled 1 km along the plain, came down from the 80-m Endongo* hill. Twenty-nine homes with 117 residents were buried under a mass of earth 1000 m long, 700 m wide, and 6 m thick. The loose soil covers on the island were dis- /235
sected by numerous cracks; water gushed forth from some of them; some areas of the ground subsided. In particular, the Menalu plain subsided; some areas of beach disappeared here and to the north; here and there the sea wedged into the land in narrow winding branches. As a result of the subsidence of the ground, ground waters came to the surface. All this led to the swamping of the plain and the residents of Menalu were obliged to move elsewhere. In Peta Bay, a strip of the south shore 200 m long subsided 2 m; the top of the bay was also swamped. The coast at Tamako subsided by 1/2 m, and an area of coast 180 m long subsided 1 m at Tabukan. The relief of the sea bottom apparently was unchanged, as all the anchorages continued to function.

The Endongo* mud flow backed up a small river. It overflowed.

After the earthquake, pouring rain began. The water breached the blockage and flooded the underlying locality. The river at Manganitu also overflowed catastrophically, washing out all the bridges.

The earthquake was less strong on the other small islands between the islands of Sulawesi and Mindanao (see Fig. 97). Nevertheless, on Siau Island, people could not remain standing; at many places the ground cracked, avalanches and rockfalls occurred, various brick structures were damaged and some huts sank to one side; one person died and several were injured. There were no reports on the subsidence of sections of the coast.

On the Talaud Islands as well, cracks appeared in the ground at many places and water issued from them; public buildings (the kirk, the school, etc.) cracked substantially; domestic equipment was smashed; there were no victims. One local captain stated that at the same time as the roar, he saw a large elevation form at sea several kilometres to the west of the island.

Nothing out of the ordinary occurred on Tahulandang Island. At Amurang, a crack 120 m long cut off a crescent-shaped part of the sandy beach, which was soon washed out by the waves.

The earthquake lasted 1/2 minute on the Sarangani Islands, south of Mindanao Island; pillars and large trees fell. At Davao, very strong oscillations lasted, according to different estimates, from 2 to 5 minutes. The cracks which formed in the ground ejected water and sand. People were thrown to the ground. Several stone walls collapsed. Huts made of palm leaves sank to one side.

Strong tremors, with almost no damage, were recorded at Bàgànga, Talakogon, Kotabato, and Butuan. The water in the Agusan River began to move markedly in an east-west direction; boats rocked strongly. Seamen in boats, sailing near Surigao, felt the earthquake; waves appeared on the surface of the water.

The earthquake was felt on the islands of Cebu, Bohol and Leyte. It was not felt on the islands of Negros and Panay.

The earthquake was preceded by several foreshocks and was accompanied by aftershocks.

Gutenberg, Richter (1954): 14.III; 8^h45^m; 4.5° N., 126.5° E.; 40 km; M=7.9.

1914, December 3, 22:30. The ship "Baud," riding at the moorage at Ambon, was suddenly carried 20 m away from the moorage, and the bollard, on which the end of the rope was wound, was ripped up together with its foundation. Looking overboard, the captain established that a powerful current was passing under the moorage, from the shore to sea. He estimated its speed at 6 knots. This continued for about 20 minutes, and its only further result was that the hose with which the ship was pumping in fresh water was broken. The cause of this current, according to the captain, could have been an earthquake or a landslide (Anon., 1916).

1915, May 23, 5:50. At Kaimana (New Guinea), a shock lasting 2-3 seconds was felt. Then another three strong shocks were felt. Buildings swayed heavily. At night on the 22nd-23rd of May, there was a strong thunderstorm and a downpour. The level of the sea rose 1/2 m above the level of the spring high tides (Anon., 1917; Visser, 1928).

1915, July 26, 6:30. At Lais (Sumatra Island), there was a weak /236
earthquake and oscillations of the sea [a seaquake?]. A weak earthquake was also felt at Kepaijang at 8:10 (Anon., 1917).

1915, August 2 and 3. Large tidal waves, caused by a storm raging on the southwest of the Indian Ocean, rolled in from the southwest onto the coast of Java in the region of Genteng and Tjisolok. The weather was comparatively good and almost still; far from shore, the sea was quite calm.

In Genteng Bay, the strongest rises of water were apparently observed at 9:00, 11:00 and 15:00 on the 2nd. The last occurred in the ebb tide phase, and had, according to estimates, a height of about 4 m. The rollers flowed over the coral reefs, which enclosed the bay, and passed 10 m inland, to the coconut plantations. All this time, the water in the bay churned, and 2 m waves moved over its surface. The anchor chains snapped in all the ships riding at anchor in the bay; some of the ships ran aground and were covered with sand, others were carried out to sea. Sea water entered the rivers and channels in the vicinity.

At Tjisolok, three high flood tides were also observed on the 2nd and 3rd. The rice fields and a road were damaged. Six bridges were completely or partially destroyed. At a shore cliff protruding into the sea in the Karanghawu* region, the water rose almost 8 m, and all the vegetation up to the top was destroyed. At Pelabuhanratu, the sea was quite rough, but there was no damage (Anon., 1917).

1917, January 9, evening. A ship was situated at 1° 34' N., 122° 43' E., off the northern coast of Sulawesi Island, near Kuandang. It was raining heavily, both on sea and land. The sea was calm, although a mild swell was advancing from the north. The wind was of variable direction, 1-2 points. Suddenly, at 21:30, the sea became very rough, with enormous whirlpools. All this was like a heavy surf on shore and instilled fear. Water fell on the deck with heavy blows. The keel rocking was such that the compass card flew off its point. The troughs which formed on the surface of the sea appeared to the eye to reach a depth of 4 m. Especially strong waves came from the north. The stormy sea lasted until 9:45 [21:45?], but came to an end completely by 10:00. Any surge had completely disappeared by 12:00. The pressure and temperature of the air varied negligibly during this phenomenon. Redetermination of the location of the ship showed that on that day it was situated in the zone of a western stream with a speed of about 2 knots (Philipp, 1918).

1917, January 21, 6:50. There was an earthquake with source, according to the Wiechert seismograph at Djakarta (Batavia), southeast of Bali Island. On Bali Island, there were very strong regular horizontal oscillations, here and there accompanied by vertical shocks, which lasted 50 minutes [seconds?]. The force of tremors depended very much on ground conditions, but on the whole decreased markedly from the south coast of the island to the north coast. Bamboo huts on loose grounds on the south of the island collapsed; stone houses cracked and partly collapsed. There were numerous landslides and avalanches, which buried houses and people (about 80% of the total number of victims in the earthquake were due to avalanches). The earthquake was also very strong on Lombok Island, from Mataram to Selong, and weak on Sumbawa Island and on the east of Java Island (at Bondowoso, Djember and Kraksaan). It was preceded by a foreshock, which was felt lightly at Denpasar on January 7, and was accompanied by a rather large number of aftershocks.

A small tidal wave was observed on the southeastern shore of Bali Island from Klunkung to Benoa. The wave did no damage (Kemmerling, 1918; Anon., 1919 a).

[20.I; $23^h11^m34^s$; 7°? S., 116°? E.; M=6.6.]

1917, January. A flood tide higher than any previous one was observed on the Linga archipelago. This led to the spoilage of various plots of land on the coast (Anon., 1919 a).

1917, March 16. According to the lighthouse keeper on the Sambergelap Islands (off Kalimantan Island), a flood tide appeared from the southeast at 8:00. The level of the water rose 1.5 m (5 feet) in ten minutes, and then fell rapidly to the usual height. At that time, it was /237
the flood tide phase, and a northeastern wind was blowing. On the same day, in the morning, a tidal wave was observed at Pagatan, where great damage was done (Anon., 1919 a).

1917, August 23, 22:00. Strong oscillations in the water level were observed at Saparua Bay (Anon., 1919 a).

1918, July 18, 10:30. An eruption of an underwater volcano occurred near Mahengetang Island (to the south of Sangihe Island). The water was thrown high up, and was like a great flood. As far as the eye could see, the sea was covered with floating pumice. A loud roar was heard at 1:30 and again at about 4:00.

The eruption recurred on August 20 at 23:00. This time, there was a strong sulphur smell and many poisoned fish were washed up on shore.

In December 1918, the residents of Mahengetang Island moved to neighboring islands. The eruptions of the volcano continued at the beginning of 1919. The local superintendant, inspecting the island on February 2, witnessed a new eruption. At 16:00, two cliffs appeared from under the water. One of them soon disappeared, but the other remained until morning of the following day. It was impossible to approach the cliffs because of the heat. The surface of the sea was strewn with yellow stinking slag. A thick layer of ash settled on the island.

In March and April, the residents returned, but the volcano continued to be active. On April 2, a new strong eruption began, and a column of steam 4-5 km high rose over the volcano on the morning of April 3. A number of homes caught fire in the ash- and rockfall. The residents could not evacuate because of the rough sea. Water rose 1-2 m, sometimes 5 m, on an area of 16 m^2 over the volcano. This was accompanied by muffled shots. The temperature of the water and air was high (Anon., 1919 b, 1920).

1919, February 13. An unusually high flood tide doing slight damage was observed at Atapupu (Timor Island). No reports of an earthquake were received (Anon., 1920).

1920, January 29, 22:00. There was an earthquake at Kuandang and Manado. There was a tidal wave in the region of Gorontalo (Visser, 1921 b).

1920, January 30, 23:00. At Donggala (Sulawesi Island), during an earthquake, the lighthouse inspector noted a tidal wave, which came from the east. It lasted 2 minutes and had a height of 2 m. This phenomenon is probably identical to the peceding one (Visser, 1921 b).

1921, May 14. There was an earthquake on Kalimantan Island with a maximal intensity of 7 degrees (VIII - Rossi-Forel). It caused damage at Sankulirang and more considerable damage on Rending Island. Homes partially collapsed at Kariorang (Tandjung - Setlu) and Sekurau. A drill hole began to gush; a gaping crack 10 m long, 2 m deep and 20 cm wide formed in the ground and ejected sand and clay. The radius of the area of the tremors was 250 km. At least 10 recurrent shocks were felt.

The earthquake generated tidal waves, which caused considerable damage at Sekurau (according to eyewitnesses, the water inundated the road to a depth of 1 m) (Visser, 1922 b; Soetadi, 1962; Berninghausen, 1969; Cox, 1970).

[14.V: $11^h17^m45^s$; 0.7° N., 117.9° E.; M=6.2.]

1921, September 11, 11:00. There was a strong earthquake with source south of Java Island. It was felt from Krui (Sumatra Island) on the west to Taliwang (Sumbawa Island) on the east. A seaquake was felt at 8° 41' S., 112° E. The earthquake occurred with greatest force, equal to 5 degrees (VI - Rossi-Forel) on the south coast of Java Island from Tjilatjap to Wlingi; here several walls collapsed or cracked. The tremors lasted, according to different estimates, from 1 to 4 minutes. There were many aftershocks. A small tsunami arose. It was noted at Parang Tritis and was registered by the tide gauge at Tjilatjap, beginning at 12:15 with a maximal amplitude of 10 cm (Fig. 98) (Visser, 1922 a,b).

Gutenberg, Richter (1954): 11.IX; $4^h01^m38^s$; 11° S., 111°

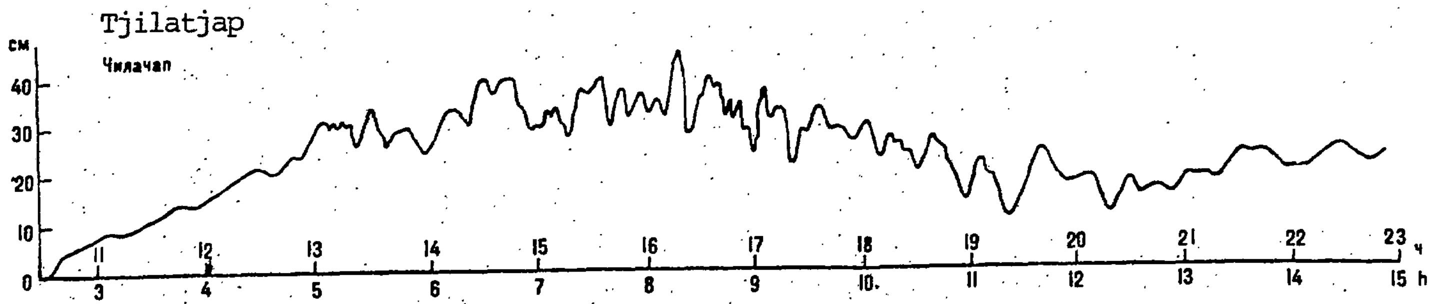

Fig. 98
Record of the tsunami of 11.IX.1921
(Visser, 1922b).

E.; M=7.5.

1922, February 22. At Amahai (Ceram Island, southwest, Fig. 96) at 19:45, there was an earthquake with a force of 4 degrees, preceded by a roar. According to reliable accounts of fishermen, two underground shocks occurred again towards midnight, and the sea was very rough all this time. No earthquake was registered on the instruments (Visser, 1923). /238

1922, April 10, 3:45. At Padang (Sumatra Island), there were two underground shocks of force 3 degrees. The sea was very noisy. No earthquake was registered on the instruments (Visser, 1923).

1922, July 8, 22:15. There was an earthquake at Tjalang and Lhoknga (Atjeh), force 3 degrees. At Lhoknga, the shock was preceded by a hurricane and was accompanied by a seaquake (Visser, 1923).

1925, January 8, 7:26. There was an earthquake, which was felt on the islands of Bali and Lombok and at Banjuwangi with a force of about 3 degrees and was registered at Djakarta (Batavia) and at Malabar.

At 10:00, at Baubau, on the west coast of Butung Island, with a mirror surface on the water and still weather, a wave like a very long swell about 1 m high appeared suddenly. It was followed by several other similar waves of lesser height. The surface of the sea again returned to complete calm in about half an hour. The waves did no damage. No additional reports about unusual phenomena at sea were received in response to inquiries sent by the observatory at Djakarta (Batavia) to other points on the coast of Sulawesi Island and the Lesser Sunda Islands. The time of appearance of the tsunami at Baubau corresponds to the calculated travel time of the tsunami from the source of the earthquake (Visser, 1926). [The earthquake was not registered at remote stations.]

1926, June 28. There was a strong earthquake in the region of Sinkarak Lake (Sumatra Island). The south coast of the lake collapsed in places and tidal waves arose. They reached the north shore in about 10 minutes (Visser, 1949).

Gutenberg, Richter (1954): 28.VI; $3^h23^m25^s$; 1.5° S., 99.5° E.; M=6.75.

1927, August 4 and 7. Some papers (Heck, 1934, 1947; Neumann van Padang, 1951; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969; Cox, 1970) give this date for the eruption and tsunami of 4.VIII.1928.

1927, August 23, 21:00. In the harbor at Djakarta (Batavia), an unusual rise of water was observed. It was caused by a hurricane, which blew up after noon from the north. At Tandjungperiuk*, the water level rose 95 cm above the highest mark registered to that time. At the moment of the highest water, the wind force intensified, and the wind was accompanied by a thunder storm and rain. According to reports from ships, the hurricane was situated off Banka Island at about 15:00

(Visser, 1928).

1927, December 1, 12:37. There was a strong earthquake with source in the region of Palu Bay (Sulawesi Island). At Palu, three large stalls collapsed completely at the market. All the remaining structures suffered some damage. The main road, leading to the corn market, was heavily damaged, and some side streets behind the bazaar subsided about 1/2 m.

At Borowaru*, market stalls were completely destroyed and the building of the district administration was heavily damaged. At Donggala, the gallery of the office of the local official partly collapsed. The earthquake was felt clearly all over the west of the middle part of Sulawesi Island. The maximal radius of perceptibility was 230 km.

At the same time, a tidal wave appeared in Palu Bay. It lasted 30 seconds and had a height of 15 m. The wave destroyed huts in the shore zone; 14 people died and 50 were injured. At Talise, a pier with a ladder was completely washed away. The sea became 12 m deeper.

Subsequent shocks of the earthquake were felt on December 1, 2, 3, 5, and 17 at Parigi, Malitou, Palu, and Talise (Visser, 1928; Soetadi, 1962).

[1.XII; $4^h37^s27^s$; 0.7° S., 119.7° E.; M=6.3.]

1928, March 26. An eruption of Krakatau Volcano was accompanied /239
by waves which were observed in the vicinity of the volcano. The sea level rose and fell nine times (Berninghausen, 1966, based on press accounts).

1928, August, on the night of the 4th-5th. There was a very strong eruption of the Rokatinda Volcano on Palu Island north of Flores Island. Three new craters were formed. A large amount of pumice, ash and bits of congealed lava were ejected. On falling, the eject set fire to the island's vegetation which was dry at that time of year. The entire island was showered with bits of pumice, but an especially thick layer of ash and pumice covered the southwestern quadrant of the island, including the settlements there. On the 5th and 6th, the ashes fell out as far as the Tenger Mountains on the east of Java. The volcano showed only slight activity after August 8.

In the eruption, 226 people died, 128 of them in the tsunami which occurred as the result of the displacement of the ground on the coast. Three waves 5-10 m high were observed both off Palu Island and on the nearest section of the coast of Flores Island. Twenty boats sank (reports appeared in the newspapers that the waves generated during the catastrophe on Palu Island were supposedly observed as far as India, and that at Allegri near Allahabad, the sea supposedly retreated 2 km (1 mile), leaving many ships high and dry; there is absolutely no connection between the two above-mentioned phenomena).

On September 9, the eruption revived and ash was ejected and spread over the entire island. The activity of the volcano continued until September 25 (SN, 1928, vol. 18, No. 3; Visser, 1929; Sieberg, 1932; Heck, 1934, 1947; Umbgrove, 1947; Neumann van Padang, 1951; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

1929, November 9, 2:20. On the outer roadstead at Tjalang (Sumatra Island), with a calm sea, a suddenly advancing high roller with breakers capsized a sloop, as a result of which six people drowned. The cause of the wave is unknown. It was the ebb tide phase. No earthquake was felt, and the nearest seismograph at Medan did not register anything unusual (Visser, 1930).

1930, March 17. In 1930, the Krakatau Volcano erupted with the formation of a mud island. At one of the intermediate stages (the 12th), between March 10 and April 5, the surface of the sea repeatedly swelled up above the volcano, on March 17 to a height of 500 m (Anon., 1930-1932).

1930, June 19, 20:00. Two strong shocks at 20 minute intervals in the region of Telukbetung were felt as far as Djakarta (Batavia) (radius of perceptibility 300 km). There was no damage, but the residents in the vicinity of Telukbetung were terrified and ran screaming from their huts. The captain of a motor boat, tied up at a small moorage at Telukbetung, related that during calm weather with a smooth water surface, a roar like remote artillery fire was heard. The ship began to vibrate extremely strongly 2 seconds later. In another 2 seconds, the water fell 1/2 m (2 feet), but then rose 1-1 1/2 m (4 feet); a strong ripple appeared on the surface of the sea. The roar and rocking recurred about 20 minutes later and again at 23:50 and 0:08 (Visser, 1931).

[19.VI; $13^h07^m27^s$ and $13^h27^m18^s$; 5.6° S., 105.3° E.; M=6 and 5.8.]

1930, July 19/20. On the 19th at 22:20, on the east of Java Island and on the islands of Bali and Lombok, there was an earthquake with a maximal intensity of 4 degrees. At Djember, it was preceded by a roar. The radius of the zone of perceptibility was 330 km; on the 20th at 2:00, the lighthouse keeper at Bansiring (Besuki) noted a tidal wave 10 cm high (Visser, 1931).

Visser (1931): 19.VII; $15^h20^m12^s$; 9.3° S., 114.3° E. [M=5.5].

1930, September 11, 20:00. At Amurang (Sulawesi Island), there was a roar and an earthquake about 4 degrees in force. There were numerous subsequent shocks, some of which were felt at Kotamobagu and Tomoon. At Amurang, the residents fled from the coast, since the sea level had apparently risen. A section of coast at the mouth of the Ranowanko River subsided (Visser, 1931).

1931, September 25, 12:50. There was a strong earthquake with /240
source between the islands of Enggano and Sumatra. On Enggano Island, a

loud booming roar was heard from the south before the earthquake. Then strong tremors occurred, which were accompanied by weaker shocks. The huts on piles dug vertically into the ground were shifted about 1/2 m. In those huts whose floor was 1 m from the ground, the lower part of the piles fell away and the huts settled to the ground, without undergoing any other destruction. None of the huts collapsed, but accidents occurred among the population. It was impossible to walk during the strongest tremors; pedestrians were bowled over and could move only by crawling.

At other places, the earthquake did not cause destruction, but was felt on a large area, as far as Padang (more than 500 km from the epicenter) and Bandung (600 km). Apparently, one resident even noticed the earthquake at Pamekasan on Madura Island (1250 km).

On Enggano Island, as a result of the earthquake, the sea became very rough, and the waves rose almost to the terrace of Pulau* Island, at about 1 m above the highest high tide mark (Visser, 1932).

Gutenberg, Richter (1954): 25.IX; $5^h59^m44^s$; 5° S., 102.75° E.; M=7.4.

<u>1932, September 9, after 22:00</u>. There was an earthquake with a force of 6 degrees (VII - Rossi Forel) on Ambon Island and the south of Ceram Island (see Fig. 95 and 96). The radius of the zone of perceptibility was 100 km. Many aftershocks were registered. The shocks registered by the seismograph at Ambon during September to December had the following S-P distribution:

S-P, sec.	1	2	3	4	5	6
no. of shocks	1	12	49	45	14	2

The main shock was strongest on the east of Ambon Island. At Tuleu, many homes and the school were destroyed and a mosque was partly destroyed. At Wai, it was necessary to rebuild 73 homes after the earthquake. Between these settlements, new thermal springs appeared and two pits were formed in the ground. At Tengatenga, on the eastern coast of the Hitu Peninsula, much material damage was done, but there were no victims. Many cracks appeared in the ground and landslides occurred in the vicinity. The population, fearing a tsunami, spent the night in the neighboring hills. Fortunately, no wave appeared.

Reports of a tsunami were received from the south coast of Ceram Island, from Piru and Loki.

The assumed position of the epicenter of the earthquake (see Fig. 95) agrees, according to Visser, with the macroseismic data, the S-P difference at Ambon for the aftershocks and the observations of East Asian stations (Visser, 1933).

Visser (1933): 9.IX; $13^h38^m52^s$; 3.57° S., 128.35° E.; 17 km.

Gutenberg, Richter (1954): $13^h39^m04^s$; 3.6° S., 128.5° E.; 17 km; M=6.25.

1935, December 28, 9:06. There was a destructive earthquake on the Batu Islands and the adjacent coast of Sumatra Island.

On Bodjo Island, cracks appeared in a hill 60 m high, which served as the base of the lighthouse. In the lighthouse itself, the system of lenses and the rotating mechanism were damaged, and the light dimmed. Some walls of outbuildings cracked. Two people were injured by falling tiles.

At Pulu Tello, several residences collapsed and there were injured. Slight damage was done to the lighthouses on Sigata Island and at Muarasiberut. The islands of Tanahbala and Sigata possibly rose somewhat, since the lowlands, which had previously been inundated during flood tides, dried up.

At Padang and vicinity, trees and the posts of the telephone and power networks, as well as the wires swayed strongly; several intercity telephone lines were cut in the vicinity; the lighting network was damaged at many places. Some walls cracked. Glassware broke in homes and stores. Stucco fell off in sheets. Water splashed over the sides in a /241
basin. Moving automobiles were thrown to the side, and they could only be controlled with great difficulty. At Sibolga, several huts collapsed but there were no victims.

At Muarakuang (Palembang residence) tidal waves were registered in the Ogan River on the 28th, although no earthquake was mentioned (Berlage, 1936).

Gutenberg, Richter (1954): 28.XII; $2^h35^m22^s$; 0° latitude, 98.25° E.; M=7.9 [evidently, seiches].

1936, April 1, 10:10. There was a destructive earthquake on Sangihe and the Talaud Islands, about which 13 reports were received. In all, 127 huts collapsed. There were many aftershocks. At Lirung, several cupboards and chests were overturned; the stucco fell off the walls in pieces; cracks appeared in the walls; several huts collapsed partly or completely; the ground collapsed at some places. The tremors were apparently somewhat weaker on Kabatuan* Island. On Karakelong Island at Taruan, three people were injured and 42 dwellings were damaged. The tremors were even weaker on the Nenusa Islands, and only the main earthquake, but not the aftershocks, was felt on Miangas Island.

On Salebabu Island, the sea retreated 500 m from shore and exposed the floor of the bay; the channel of the river also dried up. However, the water then rose again and surpassed the usual flood tide level by 3 m. This phenomenon recurred eight times during the day. At Beo, sea water leaked into a well at the church mission.

At Manganitu, on Sangihe Island, during the ebb phase, the water rose to the flood tide level twice between 10:00 and 12:00. The tsunami was less intensive on the western coast of the island than on the eastern coast (Berlage, 1938).

Gutenberg, Richter (1954): 1.IV; $2^h09^m15^s$; 4.5° N., 126.5° E.; M=7.7.

1937, November 6, 18:30. At Fakfak (New Guinea), there was a weak seaquake, accompanied by a tidal wave 1/2 m high (De Boer, 1939).

1938, February 2, 3:34. There was a strong earthquake on the east of Indonesia, including the west of New Guinea, with a maximal intensity of 7 degrees (VIII - Rossi-Forel). On the Kai Islands at Tual, stucco collapsed, domestic equipment was smashed and clocks stopped. On New Guinea, at Fakfak, the lighthouse was put out of service. At Tanahmerah (see Map X), regular, but not very strong, oscillations occurred for about 1 1/2 minutes; some residents did not wake up; empty bottles fell from a shelf. At Tanahtingi, the earthquake was perhaps somewhat stronger. It was felt all over the western part of New Guinea, as far as Merauke, and even at Darwin (Australia). There were many recurrent shocks.

Reports were received that near the epicenter, at 5° 43' S., 132° 37' E., in the Kai group of islands, a new small island rose from the water. The island was 56 m long, 52 m wide and 5-6 m high.

In the epicentral area the greatest damage was done not by the earthquake, but by the tsunami which it generated. In Djamru* settlement on the Tajandu Islands, 24 homes were destroyed and eight were heavily damaged. At Banda Elat, where, as at Tual, the height of the wave was estimated at 1 m, bridges were washed away and the moorage was damaged. At Bandaneira, a public pier and a goods warehouse were damaged; the damage to privately owned structures was slight.

The tsunami also appeared at Fakfak, where only slight damage was done (Berlage, 1940; Soetadi, 1962; Berninghausen, 1969; Cox, 1970).

Gutenberg, Richter (1954): 1.II; $19^h04^m18^s$; 5.25° S., 130.5° E.; M=8.2.

1938, February 13, 3:35. There was an earthquake on Pandjang Island at Fakfak. Rocks collapsed; the motor stopped at the lighthouse, and the cowl fell off the lamp; stucco cracked a bit in homes. Between 4:00 and 8:00, the lighthouse keeper observed tidal waves about 1/2 m high (Berlage, 1940).

1938, May 20, 1:00. There was a destructive earthquake with source in Tomini Bay. It was felt almost all over Sulawesi Island and on the east of Kalimantan Island (Fig. 99). It reached its greatest force in /242
the region of Parigi. Here 942 homes (more than 50%) collapsed in 34 villages and 184 homes were damaged. In Pelawa settlement, trees were uprooted. At the settlement of Marantale, the ground cracked and split

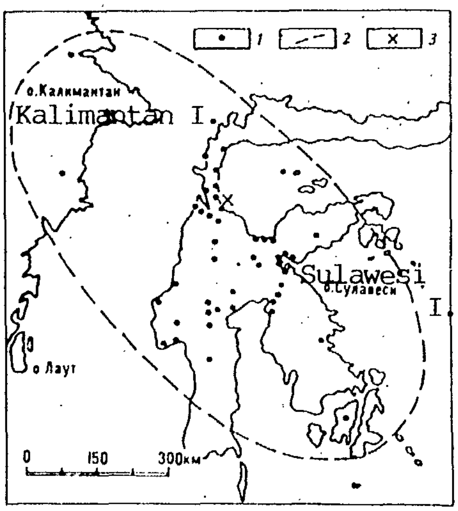

Fig. 99
Surface effect of the earthquake of 20.V.1938 (Berlage, 1940).
1 - places at which earthquake was felt
2 - tentative boundary of the zone of perceptibility
3 - epicenter

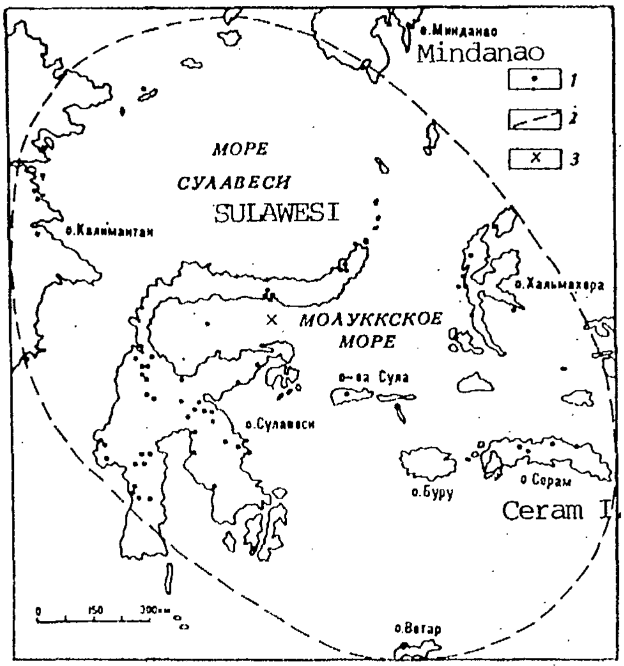

Fig. 100
Surface effect of the earthquake of 22.XII.1939 (Berlage, 1941).
Symbols, see Fig. 99.

in the coconut plantation; one home and the surrounding banana plantations shifted 25 m. The roads were covered with numerous cracks up to tens of metres long and 50 cm wide; here and there, mud flowed out of them; some plots of ground subsided. At Parigi, the school and the kirk collapsed; most wood, concrete and brick structures did not suffer. In the region of Palu and Donggala, the damage was slight, and in the regions of Poso and Tinombo, there was no damage at all, despite the strong tremors. There were many aftershocks.

Following the earthquake, a tidal wave 2-3 m high, according to some sources, surged onto the coast of the bay from about Toribulu to Parigi. At Toribulu, the sea suddenly retreated 80 m and then returned with force. Between Lemo and Makatate, 14 villages suffered from the wave. In places, the water encroached 40-80 m inland. Seventeen people drowned, one at Ampibabo and the rest at Parigi. At Parigi, a pier was washed away, and warehouses and navigation signals were damaged. Many cattle and coconuts were washed away.

Oscillations in sea level with a range of 8 cm (3 inches) were registered by the tide gauge at Santa Monica (California, USA) (Rothé, 1939; Berlage, 1940; Neumann, 1940; Heck, 1947; Anon., 1961; Soetadi, 1962; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969; Cox, 1970). [D. Cox investigated the marigram and arrived at the conclusion that it was a usual seiche and not the Indonesian tsunami (written communcation).]

Gutenberg, Richter (1954): 19.V; $17^h08^m21^s$; 1° S., 120° E.; M=7.6.

1939, December 22, 5:01. There was a destructive earthquake with source in Tomini Bay. Several structures collapsed at Langoan*. At Gorontalo, a number of buildings were damaged. Cracks appeared in walls; doors and windows opened; chests were toppled over; many residents were slightly injured. At Kolo, 21 homes collapsed, six of them completely. At Luwuk, cracks appeared in stone walls; several pile wooden homes collapsed; the ground cracked.

In the Bangai district, several settlements were completely destroyed. The shore slopes slumped into the water in "chunks." At Labuha, three homes collapsed; the ground cracked. Homes also fell in the villages of Pasi Ipa* and Gela on the Sulu Islands.

In the centre of Sulawesi Island, at Mandar and Meulaboh*, homes swayed strongly and cracked. The zone of perceptibility of the earthquake (Fig. 100) extended to the east of Kalimantan Island, the south of Mindanao Island, and the islands of Ceram and Wetar. The earthquake was accompanied by several recurrent shocks.

During the earthquake, oscillations in sea level apparently developed. They were especially marked on the south coast of the Minahassa Peninsula. Rice fields were flooded at Langoan* (Berlage, 1941).

Gutenberg, Richter (1954): 21.XII; $21^h00^m40^s$; 0° latitude, 123° E.; 150 km; M=8 [seiches?]. /243

1948, June 2. An earthquake generated a tsunami which was observed at Sabang, north of Sumatra Island (Rothé, 1951).

[1.VI; $18^h58^m18^s$; 6° N., 95° E.; M=6.3.]

1950, October 8. A call for help came from Ambon Island because of a strong earthquake and gigantic tidal wave. A large number of victims was feared (SN, 1951, vol. 41, No. 1; Hamamatsu, 1966). The existence of this great wave (according to press accounts, it had a height of 200 m [?]) could not be confirmed from the tide gauge records (Murphy, Ulrich, 1952; Berninghausen, 1969).

[8.X; $3^h23^m09^s$; 4° S., 128° E.; M=7.3.]

1957, September 26, 12:00. There was an earthquake, about which there are nine reports from Bogor, Priangan and Banjumas districts. The intensity was 2-4 degrees. Homes trembled, and there was a roar. The earthquake was accompanied by tidal flooding. The epicenter, according to the station at Djakarta, was located at 8.2° S., 107.3° E. (Anon., 1959). [There are no other instrumental data on the earthquake.]

1957, October 26, 22:00. There was an earthquake in the southern and eastern parts of Kalimantan Island, about which there are 37 reports. The intensity was 2-4 degrees. Many people woke up and there was a roar. The earthquake was accompanied by tidal flooding (Anon., 1959).

BCIS: 26.X; $14^h16^m57^s$; 2° S., 116° E.

1958, April 22, 5:40. There was an earthquake at Bengkulu, Palembang, Telukbetung and Banten, about which 10 reports are available. The intensity was 5-7 degrees. Three strong shocks were recorded. The earthquake was accompanied by tidal flooding, and the height of waves gradually increased (Anon., 1959).

[21.IV; $22^h37^m36^s$; 4.5° S., 104° E.; 200 km; M=6.7.]

1963, December 16, 8:52. There was an earthquake, which caused light destruction at Labuhan and Menes. A weak tsunami was reported from Labuhan (BCIS: Hake, Cloud, 1965).

[16.XII; $1^h51^m31^s$; 6.4° S., 105.4° E.; 64 km; M=6.6.]

1964, April 2, 8:12. There was a strong earthquake off the northern tip of Sumatra Island, in Atjeh province. It reached an intensity of 7 degrees and was felt on the southeast of Langsa.

In the coastal village of Kruengradja, situated on a river terrace, the walls cracked in the only well-built brick building, the mosque; five old wooden homes on piles collapsed and more than 80 similar homes were damaged; the wooden school building tilted to one side; a bridge shifted; people were thrown to the ground; cracks opened up in the valley, and ejected water and sand. The force of the oscillations intensified gradually, which allowed the residents to jump from their homes before they collapsed.

At Banda Atjeh, situated on alluvial grounds 10-15 km from the /244 coast, 30-40% of the adobe buildings were damaged. Brick-wood buildings suffered little, and wooden pile homes and concrete buildings on the whole did not suffer. Between Banda Atjeh and Kruengradja and at other places, cracks up to 400 m long and 1/2 m wide appeared in the ground;

some areas of ground subsided; mud and sand gryphons appeared.

The village of Lamtaba, situated at the foot of a volcano and built up with wooden pile homes, was 90% destroyed; more than 50 homes collapsed completely; stones rolled down from the slopes of the volcano.

At Lamtamot, a highway bridge was twisted and a railway embankment collapsed, but the brick station building and new wooden homes hardly suffered. At Seulimeum, only one old wooden home collapsed. Buildings cracked at Sigli.

At Uleelheo, situated on alluvial grounds, buildings suffered little, but a considerable stretch of the coast and the floor of the bay subsided about 1/2 m so that water came right up to the houses.

In addition, a tidal wave was observed here. Instrumental data: 2.IV; $1^h11^m51^s$; 5.8° N., 95.8° E.; 100 km (Soetadi, Soekarman, 1964).

[2.IV; $1^h11^m51^s$; 5.8° N., 95.4° E.; M=6.9.]

1965, January 24. There was a large destructive earthquake on Sulawesi Island. It was accompanied by a tsunami. It was preceded by foreshocks for a week. According to press accounts, 3,000 homes and 14 bridges were destroyed; 71 people were killed. The earthquake was felt on Halmahera Island and at Davao, in the Philippines. The tsunami destroyed 90% of the houses of Sanana City and also did damage to Namlea on Buru Island and on Mangole Island (SN, 1965, vol. 55, No. 3; Rothé, 1966; Hake, Cloud, 1967; Iida et al., 1967; Berninghausen, 1969).

[24.I; $0^h11^m15^s$; 2.4° S., 126.1° E.; 6 km; M=7.4.]

1967, April 11, 13:15. There was an earthquake on Sulawesi Island in the region of Tinambung and Madjene. Fifty-eight died and 100 were injured on the coast of Mandar Bay. A tsunami arose and caused heavy material losses in coastal settlements. At Tinambung, according to accounts, the water suddenly retreated, and then rose to twice the height of regular flood tides. Thirteen fishermen drowned in boats riding at anchor near the mouth of the Tinambung River (Iida et al., 1967; Hake, Cloud, 1969; Anon., 1970 b).

USCGS: 11.IX; $5^h09^m12^s$; 3.3° S., 119.4° E.; 20 km; M=5.5.

1967, April 12, 11:51. There was an earthquake with source in the Malacca Strait. At Penang (Malaysia), the residents ran from their homes. At Atjeh, 11 people died and 2,000 homes were destroyed (at Djunib*, Purul*, Biruen* and other places). The earthquake was accompanied by numerous aftershocks. At Sigli, an enormous sea wave was observed (Iida et al., 1967; Hake, Cloud, 1969; Anon., 1970 b).

1968, August 10, 10:07. There was a strong earthquake with source in the Maluku Sea. Slight damage was done at Manado. A tsunami

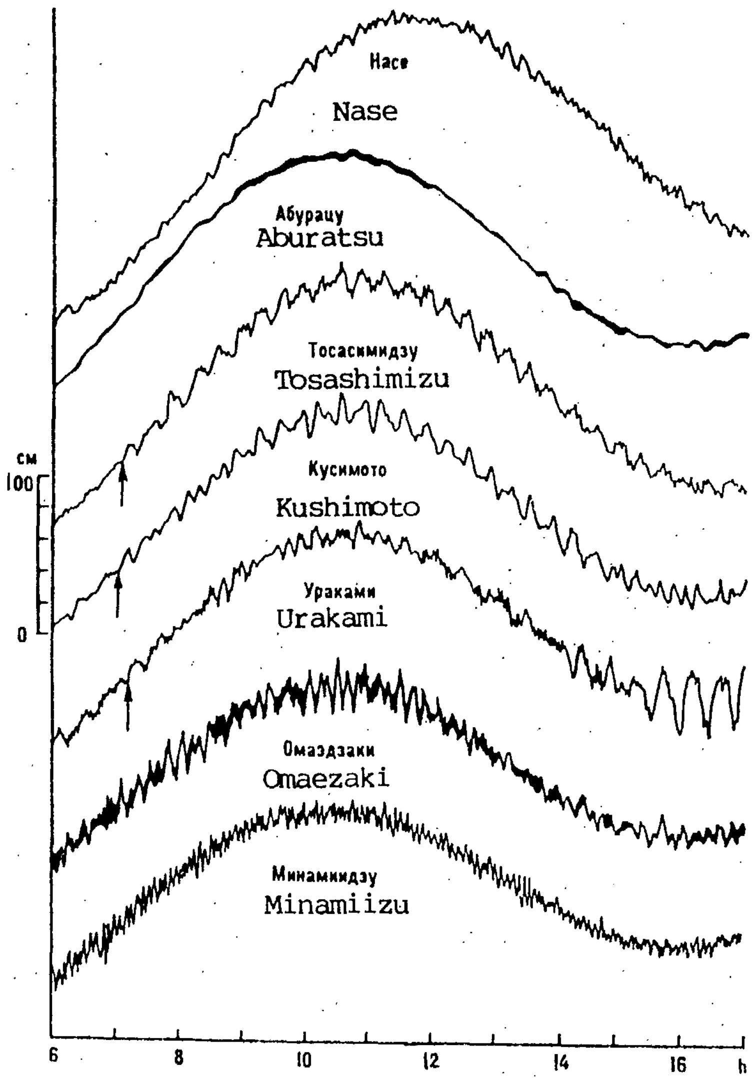

Fig. 101
Records of the tsunami
of 10.VIII.1968 in Japan
(Hatori, 1969c).

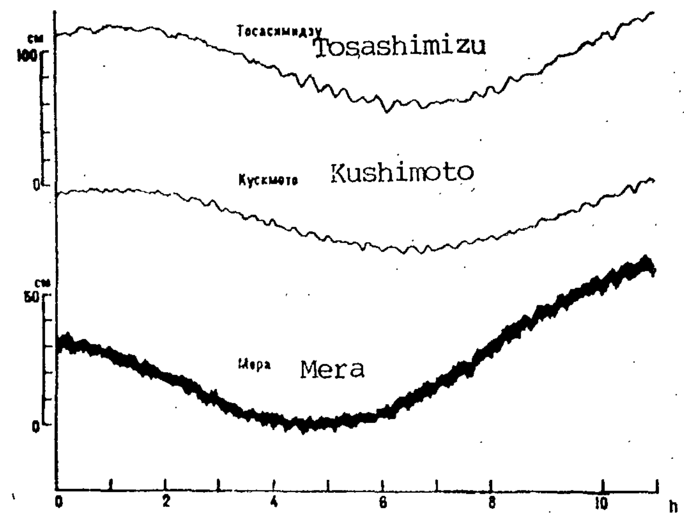

Fig. 102
Records of the tsunami
of 14.VIII.1968 in Japan
(Hatori, 1969c).

arose.

It was registered by tide gauges on the south coast of Japan (Fig. 101, Table 66), with a mean height of up to 14 cm and a maximal height of 40 cm at some capes. At this time the tide gauges on the eastern coast registered a swell 25-40 cm high, caused by a passing typhoon, and for this reason it is difficult to trace the tsunami on the records. The tsunami can hardly be detected on the records of the special automatic recorders set up on the islands of Enoshima (Miyagi Prefecture) and Oshima (off the Izu Peninsula), as well as of the portable tide gauge, temporarily in operation on Iwojima Island (Nampo Islands) (Hatori, 1969 c; Coffman, Cloud, 1970).

[10.VIII; $2^h07^m03^s$; 1.5° N., 126.2° E.; 25 km; M=7.8.]

1968, August 15, 6:14. There was a strong earthquake off the northwestern coast of Sulawesi Island. In the region of Manimbaha* Bay, between Tandjung*, Manimbaha* and Sabang, displacements along faults caused the coast to subside by 2-3 m. A destructive tsunami arose. According to the Indonesian Hydrographic Service, waves 9-10 m high fell on the coast in the region of Donggala; they penetrated 500 m inland. One hundred sixty people died, 40 people were lost and 58 were injured; 800 coastal homes were destroyed and large areas of coconut plantations were flooded. The villages of Tambu and Mapaga* suffered especially. /247

Tuguan Island, where several hundred people lived, was flooded by waves and partly subsided. A police launch, sent from the lighthouse on Mankalihat Cape, supposedly could not find any trace of the island or its inhabitants. According to other sources, Tuguan Island rose.

Slight traces of the tsunami are made out with difficulty on the records of the most sensitive tide gauges on the south coast of Japan (Fig. 102): Tosashimizu, Kushimoto and Mera (NL, 1968, vol. 1, No. 2; 1969, vol. II, No. 2; Hatori, 1969 c; Coffman, Cloud, 1970; Cox, 1970).

[14.VIII; $22^h14^m21^s$; 0.2° N., 119.8° E.; M=7.4.]

ISLANDS OF NEW GUINEA, NEW BRITAIN AND NEW IRELAND

1768, June 22, about 10:30. There were many shocks in Kambotoros Bay (Port Praslin), not far from Cape Saint George at the southern tip of New Ireland (Map X). The duration was about 2 minutes. Tremors were also felt on ships riding in the bay, and the sea rose and fell several times (Sieberg, 1910, 1932; Wichmann, 1918; Iida et al., 1967).

1857 (1856), April 17, immediately after sunset. There was a powerful tremor on Umboi Island (Rooke), in the passage between New Guinea and New Britain. A few seconds later, a second, stronger shock knocked down a stove. An icon fell and all the window panes broke. This was followed by more shocks, but of lesser force. In the morning it was found that large landslides had occurred; cracks 1 m wide had formed in the ground and extended from Nurua* village to the sea shore. West of Tolociwa Island (Lotten), a volcano supposedly rose from the water and smoked for a long time. After the tremor, the sea "began to move" (Perrey, 1864 a, 1865 a; Sieberg, 1910, 1932; Wichmann, 1918; Iida et al., 1967).

Between 1856 and 1858. The Miklucho-Maklay coast in Astrolabe Bay. According to local residents, the village of Aralu*, situated between the mouths of the Kabenau and Koli Rivers, was destroyed by an earthquake and a subsequent tidal wave. Since this happened at night, only a few men and two women could be saved. They founded a new village, and called it Gambu. A tsunami was observed in Irian Bay (Sieberg, 1910, 1932; Wichmann, 1918; Iida et al., 1967).

[Evidently, this is the same event as the preceding.]

1864, May (mistakenly June), on the night of the 22nd-23rd, about 0:30. There was an earthquake, lasting at least 3 minutes, in the region of Irian Bay. The shocks were so strong in the Dore district that most of the huts of local residents on shore were overturned at the Mausinam mission in the Manokwari region. A roar, like peals of thunder, accompanied the shocks. Huge collapses and landslides occurred in the mountains. At dawn, it could be seen that many mountain slopes had been completely denuded of vegetation and soil cover. The ground subsided at many places. Three shocks were noticed at Amberbaken. The earthquake must have been especially strong on Superiori Island.

Immediately after the earthquake, the sea at Mausinam rose three times to a height of 2 1/2 to 3 m (8 and 10 feet) above its usual level and washed away all the local settlements on shore; 250 people died.

The shocks, accompanied by a rumble, continued at short intervals, right up to the 24th. After the 25th, the shocks resumed but with lesser force (Perrey, 1870 a; Sieberg, 1910, 1932; Wichmann, 1922; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967; Cox, 1970).

1873. ("A few months after 24.XII.1872.") When Miklucho-Maklay landed in New Guinea for the second time on 27.VI.1876, he noticed great changes in the landscape. The Finisterre Range had lost its rich foliage in places. In many places on the coast, solitary maimed tree trunks remained in place of the dense forest, particularly in the mouths of the Kamrau*, Koli, and Kabenau Rivers and on Cape Gabina.

According to local residents, one night there was an earthquake, consisting of several shocks, and the huts crumbled. The mountain settlements of Englam-Mana*, Sambal-Mana* and Saguana-Mana* suffered especially. Somewhat later, at dawn, strong waves fell on shore, and /249 destroyed the forest in many places. It washed up pebbles on shore in such amounts that not a few rivers were dammed. High flood tides an a heavy surf were still noticed at sea during the whole of the next day.

On visiting the mountain villages, he found numerous yawning cracks in the ground running north-south. The blockage of the mouths of the rivers entailed a change in their channels, while the subsidence of some parts of the coast led to the formation of numerous lagoons and swamps (Miklucho-Maklay, 1878; Miclukho-Maclay, 1885; Sieberg, 1910, 1932; Wichmann, 1922; Miklukho-Maklai, 1950, 1952 a,b; Iida *et al.*, 1967).

1878, February, on the night of the 3rd-4th. There was a very strong earthquake along the coast of Blanche Bay, including at Rabaul. It was barely felt on the Duke of York Islands (30 km east of Rabaul). The earthquake was accompanied by two tsunami waves, which washed out a large section of the coast of Matupi Island (according to other sources, the earthquake occurred two days before the tsunami).

Soon after the earthquake, clouds of steam could be seen rising out of the water along the line joining the Raluan Volcano and the Tawurwur (Ghaie) Volcano. An hour later, the old crater of the Ghaie Volcano exploded with "terrible force." Flames and enormous masses of smoke and ashes were ejected. There were apparently no lava flows. A thick layer of ash and pumice covered the coast and Saint George's Channel. At Ghaie, a new cone was formed. At the site of the underwater eruption, a cone-shaped, but rather flat elevation 20 m high formed out of loose material. This later became Raluan (Baluan) Island. The eruption of the Raluan Volcano lasted three days, during which time total darkness reigned; fishes and turtles died. The eruption of the Ghaie Volcano lasted three weeks. Due to the prevailing northwest winds, the ejecta settled mainly in the sea, and on land only the regions immediately adjoining the volcanoes suffered. Blanche Bay and Saint George's Channel were plugged up with islands of floating pumice for a month (Anon., 1900; Sieberg, 1910; Sapper, 1927; Klein, 1938; Fisher, 1939 a; Heck, 1947; Ponyavin, 1965; Iida *et al.*, 1967).

1888, March 13, early morning. The Sakar (Ritter) Volcano exploded. The cone of this volcano formed the island of the same name and had a height of 790 m above the water. The bulk of the volcanic structure flew into the air; only the eastern third of the cone remained in the form of a slope 120 m high, arc-shaped in plan, with steep inner and outer walls. In place of the part of the volcano which disappeared, depths formed with marks of more than 100 m. The total mass of ejecta was estimated at 1 3/4 km^3.

The explosion generated an enormous tidal wave, which was observed along the coast of New Guinea from Hatzfeldt Bay to Cape Huon (Salamoa Harbor), and along the entire coast of New Britain, including Rabaul. Many residents from the coastal villages of Umboi Island died in the flooding; villages on the north coast of the island were apparently in general washed away. No earthquake was recorded.

On the night of March 12 to 13, a small German expedition headed by Von Belov and Hunstein was situated on the western coast of New Britain Island, on a narrow beach at a steep cliff. The expedition was apparently washed away by tsunami waves, since two special groups sent to search could not find any traces of it, except for tent pegs. From marks left on the coastal slopes, the rise of water has been estimated at 12 m. In places, it passed 1 km inland. The dense forest in the flood zone was completely destroyed, and the coast was washed over with sand and littered with tree trunks, bits of coral reef and dead fish; the thickness of the layer of detritus was 1.2 m (4 feet). The coast was substantially eroded in places.

The waves approached the Kelanoa Plantation, which had just been established in the region of Cape King William, from the northeast at 6:30. The first tidal wave travelled 7 1/2 m (25 feet) on land [apparently, this still refers to the rise of water along the vertical], while the fourth wave, which was the greatest of the 20 waves observed, travelled 10 1/2 m (35 feet). The whole phenomenon was observed for an hour; the wave period was 3 minutes. No unusual phenomena were observed subsequently, but on the morning of the 14th, the coast and the entire surface of the sea were covered with bits of pumice. /250

In Hatzfeldt Bay, on the 13th immediately after 6:00, the sound of shots was heard from the north-northeast. At 6:40, there was a surprisingly high flood tide, which came from the north and rose 2 m (6 feet) above the highest high tide mark. The water surged back exceptionally quickly, so that the harbor half dried up. Alternating floods and ebbs continued until 9:00 at 3-4 minute intervals. At 8:00, the height of a tidal wave reached 7-8 m (23-26 feet); the population was in serious danger. Before noon, the oscillations gradually abated, although the water still rose and fell continuously; the original level was restored only by 18:00.

On Matupi Island, from 8:15 to 11:00, the water retreated 3 1/2 - 4 1/2 m (12-15 feet) beyond the lowest low tide mark several times and then flooded the land to the same distance beyond the highest high tide mark (according to other sources, the level rose and fell 3 m (10 feet) past the usual flood and ebb marks). The oscillations in level were most substantial on the southeastern and northern coasts of the island, and they were almost non-existent on its western coast. The waves, it appeared, came partly from the south, and partly from the west-northwest.

The movements apparently affected the entire layer of water, since the water was turbid and was covered with dirty foam. No underground shocks or rumble was noticed; the weather was good. Similar oscillations in sea level were noticed on a steamship riding off the southern coast of the Gazelle Peninsula.

According to the journal "Nature," the record of the tide gauge at Sydney on March 15, 16 and 17 showed strange deviations from the regular shape of flood tides. These can apparently be considered as a tsunami.

According to newspaper reports, a small wave was observed at Arica (Chile) on March 14, at about 17:00, far at sea. It grew rapidly as it approached the shore and broke on the breakwater with great force. Soon another three large waves followed one after another. Many of the ships which were unloading were smashed and some capsized. The sea was so unsteady for a long time that it was only possible to unload the ships with great difficulty. A strong swell was observed for a long time off the island which screened the harbor (Anon., 1888, 1900; Sieberg, 1910, 1932; Krümmel, 1911; Klein, 1938; Fischer, 1939 a,b, 1957; Heck, 1947; Ponyavin, 1965; Iida *et al.*, 1967).

1888, May 20. Apparently, this is a mistaken date (Detaille, 1889) for the eruption and tsunami of 13.III.1888.

1899. On the eastern coast of New Ireland, there was an earthquake and a destructive tsunami which destroyed many huts on the coast. Waves were also observed in Albatros Strait between New Ireland and Bandissin Island (Sieberg, 1910, 1932; Iida *et al.*, 1967).

[It is possible that these data relate to the earthquake of 19.X.1899, at 9^h16^m, which was registered by seismic stations in the region of New Britain (Milne, 1912 a).]

1900, September 11. There was a heavy earthquake somewhere, with serious destruction of structures on the Gazelle Peninsula. There were slumps along the shores of Blanche Bay. There was a tsunami (Sieberg, 1910, 1932; Iida *et al.*, 1967).

[Apparently, this report refers to the events of 18.IX.1900.]

1900, September 18, after 8:00. At Rabaul, there was a strong earthquake lasting 40 seconds; many objects were smashed, but homes did not suffer. It was felt at Kokopo (Herbertshoe). It was registered by the seismograph at Djakarta (Batavia). There were aftershocks.

The water began to oscillate in Rabaul harbour. This continued until 10:30. According to the captain of a ship riding in the bay, the depth of the water decreased from 12 m (40 feet) to 6 m (19 feet) when the level fell (Anon., 1902; Milne, 1912 a). /251

Milne (1912 a): 17.IX; 21^h45^m; 5° S., 148° E.

1900, October 8, 6:00-7:00. There was an earthquake and a seaquake in the region of Wandammen Bay lasting 15 seconds. There were many aftershocks; it was registered by the seismograph at Djakarta (Batavia).

It was accompanied by tsunami waves. At Napan settlement, one home was washed away and tossed onto a hill and five people died, but for the rest, the damage was minor. The tsunami did not do any harm at Windessi (Anon., 1902).

Milne (1912 a): 7.X; 21^h00^m; 0° latitude, 130° E.

Richter (1963): 7.X; 21^h04^m; 4° S., 140° E.; M=7.8.

[The instrumental data on the earthquake are in poor agreement with the macroseismic data.]

1906, September 15, 1:30. There was an earthquake with source near the Huon Peninsula. It was registered all over the globe. It began with light oscillations, which rapidly intensified and lasted about a minute. The main earthquake was followed by countless weaker shocks, which occurred at intervals of a few minutes. It was especially strong in the coastal mountains from Cape Hardenberghuk in the north to the Lugaueng Mountains in the south and for 20 km inland, and also on the western coast of New Britain. Here, frequent yawning cracks opened up everywhere in the ground; numerous and extensive slumps, landslides and rock falls occurred, which completely changed the appearance of the locale from [Cape?] Festunghuk to [Mount?] Sattelberg, and especially in the valley of the Bussim River. Several (from 10-20 to 100) local inhabitants were buried. Their custom of settling on the steep slopes as being the safest places in the frequent sudden attacks by their enemies, contributed to the fatalities.

All the channels were buried under piles of earth for several weeks. Then torrential rains washed them out, and an enormous amount of forest was carried out to sea. According to Sieberg's estimates, the force of tremors was 9 degrees at Wareo, since all the structures here suffered serious destruction, and a just completed home was ripped from its piles and shifted 90 cm; all the stoves were destroyed, and reservoirs filled with water were torn from their foundations and flattened. The tremors had a force of 10 degrees, according to his estimates, at Sattelberg and Lugaueng. At Sattelberg, a very old home with weak foundations was torn from its piles and displaced 2 m, and the church sank so much to one side that it had to be pulled down. At Lugaueng, trees were broken. The oscillations were only a little weaker in the region of Finschhafen Bay. In fact, on Madang Island, two old dilapidated homes were ripped from rotten piles and displaced 1-2 m. At Pola*, unsecured objects fell to the ground in all the homes, palm trees were bent almost to the ground, and people were unable to move. Similar effects - the collapse of stoves, the tilting of homes, the falling of cupboards and shelves - were reported from all coastal points.

The pleistoseismic zone of the earthquake, according to Hall, who investigated the effects of the earthquake at the beginning of February, extended from Cape King William to Cape Cretin; on land, its boundary apparently passed between Sattelberg and Nanson Mountain*. Changes in relief also occurred, as has already been mentioned, on the western coast of New Britain; a landslide was seen on the slopes of Mount Hunstein which apparently destroyed the underlying village.

At Bulesoma, Deinzerhoe and on Cape Arcona, Sieberg estimates the force of tremors at 5 degrees. A landslide was reported at the mouth of the Markham River between Cape Arcona and Huon Gulf (the Preusen Reede). On Tami Island, the tremors had a force of about 4 degrees, while they were apparently even weaker on the Siassi Islands and Umboi Island (Rooke). At the same time, the earthquake was strong in Astrolabe Bay and it was noticed at Potsdamhafen.

The tidal waves which arose were observed along the entire coast from Heldsbuch on the north to Busega in Huon Gulf, and also on the islands of Tami, Siassi* and Umboi. According to observations at Finsh Harbor, about 15 minutes after the earthquake, the sea "began to rumble" and a large roller surged in, as a result of which the water level rose 1.2-1.5 m above the flood tide mark. The lowlying part of the coast was flooded, and the dike between the land and Madang Island, which was built of large coral blocks, was washed out. "Freezing" for 1/2 minute, the flood tide receded just as quickly and unexpectedly as it had appeared and the subsequent ebb tide was a good 1 1/2 m lower than the strongest equinoctial ebb tides. The flood tide recurred many times, but an unusually low level of the sea in general obtained until 10:00. Only after that did the water again return slowly to its normal level. The inhabitants of the villages on the islands escaped to "the big land" from the oncoming flood tide and dared to return to their homes only many days later. According to a missionary, on Umboi Island, the water retreated from shore, but no tidal waves were observed (Montessus de Ballore, 1907; Sieberg, 1910, 1932; Krummel, 1911; Heck, 1947; Ponyavin, 1965; Iida *et. al.*, 1967). /252

Gutenberg, Richter (1954): 14.IX; $16^h04.3^m$; 7° S., 149° E.; M=8.1.

1906, October 2, 11:35. The strongest aftershock of the preceding earthquake occurred. It affected an enormous area, at least from Buna to Astrolabe Bay. In Finsh Harbor, the force of tremors was 7-8 degrees (VIII-IX Rossi-Forel). At Buna, the earthquake lasted 3 minutes and caused some destruction. This earthquake was again followed by tidal waves, which lasted a little less than 2 hours in Finsh Harbor. The harbor dried up almost completely. Although the water level rose only 1 m above the normal mark, the movement of the water was much stronger than it had been a month ago (Sieberg, 1910;, 1932; Scheu, 1911; Milne, 1912 a, 1913 b; Iida *et al.*, 1967).

[2.X; 1^h55^m; 6° S., 148° E.; M=7.2.]

1910, February, on the night of the 24th to the 25th. A strong earthquake occurred in Matupi Harbour (Rabaul). It began with an abrupt shock lasting 4 seconds. A second shock, lasting 6 seconds, occurred a minute later. Another seven shocks were registered between 0:52 and 0:57. The shocks were exceptionally strong on the coast: lamps, pictures, dishes, etc., fell to the floor in homes. Immediately after the first shock, a comparatively strong swell appeared from the southeast (Sieberg, 1910; Fisher, 1939 a).

1911, May 8. There was a strong earthquake on the coast of Blanche Bay and on Matupi Island. There was a large number of separate shocks in the following hours. There was a tsunami (Sieberg, 1932; Iida et al.,1967).

1913, October 11. There was an earthquake with source near New Guinea. There are no data on the effects of the tsunami near the source, but at the appropriate time, a tsunami with an amplitude of 10 cm and a period of 17 minutes was registered by the tide gauge at Honolulu (Heck, 1947; Shepard et al., 1950; Anon., 1961; Iida et al., 1967).

[11.X; $4^h06^m03^s$; 7° S., 148° E.; M=7.]

1914, May 26, 23:00. There was an earthquake with source in the region of Irian Bay. All brick buildings collapsed on Japen Island. Ansus and Pom suffered from a tidal wave. There were many victims, and many aftershocks were registered. Strong horizontal tremors were felt at Ende. The first of them was very prolonged and strong; a roar like peals of thunder or cannon shots was heard. At that same time, three large sea waves were observed. Arising at ebb tide, they reached the flood tide line. Weak undulating tremors were felt at Bandaneira. The tsunami was registered by the tide gauge at Honolulu (Anon., 1916; Heck., 1934, 1947; Shepard et al., 1950; Anon., 1961; Soetadi, 1962; Ponyavin, 1965; Iida et al., 1967; Berninghausen, 1969).

Gutenberg, Richter (1954): 26.V; $14^h22.7^m$; 2° S., 137° E.; M=7.9.

1914, July 26, 23:00. There were strong horizontal tremors at Ende. There was a rumbling like artillery fire or thunder. There were weak oscillations at Ambon. There were aftershocks. At Ende, three /253
large waves appeared during the first tremor. These waves, which appeared during the ebb tide, reached the flood tide level. This recurred twice (Anon., 1916). [Most likely, the date has been confused and the matter relates to the events of 26.V.1914].

1915, November 6, 19:00. There were rather strong horizontal shocks lasting 15 seconds at Korim. A high sea level was observed on the following days. A shock lasting 3 seconds was felt at Serui (Anon., 1917).

1916, January (mistakenly December) 1, 23:28. There was a very strong earthquake at Rabaul. It was accompanied by several recurrent shocks. Homes were shifted from place, cisterns rolled and cracks appeared in the ground. The dike connecting Matupi Island with the Gazelle Peninsula subsided 1.8-4.5 m (6-15 feet) and was completely hidden under water. Several homes collapsed in the region of Toma (see Fig. 103).

The water level in Rabaul Harbor fell 4 1/2 m (15 feet) in a few seconds. Then it rose again with "terrifying" speed. The small steamship "Siar" was tossed by the wave from Rabaul Harbor to Matupi Harbor (Fischer, 1939 a).

Gutenberg, Richter (1954): 1.I; $13^{h}20.6^{m}$; 4° S., 154° E.; M=7.75.

[The instrumental data on the earthquake do not agree fully with the macroseismic data.]

<u>1919, May 7</u>. There was an earthquake and tsunami at Rabaul. The first shock occurred at 5:40 and preceded a stronger prolonged earthquake (or series of shocks). The earth's surface oscillated in the "most terrifying way," trees swayed, cracks appeared in the ground, and considerable damage was done to structures. Wooden bungalows rocked in every direction; in the barracks, the rifles fell out of their piles; the sleeping soldiers were thrown out of their bunks which collapsed on top of them.

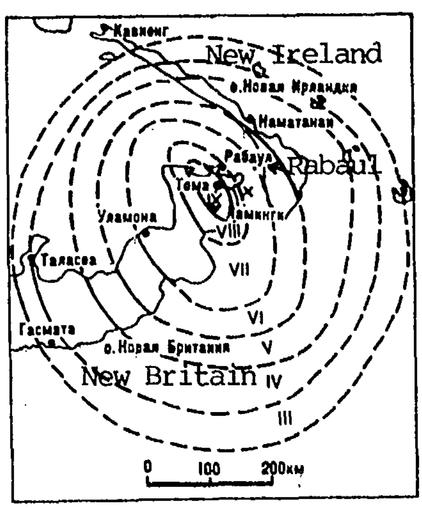

Fig. 103

Epicenter and isoseismals of the earthquake of 14.I.1941 on the Rossi-Forel Scale (Fisher, 1944).

The earthquake was very strong beyond Rabaul on Namanula Mountain. The seat of government was on the peak of this mountain. Two parts of the building, separated by a wide passage, oscillated towards each other so that people on the veranda felt just as if they were being rocked heavily at sea. In all the bungalows, the furniture shifted and many glass and glazed dishes were broken. When the earthquake was over, most of the homes built on the hill presented an unusual spectacle, since their support pillars were inclined to the ground at every possible angle. A heavy 4500-litre tank was shifted like a toy, and the government press building was completely destroyed.

As a result of the earthquake, the submerged dike which connects the Gazelle Peninsula with Matupi Island rose 1/2-1 m (2-3 feet). The roads suffered considerably. Thus, the excavations through which the road from Rabaul to Namanula passed, were completely filled in at many places by collapses of hills. At other places, stretches of this road which ran along hillsides, themselves slid down into the valleys.

The earthquake was accompanied by an intensification of the activity of the sulfur springs at the foot of the Tawurwur Volcano and on Matupi Island. Greenish vapors from the springs spread over the sea to a height of about 30 m.

Despite the great material damage, there was not a single victim. This is partly explained by the fact that the earthquake occurred when the majority of inhabitants were outside their homes, and partly by the fact that the local huts were constructed on tall columns, that is, they had a primitive, earthquake resistant construction. For almost two weeks after the earthquake, not a day passed without several weak shocks.

After the earthquake, the water at the pier at Rabaul fell 2-2 1/2 m (6-8 feet) and rose again quickly. Thousands of fish were left on shore above the high high tide mark. A noticeable tsunami was observed at Kokopo, where the vessel "Nuza"* was forced to hurry to open sea to avoid running aground. The waves lifted up and ran a large whaler against the moorage and then retreated so far that the bottom of the /254
harbour was completely dry for some time (Johnston, 1920; Turner, 1922; Fischer, 1939 a).

Gutenberg, Richter (1954): 6.V; $19^h41^m12^s$; 5°? S., 154°? E.; M=7.9.

[The instrumental data do not fully agree with the macroseismic data.]

1919, November 21. There was a 7-8 degree earthquake at Sukarnapura (Hollandia) city. A tsunami occurred during low water (Anon., 1920).

1930, December 24. The radiotelegraph station on the eastern part of New Guinea broadcast that, according to a report from the "Duris"* steamship, on December 24, 1930, the Western Islets were hit by a destructive earthquake.

The waves flooded the land to a height of 2 1/2 m (8 feet). Homes and cattle were washed away on Awin Island. The newspapers also reported that one European and many local residents escaped by scrambling up the palm trees. No reports of a tsunami were received from Indonesia. One letter mentions that at Sydney the tide gauge registered a distinct group of waves on December 24. The first indisputable oscillation occurred at 18:00, and the oscillations continued for 7 hours (SN, 1931, vol. 21, No. 1; Van Dijk, 1932).

ISS: 23.XII; $21^h35^m36^s$; 1.3° S., 144.3° E. [M=5 3/4 ± 1/4].

1931, January. A large tsunami was reported in New Guinea (Burkey, 1931). [Apparently, this concerns the tsunami of 24.XII.1930.]

1937, May 28/29. There was an eruption of the Raluan and Tawurwur Volcanoes in Blanche Bay. The eruption was accompanied at different stages by oscillations of the water level in the bay.

The first strong earthquake struck on May 28 at about 13:20. It lasted half a minute and reached a force of 7 degrees (VIII Rossi-Forel). Slumps occurred in the region of the road to Kokopo. The surface of the ground cracked on the southwest of Raluan Island and a cliff disappeared on the west bank of the lagoon on this island. Buildings suffered at Keravia, but the damage was slight at Rabaul.

The intensity of the earthquake rapidly decreased with distance from Blanche Bay. It was weak at Kokopo, Malabunga and Keravat and was not felt at all near the Warangoi River (region from Lamingi to Toma, see Fig. 103).

Tremors were felt almost continuously until the morning of the following day at Rapindik, Keravia and Talillgap, but it was quiet at Rabaul.

At about 14:00, the water in Rabaul Harbor quietly retreated 90 m (100 yards) from shore and then returned to its usual boundary. On Raluan Island, the water also retreated slowly, then flooded the shore to 140 m (150 yards) beyond the high high tide line, after which it returned to its usual mark, leaving many fish on shore. In Keravia Bay, at about 13:30, the water flooded a road, rising 1 1/2-2 m (6 feet or thereabouts) above the usual level.

On May 29, at about 5:30, a new shock was felt at Rabaul. It was strong enough to awaken sleepers and to knock down bottles, pictures, etc. It was followed by a continuous series of shocks of different intensity which lasted right up until the eruption of the volcano. During the calm between strong shocks, regular rocking of the ground occurred. Especially strong shocks were observed about 10:00. During the entire morning, it was impossible to write. As a result of the shocks, further avalanches occurred in the region of the road to Kokopo, cement floors cracked at Rapindik, reservoirs sprang leaks, and yawning crevices opened up in the ground on Matupi Island.

Between 8:00 and 9:00, an elevation of Raluan Island was observed. It was especially strong in the passage between the island and the westward lying coast, where several small islands appeared from under the water.

At 11:00, it was noticed that the reef south of Matupi Island had become exposed. This had never happened before.

At 13:10, the water off the west coast of Raluan Island became turbid and rough. At about the same time, the reef here dried up; the reef was hidden under water at 13:15, but it came to the surface again at 13:20. During the day, many residents collected fish on the reefs, and about 20 of these people died during the eruption.

The eruption of the volcano began at 16:15. The island and the /255 adjacent sections of bottom began to rise quickly; the little islands in the passage began to grow and merge, and soon a broad isthmus formed between the island and the mainland. Then the volcano exploded, and a black pillar of ash and steam 9 m wide and 12 m high rose into the air. The column grew with each subsequent explosion, and reached a height of 3 km. Masses of flames the size of a room or smaller flew up to a height of 1 1/2 km and then fell to the earth or into the water with a deafening noise. There were no lava flows.

The eruption of the volcano lasted more than twenty-four hours. According to rough estimates, it ejected 0.3 km^3 of material, which spread in the form of ash, mainly to the northwest of the volcano due to the prevailing southeast winds; 60,000,000 m^3 of fresh material was deposited immediately around the volcano under water and 190,000,000 m^3 was deposited above the water level. The height of the island increased from 9 to 200 m. Fields of pumice and ash 1/2 m thick floated in the bay.

The eruption of the Tawurwur Volcano began on May 30, after 13:00. The eruption lasted until the morning of the following day; about 2,300,000 m^3 of material was ejected. It also settled to the northwest of the volcano, that is, in the region of Rabaul, where the layer of ash was several centimetres thick.

During the first explosions of the Raluan Volcano, the underground shocks for the most part stopped. The water near Raluan Island was markedly agitated. At Rabaul, the water retreated 45 m (50 yards) several times, returned to the high high tide mark, and retreated again. Then the eruption was almost continuous for 3 hours, but there were no noticeable oscillations in level.

Beginning at 19:00, the eruption began to pulsate, and periods of explosions began to alternate with periods of relative calm. It was precisely during such a period of calm and before 21:00, that is, before the lip of the new crater of the volcano had completely risen above the water, that considerable oscillations in level were observed in the harbor. Four to five minutes passed between the rise and fall of the water. The amplitude of at least three of these waves was 2-2 1/2 m (7-8 feet) above and below the mean water level. A schooner was run aground by the wave onto a small pier and then dragged to the depths of the bay together with the pier. Several boats ran aground, and one or two sank. Subsequently, the oscillations apparently diminished, but their range was still 1/2 m (2 feet) early in the morning on the 30th.

During the eruption, more than 500 people perished, including those who drowned. At Rabaul, two homes and several small ships were destroyed in the rock and ash fall. After the earthquake and eruptions, a stretch of coast from Sulphur Creek to Matupi Island subsided. The dike joining this island with the mainland subsided 1 m (3 feet) (SN, 1937, vol. 27, No. 3; Klein, 1938; Rothé, 1938; Fisher, 1939 a, 1957).

1941, January 14, 2:28. The strongest earthquake since 1916 occurred on the Gazelle Peninsula. It was accompanied by a thunderous roar. Its effects were investigated from the air and by land surveys and by questionnaires sent out by N. Fisher (Fig. 103).

At Rabaul, strong tremors lasted 2-3 minutes. According to some eyewitnesses, they were preceded by not very strong, nor very prolonged oscillations, but since it was night, it was difficult to establish the nature of the beginning of the oscillations.

The belt of the strongest tremors cut across the peninsula from Ataliklikun Bay in a southeastern direction, on the whole coinciding with the corresponding diagonal trough. At Lamingi, at the upper reaches of the Warangoi River, and at other places in the watershed southwest of the trough, numerous avalanches, collapses, and swellings occurred, mainly in loose weathered volcanic formations and on steep slopes. Many streams were backed up by the resulting dams. In one of the small valleys, a loose layer measuring 400 X 500 m came down from the slope, baring the rocks to a height of 100 m; the resulting dam had a length of 400 m, a width of 14 m and a thickness of 12 m three weeks after the earthquake. /256
After the earthquake, the dams burst; three children died in the resulting streams of water and mud in the Warangoi Valley.

Numerous cracks appeared in the surface of the ground in the Warangoi Valley. Here and there, mainly at places with a high ground water level, there were water, mud and sand gryphons. A number of new springs appeared which, however, soon dried up.

The cracking of the ground was caused both by its compaction, and probably by tectonic dislocations of the buried crystalline base. According to Fisher, the system of faults revived by the earthquake extended in a southeastern direction; the southwestern flank of the system apparently subsided, while the northeastern flank rose. This is indicated by the subsidence, by about 1 m, of the western section of the coast of Ataliklikun Bay, and by the slowing down somewhat of the streams to the northeast of the assumed fault line.

In the pleistoseismic zone, 15 European homes and a large number of huts of local residents were seriously damaged. However, only one old wooden frame home collapsed completely, while the others were simply shifted off their foundations, to which they were not firmly attached, and which themselves were weak. In addition, some homes rested on piles which stood unsecured on the ground. A child was killed by a falling beam in one of the homes.

Everywhere, reservoirs with water, especially those standing on high props, were smashed or burst in the regions of Rabaul, Kokopo and Beinings*. Everywhere, dishes, furniture, etc. were overturned and smashed. In Blanche Bay and on North Coast, many stretches of steep shores, made up of loose material, deposited, in particular, during the volcanic eruptions of 1937, went under water.

The earthquake was felt in the eastern half of New Britain, over almost all of New Ireland and on the adjacent islands. At Ulamona and Namatanai, the tremors were moderate in force and not as prolonged as at Rabaul; at Talasea and Gasmata, they were weak, while the earthquake was not felt at all at Kavieng and on the Arawe Islands*. The high-point isoseismals, in Fisher's opinion, were somewhat extended in a north-western direction.

The tilt meters installed a month before the earthquake at the Rabaul volcanological observatory registered a marked intensification in the rate of tilts, which stopped immediately after the shock. For several hours after the earthquake, aftershocks up to 5 degrees in intensity were felt at intervals of a few minutes. The frequency and force of the aftershocks then began to abate gradually, but they continued for more than a month.

The earthquake generated oscillations of the seiche type with a maximal range of 30 cm, periods of about 30 and 8 minutes and a duration of at least 4 1/2 hours in Blanche Bay. These oscillations were registered by the tide gauge at Rabaul (Fig. 104). Off North Coast and in the region of Beining*, according to visual observations, the water slowly retreated from shore, exposing the reefs to a considerable depth, and then surged back again, submerging them (Fisher, 1944). /257

Gutenberg, Richter (1954): 13.I; $16^h27^m38^s$; 4.5° S., 152.5° E.; M=7.3.

1949, October 20. A tsunami, generated by an earthquake, was registered on two tide gauges. At Rabaul, the maximal range of the oscillations was about 0.6 m (2 feet). A very small wave about 3 cm (0.1 foot) in height was registered at Dreger Harbor (New Guinea) (Murphy, Ulrich, 1951 b; Hamamatsu, 1966; Iida et al., 1967).

Gutenberg, Richter (1954): 19.X; $21^h00^m19^s$; 5.5° S., 154° E.; 60 km; M=7.25.

1953, April 24. There was an earthquake in New Britain.

Structures were damaged and fractures formed in the ground. There was a tsunami, which according to press reports, spread to the Hawaiian Islands (ISS; Rothé, 1955; Anon., 1961; Hamamatsu, 1966; Iida et al., 1967).

[23.IV; $16^h24^m22^s$; 4.5° S., 153.3° E.; M=7.4.]

1953, June 27. A clearly audible noise heralded an underwater eruption in Saint Andrew Channel. Soon afterwards, puffs of smoke became visible as they rose above the water surface at a point 2/3 of the way from Baluan Island to Lou Island. A small tsunami arose, which did only slight damage to a number of canoes on Pom-Mandrian Island. This was the extent of the losses caused by the eruption.

The preliminary seismic activity was so negligible in intensity, that the shocks passed unnoticed by the population of the surrounding islands. During the eruption, seismic activity perceptible without instruments was also negligible, both with regard to the intensity of shocks, as well as their frequency. The correlation between the tremors and the explosions in the crater was obvious (Best, 1956).

1960, June 12, 2:38. There was an earthquake which was felt on Murua Island (Woodlark). There were numerous aftershocks for many weeks. There were many small tsunamis on the southeastern coast of the island (Rothé, 1962).

[11.VI; $16^h37^m45^s$; 9° S., 152.5° E.; M=7.]

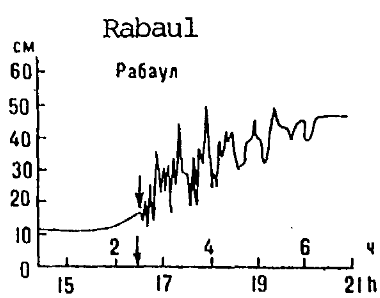

Fig. 104
Record of oscillations in water level in Rabaul Harbor caused by the earthquake of 14.I.1941 (Fisher, 1944).

SOLOMON ISLANDS, SANTA CRUZ, NEW HEBRIDES

1863, August 17. There was a weak underground shock, which passed almost unnoticed, at Nouméa (Port de France) in New Caledonia (Map XI) on the 15th at 19:30. There was a more perceptible shock on the 17th at 20:00. It considerably disturbed the instruments at the astronomical observatory. The cross lines of the tubes of the transit instrument after the shock experienced spasmodic oscillations which were larger north-south than east-west.

Then came news that the shocks may have been connected with an eruption of the volcano on Tanna Island. The news was delivered to the Vagap post office by a small English schooner, which had been situated near the volcano at the time of the eruption. According to the captain, lava covered half the island, causing numerous victims among the population.

Another schooner, the "Ariel," which had been situated off neighboring Eromanga Island, brought a report on passing Port de France on August 26, that the shock of August 17 was felt on Eromanga Island with great force and was accompanied by an unusual movement of the sea. A large wave made the schooner "dance" on its anchors, putting it in extreme danger. This wave must have done great damage on land, but the captain could not give any information about this, since they did not land. At this time, there were no Europeans on the New Hebrides, and no written reports could be received from the islands about the earthquake and volcanic eruption.

According to the director of the astronomic observatory at Port de France, the earthquake of August 17 on New Caledonia was felt most strongly at Kanala and Vagap. No oscillations in sea level were noticed on the coast of New Caledonia (Perrey, 1865 a; Krummel, 1911).

1875, March 28. There was an earthquake on Lifou Island, the largest of the Loyalty (Loyauté) Islands. The shocks weakened on the next day, but intensified again on the 30th. Many settlements were damaged. A high wave which followed the earthquake washed away three settlements, and their residents for the most part perished. Off Aneityum Island, two sand banks more than 4 m high on the outer side of a reef were washed away; they later reformed. The wave flooded a number of other low-lying islands of the archipelago (Fuchs, 1876, 1885 b; Bourge, 1906; Milne, 1912 b; Sieberg, 1932; Heck, 1947; Anon., 1961; Ponyavin, 1965; Iida *et al.*, 1967).

1875, May 10. On Eromanga Island, following the earthquake, there were waves on the coast, which rolled stones back and forth (Rudolph, 1895; Iida *et al.*, 1967).

1878, January 10, 10:00. There was a strong earthquake on Tanna Island; the subsequent tremors lasted four weeks. A new pit or crater formed near the "sulphur bay" [in Sapper's unlikely opinion, this was the result of a volcanic explosion]. Two minutes [?] later, the coast rose 6 m (20 feet) along the entire western side of Resolution Harbor. The anchorages in the bay were correspondingly restricted; at one place, where ships with a displacement of 1000-1500 tons used to ride freely, an old sunken anchor became visible.

The earthquake generated a roller 12 m (40 feet) high, or 15-17 m high, according to other sources, which inundated the eastern tip of the harbor and destroyed all the canoes of the local residents and all the plantations. When the water surged back, many fish were left in the bushes (Fuchs, 1885 b; Davillé, 1894; Bourge, 1906; Milne, 1912 b; Sapper, 1927; Davis, 1928; Sieberg, 1932; Heck, 1934, 1947; Rue, 1937; Ponyavin, 1965; Iida *et al.*, 1967). /259

1878, February 11. There was an even stronger earthquake on Tanna Island with the formation of a large sea wave.

The hydrography of the port changed. One of the cliffs, Cook's Pyramid, rose 12 m and joined up with the surrounding blocks. On the other hand, one of the high hills collapsed into the sea, forming a new cape. According to Sapper, the volcano began to erupt on February 9 until the 11th (Fuchs, 1885 b; Bourge, 1906; Milne, 1912 b; Sapper, 1927; Davis, 1928; Heck, 1934, 1947; Ponyavin, 1965; Iida *et al.*, 1967).

1878, August. A third earthquake again changed the relief of Resolution Port, raising the bottom of the harbor above the water level on a 30 m stretch of the western shore (Bourge, 1906) [nothing is reported about a tsunami].

1892, August, first week [no date], about 0:20. At Luganville (Espiritu Santo Island), there was a very strong shock. At about this time, an eyewitness, Davillé, who was sleeping on the top deck of a small schooner, abeam of Requin, suddenly woke up and saw that a gigantic foaming roller had suddenly appeared on the hitherto calm sea surface and was advancing on the schooner from the south to north. Davillé had barely time to grab onto the first ledge to come to hand, when the roller reached the ship in a few seconds, lifted it up in a single blow and set it down on its side, with a dangerous list, rapidly turned the ship onto its opposite side, made several more steep slopes and rushed on. The weather was calm, with a mild south-eastern breeze (Davillé, 1894).

1893, July 31, 11:30. There was a strong, very rapid shock at Port Vila (Efate Island). The weather was bad, and it was raining with strong gusts of wind. There was a heavy swell at sea (Davillé, 1894).

1893, August 27. A wave crossed Port Vila Bay (Efate Island). It reached the shops and the café of the French merchant company. Immediately after, there was a prolonged tremor of slight intensity, which seemed to come from the north (Davillé, 1894). [A possible explanation is seiches from a distant strong earthquake.]

1920, September 21. There was an earthquake with source off the New Hebrides Islands. The tsunami which arose was registered at Apia (Samoa Islands) 4 hours and 28 minutes after the earthquake (Angenheister, 1923; Heck, 1947; Gutenberg, Richter, 1949, 1954; Ponyavin, 1965; Iida et al., 1967).

Gutenberg, Richter (1954): 20.IX; 14h39m00s; 20° S., 168° E.; M=8.

1926, September 17 (mistakenly 18), about 4:20 + min. At Ovi (Guadalcanal Island), after a roar which seemed like peals of distant thunder, which came from the west and intensified as it approached, oscillations and spinning of the earth's surface began and continued for several seconds. Then they abated, but did not stop, and then the main tremor began, which was predominantly vertical and lasted a minute. Homes collapsed, dishes and other objects were broken, and reservoirs with water collapsed to the ground. At Tudol, 110 km to the east, great damage was done to buildings and stores of goods at warehouses. The earthquake was felt at Makambo, on San Jorge Island, at Tuilagi and Vidun*.

The tremors lasted all day and then continued for a week, with lesser intensity and at increasing intervals, although the force of shocks suddenly increased from time to time. Separate shocks continued for a year.

The phenomena, which preceded the earthquake, included in particular unusually low ebbs, which may however have been connected with the equinox and phases of the moon. The sea water was inky black, and all the denizens of the sea floated belly up in various stages of paralysis and even death, so that the stink at ebb tide was disgusting.

At the end of the earthquake, the lagoon at Ovi, 200-400 m (10-20 chains) wide and 1-3 1/2 m (from 3 feet to 2 fathoms) deep, and closed in by a broad flat coral reef which was exposed during ebb tides, but which /260
rose 1-2 m (4-6 feet) above flood tides in two places right at the the lagoon, dried up completely. Then a flood tide began as a series of waves (about seven) with "white horses," which chased each other and flooded the beach, sweeping away everything in their path. The waves entered through the northern entrance to the lagoon, colliding and surging onto one another at the centre of the lagoon. Whirlpools and surges arose. Then the water left the lagoon and returned again. This phenomenon recurred three times and then continued with each new advance being smaller than the last one until, finally, all quieted down.

The zone of the greatest effect of the tsunami, according to Svensen, occupied 55 km (30 miles) of the western coast of Guadalcanal Island between Cape West and Cape Esperense. The tsunami flooded all the lowlands, as well as Kokumariki Island. So far as Svensen could remember a year after the events, it was lowest low tide, and the moon was in the fourth quarter before the tsunami (Svensen, 1927; Sieberg, 1932; Heck, 1934, 1947; Ponyavin, 1965; Iida et al., 1967).

Gutenberg, Richter (1954): 16.IX; $17^h59^m12^s$; 11.5° S., 160° E.; 50 km; M=7.1. [The instrumental and macroseismic data on the earthquake are not in satisfactory agreement.]

1931, October 4, 6:15. There was an earthquake on San Cristobal Island. It was apparently incomparably stronger than all other earthquakes in the memory of the European settlers. Neither could any of the local residents, except for a few old men and women, remember the like. The first and strongest shock lasted about 2 minutes. The second strong earthquake occurred at 11:30 on the 10th.

A tidal wave appeared (in Tuilagi) about 10 minutes after the earthquake on the 4th. At Kira Kira, the rise of water was about 2 m (6 feet), but since it was ebb tide, the water rose only to the high tide mark, without doing any damage except to one recently built stone moorage, which had already been partly destroyed by the earthquake.

This wave was observed along the entire northern coast of San Cristobal Island, being somewhat larger in the eastern part of the shore and gradually diminishing to nothing in the direction to the western tip of the island.

At Port Mary (Santa Ana Island), the water, according to H. Kuper, retreated a very large distance, and then, after a brief pause, rose quickly and reached the highest high tide mark. This cycle of movements, which required about a minute for its completion, recurred three times with diminishing amplitude. According to depth measurements made by Kuper after the sea had calmed down, the lowest level reached by the water was about 3 1/2 m (12 feet) below the lowest low tide mark, so that the total rise and fall of water was about 5 1/2 m (18 feet).

Judging by available data, on the south coast of San Cristobal Island, between Cape Surville and Cape Sydney, the water first retreated from shore some distance beyond the lowest low tide mark (it was ebb tide) and then returned and rose, and the water surface became like a wall, which arose at the edge of the reefs. This wall advanced on land like a monolith, carrying away everything in its path. As also on Santa Ana Island, the cycle recurred three times.

The highest level reached was clearly marked on the trees which withstood the onslaught of the water and at most places was about 6 m (20 feet) above the high high tide mark, although at the centre of the effected area, whether because the disturbance of the surface of the water nearby was greater, or because of the shore configuration, the level reached was at least 9 m (30 feet) above the high water mark.

West of Cape Sydney, there was no noticeable tide wave on a stretch of many kilometres along the coast, but a weak wave in the vicinity of Makira Bay caused minor damage at several villages. One can assume, however, that this does not relate to the wave of October 4, but to some other subsequent wave.

Considerable changes in the land level occurred at different places on the island. Some 5 1/2 km (3 miles) west of Kira Kira, the sea bottom rose about 10 m (30 feet) on a stretch (of unknown length). In the vicinity of Star Harbor, the reefs, it seems, rose 30 cm (1 foot), although a narrow strip of land to the west, crossing the island in a northeast direction, subsided, almost turning Cape Surville into an island. /261

All of Santa Catalina Island subsided at least 1 m (3 feet). Considerable changes occurred in the reefs off its southern coast: some parts of the reefs rose, while others completely disappeared.

According to Stephens, San Cristobal Island is dissected by a number of fractures, which are oriented roughly in a southwest-northeast direction. Considerable shifts occurred along some of these fractures, causing changes in relief which were observed on a large expanse.

Tsunami waves destroyed 18 villages on San Cristobal Island; 50 people died (according to other sources, 26 people).

The earthquake was strong, but did not do any damage, in the central part of the Solomon Islands.

During the day on the 4th, a tsunami was observed at Hienghene (east coast of New Caledonia Island). It began at 8:30 zone time and lasted all day. The strongest oscillations in level occurred from 8:30 to 11:00-12:00. The tsunami began with flooding of the coast by strong "churning and roaring" waves 1 1/2 m high. Then the sea retreated far from shore, devastating the coast and capsizing boats.

The times of the floods and ebbs were as follows: 1) flood at 8:30, ebb at 8:50; 2) flood at 9:00, ebb - the strongest change in level - at 9:10; 3) flood at 9:20, ebb at 9:30. The highest point reached by the water was 1.3 m above the mean sea level, and the tsunami occurred during a full ebb.

The tsunami capsized several boats. The population, warned by the first flood, was on the alert, and no one was injured. The tsunami was strongest 4 km up the river, at its narrowest part; here the second, strongest wave, destroyed an 8-metre part of a stone moorage with a total length of 20 m.

According to the record of the tide gauge in Hilo Bay, the tsunami began with an ebb at 17:03 Hawaiian time (Fig. 105). Floods and ebbs occurred at 15 minute intervals for 48 hours. The mean range of oscillations was 15 cm (1/2 foot), with a maximum of 40 cm, and the movement was so slow that it was not noticed during visual observations. [In Honolulu, the range of oscillations was 5 cm, period 15 minutes.]

The tsunami was also registered at Santa Barbara (California, USA) (Jones, 1931; Bois, 1932; Anon., 1933, 1961; Stephens., 1934; Gutenberg, Richter, 1936, 1949, 1954; Heck, 1947; Shepard *et al.*, 1950; Ponyavin, 1965; Iida *et al.*, 1967).

Gutenberg, Richter (1954): 3.X; 19h13m13s; 10.5° S., 161.75° E.; M=7.9.

1934, July 19. An earthquake with source off the New Hebrides generated a tsunami which was observed at New Caledonia. Strong flood tides were recorded between 8:00 and 14:00 in Hienghene Bay on the 19th. The phenomenon recurred about 20 times. The sea would rise, then retreat to the usual ebb tide level in almost 10 whole minutes. In Touho Bay, similar floods and ebbs were registered from 8:00 to 14:00. Similar oscillations were observed at Poindime between 19:00 and 20:00. The range of tidal oscillations at New Caledonia was from 1.2 to 1.3 m. The weather was good during these observations; the wind blew from the southeast with a force of 4 degrees. No such reports were received from the west coast (Anon., 1935; Kellar, 1935).

Gutenberg, Richter (1954): 18.VII; 19h40m15s; 11.75° S., 166.5° E.; M=8.2.

1934, July 21. During a new strong earthquake on the New Hebrides Islands, another tsunami was generated and was observed on New Caledonia Island. Stronger, though at the same time briefer, oscillations than on the 19th, occurred at Touho on the 21st between 20:00 and /262
21:00. Strong floods and ebbs were recorded in Thio Bay between 20:00 and 21:00. The oscillations recurred at intervals of about 15 minutes. The rise of water each time reached the level of high high tides.

In Magenta Bay*, near Nouméa on the south coast, on the 22nd during an ebb tide, the sea rose, and then retreated 3-4 m, only to rise again in the same way. These phenomena lasted about 45 minutes and recurred almost every 10 minutes, and the sea quickly retreated each time, right out to the ebb tide line. No special sounds or roar was noticed. The weather, as on July 19, was good (Anon., 1935; Kellar, 1935).

Gutenberg, Richter (1954): 21.VII; 06h18m18s; 11° S., 165.75° E.; M=7.3.

1938, March 7, 1 1/2h (15:30 on the 6th). The tide gauge at Honolulu registered waves with a period of 30 minutes and a range of oscillations of 4-5 cm (1.5-2 inches); the epicenter of the earthquake and tsunami was situated at 8° S., 165° E., in the region of the Solomon Islands (Neumann, 1940; Iida et al., 1967).

ISS: 6.III; 16h50m+; epicenter on the south of the Pacific (not established from available data). [Neumann's data are doubtful.]

1939, January 30, 12:18. There was a strong earthquake on Bougainville Island, Solomon Islands. The zone of greatest destruction was in the vicinity of Buin and Kangu.

At Buin, the earthquake began suddenly and reached 9 degrees. It was impossible to remain standing. Many homes of local residents were destroyed. Church buildings were heavily damaged at Kihili, Toriboiru, Mugai and Papapatuai*. Cracks 30 cm wide appeared in the roads. An old bridge across the Muliko River collapsed and other bridges suffered heavily. At Barillo*, two women died in the collapse of a building. Three residents died under falling trees at Tualagai* and Lukarua. There were many injured.

At Kieta, the earthquake lasted 45 seconds and reached 6 degrees; bottles and dishes fell from shelves and broke. A seaquake was felt on a steamship near Arigua (it seemed that the steamship was being hit on the bottom). The intensity was 3 degrees on New Britain Island (at Rabaul, Kokopo, Beining* and Morobe). The earthquake was accompanied by numerous aftershocks.

A 10 km stretch of coast to the northeast of the police station at Buin subsided 0.3 m (1 foot).

After the earthquake, a tsunami was observed on the Solomon Islands. At Kokopo, at 17:30 on the 31st, the sea retreated beyond the usual ebb tide line, and then quickly rose almost to the flood tide line. This occurred three times, at intervals of about 20 minutes. Unusually high flood tides occurred on February 2 and 3 (O'Connel, 1939; Rothé, 1941).

Gutenberg, Richter (1954): 30.I; $2^h18^m27^s$; 6.5° S., 155.5° E.; M=7.8.

1939, April 30, 13:56. There was a strong earthquake on the Solomon Islands. The shocks lasted several days. Guadalcanal was one of the islands most seriously affected. A number of buildings were damaged there. Buildings were damaged on Santa Isabel Island, and buildings and moorages were damaged in the region of Cape Marsh (Russell Islands). On Savo Island, visible surface fractures appeared. The earthquake was followed by a tsunami, which flooded a number of villages. Nine children and three adolescents drowned (Anon., 1939 a, 1961; ISS; Rothé, 1941; Iida et al., 1967).

Gutenberg, Richter (1954): 30.IV; $2^h55^m30^s$; 10.5° S., 158.5° E.; 50 km; M=8. [The instrumental data on the earthquake do not fully agree with the macroseismic data.]

1952, July 13. A "trembling" on the tide gauge record on Canton Island (Phoenix Islands) was apparently the result of an earthquake with source near the New Hebrides Islands (Murphy, Cloud, 1954). The catalogue of Iida et al. (1967) mentions that there are no traces of a tsunami on this gauge record at the appropriate time. /263

[13.VII; $11^h58^m33^s$; 18.7° S., 170.3° E.; 260 km; M=7.2.]

1958, October 7, 21:00 (10h). The residents of Epi Island noted unusual waves at sea to the southeast of the island. The waves seemed to come from an underwater volcanic eruption. An airplane survey of the region showed spots and streams of unusual color (Fig. 106) as well as a

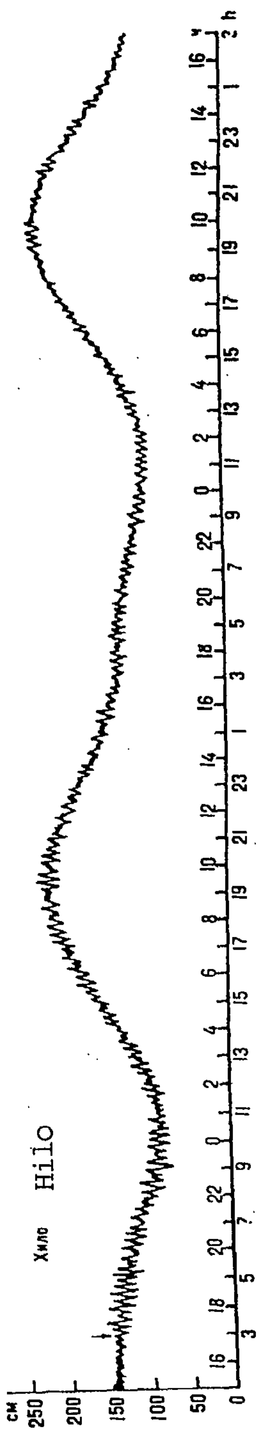

Fig. 105

Record of the tsunami of 3.X.1931 on Hawaiian Islands (Jones, 1931).

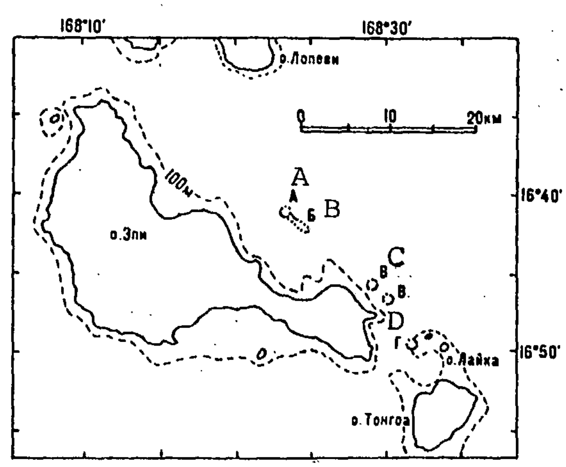

Fig. 106

Effects of the underwater volcanic eruption of 7.X.1958 (Anonym, 1958).

A – oily yellow patch with diameter 500 m;

B – similar strip 2000 m long;

C – pale green patches;

D – churning water in circle with diameter 20 m in the middle of a pale green patch with diameter 200 m (Anonym, 1958).

center of churning water (Anon., 1958).

1961, July 24, 8:51. There was a 6-degree earthquake on the islands of Efate and Eromanga. The earthquake was 4 degrees on the islands of Tanna, Epi, Malekula and the Loyauté Islands. About 10 minutes after the earthquake, a tsunami with a range of oscillations of 1-1 1/2 m was observed in the Port Vila roadstead and at Torari (Efate Island). Minor damage was done at both places (BCIS; Lander, Cloud, 1963; Hamamatsu, 1966; Iida et al., 1967).

[23.VII; $21^h51^m07^s$; 18.5° S., 168.5° E.; 45 km; M=6.8.]

1965, August 12. There was a series of shocks on the New Hebrides Islands. The shocks included the following strong earthquakes (according to Rothé):

No. 1	11.VIII,	$3^h40^m56^s$;	15.4° S.,	166.9° E.;	26 km;	M=7.
No. 2		$19^h52^m29^s$;	15.7° S.,	167.1° E.;	33 km;	M=6.5.
No. 3		$22^h31^m49^s$;	15.8° S.,	167.2° E.;	33 km;	M=7.25.

In all, 62 earthquakes were registered between August 11 and 13. The shocks continued until September.

Two of the strongest earthquakes (No. 1 and 3) caused collapses, landslides and cracking of the ground on the islands of Malekula and Espiritu Santo and caused material damage there. A moorage was destroyed at Port Sandwich, and an embankment was destroyed at Luganville. In many places, for example at Luganville, Norsup, Sarmetta, Lakatoro and Lamap, buildings were heavily damaged, water conduits were broken and telephone lines were cut. Fig. 107 presents a map of the isoseismal lines of these earthquakes. The earthquakes were also felt at Port Vila with a force of 3 and 4 degrees.

During the main earthquake (August 12), the north-western part of Malekula Island rose 1/2-1 m. According to Rothé (1966), a tsunami arose with a height of 7 m in some bays. Since the seismic station at Port Vila had broadcast a tsunami warning on the radio after the start of the shocks and before the main earthquake, the necessary safety precautions had been taken and there were no victims. According to Hake and Cloud (1967; Iida et al., 1967), the height of the tsunami was 2.5 m on Tongoa Island and 1.2 m at Port Vila. On the other hand, Benoit and Dubois (1971) state that there was no tsunami after either strong earthquake.

[11.VIII; $22^h31^m46^s$; 15.8° S., 167.2° E.; 13 km; M=7.2.]

1965, August 13. One of the small aftershocks of the earthquake /265
of August 12 generated a tsunami 2 m high, as a result of which several small vessels were lost and coastal structures were destroyed on the western shore of Espiritu Santo Island. The instrumental records of this and the other aftershocks have intensive T phases (Benoit, Dubois, 1971).

1966, June 15, 12:00. There was an earthquake which was felt on

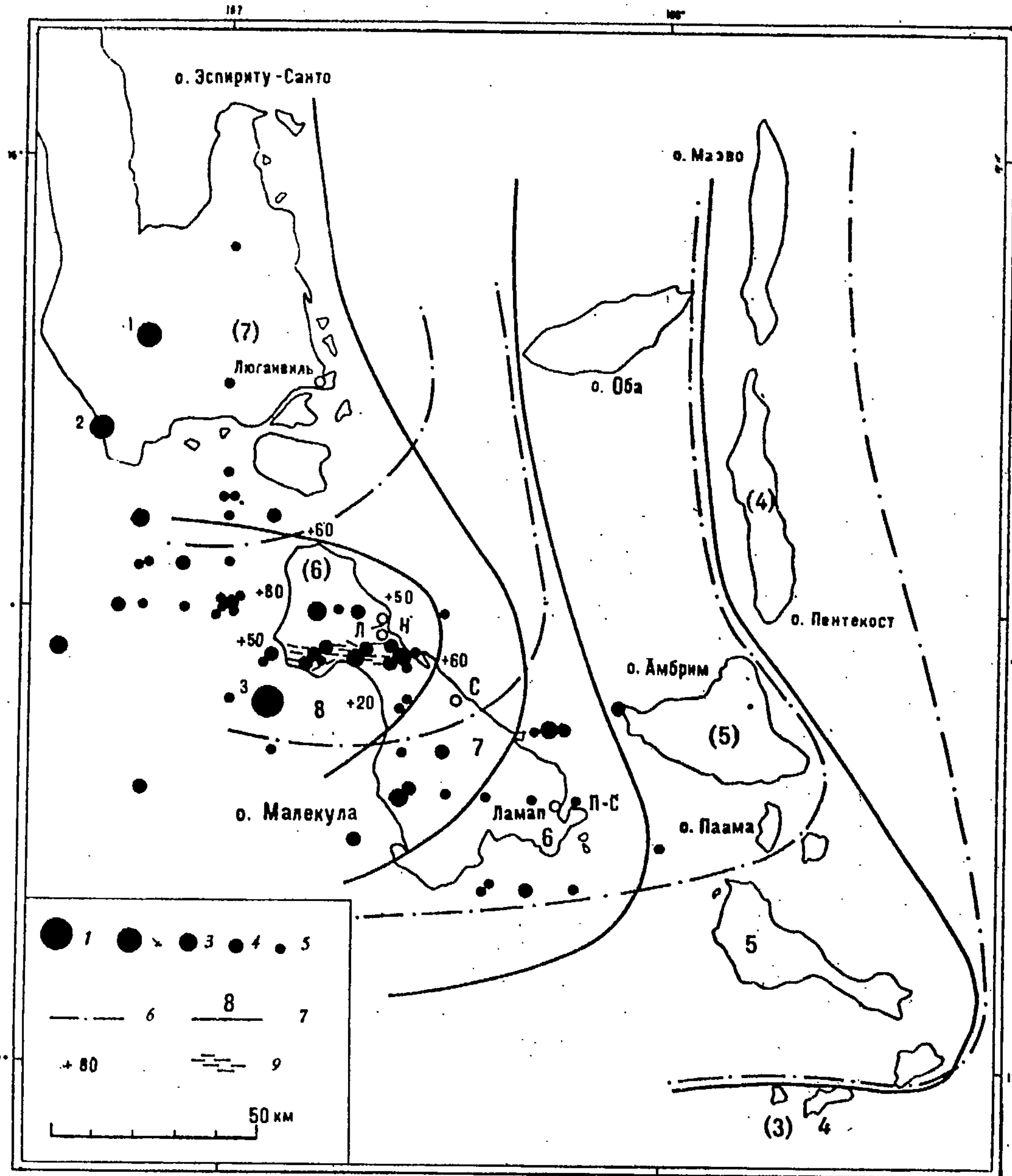

Fig. 107

Data on the earthquakes of 11 and 12.VIII.1965 (Benoit, Dubois, 1971).

1-5 epicenters of earthquakes and their aftershocks: 1-M>7; 2-M=7; 3-6≤M<7; 4-5≤M<6; 5-M<5;

6 - force of tremors in degrees and isoseismals for earthquake No. 1 (for numeration see text).

7 - the same for earthquake No. 3

8 - height of rise of coast (in cm)

9 - zone of tectonic fractures

The letters denote the following settlements:

H - Norsup

L - Lakatoro

C - Sarmetta

П-C - Port Sandwich

the islands of Guadalcanal, Malaita and San Cristobal. A weak tsunami was observed at different places on the islands of Guadalcanal and San Cristobal. A tsunami was observed at 1^h35^m with a maximal height of 20 cm at Point Cruz, Honiara (Anon., 1970 a).

[15.VI; $0^h59^m46^s$; 10.3° S., 160.8° E.; 31 km; M=7.6.]

1966, November 28. In Mohawk Bay (Santa Cruz Islands), a tsunami appeared at 13:00 (2^h00^m). There was no earthquake (Iida *et al.*, 1967).

1967, January 1, 5:23. There was an 8-9 degree earthquake on Vanikoro Island. There were avalanches and a tsunami within the lagoon. The height of waves was 2 m. The tsunami was registered at Suva and Pago Pago with heights of 9 and 6 cm, and also perhaps on Easter Island, at Kahului and Unalaska (SN, 1967, vol. 57, No. 2; Iida *et al.*, 1967; Hake, Cloud, 1968; Anon., 1970 a).

[31.XII; $18^h23^m04^s$; 11.8° S., 166.5° E.; 33 km; M=8.1.]

1967, January 1, 9:05. There was an aftershock of the preceding earthquake. It was felt on Vanikoro Island. There was a tsunami in a lagoon with an amplitude of 0.8 m (2 1/2 feet). No traces of it have been found on the records of remote tide gauges (SN, 1967, vol. 57, No. 2, Iida *et al.*, 1967; Hake, Cloud, 1968).

[31.XII; $22^h15^m16^s$; 11.5° S., 164.8° E.; 33 km; M=7.3.]

Table 1

Tide gauge data on the tsunami of 10.XI.1938.*

Observation Point	Travel Time, hr	Period, min	Maximal Amplitude cm
Dutch Harbor	1.7	50	10
Seward	1.5	70	10
Sitka	2.4	100	10
Santa Monica	6.0	35	10
Hilo	-	-	30
Honolulu	5.0	30	10

*The tables of tide gauge data presented in this book are taken from the primary sources, but have sometimes been corrected from copies of the tide gauge records.

Table 2

Tide gauge data on the tsunami of 9.III.1957.

Observation Point	Travel Time, hr	Period of Head Wave (from 1st to 2nd crest), min	Maximal Amplitude [semirange] of oscillations in level, m
Oceania			
Guam Island, Apra Bay	6.7	54	0.05
Truk Island	7.2	14	0.1
Eniwetok Island	6.5	9	0.3
Kwajalein Island	6.3	8?	0.3
Wake Island	4.8	9	0.35
Canton Island	7.5	12	0.1
Johnston Island	4.9	10	0.1
Christmas Island	7.3	12	0.15
Easter Island	9.0	25?	–
Apia	9.1	22	0.2
Pago Pago	13.9	9	0.9
Hawaiian Islands			
Midway Island	3.2	12	0.4
Nawiliwili	4.3	11	0.9
Honolulu	4.5	14	0.6
Kahului	4.7	22	1.8
Hilo	4.8	19	1.3
Aleutian Islands and Alaska			
Attu Island, Massacre Bay	1.1	7?	0.6
Unalaska Island, Dutch Harbor	1.4	27	0.7
Kodiak Island, Women's Bay*	2.2	13	0.15
Yakutat	4.8	9	0.3
Sitka	4.9	10	0.4
West Coast of USA			
Neah Bay	5.0	7	0.15
Astoria	–	–	0.07
Crescent City	5.2	14	0.65
Bodega Bay	5.3	30	0.3
San Francisco	5.9	11	0.25
Alameda	6.2	12	0.2
Avila	5.8	18	0.5

Table 2 (continued)

Tide gauge data on the tsunami of 9.III.1957.

Observation Point	Travel Time, hr	Period of Head Wave (from 1st to 2nd crest), min	Maximal Amplitude [semirange] of oscillations in level, m
Port Hueneme	6.5	15	0.5
Santa Monica	6.6	11	0.45
San Pedro	7.0	13	0.2
Los Angeles, Terminal Island	-	-	0.1
Los Angeles, moorage 60	7.0	28	0.3
Los Angeles, moorage 174	9.0	55	0.5
Long Beach	6.6	40	0.25
Anaheim Beach	6.7	24	0.4
Newport Beach	6.6	21	0.15
La Jolla	6.6	14	0.3
San Diego	6.9	18	0.2
Mexico			
Ensenada	6.8	13	0.5
Mazatlan	9.3	14?	-
Manzanillo	9.6	7?	-
Acapulco	10.8	25?	0.3
Salina Cruz	-	-	0.2
Socorro Island	9.8	7?	-
Central America			
San Jose	-	-	0.1
La Union	-	-	0.03
Puntarenas	-	-	0.1
South America			
La Libertad (Ecuador)	16.1	20	0.5
Talara	15.0	12	0.4
Chimbote	-	-	0.4
Callao	16.2	21	0.15
Matarani	-	-	0.6
Arica	-	-	0.45
Antofagasta	17.7	14	0.45
Caldera	17.9	16	0.6
Valparaiso	18.4	8	1.0
Talcahuano	19.0	24	0.7

Table 3

Tide gauge data on the tsunami of 3.II.1965.

Observation Point	Travel Time, hr	Period of Head Wave, min	Maximal Amplitude [semirange] of oscillations in level, m
Aleutian Islands and Alaska			
Attu Island, Massacre Bay	3.0	–	1.6
Adak Island, Sweeper Cove	0.6	–	0.4
Unalaska Island, Dutch Harbor	0.2	–	0.1
Kodiak Island	–	–	0.05
Sitka	–	–	0.1
USSR			
Yuzhno Kuril'sk	4.1	25	0.25
Japan			
Mombetsu	3.0	20	0.1
Hanasaki	3.5	40	0.2
Hiroo	3.6	20	0.3
Urakawa	3.8	–	0.3
Hakodate	4.4	27	0.2
Hachinohe	4.0	48	0.4
Miyako	3.8	48	0.1
Kamaishi	3.7	30	0.4
Ofunato	4.0	20	0.4
Enoshima	3.8	14	0.1
Onagawa	4.1	35	0.3
Onahama	4.3	18	0.2
Kanaya	4.4	13	0.15
Tokyo	5.5	70	0.1
Yokosuka	4.7	20	0.1
Aburatsubo	4.3	14	0.3
Oshima Island	4.1	20	0.05
Miyako Island	4.2	–	0.2
Hachijo Island	4.2	7	0.25
Minamiizu*	4.4	22	0.3
Onizaki*	5.7	20	0.1
Urakami	5.1	19	0.3
Kushimoto	5.3	18	0.55
Kainan	6.1	25	0.15
Kochi	5.7	–	0.2

Table 3 (continued)

Tide gauge data on the tsunami of 3.II.1965.

Observation Point	Travel Time, hr	Period of Head Wave, min	Maximal Amplitude [semirange] of oscillations in level, m
Tosashimizu	5.6	30	0.35
Hosojima	5.9	15	0.1
Aburatsu	5.8	28	0.3
Nase	6.2	22	0.4
Hawaiian Islands			
Midway Island	-	-	0.1
Kauai Island, north shore	-	-	0.6?
Kauai Island, Nawiliwili	-	-	0.15
Honolulu	-	-	0.05
Hilo	-	-	0.2
Oceania			
Marcus Island	-	-	0.1
Wake Island	-	-	0.1
Kwajalein Island	-	-	0.1
Samoa Islands, Pago Pago	-	-	0.15
West Coast of USA			
Crescent City	-	-	0.3
Santa Monica	-	-	0.1
South America			
La Libertad (Ecuador)	-	-	0.2
Callao	-	-	0.15
Talara	-	-	0.1

Table 4

Rise of water on 15.VI.1896 at different places on the Sanriku coast

Observation Point	Height, m	Observation Point	Height, m
Aomori Prefecture		Namiita	10.5
Sirogane	3.0	Kirikiri	10.5
Same	3.0	Ozuchi Bay	
Kofunato	6.0	Ando	4.2
Iwate Prefecture		Ozuchi	2.7
Taneichi	9.0	Hakozaki	5.7
Syukunohe	10.5	Shirahama	8.4
Yagi	10.5	Ryoishi Bay	
Kokonai	12.0	Kariyado	17.4
Siramae	18.6	Ryoishi	11.1
Natsui	11.5	Kamaishi Bay	
Shimomugiu*	8.4	Kamaishi	4.5-8.1
Kuji	8.5	Ureishi	4.2
Osaki*	7.5	Heita	5.1
Kosode	13.5	Hongo	13.8
Kuki	12.0	Kozirahama	16.2
Tamagawa	18.0	Arakawa River	10.5
Horiuchi	12.0	Yoshihama	24.0
Otanabe	15.0	Okkirai Bay	
Akedo	12.0	Urahama	9.6
Raga	22.5	Okkirai	10.5
Omoto	12.0	Koishihama	10.2
Taro	14.4	Shirahama	21.6
Miyako Bay		Ryori	10.5
Kuwagasaki	9.0	Akazaki	3.6
Miyako	4.5	Ofunato	3.3
Sokei	6.0	Shimofunato	5.4
Takahama	3.0	Hoso'ura	6.7
Kanahama	3.9	Hirota Bay	
Shirahama	21.6	Tadaide	10.6
Otobe	9.0	Onahama	7.8
Omoe	10.8	Tomarihama	7.5
Aneyosi	18.6	Mikkaichi Bay	2.4
Tikei	16.8	Katsugida	2.7
Yamada Bay		Osabe	3.3
Oosawa	3.9	Minahama*	6.0
Yamada	5.4	Miyagi Prefecture	
Origasa	3.3	Tadagoshi	8.4
O'ura	4.8	Ishihama	8.4
Funakoshi Bay		Babahama*	9.6
Koyadori	15.0	Syuku	4.2
Tanohama	9.0	Kesennuma Bay	
Funakoshi	15.0	Tsuruga'ura	4.2

Table 4 (continued)

Rise of water on 15.VI.1896 at different places on the Sanriku coast

Observation Point	Height, m	Observation Point	Height, m
Komagata	4.2	Omaehama	3.0
Nagasaki	6.6	O'ura	2.4
Uranohama	2.1	Onagawa Bay	
Kashigasaki*	1.5	Takeno'ura	2.1
Katahama	2.1	Ishihama	2.4
Saichi	2.4	Onagawa	2.7
Koizumi Bay		Onorihama	1.8
Ooya	5.1	Takashiro	2.4
Hikado	5.1	Yokohama	2.7
Osawa	8.1	Nonohama	3.0
Nijuichihama	6.0	Iikonohama	2.7
Kurauchi	6.0	Narahama	3.3
Minatohama	3.3	Urahama	3.0
Tano'ura	4.8	Sameno'ura Bay	
Shizukawa Bay		Yoriiso	2.7
Isatomae	3.3	Maeami	2.4
Hoso'ura	3.6	Sameno'ura	3.0
Shimizuhama	3.3	Yakawa	3.3
Hiraisho	3.9	Tomarihama	6.0
Shizukawa	2.1	Niiyama	3.0
Hayashihama	1.8	Yamadori	4.2
Oritate	2.7	Ojika Peninsula, west coast	
Mitobe	2.4	Ayukawa	2.1
Tsunomiya	3.9	Kobuchi	2.4
Takihama	3.9	Oharahama	1.8
Fujihama	5.1	Koamik'ura	2.1
Nagashimizu*	4.8	Kitsunezaki	0.6–0.9
Kotaki	6.0	Oginohama	2.1
Oppa Bay		Momono'ura	1.2
Osashi	5.1	Hamagurihama	1.8
Kosashi	4.5	Watanoha	1.5
Aikawa	4.5	Ishinomaki	
Komuro	3.9	(mouth of river)	0.6
Shirahama	2.7		
Naburi	3.3		
Okachi Bay			
Miojinhama	2.4		
Okachi	3.0		
Funato	2.7		
Karakuwa	1.8		
Wakehama	2.1		
Namiita	2.4		
Sashihama	2.7		

Table 5

Effects of the earthquake and tsunami of 15.VI.1896 on the Sanriku Coast.

Damage	Prefecture			
	Miyagi	Iwate	Aomori	Total
Killed	345	18,158	299	21,909
Injured	1,241	2,943	214	4,397
Missing without trace		Unknown	44	44
Completely destroyed	164* 221	344 3	29 25	537 239
Brought down	242 227	370 9	24 8	636 244
Heavily damaged	00	No data	135 53	135 53
Washed away	954 2,169	4,744 57	351 251	6,049 2,477
Total of above	1,360 2,617	5,458 69	539 327	7,357 3,013
Flooded	1,027 1,399	1,175 0	70 23	2,272 1,422
Swept away	1,145	4,453	122	5,720
Heavily damaged	0	1,003	207	1,210

* The top figures relate to homes, the bottom figures to schools, churches, barns and other structures.

Table 6

Data on the tsunami of 5.VIII.1897

Observation Point	Travel Time, min	Wave Period, min	Rise of Water, m
Taneichi	5-6	-	1.2
Natsui	5	-	2.1
Kuki	15	3	0.8
Noda	15	-	1.2
Miyako	30	10	1.2
Ozuchi	5	-	1.2
Unosumai	30	5	1.8
Kamaishi	30	15	1.5
Kojirahama	60	15	1.8
Yoshihama	10	10	2.4
Okkirai	30	5-6	2.7-3.0
Ryori	30	-	2.7
Sakari	-	10	2.3
Ofunato	30	20	1.5
Hirota	20	-	3.0
Omoto	40	10-15	2.1
Katsugida	40	15-20	1.2
Takada	30	20	2.4
Kesennuma	15	20	1.2
Shizukawa	15	5-20	1.5
Okachi	30	15-20	2.1
Onagawa	33-40	-	3.0
Oharahama	30	30	3.0
Ishinomaki	-	-	3.6
Arahama	-	-	1.5

Table 7

Tide gauge data on the tsunami of 5.VIII.1897.

Observation Point	Travel Time, hr	min	Nature of First Wave	Maximal Amplitude of Oscillations in Level, cm	Duration of Oscillations, hr
Ayukawa	–	18 or 40?	fall	50	21
Hanasaki	–	28?	rise	8	16
Aburatsubo	–	58?	–	3	15
Kushimoto	1	48	rise?	15	28
Miyako	–	35?	–	–	–
Onahama	–	45?	–	–	–
Choshi and Mera	–	50?	–	–	–

Table 8

Tide gauge data on the tsunami of 1.IX.1923.

Observation Point	Travel Time, hr	min	Head Wave: Nature and Height, cm	Head Wave: Period, min	Maximal Range of Oscillations in Level, cm
Same	2	17	fall	48	33
Ayukawa	2	08	–	26	26
Minatomachi	–	52	–	80	30
Yosohama	–	52	–	80	50
Choshi	–	41	+15	45	30
Chiba	–	27	–	–	75
Fukagawa	–	42	–	–	60
Siba'ura	–	32	–	–	79
Gofukubashi*	–	42	–	–	52
Honjo	–	02	–	–	27
Yokosuka	–	02	–	24	170
Owase	–	45	+30	24	54
Kushimoto	1	02	+20	22	80
Osaka	2	02	+5	75	60
Tsurushima	1	42	–	60	15
Mikita*	1	30	+2	45	40
Urado	1	20	+0.5	60	25
Hosojima	1	52	rise	58	26

Table 9

Rise of water on 1.IX.1923 on south of Boso Peninsula.

Observation Point	Height, m	Observation Point	Height, m
Mera	4.5-6	Iwai*	3.0
Ainohama	4.5-9.3	Katsuyama*	2.2
Fujiwara	7.2	Haraoka	1.3
Sakataru	3.0	Toyooka	1.7
Ito	1.5-3.0	Ko'ura	2.1
Kawana	3.0	Takasaki	3.0
Suzaki	4.0-8.1	Kanaya	1.0
Hasama	1.5	Minato*	1.0
Hamada	3.9	Futsu*	0.6
Tateyama	1.8	Kisarazu	1.8
Tomi'ura	2.8	Urayasu*	0.3

Table 10

Tide gauge data on the tsunami of 6.VIII.1927.

Observation Point	Travel Time, min	Nature of Head Wave	Wave Period, min	Maximal Range of Oscillations in Level, cm
Hachinohe	60	–	–	–
Miyako	40?	–	–	–
Tsukihama	34	fall?	20	5
Ayukawa	30?	–	–	–
Ishinomaki	42	fall	18	5
Shiogama (Hanabuchi)	41	fall	25	15

Table 11

Tide gauge data on two tsunamis of 19.VIII.1927.

Observation Point and Tsunami Number	Travel Time, min	Period of Head Wave, min	Maximal Range of Oscillations in Level, cm
Choshi (I)	34	5	36
(II)	–	–	30
Mera (I)	34	5	30
(II)	–	–	20

Table 12

Tide gauge data on the tsunami of 27.V.1928.

Observation Point	Travel Time, hr	min	Nature of Head Wave	Period of Waves, min	Maximal Range of Oscillations in Level, cm
Hachinohe	–	44	fall?	15	20
Miyako	–	24?	–	–	–
Tsukihama	–	42	fall?	12	11
Ayukawa	–	45?	–	–	–
Ishinomaki	1	22	fall	15	7
Shiogama (Hanabuchi)	1	20	–	–	18
Onahama	1	25?	–	15	9
Choshi	1	25?	–	5	1

Table 13

Tide gauge data on the tsunami of 9.III.1931.

Observation Point	Travel Time, hr	min	Nature of Head Wave & Height, cm	Period of Waves, min	Maximal Range of Oscillations in Level, cm
Hachinohe	–	53	+25	28	39
Miyako	–	36?	–	–	–
Tsukihama	1	46	-15	27	17
Ayukawa	1	00?	–	–	–
Ishinomaki	1	47	–	25	14
Shiogama (Ojima)	1	46	rise?	–	6
Onahama	1	53	fall?	15	8

Table 14

Tide gauge data on the tsunami of 2.XI.1931.

Observation Point	Travel Time, hr	Maximal Amplitude of Oscillations in Level, cm
Cape Shionomisaki	0.8	10
Cape Muroto	0.7	40
Tosashimizu	0.5	30
Hosojima	0.5	30
Aburatsu	0.5	30

Table 15

Tide gauge data on the tsunami of 19.VI.1933.

Observation Point	Travel Time, hr	min	Nature of Head Wave & Height, cm	Wave Period, min	Maximal Range of Oscillations in Level, cm
Hakodate	1	02	–	30	–
Hachinohe	1	05	rise?	15	18
Miyako	–	40?	–	–	–
Tsukihama	–	22	+5	20	14
Ayukawa	–	22?	–	–	–
Ishinomaki	–	52	+8	18	10
Shiogama (Hanabuchi)	–	22	+6	10	14
Shiogama (Ojima)	–	35	–	–	10

Table 16

Tide gauge data on the tsunami of 13.X.1935.

Observation Point	Travel Time, hr	min	Nature of Head Wave	Wave Period, min	Maximal Range of Oscillations in Level, cm
Hachinohe	–	37-40	rise	12	33
Miyako	–	26?	–	–	–
Kesennuma	–	43	–	–	24
Tsukihama	1	01	rise	12	10
Onagawa	–	51	fall	8	18
Ayukawa	–	50?	–	–	–
Ishinomaki	1	00	rise	–	3
Onahama	1	15	rise	7	15

Table 17

Tide gauge data on the tsunami of 3.XI.1936.

Observation Point	Travel Time, hr	min	Nature of Head Wave	Wave Period, min	Maximal Range of Oscillations in Level, cm
Hachinohe	1	09	fall?	32	30
Miyako	–	36	–	–	–
Kesennuma	–	34	fall	22	28
Tsukihama	–	28	rise	25	23
Onagawa	–	00	rise	30	67
Ayukawa	–	20	–	–	–
Ishinomaki	–	34	rise	40	20
Shiogama (Ojima)	–	50	rise	15	8
Onahama	–	53	rise	21	18
Iwaimachi	1	03	rise	21	15

Table 18

Tide gauge data on the tsunami of 23.V.1938.

Observation Point	Travel Time, hr	min	Nature of Head Wave	Wave Period, min	Maximal Range of Oscillations in Level, cm
Hachinohe	2	26	rise	15	22
Tsukihama	–	41	rise	23	13
Onagawa	1	05	rise	18	32
Ishinomaki	–	14	rise	19	9
Shiogama (Hanabuchi)	–	37	rise	16	45
Onahama	–	24	rise	20	83
Choshi	–	32	rise	23	18

Table 19

Tide gauge data on the first tsunami of 5.XI.1938.

Observation Point	Travel Time, hr	min	Nature of Head Wave	Wave Period, min	Maximal Range of Oscillations in Level, cm
Hachinohe	1	30	rise	22	24
Miyako	–	56	rise	25	42
Kesennuma	–	50	rise	18	28
Tsukihama	1	00	rise	20	64
Ayukawa	–	43	rise	20	105
Ishinomaki	1	15	rise	25	35
Shiogama	1	18	rise	28	32
Shiogama (Hanabuchi)	1	30	rise?	27	113
Onahama	–	22	rise	21	107
Choshi	–	35	rise	18	28
Hakodate	1	53	rise	25–40	5
Muroran	2	16	–	–	–
Kushiro	1	27	–	–	–

Table 20

Tide gauge data on the second tsunami of 5.XI.1938.

Observation Point	Travel Time, hr	min	Nature of Head Wave	Wave Period, min	Maximal Range of Oscillations in Level, cm
Hakodate	2	15	rise	–	–
Hachinohe	1	30	rise	25	44
Miyako	1	10	–	–	–
Kesennuma	–	40	rise?	15	49
Tsukihama	1	00	rise?	20	63
Ayukawa	–	40?	–	–	–
Ishinomaki	1	14	rise	25	30
Shiogama	1	01	rise	20	29
Shiogama (Hanabuchi)	1	10	fall?	15	112
Onahama	–	32	rise	15	79
Choshi	–	30	rise	25	28

Table 21

Tide gauge data on the tsunami of 6.XI.1938.

Observation Point	Travel Time, hr	min	Nature of Head Wave	Wave Period, min	Maximal Range of Oscillations in Level, cm
Kushiro	1	45	–	–	–
Hakodate	1	45	fall?	–	5
Hachinohe	1	23	fall?	10	15
Miyako	–	53	fall?	10	21
Kesennuma	–	46	fall?	10	56
Tsukihama	–	43	fall?	12	15
Onagawa	–	45	–	11	55
Ayukawa	–	35	–	15	126
Ishinomaki	1	5	fall	13	10
Shiogama	1	25	fall	25	10
Shiogama (Hanabuchi)	1	30	fall	20	85
Onahama	–	25	fall	11	40
Choshi	–	39	fall	10	14

Table 22

Tide gauge data on the tsunami of 7.XI.1938.

Observation Point	Travel Time, hr	min	Nature of Head Wave	Wave Period, min	Maximal Range of Oscillations in Level, cm
Hachinohe	1	23	fall?	10	33
Kesennuma	–	54	rise	11	25
Tsukihama	–	50	rise	10	14
Onagawa	–	54	rise	11	35
Ayukawa	–	50	rise	–	125
Ishinomaki	1	12	rise	13	6
Shiogama	1	35	rise	23	6
Shiogama (Hanabuchi)	1	20	rise	18	118
Onahama	–	24	rise	8	50
Choshi	–	31	rise	9	15

Table 23

Tide gauge data on the tsunami of 14.XI.1938.

Observation Point	Travel Time, hr	min	Nature of Head Wave	Wave Period, min	Maximal Range of Oscillations in Level, cm
Kesennuma	–	59	rise	12	21
Tsukihama	–	41	rise	11	13
Onagawa	–	29	rise	11	41
Ishinomaki	1	19	rise	10	6
Shiogama	1	20	rise	10	5
Onahama	–	27	rise	10	71
Choshi	–	41	rise	15	12

Table 24

Tide gauge data on the tsunami of 22.XI.1938.

Observation Point	Travel Time, min	Nature of Head Wave	Wave Period, min	Maximal Range of Oscillations in Level, cm
Onagawa	26	fall	17	15
Shiogama	23	fall?	5	4
Onahama	38	fall	6	29
Choshi	44	fall	15?	6

Table 25

Tide gauge data on the tsunami of 30.XI.1938.

Observation Point	Travel Time, hr	min	Nature of Head Wave	Wave Period, min	Maximal Range of Oscillations in Level, cm
Hakodate	3	00	rise?	25	15
Hachinohe	3	35	rise?	18	19
Kesennuma	1	03	fall	12	12
Tsukihama	2	00	fall	12	11
Onagawa	–	30	fall	14	18
Ishinomaki	2	30	fall	18	9
Onahama	–	20-30	fall	20	13
Choshi	–	44?	fall	–	–

Table 26

Rise of water on 7.XII.1944 at different places.

Observation Point	Height, m	Observation Point	Height, m
Sizuoka Prefecture		Katada	3.0
Hamasaki (Susaki*)	2.0	Fuseda	2.2
Matsuzaki	1.5	Wagu	5.5
Shimizu	1.1	Goza	2.5
Cape Omae	2.0	Ugata	2.0
Maisaka	0.8	Nakajima	3.5
Aichi Prefecture		Yoshizu	6.0
Fukue	0.5	Shimazu	6.0
Katanohara	0.5	Nagashima	4.0
Morozaki	0.5	Nishiki	6.0
Mie Prefecture		Kaino	4.6
Kuwana	0.5	Katsuragi	4.0
Tsu	1.0	Sugari	5.0
Kawana*	0.5	Yanoguchi	7.5
Matsuzaka	1.0	Hikimoto	3.0
Ominato	2.0	Tenman'ura	6.5
Kagami'ura	2.0	Owase	5.0
Nagaoka	2.0	Mukai	4.0
Matoya	3.0	Yukino	4.0
Nakiri	3.5	Motoyukino	4.0
Funakoshi	3.5	Kuki	2.8

Table 26 (continued)

Rise of water on 7.XII.1944 at different places.

Observation Point	Height, m	Observation Point	Height, m
Nako	3.5	Nishimukai	1.9
Hayata	4.0	Oshima	2.0
Morimatsu	4.0	Kushimoto	2.0
Mori'ura	5.0	Fukuro	6.2
Miki'ura	5.0	Esumi	2.5
Kowaki	5.0	Hiki	1.0
Nagara	4.5	Asaragi (Tomita)	4.5
Mikisato	5.5	Tanabe	1.0
Furue	6.0	Gobo	0.5
Nanbari	3.5	Shimotsu	0.5
Gokasyo'ura*	3.0	Ukui	3.0
Konza*	3.4	Okarachi*	3.0
Gata	7.5		
Sone	6.0		
Suno	4.5		
Hobo	5.5		
Nikishima	6.0		
Minamiwauchi	5.5		
Kajiga	4.9		
Arasaka*	7.1		
Arashika	8.4		
Arata	5.0		
Yuki	6.0		
Atashika	5.5		
Homoto*	5.0		
Odomari	5.0		
Kodomari	5.5		
Kimoto	3.0		
Matsubara	7.0		
Nanji*	4.5		
Hama*	4.0		
Atawa	4.0		
Udono	3.5		
Narikawa	2.0		
Wakayama Prefecture			
Shingu	3.0		
Nachi	4.5		
Nachikatsu'ura	2.4		
Taiji	4.5		
Shimosato	2.5		
Urakami	6.2		
Tahara	2.5		
Koza	3.5		

Table 27

Tide gauge data on the tsunami of 7.XII.1944.

Observation Point	Travel Time, hr	Wave Period, min	Maximal Range of Oscillations in Level, m
Attu Island, Massacre Bay	5.4	10	0.3
Adak Island	6.4	12	0.1
Los Angeles, Terminal Island	-	16	0.1
San Diego	13.9	14	0.1
Honolulu	8.3	21	9.1

Table 28

Rise of water on 21.XII.1946 at different places.

Observation Point	Height, m	Observation Point	Height, m
Kanagawa Prefecture		Hiyamaji	1.0
Misaki	0.8	Hamajima	1.0
Shizuoka Prefecture		Nanbari	2.0
Ito	0.7	Syukudaso	1.0
Shimoda	3.0	Shimotsu'ura	1.6
Uchi'ura	1.0	Gokasho'ura	1.6
Cape Omae	2.0	Hazama'ura	1.6
Maisaka	1.0	Nishiki	2.0
Aichi Prefecture		Sugari	1.1
Fukue	0.5	Yanoguchi	2.3
Morozaki	0.5	Iguma	1.9
Nishi'ura	0.5	Hikimoto	0.8
Mie Prefecture		Tenman'ura	2.0
Ominato	1.0	Owase	2.0
Toba	1.2	Mukai	2.5
Nakiri	1.0	Yukino	2.0
Funakoshi (Soto'ura)	1.2	Motoyukino	1.5
Funakoshi (Uchi'ura*)	1.8	Kuki	0.8
Katada	2.2	Nako	0.6
Fuseda	1.0	Hayata	0.8
Wagu (Soto'ura)	1.0	Cape Mikizaki	1.5
Koshika	1.5	Morimatsu	2.5
Goza	1.6	Mori'ura	3.0
Shioya	1.0	Miki'ura	2.8

Table 28 (continued)

Rise of water on 21.XII.1946 at different places.

Observation Point	Height, m	Observation Point	Height, m
Kowaki	3.0	Ikeda*	3.0
Nagara	2.8	Uchino'ura	4.4
Mikisato	3.8	Atono'ura	4.4
Furue	3.0	Mikonohama	3.2
Gata	5.5	Morinominato*	4.7
Sone	4.5	Tanabe	2.7
Suno	2.5	Matsubara	2.5
Hobo	3.0	Nabemachi	1.2
Nikishima	3.5	Shioya	2.8
Arata	2.0	Kiribe	1.7
Yuki	3.5	Inami	4.9
Atashika	3.0	Gobo	3.0
Homoto*	3.5	Hachimanbashi*	2.7
Kajiga	2.1	Mio	3.8
Odomari	2.0	Ao	2.9
Kodomari	2.1	Ubuyu	3.0
Kimoto	4.0	Ko'ura	3.3
Matsubara	3.8	Katakui	2.5
Hama*	2.5	Okui	2.5
Atawa	2.0	Kashiwa	3.0
Udono	1.5	Oshi*	3.3
Narikawa	0.5	Ato	3.9
Wakayama Prefecture		Yura	4.0
Shingu	3.5	Fukui	3.8
Nachi	3.0	Itotya	3.5
Katsu'ura	2.0	Jin*	1.3
Urakami	3.0	Hiro	4.9
Koza	3.6	Yuasa	3.2
Hime	4.3	Tatsugahama	1.5
Hashikui	4.6	Minoshima-Sunohara	1.9
Kushimoto	4.2	Minoshima-Yaki	1.8
Fukuro	6.2	Shimotsu	3.0
Arita	5.4	Kata	2.5
Tanami	4.1	Osaki'ura	2.3
Eda	4.8	Tosaka*	2.5
Susami	4.2	Shio'ura*	2.5
Hiki	3.0	Koto'ura*	2.4
Asaragi (Tomita)	4.0	Nadaka	4.1
Fukurotani	4.0	Torii*	4.1
Shirahama	3.7	Shimizu*	3.6
Amishirazu*	2.9	Suwazaki*	4.2
Koga'ura*	3.2	Dejima*	2.7
Hosono	3.1	Waka'ura	1.9

Table 28 (continued)

Rise of water on 21.XII.1946 at different places.

Observation Point	Height, m	Observation Point	Height, m
Kata*	1.6	Asakawa	4.7
Kainan	2.4	Sabase	2.9
Wakayama	1.9	Dewashima Island*	3.2
Osaka Prefecture		Tomooku*	1.6
Osaka-Tikko*	0.6	Nasa	3.7
Hamadera*	1.0	Hamasaki	2.0
Kabuto*	1.6	Shishikui	4.5
Kishiwada	1.0	Kochi Prefecture	
Sano*	0.3	Kanno'ura	3.9
Tannowa	0.3	None	5.0
Awaji Island		Shiina	3.0
Sumoto	0.9	Muroto	2.0
Fuk'ura	1.8	Aki	3.0
Yura*	0.9	Tei	2.9
Nada	1.5	Tanesaki	1.4
Nujima*	1.5	Kochi	0.5
Ama*	1.5	Urado	1.5
Minato*	0.3	Mimase*	1.3
Sitsuki*	1.0	Hashida*	3.9
Naya*	0.3	Usa	3.7
Sano*	0.3	Fukushima*	1.2
Tokushima Prefecture		Yokonami*	1.3
Muya	0.6	Ko'ura*	4.6
Tokushima	2.0	Miyakotani*	5.2
Komatsushima	2.0	Nomi	4.2
Okata*	2.0	Onogo*	2.7
Tomosaki*	1.9	Susaki	3.3
Tachibana	3.3	Anwa*	4.7
Kogui*	3.6	Kure	3.9
Akaishi	2.5	Kamata	2.8
Tsubakidomari	1.9	Kaminokae	2.7
Kobukikawara*	2.2	Saga	4.7
Tsubaki	3.0	Kamikawaguchi	4.5
Hiramatsu	2.8	Tosashimoda	3.5
Shirigui	1.4	Nuno	2.0
Yuki	4.0	Shimonokae	3.2
Tai	2.0	Iburi	2.7
Kiki	4.2	Tosashimizu	0.8
Ebisu	3.6	Komame	3.0
Tai (Hiwasa Bay)*	1.5	Urashiri	1.2
Inoue*	4.4	Sukumo	1.2
Mugi	4.5	Ioki*	3.0
Awa'ura	4.0		

Table 29

Remote tide gauge data on the tsunami of 21.XII.1946.

Observation Point	Wave Period, min	Travel Time, hr	Maximal Range of Oscillations in Level, cm
Honolulu	14	9.3	10
San Francisco	12	–	10
Crescent City	14	13.0	30
Talara (Peru)	11	21.2	10

Table 30

Data on the tsunami of 4.III.1952.

Observation Point	Travel Time, min	Maximal Rise of Water, m	Effects of Tsunami
Hokkaido Island			
Habomai	–	–	No trace of tsunami observed.
Hanasaki	–	2.6	Coastal strip 20 m wide flooded.
Nagafusa	67	–	Weak tsunami observed.
Ochiishi	–	–	Large ebb registered.
Hamanaka	47	–	Negligible damage.
Kiritappu	32	3.2	
Biwase	100	2.0	
Tokotan	35	5.0	37 homes destroyed and 100 homes flooded; boats washed away.
Monshizu	–	3.9	
Tomata	30	–	Water level rose gradually.
Senhoshi	25	6.5	Wave approached in form of usual flood tide, but with rapid increase in level.
Kombumori	–	3.8	Tsunami began with flood tide.
Kushiro	35	2.8	58 homes flooded, 3 boats sunk & 99 boats damaged.

Table 30 (continued)

Data on the tsunami of 4.III.1952.

Observation Point	Travel Time, min	Maximal Rise of Water, m	Effects of Tsunami
Shiranuka	20-23	2.7	Two homes flooded.
Atsunai	30	1.5	Flood tides registered three times.
Otsu	-	-	Sea retreated about 20 m.
Aiboshima	22	3.3	
Komombetsu	5	3.25	3 or 4 waves registered.
Hiroo	5	-	
Meguro	27	1.5	
Sakiume	15	2.0-2.5	
Shoya	20	1.6	
Chibira	27	1.5-2.0	
Cape Erimo	12	2.5-2.7	Launch sunk; underwater roar.
Aburakoma	15	1.5	
Oshiyorosuke*	12	2.0-2.5	
Yankebetsu	20	2.5	
Sanboniwa*	30	2.0	
Utatsuyu	30	1.5-2.0	Underwater roar.
Higashiutabetsu*	37	2.0-2.5	
Utabetsu	40	(3.0)*	
Horoizumi	67	2.0	
Sakkotsu	75	3.0	
Fuemai	67	(3.0)	Boats damaged, water flooded over dam at some places.
Shimochika'ura*	40	1.5	
Chika'ura	37	2.0	
Asahi*	37	1.5	
Horoman	37	1.8	
Ehaoi	-	1.0	
Higashifuyujima*	32	1.5	
Fuyujima	40	3.0	
Sanushibe*	-	1.5	
Hirau	47	1.2-1.3	
Samani	40	2.0	
Utoma	67	1.3	
Urakawa	37	1.5	
Ikandai	67	-	
Mitsuishi	97	2.0	

* Figures in brackets are uncertain data.

Table 30 (continued)

Data on the tsunami of 4.III.1952.

Observation Point	Travel Time, min	Maximal Rise of Water, m	Effects of Tsunami
Harutachi	97	2.0	
Higashishizunai	127	1.5	
Shizunai	87	2.0	
Mombetsu	127	2.0	
Aomori Prefecture			
Sabishiro	–	–	No traces at all found of tsunami.
Nikawame	–	–	Water retreated 300 m during first ebb.
Furukawa	–	–	Water retreated 200 m during first ebb.
Kawaguchi	–	1.5	
Momoishi	–	–	Small tsunami, did no damage.
Same	57	2.0	Wave approached slowly.
Hachinohe	47	1.5–1.6	Serious damage to three ships.
Niida	–	0.3	One boat damaged.
Tanesashi	22	–	Negligible flood tide.
Okuki	–	0.9	
Hashikami	–	–	Weak tsunami.
Kofunato	47	–	Slow flood tide.
Iwate Prefecture			
Taneichi	57–62	1.2	
Yagi	57	2.7	
Nakano	57	–	
Kuzi	57	2.2	Wave approached slowly.
Minato*	–	2.0	
Kuki	–	2.2	
Noda	–	(2.2)	
Shimoakka	–	2.5	
Horiuchi	–	(2.5)	
Otanabe	–	(2.5)	
Akedo	–	(2.3)	
Raga	–	2.5	
Hiraiga	55	(2.3)	
Omoto	–	2.0	
Moshi	–	(2.0)	
Taro	37	1.0	
Takahama	67	1.5	
Kanahama	67	2.0–2.5	
Tsugaruishi	52	1.5–2.0	

Table 30 (continued)

Data on the tsunami of 4.III.1952.

Observation Point	Travel Time, min	Maximal Rise of Water, m	Effects of Tsunami
Shirahama	37	1.0-2.0	
Otobe	-	1.5	
Iona	-	1.2	
Hoshitori*	37	-	Flood tide began about 2 or 3 minutes after ebb.
Ishihama	52	-	Several waves were observed.
Yamada	42	1.8	
Origasa	50	1.8	
Tanohama	47	1.5	
Kirikiri	47	-	Difference between crest and trough of first wave 2.5 m.
Ozuchi	42	1.0	
Ryoishi	47	2.5	
Kamaishi	47	2.5	
Kojirahama	27	0.6	Wave destroyed dike 30 m long.
Urahama	40-50	2.5	Sea retreated 400 m during first ebb.
Ryori	57	2.0	
Ofunato	52	-	Weak wave; tsunami began with ebb tide.
Hirota	-	-	Tsunami began with ebb tide.
Miyagi Prefecture			
Todagoshi	-	-	Water retreated 300 m during ebb; ebb was quick while flood was slow.
Osawa	67	1.5	
Kesaiso	35	1.0	
Kurauchi	30	0.3	
Isatomae	47	0.3	
Shizukawa	62	0.6	
Okachi	90	2.0	
Onagawa	75	0.9	
Sameno'ura	-	1.35	Water flooded land on a strip 20 m wide during flood tide.
Oyakawa	-	1.0	
Yakawa	-	1.2	
Ayukawa	67	0.8	

Table 30 (continued)

Data on the tsunami of 4.III.1952.

Observation Point	Travel Time, min	Maximal Rise of Water, m	Effects of Tsunami
Shiogama	107	0.14	
Hanabuchi	102	0.4	
Kanjo	–	0.1	
Arahama	–	–	Trace like the onset of a tsunami registered on tide gauge record.

Table 31

Tide gauge data on the tsunami of 4.III.1952.

Observation Point	Travel Time, hr	min	Head Wave: Sign & Height, cm	Head Wave: Period, min	Maximal Amplitude of Oscillations in Level, cm
Japan					
Kushiro	–	25	+ 90	40	90
Hiroo	–	–	160	–	180
Muroran	1	00	+ 15	60	16
Hakodate	1	10	+ 17	60	32
Aomori	1	15	15	30	37
Hachinohe	–	55	+ 81	50	200
Miyako	1	00	+ 65	25	65
Jyusanhama*	–	55	+ 82	20	82
Onagawa	1	10	+110	25	110
Ayukawa	1	10	+ 42	15	42
Ishinomaki	1	25	+ 35	65	60
Onahama	1	20	+ 18	25	19
Mito	1	25	+ 12	90	20
Choshi	1	10	+ 13	55	16
Mera	1	45	17	15	17
Yokohama	2	05	55	70	55
Ito	–	–	–	–	5
Aleutian Islands					
Attu Island	–	–	–	18	20
Adak Island	–	–	–	21	10

Table 31 (continued)

Tide gauge data on the tsunami of 4.III.1952.

Observation Point	Travel Time, hr	min	Head Wave: Sign & Height, cm	Head Wave: Period, min	Maximal Amplitude of Oscillations in Level, cm
Unalaska Island	–	–	–	33	10
Hawaiian Islands					
Honolulu	–	–	–	27	20
Kahului	–	–	–	23	30
Hilo	–	–	–	19	10
West Coast of USA					
Crescent City	–	–	–	25	20
San Francisco	–	–	–	–	60
Los Angeles	–	–	–	–	80
Central America					
San Juan del Sur	–	–	–	13	10
South America					
La Libertad (Ecuador)	–	–	–	22	10
Callao	–	–	–	43	30
Oceania					
Guam Island	–	–	–	21	10
Wake Island	–	–	–	14	10
Yap Island	–	–	–	23	10
Palau Island	–	–	–	15	40
Kwajelein Island	–	–	–	20	10

Table 32

Data on the tsunami of 26.XI.1953

Observation Point	Travel Time, hr	min	Wave Period, min	Maximal Amplitude, m
Miyako	1	07	36	0.27
Ayukawa	1	06	10	0.4
Onahama	–	48	12	0.15
Choshi	–	38	13	0.5–3.0
Katsu'ura	–	–	–	0.66
Kominato	–	–	–	1.50
Mera	–	22	12–15	0.5–1.82
Ito	–	18	6	0.1
Oshima Island	–	48	7	0.2
Shimoda	–	–	8	0.85
Hamamatsu	–	44	11	0.1
Kushimoto	1	12–24	12	0.4
Tosashimizu	1	24–34	15	0.2
Hachijo Island	–	–	12	2.8

Table 33

Tide gauge data on the tsunami of 22.I.1959.

Observation Point	Travel Time, min	Head Wave: Sign & Height, cm	Head Wave: Period, min	Maximal Range of Oscillations in Level, cm
Miyako	48	– 3	10	8
Kamaishi	42	– 8	12	18
Tsukihama	44	+10	20	13
Enoshima	32	+ 5	8	6
Ayukawa	36	+15	8	45
Matsukawa'ura	54	+18	8	30
Onahama	38	+ 3	8	8
Nakaminato	40?	+ 4	15	8

Table 34

Tide gauge data on the tsunami of 26.X.1959.

Observation Point	Travel Time, min	Head Wave: Sign & Height, cm	Head Wave: Period, min	Maximal Range of Oscillations in Level, cm
Miyako	42	+ 2	10	4
Kamaishi	?	–	–	5
Enoshima	32	+ 2	3	2
Ayukawa	38	+ 3	5	11
Onahama	44?	+ 1	15	3
Nakaminato	?	–	–	5
Choshi	?	–	–	4

Table 35 /113

Tide gauge data on the tsunami of 21.III.1960.

Observation Point	Travel Time, hr	Travel Time, min	Head Wave: Sign & Height, cm	Head Wave: Period, min	Maximal Range of Oscillations in Level, cm
Hanasaki	–	50	+ 7	20	12
Kushiro	–	46	+ 6	26	17
Urakawa	–	42	+13	12	46
Muroran	1	14?	–	–	20
Hakodate	1	10	+ 4	24	27
Hachinohe	–	43	–	–	–
Miyako	–	22	+22	25	32
Kamaishi	–	26	+14	20	28
Enoshima	–	40	4	10	9
Ayukawa	–	44	+10	8	40
Onahama	–	60	9	20	32

Table 36 /115

Tide gauge data on the tsunami of 23.III.1960.

Observation Point	Travel Time, min	Head Wave		Maximal Range of Oscillations in Level, cm
		Sign & Height, cm	Period, min	
Hanasaki	54?	+ 4	15	8
Kushiro	?	–	–	8
Urakawa	52?	+ 7	10	10
Hakodate	?	–	–	12
Miyako	28	+ 7	9	11
Kamaishi	38	+ 9	7	19
Enoshima	28	+ 3	10	3
Onagawa	46	+ 6	12	10
Ayukawa	44	+12	8	27
Onahama	56?	–	10	18

Table 37 /115

Tide gauge data on the tsunami of 30.VII.1960.

Observation Point	Travel Time,		Head Wave		Maximal Range of Oscillations in Level, cm
	hr	min	Sign & Height, cm	Period, min	
Hakodate	1	02?	+5	30	11
Kuji	–	22	+8	20	18
Miyako	–	22	–4	14	8
Ayukawa	–	?	–	–	6

Table 38 /116

Tide gauge data on the first tsunami of 16.I.1961.

Observation Point	Travel Time, min	Head Wave		Maximal Range of Oscillations in Level, cm
		Sign & Height, cm	Period, min	
Ayukawa	52	+6	8	34
Onahama	30	+6	10	40
Nakaminato	28	+5	12	13
Choshi	36?	+6	–	8

Table 39 /117

Tide gauge data on the third tsunami of 16.I.1961.

Observation Point	Travel Time, min	Head Wave		Maximal Range of Oscillations in Level, cm
		Sign & Height, cm	Period, min	
Ayukawa	54	+4	8	11
Onahama	32	+7	12	35
Nakaminato	30	+3	15	5
Choshi	36?	–	–	–

Table 40 /118

Tide gauge data on the tsunami of 27.II.1961.

Observation Point	Travel Time, hr	min	Head Wave: Nature of wave	Head Wave: Period, min	Maximal Range of Oscillations in Level, cm
Nase	01	12	rise	20	13
Nishinoomote	00	49	rise	–	25
Makurazaki	01	16	rise	16	13
Namimi	00	19	rise	–	12
Suzureishi	00	19	rise	–	12
Aburatsu	00	03	rise	22	45
Miyazaki	00	24	rise	–	12
Hosojima	00	11	rise	20	78
Hosojima (New port)	00	14	rise	–	124
Tokai	00	24	rise	18	13
Hebizaki	00	49	rise	19	10
Yawatahama	01	14	rise	22	28
Uwajima	01	01	rise	22	18
Hosogi	00	47	rise	20	17
Misyo	00	57	rise	30	70
Tosashimizu	00	31	rise	22	96
Tosashimoda	00	44	rise	20	10
Urado	00	57	rise	13	20
Kochi	01	04	rise	20	17
Kushimoto	00	35	rise	23	36
Aburatsubo	02	25	rise	16	6
Mera	02	21	rise	22	35
Hachijo Island	01	59	?	–	3

Table 41 /120

Tide gauge data on the tsunami of 12.VIII.1961.

Observation Point	Travel Time, hr	Travel Time, min	Head Wave: Sign & Height, cm	Head Wave: Period, min	Maximal Range of Oscillations in Level, cm
Hanasaki	–	30	–4	24	10
Kushiro	–	34	+3	26	10
Hiroo	–	44	+7	12	7
Hakodate	–	?	–	–	6
Kuji	1	05	+4	13	6

Table 42 /120

Tide gauge data on the tsunami of 15.XI.1961.

Observation Point	Travel Time, min	Head Wave: Sign & Height, cm	Head Wave: Period, min	Maximal Range of Oscillations in Level, cm
Hanasaki	31	+6	16	12
Kushiro	28	+3	16	6
Hiroo	40	+6	10	10
Urakawa	54?	+4	6	10
Hakodate	?	–	–	7
Miyako	?	–	–	4
Kamaishi	?	–	–	6

Table 43 /122

Tide gauge data on the tsunami of 12.IV.1962.

Observation Point	Travel Time, min	Head Wave		Maximal Range of Oscillations in Level, cm
		Sign & Height, cm	Period, min	
Miyako	34	+ 2	10	4
Kamaishi	29	+10	11	28
Tsukihama	32	+12	20	18
Onagawa	?	–	–	42
Ayukawa	30	+29	8	51
Matsukawa'ura	56	+18	8	26
Onahama	49	+ 5	18	28
Nakaminato	54	+ 5	15	7
Choshi	54	+ 3	14	8

Table 44 /123

Tide gauge data on the tsunami of 23.IV.1962.

Observation Point	Travel Time, min	Head Wave		Maximal Range of Oscillations in Level, cm
		Sign & Height, cm	Period, min	
Hanasaki	50	+4	16	6
Kushiro	26	+5	35	9
Hiroo	20	+3	12	12
Urakawa	48	+3	10	8
Hakodate	?	–	–	14
Kuji	58	+4	10	7
Miyako	?	–	–	4

Table 45 /124

Tide gauge data on the tsunami of 1.IV.1968.

Observation Point	Travel Time, hr	min	Head Wave: Sign & Height, cm	Head Wave: Period, min	Maximal Range of Oscillations in Level, cm
Kozu Island	1	17	5	15	19
Minamiizu*	1	28	6	–	20
Nagashima	–	56	+ 6	23	24
Owase	–	50	– 7	14	42
Urakami	–	41	+ 8	14	46
Kushimoto	–	42	+16	15	92
Shirahama	–	51	2	28	12
Wakayama	1	08	9	14	18
Komatsushima	1	06	+10	14	22
Muroto	–	33	+25	12	124
Urado	–	47	+11	20	38
Kamikawaguchi	–	30	+34	22	140
Tosashimoda	–	28	+14	15	30
Tosashimizu	–	21	+80	18	236
Sukumo	–	–	–	–	224
Uwajima	–	–	22	–	46
Yawatahama	–	52	+40	20	80
Oita	1	05	+12	23	22
Saganoseki	–	–	–	–	12
Usuki	–	50	+50	20	135
Tsukumi	–	40	35	22	62
Saeki	–	34	-32	18	65
Kitano'ura	–	–	–	–	150
Nobeoka	–	18	–	–	27
Hosojima	–	17	+44	20	132
Aburatsu	–	27	+24	20	66
Odomari	–	56	+26	12	80
Makurazaki	–	–	–	–	22
Nishinoomote	–	–	–	–	32
Nase	–	–	–	–	64
Attu Island (Aleutian Islands)	–	–	–	–	3

Table 46 /129

Data on the tsunami of 16.V.1968.

Observation Point	Travel Time, min	Maximal Rise of Water, m
Hokkaido Island		
Hanasaki	52	1.1
Akkeshi	–	0.8
Kushiro	38	2.3
Shiranuka	–	3.9
Tokachi River	–	0.2
Aiboshima	–	4.6
Hiroo	42	3.7
Oshirabetsu	–	2.8
Shoya	36	3.7
Cape Erimo	–	3.0
Horoizumi	–	3.0
Hirau	–	3.8
Samani	–	1.7
Urakawa	18	5.0
Mitsuishi	20	0.9
Harutachi	–	1.0
Higashishizunai	–	1.3
Seppu	16	1.2
Tomakomai	31	–
Muroran	45	0.8
Mori	56	1.0
Yamasedomari	26	2.0
Hakodate	50	2.0
Esashi	–	0.3
Aomori Prefecture		
Aomori	–	0.4
Yokohama	–	0.1
Kawauchi	–	0.7
Oma	–	1.1
Ohata	–	2.2
Cape Shiriya	–	2.2
Odanozawa	–	2.7
Shiranuka	–	0.9
Tomari	–	2.5
Obuchi	–	1.4
Shiogama	–	5.1
Mukawame	–	2.1
Yokawame	–	4.0
Mikawame	–	1.7
Momoishi	–	4.0
Hachinohe	33	2.6–3.7
Tanesashi	–	3.2

Table 46 (continued)

Data on the tsunami of 16.V.1968.

Observation Point	Travel Time, min	Maximal Rise of Water, m
Kofunato	–	2.6
Iwate Prefecture		
Taneichi	–	5.0
Yagi	–	2.6
Kuji	–	3.7
Noda	–	4.6
Horiuchi	–	3.4
Otanabe	–	2.7
Raga	–	3.7
Shimanokoshi	27	1.3
Omoto	–	1.5
Moshi	–	1.5-2.0
Masaki	–	1.3
Taro	28	1.2-1.5
Miyako	28	2.0-4.0
Omoe	–	3.5
Yamada	–	0.9-2.2
Funakoshi	–	3.4-3.7
Ozuchi	–	2.6-3.8
Ryoishi	–	2.0
Kamaishi	–	2.0-3.5
Heita	–	3.5
Kozirahama	–	1.1-2.6
Yoshihama	–	1.6
Urahama	–	1.5-1.8
Nagasaki	–	1.0
Ofunato	39	0.9
Osabe	–	1.5
Miyagi Prefecture		
Tadagoshi	–	0.8-1.6
Kesennuma	40	0.7
Ooya	–	0.7
Isatomae	–	2.5
Shizukawa	–	1.2-1.8
Terahama	–	2.8
Aikawa	–	1.6
Tsukihama	40	1.7
Onagawa	50	1.3
Nonohama	–	2.0
Yakawa	–	3.0
Niiyama	–	3.2
Ayukawa	53	0.8
Ishinomaki	–	0.5-0.9

Table 47 /131

Tide gauge data on the first tsunami of 16.V.1968.

Observation Point	Travel Time, hr	min	Head Wave: Sign & Height, cm	Period, min	Maximal Amplitude of Oscillations in Level, cm
Hanasaki	–	52	+ 59	20	55
Akkeshi	–	–	+ 30	–	25
Kushiro	–	38	+130	42	98
Hiroo	–	42	+170	20	(150)
Urakawa	–	18	– 36	12	84
Muroran	–	45	– 6	42	30
Mori	–	56	– 10	8	44
Yamasedomari	–	26	– 6	10	88
Hakodate	–	50	– 3	36	80
Matsumae	–	–	–	–	11
Esashi	–	–	–	–	5
Asamushi	1	24	+ 18	16	19
Ominato	–	–	–	–	11
Iwasaki	–	–	+ 6	26	8
Hachinohe	–	33	– 54	21	(240)
Kabushima Island	–	27	– 40	20	235
Shimanokoshi	–	27	+203	–	–
Taro	–	28	+162	14	145
Miyako	–	28	+185	23	232
Okkirai	–	32	+146	23	230
Ofunato	–	39	+122	18	145
Nagasaki	–	36	+113	12	114
Kesennuma (Minegasaki)	–	44	+ 94	14	118
Kesennuma (O'ura)	–	38	+118	46	93
Tsukihama	–	40	+118	20	–
Onagawa	–	50	+100	32	–
Enoshima	–	44	+ 57	10	56
Ayukawa	–	53	+120	8	105
Matsukawa'ura	1	20	+ 57	22	36
Onahama	1	07	+ 39	17	55
Hitachi	1	14	+ 38	28	65
Choshi	1	03	+ 40	26	31
Katsu'ura	–	–	–	–	5
Yokosuka	1	30	+ 7	52	6
Kanaya	1	22	+ 5	66	5
Minamiizu*	1	24	+ 6	26	9
Miyake Island	1	10	+ 4	–	7
Nagashima	2	06	+ 10	36	14
Owase	1	50	+ 10	16	26

Table 48 /134

Data of remote tide gauges on the tsunami of 16.V.1968.

Observation Point	Maximal Range of Oscillations in Level, cm
Aleutian Islands and Alaska	
Attu Island	30
Adak Island	15
Unalaska Island	9
Sitka	6
West Coast of USA	
Neah Bay	9
Crescent City	123
San Francisco	9
Alameda	6
Avila	6
Rincon Island*	6
Santa Monica	30
Los Angeles, berth 60	15
Long Beach	21
Newport Beach	6
La Jolla	6
San Diego	15
Hawaiian Islands	
Midway Islands	48
Nawiliwili	12
Mokuoloe Island	9
Kahului	100
Hilo	57
Oceania	
Wake Island	15
Johnston Island	6
Apra, Guam Island	6
Kwajelein Island	9
Moen Island*, Truk Islands	6
Pago Pago, Samoa Islands	15

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Tide gauge data on the second tsunami of 16.V.1968.

Observation Point	Travel Time, min	Mean Period of Waves, min	Maximal Amplitude of of Oscillations in Level, cm
Hiroo	36	10	58
Urakawa	28	8	55
Muroran	58	17	28
Hachinohe	40	8	48
Miyako	36	10	52
Ofunato	48	10	23
Enoshima	56	8	14
Ayukawa	60	–	–

Table 50 /137

Tide gauge data on the tsunami of 12.VI.1968.

Observation Point	Travel Time, hr	Travel Time, min	Head Wave: Sign & Height, cm	Head Wave: Period, min	Maximal Amplitude of Oscillations in Level, cm
Hanasaki	–	58?	+ 2	20	6
Kushiro	–	?	–	–	5
Urakawa	–	46	– 8	12	29
Muroran	1	20?	+ 2	8	3
Hakodate	–	60?	+ 3	30	8
Same	–	48	– 4	8	17
Minato	–	50	7	10	18
Shimanokoshi	–	26	–26	8	78
Miyako	–	22	– 6	10	21
Kamaishi	–	22	– 5	9	13
Nagasaki	–	28	+13	10	7
Ofunato	–	33	+22	18	15
Enoshima	–	33	+19	7	16
Matsukawa'ura	1	11?	+10	10	15
Onahama	–	58	+ 2	10	15

Table 51

Effects of the earthquake of 7.III.1927.

Prefecture	Population			Homes			
	Dead	Injured	Lost	Completely Destroyed	Partly Destroyed	Burned Down	Partly Burned Down
Kyoto, including districts of	2,991	3,136	5	10,452	9,539	4,961	115
Yosa	551	637	–	3,763	3,380	810	25
Naka	1,635	1,338	5	3,080	2,811	2,771	36
Takano	799	1,100	–	3,133	2,077	1,378	54
Kumano	6	61	–	476	1,271	2	–
Osaka	21	127	–	121	113	–	–
Hiogo	4	17	–	56	169	–	–
Nara	1	3	–	–	–	–	–
Tottori	–	–	–	3	–	–	–
Shiga	–	2	–	1	–	–	–
Total	3,017	3,295	5	10,633	9,821	4,961	115

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Rise of water on 7.III.1927 at different places.

Observation Point	Height, m	Observation Point	Height, m
Kyoto Prefecture		Iso	1.5
Oshima	0.3	Hamazume	1.2
Tomari	1.2	Kazurano	1.5
Kyuso	1.5	Minato	1.2
Nakano	1.2	Hiogo Prefecture	
Taiza	1.2	Tsuiyama	0.3
Mizu	1.2	Takuhi*	1.5
Kakezu	1.5	Takeno*	0.9
Amino	1.0		

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Tide gauge data on the tsunami of 1.V.1939.

Observation Point	Travel Time, min	Head Wave	
		Sign & Height, cm	Period, min
Ajigasawa	32	− 5	24–26
Noshiro	32	+ 5	60?
Tsuchizaki	19	+17	9–12
Sakata	40	+10	17–20

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Data on the tsunami of 2.VIII.1940 at Mooi.

Time, hr	Time, min	Level of Flood, m	Level of Ebb, m	Period of Tsunami Waves, min
4	–	+1.2	−0.9	14
4	30	+1.1	−0.5	20
5	–	+0.5	−0.6	20
6	–	+1.2	−0.5	20
6	30	+0.7	−0.6	20
9	–	+0.4	−0.5	20

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Tide gauge data on the tsunami of 2.VIII.1940.

Observation Point	Travel Time, hr	min	Period of Head Wave, min	Maximal Amplitude of Oscillations, cm
Nevel'sk	1	09	18	50
Tetyukhe	–	34	–	–
Ishikari	1	05	15	34
Otaru	–	42	10	–
Oshoro	–	32	23	16
Iwanai	–	14	20	86
Sakata	1	22	17	15
Niigata	1	33	10	10
Wajima	1	42	21	7
Najin	1	32	8	25

Table 56 /155

Tide gauge data on the tsunami of 7.V.1964.

Observation Point	Travel Time, min	Head Wave: Sign & Height, cm	Head Wave: Period, min	Maximal Range of Oscillations in Level, cm
Oshoro	85	+ 4	26	10
Esashi	40	+ 5	12	23
Matsumae	–	+ 7	–	55
Fukushima	38	+12	11	26
Fuka'ura	–	+ 5	–	17
Iwasaki	14	+10	12	30
Noshiro	30	–	–	–
Funakawa	32	+11	12	18
Funakoshi	40	+10	14	–
Akita	40	+ 9	18	21
Tsuchizaki	43	–	–	19
Sakata	42	+ 4	18	20
Iwafune	67	+20	–	47
Nezugaseki	50	+ 5	8	16
Niigata	55	+ 3	17	23
Naoetsu	82	+ 4	–	20
Ryotsu	62	+ 7	–	18
Wajima	47	+ 2	–	6

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Tide gauge data on the tsunami of 16.VI.1964.

Observation Point	Travel Time, hr	min	Head Wave: Nature & Height, cm	Head Wave: Period, min	Maximal Range of Oscillations in Level, cm
Wakkanai	3	14	+ 4	–	27
Oshoro	1	53	+ 4	28	26
Esashi	–	54	+ 4	27	59
Fukushima	–	57	4	23	60
Hakodate	2	39	+ 4	–	80
Aomori	1	54	+ 4	–	32
Iwasaki	–	–	+ 5	17	78
Funakawa	–	43	+20	55	184
Tsuchizaki	–	59	+	20	65
Sakata	–	26	+42	15–40	70
Kamo	–	14	fall	20–50	127
Katsugi	–	–	rise	–	271
Neya	–	11	rise	–	395
Iwafune	–	15	rise	–	302
Shioya	–	20	fall	–	389
Matsugasaki	–	18	+34	28	142
Ogi	–	39	fall	–	129
Suizu	–	27	rise	21	255
Okawa	–	25	rise	20	173
Shiidomari	–	30	fall	–	171
Sumiyoshi	–	20	rise	–	177
Waki	–	60	fall	20	123
Sawane	–	19	fall	10	82
Naoetsu	–	59	+28	28	138
Toyama	–	56	+19	20	52
Wajima	1	16	+32	21	65
Mikuni	1	16	+13	23	48
Tsuruga	1	58	+ 9	23	76
Maizuru	2	08	+ 4	20	82
Saigo	1	48	+ 4	24	56
Hamada	2	18	3	22	33
Pos'et	2	09	3	20	6
Vladivostok	2	29	3	30	22
Nakhodka	1	39	8	35	22
Tetyukhe	–	–	(6)	–	12
Ternei	–	–	(4)	–	6
Adimi	2	16	1.5	(80)	3
Kholmsk	–	–	–	–	7
Nevel'sk	–	–	–	–	6
Cape Kril'on	–	–	–	–	(4)
Korsakov	–	–	–	–	(4)

Table 58 /168

Rise of water on 24.IV.1771 on Ryukyu Islands.

Observation Point	First Wave	Second Wave	Third Wave
Miyako	10.5m (35 feet?)	7.5m (25 feet?)	3.6-3.9m (12-13 feet?)
Ishigaki	11.4m (38 feet?)	8.4m (28 feet?)	4.5-4.8m (15-16 feet?)

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Tide gauge data on the tsunami of 18.VII.1961.

Observation Point	Travel Time, hr	Travel Time, min	Head Wave: Sign & Height, cm	Head Wave: Period, min	Maximal Range of Oscillations in Level, cm
Kikaigashima Island	–	28	+6	7	16
Nase	–	44	–4	10	10
Makurazaki	1	02?	+2	10	4
Aburatsu	–	36	–4	18	12
Hosojima	–	52?	+4	6	10
Tosashimizu	–	54	–8	6	20

Table 60 /176

Parameters of tsunamis caused by explosions of the Miyojin submarine volcano and registered by the tide gauge on Hachijo Island (Unoki, Nakano, 1953 c).

Date and Time of Occurrence, date	hr	min	Wave Period, sec	Height, cm
September 1952				
16	12	20	96	56
24	12	53	(93)	92
26	13	03	86	71
March 1953				
11	–	–	–	58
12	16	09	88	55
14	10	03	92	57
	14	11	68	27
	16	47	73	32
	18	40	70	30
15	03	49	72	36
	13	08	84	31
	15	16	74	25
	17	15	91	33
	18	42	83	36
	22	09	100	32
16	00	24	78	24
	00	49	93	33
	03	47	90	32
	07	34	88	50
	09	37	76	28
	11	23	78	29
	13	43	108	35
	18	46	75	37
17	02	24	58	36
	04	40	92	47
	12	36	86	42
	15	45	77	63
	19	18	90	48
	21	51	100	30
18	00	15	107	30
	02	44	83	30
	03	56	71	28
	11	06	69	25
	14	07	85	34
	16	25	88	27
	19	27	91	28
	21	39	86	40
	22	15	96	37

Table 60 (continued)

Parameters of tsunamis caused by explosions of the Miyojin submarine volcano and registered by the tide gauge on Hachijo Island (Unoki, Nakano, 1953 c).

Date and Time of Occurrence, date	hr	min	Wave Period, sec	Height, cm
March 1953				
19	02	05	95	40
	05	06	69	42
	10	35	74	32
	13	16	102	28
	16	33	76	34
	20	15	95	60
20	00	42	85	47
22	21	08	106	57
23	02	23	95	58
	13	56	119	38
25	01	02	95	50
	07	13	93	54

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Seismic activity preceding the explosion of the Hibokhibok volcano on Camiguin Island. From the records of the elder of Catarman, analyzed by Maso (1911 b).

Month	Date	Nature of Shocks	Maximal Intensity in Degrees
February	16	Two weak shocks.	
	17	Frequent shocks during the day & at night.	
	18	The same.	7 (VIII R-F)
	19	The same.	6 (VII R-F)
	20	The same.	
	21	The same.	8 (IX R-F)
	22	The same.	7 (VIII R-F)
	23-28	The same.	
March	1-3	The same.	
	4	The same.	5 (VI R-F)
	5-7	Less frequent, but still at least 10 times per day.	
	8	The same.	5 (VI R-F)
	9	The same.	
	10	The same.	
	11-13	The same.	
	14-17	Still less frequent, 4-5 times per day.	
	18-19	More frequent and stronger than on the preceding days.	
	20-31	Less frequent, but no more often than 6 times per day.	
April	1-29	Frequent, 6-10 times per day.	

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Tide gauge data on the tsunami of 15.VIII.1918.

Observation Point	Travel Time, hr	min	Range, cm	Period, min	Relative Time of Onset, hr	min	Duration, hrs
Hosojima	4	06	13	20	11	30	22.5
Kushimoto	4	12	40	22	3	25	28

Table 63

Tide gauge data on the tsunami of 2.VIII.1968.

Observation Point	First Wave: By Calculation — Travel Time, hr	min	Height of Crest, cm	Period, min	First Wave: from Record — Travel Time, hr	min	Height of Crest, cm	Period, min	Maximal Oscillation in Level: Range, cm	Delay Relative to Calculated Front, hr	min	Second Largest Oscillation: Range, cm	Delay Relative to Calculated Front, hr	min
Nase	2	23	3	10	3	57	6	14	12	2	16	10	3	40
Nishinoomote	2	28	2	16	–	–	–	–	4	2	28	–	–	–
Aburatsu	2	54	4	20	–	–	–	–	16	6	30	10	2	20
Hosojima	3	10	3	–	–	–	–	–	4	2	40	–	–	–
Kamae	3	06	6	20	3	06	6	20	12	5	33	–	–	–
Tosashimizu	3	06	3	–	3	49	10	20	16	2	50	–	–	–
Kochi	–	–	–	–	–	–	–	–	6	–	–	–	–	–
Muroto	2	51	4	8	3	04	7	15	27	2	20	21	5	10
Shirahama	3	00	2	–	3	51	4	32	6	2	23	–	–	–
Kushimoto	2	51	4	15	3	41	6	12	28	3	30	26	5	35
Urakami	3	01	3	10	4	03	7	15	12	2	56	–	–	–
Owase	3	19	4	12	4	11	6	16	12	3	01	–	–	–
Nagashima	–	–	–	–	–	–	–	–	8	–	–	–	–	–
Toba	–	–	–	–	–	–	–	–	4	–	–	–	–	–
Cape Omae	3	33	4	12	4	41	6	10	24	3	28	–	–	–
Minamiizu*	3	16	4	8	4	11	4	8	18	5	45	16	2	30
Kozu Island	3	19	3	8	4	28	6	7	16	3	02	–	–	–
Mera	3	38	4	16	4	36	5	18	27	3	06	14	6	23
Choshi	–	–	–	–	–	–	–	–	20	–	–	–	–	–
Onahama	4	15	2	22	4	41	4	22	13	7	58	11	4	05
Ayukawa	–	–	–	–	5	49	5	8	13	–	–	–	–	–
Kesennuma	–	–	–	–	–	–	–	–	12	–	–	–	–	–
Hachinohe	–	–	–	–	–	–	–	–	5	–	–	–	–	–
Urakawa	–	–	–	–	–	–	–	–	14	–	–	–	–	–
Hiroo	–	–	–	–	–	–	–	–	10	–	–	–	–	–
Kushiro	–	–	–	–	–	–	–	–	6	–	–	–	–	–
Hanasaki	–	–	–	–	–	–	–	–	5	–	–	–	–	–

Table 64 /229

Effects of the earthquake and tsunami of 30.IX.1899 on the coast of Elpaputi Bay.

Place	Number of Dead	Number of Injured	Estimated Losses in Guldens	Comments
Latu	–	–	–	
Uwalohi	52	–	–	
Tumaleu				
Sanau	–	–	–	
Paulohi	900	120	4,000	School and kirk destroyed.
Samasuru	650	40?	500?	Kirk destroyed.
Mani	48			
Sahulau	–	–	250	The same.
Liang	1	–	300	The same.
Rumalait	54	31	1,000	The same.
Tananau	–	–	350	The same.
Apisano	6	–	250	The same.
Waija	20	16	500	
Waraka	170	6	3,000	Kirk destroyed.
Rumasosal	81	–	2,500	The same.
Makariki	68	27	10,000	School and kirk destroyed.
Djalahatona	62	–	2,500	Kirk destroyed.
Amahai	348	60	70,000	

Table 65 /230

Effects of the earthquake and tsunami of 30.IX.1899 on the coast of Teluti Bay.

Place	Number of Dead	Number of Injured	Estimated Losses in Guldens	Comments
Tehoro	600	30	15,000	
Telutilama	–	–	–	
Wolu	250	49	15,000	
Hela	–	–	–	
Namiang	7	–	–	
Latumula	50	–	–	
Tehuwa	67	22	500	
Laimu	260	83	15,000	
Humusi	36	–	250	Kirk destroyed.
Laha	–	–	250	The same.

Table 66

Tide gauge data on the tsunami of 10.VIII.1968.

Observation Point	Head Wave: Travel Time, hr	Head Wave: Travel Time, min	Head Wave: Height of Crest, cm	Head Wave: Period, min	Maximal Oscillation in Level: Range, cm	Maximal Oscillation in Level: Delay Relative to Calculated Front, hr	Maximal Oscillation in Level: Delay Relative to Calculated Front, min	Second Largest Oscillation: Range, cm	Second Largest Oscillation: Delay Relative to Calculated Front, hr	Second Largest Oscillation: Delay Relative to Calculated Front, min
Nase	–	–	–	–	10	2	–	–	–	–
Nishinoomote	–	–	–	–	5	–	–	–	–	–
Aburatsu	4	33	3	18	6	4	03	6	7	10
Hosojima	–	–	–	–	4	–	–	–	–	–
Kamae	5	03	7	16	15	3	55	–	–	–
Tosashimizu	4	58	7	15	18	3	42	12	8	00
Kochi	–	–	–	–	6	–	–	–	–	–
Muroto	4	55	6	14	16	3	30	–	–	–
Shirahama	–	–	–	–	5	–	–	–	–	–
Kushimoto	4	55	6	15	20	4	03	18	7	16
Urakami	5	05	10	18	40	9	00	–	–	–
Owase	5	21	10	14	22	5	13	–	–	–
Nagashima	5	33	6	30	16	3	16	–	–	–
Toba	–	–	–	–	6	–	–	–	–	–
Cape Omae	–	–	–	–	22	–	–	–	–	–
Minamiizu	–	–	–	–	18	–	–	–	–	–

List of Basic Tsunami Parameters.
Tsunamis caused by earthquakes.

Date			Coordinates of Focus (or Site of Phenomenon)					
Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earth-quake, M	Authenticity of Tsunami[1]	Tsunami Intensity, I
Alaska-Aleutian Island Arc								
1788	VII	22(11)	54° N.	160° W.	–	8	D	4
1820	III	1-3	Umnak I.		–	–	P	0.5
1854	I	28(16)	Kodiak I.		–	–	L	0.5
1868	V	15	Unga I.		–	–	L	2.5
1878	VIII	29	Unalaska I.		–	–	P	1.5
1901	XII	30	52° N.	177° W.	–	7.8	Q	–
1911	IX	21	60.5	149	60	7	P	0.5
1925	II	23	62	146	–	6	P	1
1929	III	6	51	170	50	8	D	–
1938	XI	10	55.5	158	–	8.25	D	–
1946	IV	1	53.5	163	–	7.5	D	4
1946	XI	1	51.5	174.5	40	7	Q	–
1949	IX	27	59.75	149	50	7	E	–
1957	III	9	51.3	175.8	–	7.9	D	3

[1] Evaluated on a five-point scale: D – definite (the tsunami was registered on at least one tide gauge or there were many reliable visual observations; L – likely (there were a few comparatively reliable observations); P – possible (from available data, it is difficult to judge whether it was a tsunami or some other phenomenon, such as a seiche, a seaquake, wind tide, etc., which was observed); Q – questionable (the description suggests that an event other than a tsunami may have taken place, but the possibility of a tsunami is still not entirely excluded); E – erroneous reference to a tsunami which has entered the scientific literature.

Date			Coordinates of Focus (or Site of Phenomenon)					
Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earth-quake, M	Authenticity of Tsunami[1]	Tsunami Intensity, I
1964	III	28	61	147.8	33	8.6	D	3.5
1965	II	3	51.2° N.	178.6° E.	40	8.7	D	2.5
1965	III	29	50.6	177.8	50	7.5	D	-1
1965	VII	2	53° N.	167.6° W.	60	7.6	D	-2
Japanese Island Arc-Hokkaido Island. South Coast								
1856	VIII	23	42° N.	141.1° E.	-	6.9	D	2
1881	X	25	Kunashir I.- Kushiro		-	-	P	1.5
1894	III	22	42.3° N.	145.1° E.	-	7.9	D	1.5
1938	V	29	43.6	144.3	20	8	E	-1
1952	III	4	42.2	143.8	45	8.25	D	2
1952	III	10	41.7	143.5	0-20	7.25	L	-2
1961	VIII	12	42.8	145.6	80	7.3	D	-4
1961	XI	15	42.7	145.6	60	7	D	-3.5
1962	IV	23	42.2	143.9	60	6.75	D	-3.5
Honshu I. East Coast								
869	VII	13	38.5° N.	143.8° E.	-	8.6	D	4
1088	V	13	Miyako		-	-	L	1.5
1257	X	9	35.2° N.	140.9° E.	-	7	P	1
1605	I	31	34.3	140.4	-	7.9	D	4
1611	XII	2	38.2	143.9	-	8.1	D	4
1616	IX	9	38.1	142	-	7	L	1
1616	XII	6	Sanriku		-	-	L	1
1662	X	20	Rikuchu		-	-	Q	0
1677	IV	13	38.7° N.	144° E.	-	8.1	L	2

Date			Coordinates of Focus (or Site of Phenomenon)					
Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earthquake, M	Authenticity of Tsunami[1]	Tsunami Intensity, I
1677	XI	4	34.7° N.	141.2° E.	–	7.4	L	2.5
1680	IX	28	Totomi-Nada		–	–	P	2
1703	XII	31	34.7° N.	139.8° E.	–	8.4	D	3
1763	I	29	40.8	142	–	7.4	L	2
1763	III	15	40.7	142	–	7.1	L	1
1793	II	17	38.3	142.4	–	7.1	D	2
1835	VII	20	37.9	141.9	–	7.6	D	2
1835	VIII	19	37.9	141.9	–	7.6	Q	2
1836	IX	5	37.9	142	–	5.9	Q	1
1839	V	1	Tsugaru Pen.		–	7.3	E	–
1846	III	–	Sanriku		–	–	P	1
1850	VII	20	Rikuchu		–	–	Q	0
1861	X	21	37.7° N.	141.6° E.	–	6.4	L	2
1896	I	9	36	141	–	7.3	D	-2.5
1896	VI	15	39.6	144.2	–	7.6	D	3.75
1897	II	20	38.1	141.5	–	7.8	D	0
1897	VIII	5	38	143.7	–	7.7	D	1
1898	IV	23	39.5	143.6	–	7.8	D	-3
1901	VIII	9	40.5	141.5	–	7.7	D	-0.5
1901	VIII	10	40.5	141.5	–	7.8	D	-1
1912	VI	8	39.3	143.3	–	6?	P	0
1915	XI	1	39	142.5	–	7.5	L	0.5
1923	VI	2	35.75	141.75	–	7.25	D	-1.5
1923	IX	2	35	139.5	–	7.7	D	-1.5
1927	VIII	6	38	142	20	7	D	-3
1927	VIII	19	34.2	142	–	6.75	D	-2
1928	V	27	40	143.2	0-10	7	D	-2.5
1931	III	9	41.2	142.5	0	7.5	D	-2

Date			Coordinates of Focus (or Site of Phenomenon)					
Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earth-quake, M	Authenticity of Tsunami[1]	Tsunami Intensity, I
1933	III	3	39.1° N.	144.7° E.	0–20	8.5	D	3.5
1933	VI	19	38.1	142.3	20	7.25	D	-3
1935	VII	19	36.7	141.3	0	6.75	D	-3
1935	X	13	40	143.6	40	7.2	D	-2.5
1935	X	18	40.3	144.2	20–40	7.25	D	-3
1936	XI	3	38.2	142.2	50–60	7.5	D	-1.5
1938	V	23	36.7	141.4	10	7.5	D	-1
1938	XI	5	37.1	141.7	20	7.75	D	-0.5
1938	XI	5	37.2	141.7	15	7.5	D	-0.5
1938	XI	6	37.5	141.8	0	7.5	D	-0.5
1938	XI	7	37	141.7	0	7	D	-0.5
1938	XI	14	37	141.5	60	7	D	-1.5
1938	XI	22	37	141.8	10	6.75	D	-2.5
1938	XI	30	37	141.8	5	7	D	-3
1943	VI	13	41.1	142.7	20	7	L	-0.5
1945	II	10	40.9	142.1	30	7.25	L	-1.5
1953	XI	26	34.3	141.8	40–60	7.5	D	1.5
1959	I	22	37.5	142.3	30	7.25	D	-2
1959	X	26	37.6	143.2	20	6.5	D	-4
1960	III	21	39.8	143.5	20	7.5	D	-2
1960	III	23	39.3	143.8	20	7.25	D	-2.5
1960	VII	30	40.2	142.6	30	7	D	-3
1961	I	16	36	142.3	40	7.25	D	-2
1961	I	16	36	141.9	20	6.25	L	-2
1961	I	16	36.2	142.0	20	7	D	-2
1962	IV	12	38	142.8	40	7.5	D	-2
1968	V	16	40.7	143.6	0	8	D	2
1968	V	16	41.4	142.9	40	7.5	D	-0.5

Date			Coordinates of Focus (or Site of Phenomenon)					
Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earthquake, M	Authenticity of Tsunami[1]	Tsunami Intensity, I
1968	VI	12	39.4° N.	143.1° E.	0	7.2	D	0
Honshu, Shikoku, Kyushu Islands. South coast.								
684	XI	27	32.5° N.	134° E.	–	8.4	L	3
818	VIII	–	35.2	139.3	–	7.9	P	1
887	VIII	26	33	135.3	–	8.6	L	3?
922	–	–	33.8	136.7	–	7	P	1
1096	XII	17	34.2	137.3	–	8.4	L	2
1241	V	22	35.3	139.3	–	7	L	1
1360	XI	22	33.4	135.2	–	7	L	2
1361	VIII	3	33	135	–	8.4	D	3
1403	XII	–	33.7	136.5	–	7	Q	1
1408	I	21	33.8	136.9	–	7	P	1
1433	XI	7	34.9	139.5	–	7.1	L	1
1495	IX	12	35.5	139.2	–	–	L	2
1498	IX	20	34.1	138.2	–	8.6	D	3
1510	IX	21	34.6	135.7	–	6.7	P	0
1520	IV	4	33.6	136.3	–	7	L	1
1545	II	7	Izu Pen.		–	–	P	0
1586	I	18	36° N.	136.8° E.	–	7.9	P	1
1596	IX	1	33.3	131.7	–	6.9	L	2
1633	III	1	35.6	139.2	–	7.1	L	1
1662	X	31	31.7	132	–	7.6	L	2.5
1666	V	31	Ise Bay		–	–	P	1
1707	X	28	33.2° N.	135.9° E.	–	8.4	D	4
1708	II	13	Ise Bay		–	–	P	0
1711	XII	20	34.3° N.	134° E.	–	6.7	P	1

Date			Coordinates of Focus (or Site of Phenomenon)					
Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earth-quake, M	Authenticity of Tsunami[1]	Tsunami Intensity, I
1715	XII	29	N.E. Kyushu I.		–	–	?	–
1769	VIII	29	32.3° N.	132° E.	–	7.4	Q	0
1782	VIII	22	35.1	139.7	–	7.3	L	1
1791	IX	13	Osaka		–	–	Q	1
1792	VIII	29	34.5° N.	136.7° E.	–	–	P	0
1808	VIII	8	Shikoku I., Tokushima		–	–	L	0.5
1828	V	26	37.6° N.	138.9° E.	–	6.9	Q	0
1845	IX	–	Nagasaki		–	–	Q	0
1854	XII	23	34.1° N.	137.8° E.	–	8.4	D	3
1854	XII	24	33.2	135.6	–	8.4	D	2.5
1855	XI	11	35.8	139.8	–	6.9	Q	0
1895	V	25	Nagasaki		–	–	Q	0.5
1899	X	7	Togonoura		–	–	P	1
1899	XI	25	Kyushu I., Hosojima		–	–	D	-2
1914	I	12	31.1° N.	130.4° E.	50	6.75	L	-1
1923	IX	1	35.25	139.5	–	8.25	D	3
1929	V	22	31.7	132.2	30	7.1	L	0
1931	XI	2	32.2	132.1	20	7.5	D	-1
1939	III	20	32.3	131.7	10	6.5	P	0
1941	XI	19	32.6	132.1	0–20	7.4	D	0
1944	XII	7	33.7	136.2	0–30	8	D	2.5
1945	I	13	34.7	137	0	7	L	-0.5
1946	XII	21	33	135.6	30	8.25	D	2.5
1948	IV	18	33.1	135.6	40	7.25	D	-1
1956	VIII	13	33.8	138.8	40–60	6.5	E	-1
1961	II	27	31.6	131.8	40	7	D	-0.5
1965	IV	20	34.9	138	36	6	E	-4
1968	IV	1	32.3	132.5	30	7.75	D	1

Date			Coordinates of Focus (or Site of Phenomenon)					
Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earthquake, M	Authenticity of Tsunami[1]	Tsunami Intensity, I
1968	VIII	5	33.3° N.	132.2° E.	43	6.5	L	0
Hokkaido I. North coast.								
1956	III	6	44.3° N.	144.1° E.	0–20	6	D	-2
Hokkaido and Honshu I. West coast.								
701	V	12	35.6° N.	135.4° E.	–	7	L	2
850	XI	27	39.1	140	–	7.9	P	1
887	VIII	2	37.5	138.1	–	6.5	P	1
1614	XI	26	37.5	138	–	7.7	P	1
1644	X	18	39.4	140.1	–	6.9	P	1
1762	X	31	38.1	138.7	–	6.6	P	1
1792	VI	13	43.6	140.3	–	6.9	L	1
1793	II	8	40.7	140	–	6.9	L	2
1799	VI	29	36.6	136.6	–	6.4	P	1
1802	XII	9	37.8	138.4	–	6.6	Q	–
1804	VII	10	39	140	–	7.1	L	1
1810	IX	25	39.9	139.9	–	6.6	P	0
1828	XII	18	37.6	138.9	–	6.9	E	–
1833	XII	7	38.7	139.2	–	7.4	D	2.5
1834	II	9	43.3	141.4	–	6.4	L	1
1863	IX	20	Hokkaido I., Teshio		–	5.9	P	0
1872	III	14	34.8° N.	132° E.	–	7.1	L	1
1892	XII	9	37	136.75	–	6.5	P	0
1927	III	7	35.6	135.1	10	7.5	D	0.5
1939	V	1	40	139.8	0	7	D	0

Date			Coordinates of Focus (or Site of Phenomenon)					
Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earth-quake, M	Authenticity of Tsunami[1]	Tsunami Intensity, I
1940	VIII	2	44.1° N.	139.5° E.	0-20	7.5	D	1.5
1947	XI	4	43.8	141	–	7	D	1
1964	V	7	40.5	139.1	0	7	D	0
1964	V	8	40.4	139	0	6.6	L	-3
1964	VI	16	38.3	139.2	40	7.5	D	2
1964	XII	11	40.4	138.9	40	6.25	D	-3
Ryukyu – Taiwan Island Arc. – Ryukyu Islands.								
1768	VII	22	36.2° N.	127.5° E.	–	–	L	1
1771	IV	24	24	124.3	–	7.4	D	3
1791	V	13	32.8	130.3	–	–	L	2.5
1853	X	3	Okinawa I.		–	–	P	1
1858/59	–	–	Okinawa I.		–	–	Q	–
1865	III	1	Okinawa I.		–	–	P	0.5
1876	X	26	Okinawa I.		–	–	P	1
1901	VI	24	28.3° N.	129.3° E.	–	7.9	P	-1.5
1911	VI	15	29	129	160	8.9	P	1.5
1938	VI	10	25.3	125.2	–	7.6	L	0
1961	VII	18	30.2	131.8	80	7	D	-3
Taiwan I.								
1661	1	8/9	Taiwan I.		–	–	P	1.5
1754	IV	–	Tanshui		–	–	P	0.5
1782	V	22	Taiwan I.		–	–	P	2.5
1867	XII	18	25.2° N.	121.7° E.	–	7?	D	2

Date			Coordinates of Focus (or Site of Phenomenon)					
Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earth-quake, M	Authenticity of Tsunami[1]	Tsunami Intensity, I
1903	IX	7	Taiwan I.		–	–	Q	0
1917	V	6	23.2° N.	121.6° E.	–	5.8	D	-0.5
1963	II	13	21.5	122.3	–	7.3	D	-2
1966	III	13	24.2	122.6	48	7.5	L	0
Coast of Asian Continent.								
173	VI-VII	–	37.5° N.	120° E.	–	–	P	1
1509	VI-VII	–	31.5	121.5	–	–	P	0
1580	I	–	Korea, Kogen Do		–	–	Q	1
1640	IX	16	23° N.	117° E.	–	–	P	1
1643	VII	25	35.5	129.5	–	–	P	1
1649	XII	9	Korea, Cholla Do		–	–	P	1
1668	VII	31	38° N.	126° E.	–	–	P	1.5
1670	VIII	19	31.5	121.5	–	–	P	1.5
1681	VI	12	Korea, East Coast, Yanya & Sanchok		–	–	Q	–
1765(67)	–	–	Guanghzhou – Aomen		–	6	P	2?
1700	IX	12	36.5° N.	126.5° E.	–	–	P	1
1917	I	25	24.5	118	–	–	P	1
Nampo, Mariana, Caroline, Marshall Islands.								
1826	I	–	Chichishima I.		–	–	L	2.5
1849	I	25	Guam I.		–	7.5	L	2
1872	–	fall	Chichishima I.		–	–	L	2
1892	V	16	Guam I.		–	7.5	L	0.5
1903	II	–	Guam I.		–	–	D	2
1912	XI	1	7° N.	138° E.	–	7	Q	0

Date			Coordinates of Focus (or Site of Phenomenon)					
Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earthquake, M	Authenticity of Tsunami[1]	Tsunami Intensity, I
1912	XII	6	Yap I.		–	7	Q	0.5
Philippine Archipelago – Northwest.								
1627	IX	–	Bangui		–	8?	L	3.5
1645	XI	30	N.W. Luzon I.		–	8?	Q	–
1677	XII	7	14.5° N.	120.5° E.	–	–	P	1
1744	–	–	North of Luzon I.		–	–	P	1
1770	XII	–	Manila		–	–	Q	0
1828	XI	9	Manila		–	7.5	Q	0.5
1852	IX	16	14° N.	120.5° E.	–	7.5	P	1.5
1862	III	4	Manila		–	6	Q	0.5
1863	VI	3	14.5° N.	121° E.	–	6.5	P	1
1872	I	26	16	119	–	6?	L	1.5
1915	XI	18	18	119.5	–	6.5	P	0.5
1924	V	7	16	119	–	6.5	D	1.5
1934	II	14	17.4	119.3	–	7.5	D	0.5
Northeast.								
1901	IX	10	Lamon Bay		–	7	P	0
1949	IX	5	17° N.	121.5° E.	80	6	E	-4
1949	XII	29	17	121.5	80	7.5	Q	1
1968	VIII	2	16.5	122.2	36	7.25	D	–
Centre.								
1735	II	27	Baler		–	–	P	1.5

Date			Coordinates of Focus (or Site of Phenomenon)					
Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earth-quake, M	Authenticity of Tsunami[1]	Tsunami Intensity, I
1747	–	–	Naga		–	–	Q	–
1824	X	26	14.25° N.	121.25° E.	–	–	Q	1
1830	I	18	Manila		–	–	E	–
1840	III	22	Sorsogon Bay		–	6.5	Q	1
1865	X	19	13.25° N.	123.5° E.	–	6	P	0
1869	VIII	16	12.5	123.5	–	7	P	0
1880	VII	18	15	121.5	100	7.5	P	0
1937	VIII	20	14.5	121.5	–	7.5	L	1
1939	V	7	13.5	121.25	110	6.5	Q	0.5

West.

Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earth-quake, M	Authenticity of Tsunami	Tsunami Intensity, I
1653	VI/VII	–	Northeast Mindoro I.		–	–	Q	1
1675	III	–	Mindoro I., Pola		–	–	P	1
1887	II	2	Panay I.		–	–	Q	–
1889	V	26	13.5° N.	121° E.	–	6.75	L	-3
1897	IX	21	6	122	–	8.6	Q	1
1897	IX	21	6.75	121.5	–	8.5	D	2.5
1905	XII	8	11	123.5	–	6.5	Q	0
1922	II	28	10.2	124.1	–	6.25	P	0
1922	III	1	9	123.25	–	6	P	0.5
1925	V	5	9.3	122.7	–	6.75	P	0.5
1925	V	25	12.2	122.1	–	6.25	P	0.5
1928	VI	15	12.4	120.9	–	7	–	0.5
1948	I	25	10.9	122.1	–	8.25	L	1

South.

Date			Coordinates of Focus (or Site of Phenomenon)					
Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earth-quake, M	Authenticity of Tsunami[1]	Tsunami Intensity, I
1902	VIII	21	7.5° N.	123.5° E.	–	7.25	Q	–
1917	I	31	5.5	125	–	–	L	0
1918	VIII	15	5.5	124.5	–	8.25	D	2.5
1923	III	3	6.5	124	–	7.25	L	0.5
1928	XII	19	7	124	–	7.25	L	1
East.								
1910	XII	30	9° N.	125.5° E.	60	6.25	Q	1
1911	VII	12	9	126	50	7.75	Q	–
1921	XI	12	8	127	–	7.5	L	1
1923	VII	18	9.5	127	–	5.5	Q	1
1924	IV	15	6.5	126.5	–	8.25	P	0.5
1924	VIII	30	8.5	126.5	–	7.25	P	0.5
1925	XI	13	13	125	–	7.25	P	0.5
1929	VI	13	8.5	127	–	7.25	P	0.5
1952	III	19	9.5	127.25	–	7.75	D	–
Indonesian Archipelago – Talaud Islands and Sangihe I.								
1910	XII	18	Talaud Islands		–	6	P	–1
1913	III	14	4.5° N.	126.5° E.	–	8	E	–
1936	IV	1	4.5	126.5	–	7.75	D	2
North part of Maluku Sea.								
1673	V	20	Ternate I.		–	–	E	–
1673	VIII	12	Ternate I.		–	–	L	1

Date			Coordinates of Focus (or Site of Phenomenon)					
Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earth-quake, M	Authenticity of Tsunami[1]	Tsunami Intensity, I
1840	II	14	Ternate I.		–	–	P	0.5
1845	II	8	Kema		–	7	L	0
1846	I	25	2° N.	126.5° E.	–	7.25	D	0.5
1854	IX	27	Ternate I.		–	–	L	0.5
1857	XI	17	Kema, Ternate I.		–	–	L	1.5
1857	XI	18	Kema		–	–	P	0
1858	XII	13	1° N.	126° E.	–	7.25	P	1.5
1859	VI	28	1	126.5	–	7	D	3
1859	VII	29	0	125.5	–	7.25	D	1.5
1859	XII	17	Belang		–	–	P	0
1860	VIII	–	Minahassa Pen.		–	–	Q	0
1871	VIII	25	Gorontalo		–	–	Q	0
1889	IX	6	1° N.	126.25° E.	70	8	D	2.5
1900	I	10	Galela		–	–	Q	0
1968	VIII	10	1.4° N.	126.2° E.	–	7.5	D	1
Ceram Sea.								
1860	X	6	1.25° S.	128.5° E.	–	–	L	0
1876	V	28	3	127.25	50	6.75	L	-1
1885	IV	30	2.5	127.5	–	7.25	L	0.5
1892	XI	18	3	127.75	70	7	L	-1
1903	III	30	3	127.5	–	6.5	P	0
1915	V	23	Kaimana		–	–	Q	0
1937	XI	6	Fakfak		–	6	P	-0.5
1938	II	13	Fakfak		–	6	P	-0.5
Sulawesi I.								

Date			Coordinates of Focus (or Site of Phenomenon)					
Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earthquake, M	Authenticity of Tsunami[1]	Tsunami Intensity, I
1897	III	15	6.8° S.	120.8° E.	15	5.5	P	1
1907	III	30	3° N.	122	500	7.25	Q	2?
1920	I	29/30	Gorontalo, Dongalla		–	–	Q	1
1925	I	8	Butung I.		–	–	Q	0
1927	XII	1	0.5° S.	119.5° E.	–	6	Q	3?
1930	IX	11	Amurang		–	–	Q	0
1938	V	20	0.7° S.	120.3° E.	–	7.5	D	1.5
1939	XII	22	0	123	150	8	L	0.5
1967	IV	11	3.3	119.4	20	5.5	P	1
1968	VIII	14	0.2° N.	119.8	25	7.25	D	2.5
Kalimantan I. East coast.								
1921	V	14	0	118.1° E.	20	6.25	P	0.5
1957	X	26	2° S.	116	–	6	P	0
Sumatra I. Atjeh and coast of Malacca Strait.								
1816	IV	29	5° N.	96.5° E.	–	–	P	0
1837	IX	–	5.5	96	100±	7.25	P	0.5
1885	XII	14	Banda - Atjeh		–	–	Q	–
1886	I	31	Banda - Atjeh		–	–	Q	–
1887	V	19	Sigli		–	–	Q	–
1888	III	21	Breueh I.		–	–	Q	–
1891	V	19	Sigli		–	–	Q	–
1892	V	17	2.5° N.	99.5° E.	120	7.5	L	1
1922	VII	8	Lhoknga		–	–	Q	0
1948	VI	2	5.5° N.	94° E.	–	6.5	P	0

Date			Coordinates of Focus (or Site of Phenomenon)					
Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earthquake, M	Authenticity of Tsunami[1]	Tsunami Intensity, I
1964	IV	2	5.9° N.	95.7° E.	130	7	L	0
1967	IV	12	5.5	97.3	100	7.5	L	1.5
Sumatra I. Southwest coast.								
1770	–	–	5° S.	102° E.	–	7	L	0.5
1797	II	10	0	99	–	8	D	3
1818	III	18	4	101.5	–	7	L	1.5
1833	XI	24	2.5	100.5	75	8.25	D	2.5
1843	I	5	1.5° N.	98	70	7.25	D	2
1852	XI	11	1.5	98	–	6.75	Q	0
1861	II	16	1	97.5	70	8.5	D	3
1861	III	9	0	98	20	7	D	2
1861	IV	26	1	97.5	70	7	D	1.5
1861	VI	17	1	97.5	–	6.75	L	0.5
1861	IX	25	1.5° S.	100	–	6.5	L	1.5
1885	VII	29	0	99.5	–	6.75	P	0
1896	X	10	3.5	102.5	130	6.75	P	0
1907	I	4	1.5° N.	97	50	7.5	D	2
1908	II	6	2° S.	100	130	7.5	L	1
1909	VI	4	2	101	40	7.5	P	1
1915	VII	26	Lais		–	–	Q	0
1922	IV	10	Padang		–	–	Q	0
1926	VI	28	1.5° S.	99.5° E.	–	6.75	E	0
1930	VI	19	5.6	105.3	–	6	L	0
1931	IX	25	5	102.75	–	7.5	L	1
1935	XII	28	0	98.4	–	7.75	Q	0
1958	IV	22	4.5	104	200	6.5	P	0.5

Date			Coordinates of Focus (or Site of Phenomenon)					
Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earth-quake, M	Authenticity of Tsunami[1]	Tsunami Intensity, I
Java Island.								
1722	X	–	Djakarta (Batavia)		–	–	Q	0
1757	VIII	24	Djakarta (Batavia)		–	7.5	P	-0.5
1818	XI	8	7° S.	117° E.	600	8.5	P	2
1823	IX	9	6.5	108.5	150	6.75	P	-1.5
1840	I	4	8	110.5	150	7	P	0
1843	II	7	7.2	114	–	6	Q	0
1852	I	9	6.5	105.5	150	6.5	L	0.5
1859	X	20	9	111	–	–	P	1
1862	IV	8	Lenor River		–	–	E	–
1863	III	16	Djaringin		–	–	Q	0
1889	XI	23	7° S.	113.5° E.	–	6	P	1
1904	IX	7	Tjilatjap		–	–	Q	0
1921	IX	11	11° S.	111° E.	–	7.5	D	-2
1930	VII	19	9.3	114.3	100	6.5	P	-3
1957	IX	26	8.2	107.3	–	5.5	L	0
1963	XII	16	6.4	105.4	64	6.5	P	0
Lesser Sunda Islands.								
1814	–	–	Timor I., Kupang		–	–	P	0
1815	XI	22	8° S.	115° E.	150	7	L	1.5
1820	XII	29	7	119	80	7.5	D	3.5
1836	III	5	Bima		–	–	P	0.5
1836	XI	28	Bima		–	7.5	P	0.5
1856	VII	25	8.5° S.	116° E.	–	–	P	0
1857	V	13	8	115.5	50	7	D	2

Date			Coordinates of Focus (or Site of Phenomenon)					
Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earth-quake, M	Authenticity of Tsunami[1]	Tsunami Intensity, I
1891	X	5	9° S.	124° E.	80	7	L	0.5
1908	III	23	10	129	–	6.6	E	–
1917	I	21	Bali I.		–	6.5	L	0
North part of Banda Sea.								
1629	VIII	1	6° S.	130° E.	–	7	L	3
1648	II	29	Ambon		–	–	E	–
1657	XII	–	Buru Islands		–	–	P	1
1673	VII	12	Ambon		–	–	E	–
1674	II	17	3.75° S.	127.75° E.	40	6.75	D	1.5
1674	V	6	3.75	127.75	–	6	L	0
1708	XI	28	Ambon		–	–	L	2
1710	III	6	Bandaneira		–	–	L	1.5
1711	IX	5	4° S.	129° E.	–	7	D	1.5
1754	VIII	18	3.5	128.5	–	6.5	L	0
1754	IX	7	3.5	128.5	–	–	P	0
1763	IX	12	6	130	–	–	L	2.5
1775	IV	19	Ambon		–	–	L	0
1802	VIII	–	Ambon		–	–	P	1.5
1841	XI	26	Bandaneira		–	–	L	1.5
1841	XII	16	4° S.	127.5° E.	–	6	L	1.5
1852	XI	19	Ambon		–	–	Q	0
1852	XI	26	5.25° S.	129.75° E.	100	8.25	D	2.5
1852	XII	24	5	130.5	–	7	Q	2
1854	I	4	3.5	128.6	–	6	P	0
1859	VII	20	Lontor I.		–	–	L	0
1859	IX	25	5.5° S.	130.5° E.	–	6.75	P	0.5

Date			Coordinates of Focus (or Site of Phenomenon)					
Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earth-quake, M	Authenticity of Tsunami[1]	Tsunami Intensity, I
1882	X	10	Bandaneira		–	7.5	L	0.5
1899	IX	30	3.5° S.	128.5° E.	–	7.8	D	3
1922	II	22	Amahai		–	–	Q	0.5
1932	IX	9	3.6° S.	128.3° E.	17	6.25	P	0
1938	II	2	5.25	130.5	–	8.25	D	1.5
1950	X	8	4	128	–	7.25	L	2?
1965	I	24	2.4	126.1	6	7.5	L	2
New Guinea, New Britain, New Ireland.								
New Guinea, Irian Bay.								
1864	V	22/23	1° S.	135° E.	–	7.75	L	1.5
1900	X	8	3.5	136	–	7.8	L	1.5
1914	V	26	2	137	–	8.25	D	2
1915	XI	6	1	136	–	6	P	0
Bismarck Archipelago & Melanesian Trench.								
1930	XII	24	1.3° S.	144.3° E.	–	5.75	L	1.5
Louisiade Archipelago.								
1960	VI	12	9° S.	152.5° E.	–	6.5	L	0
New Britian Trench & Bougainville Trench[1].								

[1] This section includes the northern group of the Solomon Islands.

Date			Coordinates of Focus (or Site of Phenomenon)					
Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earth-quake, M	Authenticity of Tsunami[1]	Tsunami Intensity, I
1768	VI	22	South New Ireland		–	7.5	L	1
1857	IV	17	5.5° S.	147° E.	–	8	L	1.5
1873	–	–	5.5	146	–	8	L	2
1878	II	3/4	4.25	152.25	–	–	P	1
1899	–	–	East New Ireland		–	–	P	1.5
1900	IX	18	5° S.	152.5° E.	–	7	L	1.5
1906	IX	15	7	149	–	8	D	1.5
1906	X	1	6	148	–	7.5	L	1.5
1910	II	25	4.25	152.25	–	6	Q	0
1911	V	8	4.25	152.25	–	–	P	0
1913	X	11	7	148	–	6.75	D	–
1916	I	1	5.5	154	–	7.75	L	2
1919	V	7	6	153	–	7.75	L	1
1939	I	30	6.5	155.5	–	7.75	P	1
1941	I	14	4.5	152.5	–	7	D	-2.5
1949	X	20	5	154	60	7.5	D	-1
1953	IV	24	4.5	153.3	–	7.75	Q	0

Solomon Islands, Santa Cruz, New Hebrides.
South group of Solomon Islands.

1926	IX	17	10.7° S.	159.7° E.	50	7	D	1.5
1931	X	4	10.5	161.75	–	8	D	2.5
1938	III	7	8	165	–	–	Q	–
1939	IV	30	9.2	159.5	50	8	L	1.5
1966	VI	15	10.3	160.8	31	7.6	L	1

Santa Cruz & New Hebrides Islands.

Date			Coordinates of Focus (or Site of Phenomenon)					
Year	Month	Date	Latitude	Longitude	Depth of Focus, km	Magnitude of Earth-quake, M	Authenticity of Tsunami[1]	Tsunami Intensity, I
1863	VIII	17	19° S.	168.5° E.	–	7.5	P	1
1875	III	28	20	168.5	–	8	L	2.5
1875	V	10	18.5	168	–	7	P	0.5
1878	I	10	19	168.5	–	7.5	L	3
1878	II	11	19	168.5	–	8	L	1.5
1878	VIII	–	19	168.5	–	–	Q	–
1893	VII	31	Port Vila		–	6	Q	0
1920	IX	21	20° S.	168° E.	–	8	D	–
1934	VII	10	11.75	166.5	–	8.25	L	–
1934	VII	21	11	165.75	–	7.25	L	–
1952	VII	13	18.7	170.3	260	7.2	E	–
1961	VII	23	18.5	168.3	45	7	L	-0.5
1965	VIII	12	15.8	167.2	33	7.25	D	2.5
1965	VIII	13	15.8	167.2	–	–	P	1
1967	I	1	11.8	166.5	33	8.1	D	1
1967	I	1	11.5	164.8	33	7.3	L	0

Tsunamis caused by volcanic eruptions.

Date			Volcano			Authenticity of Tsunami	Tsunami Intensity
				Coordinates			
Year	Month	Date	Name	Latitude	Longitude		i_o
1883	X	6	Augustine	59.4° N.	153.4° W.	D	3
1883	X	8	Augustine	59.4	153.4	Q	2.5
1825	–	–	Shishaldina	54.8	164	Q	0.5
1856	VII	26	(underwater)	54.6	165	Q	–
1796	V	8	Bogoslov	53.9	168	Q	–
1640	VII	31	Kamagatake	42.1	140.1° E.	L	1
1741	VIII	28	Oshima	41.5	139.3	P	2.5
1792	V	1	Unzen	32.8	130.3	D	2.5
1780	IX	9	Sakurajima	31.6	130.7	P	0
1780	X	31	Sakurajima	31.6	130.7	P	0
1781	IV	11	Sakurajima	31.6	130.7	L	1
765	VII	–	–	31.6	130.9	Q	–
1664	–	–	Tori	27.8	128.2	P	1
1853	X	29	(underwater) east of Taiwan Island			Q	–
1850	–	–	(underwater)	20.6° N.	134.8° E.	Q	–
1854	I	15	(underwater)	20.9	134.8	Q	–
1606	I	23	Hachijo	33.1	139.8	P	–
1952	IX	16	Miyojin	31.9	140	D	-1
1952	IX	23	Miyojin	31.9	140	D	-1
1952	IX	24	Miyojin	31.9	140	D	0
1952	IX	26	Miyojin	31.9	140	D	-1
1953	III	11	Miyojin	31.9	140	D	-1
1953	III	12	Miyojin	31.9	140	D	-1
1953	III	14	Miyojin	31.9	140	D	-1
1953 (4 times)	III	14	Miyojin	31.9	140	D	-2
1953 (6 times)	III	15	Miyojin	31.9	140	D	-2

Date			Volcano			Authenticity of Tsunami	Tsunami Intensity
				Coordinates			
Year	Month	Date	Name	Latitude	Longitude		i_o
1953 (3 times)	III	16	Miyojin	31.9° N.	140° E.	D	-2
1953	III	16	Miyojin	31.9	140	D	-1
1953 (4 times)	III	16	Miyojin	31.9	140	D	-2
1953 (3 times)	III	17	Miyojin	31.9	140	D	-2
1953 (2 times)	III	17	Miyojin	31.9	140	D	-1
1953	III	17	Miyojin	31.9	140	D	-2
1953 (9 times)	III	18	Miyojin	31.9	140	D	-2
1953 (5 times)	III	19	Miyojin	31.9	140	D	-2
1953	III	19	Miyojin	31.9	140	D	-1
1953	III	20	Miyojin	31.9	140	D	-2
1953	III	22	Miyojin	31.9	140	D	-1
1953	III	23	Miyojin	31.9	140	D	-1
1953	III	23	Miyojin	31.9	140	D	-2
1953 (2 times)	III	25	Miyojin	31.9	140	D	-1
1819	-	-	Asuncion	18.7	145.4	P	1
1933	XII	25	Bulusan	12.8	124	Q	1
1871	IV	30	Hibokhibok	9.2	124.7	Q	2
1918	VII	18	(underwater) off Mahengetang Island			Q	0
1856	III	2	Awu	3.7° N.	125.5° E.	D	1
1892	VI	7	Awu	3.7	125.5	D	1
1871	III	3	Ruang	2.3	125.4	D	3.5
416	-	-	Krakatau?	6.1° S.	105.4	P	3-4

Date			Volcano			Authenticity of Tsunami	Tsunami Intensity i_o
				Coordinates			
Year	Month	Date	Name	Latitude	Longitude		
1883	VIII	26	Krakatau	6.1° S.	105.4° E.	L	1
1883	VIII	26	Krakatau	6.1	105.4	L	2
1883	VIII	27	Krakatau	6.1	105.4	L	1.5
1883	VIII	27	Krakatau	6.1	105.4	L	3
1883	VIII	27	Krakatau	6.1	105.4	D	4
1884	I-II	–	Krakatau	6.1	105.4	P	0
1928	III	26	Krakatau	6.1	105.4	P	0
1930	III	17	Krakatau	6.1	105.4	Q	–
1815	IV	10	Tambora	8.2	118	D	1.5
1928	VIII	4	Palu (Rokatinda)	8.3	121.7	L	1.5
1659	XI	11	Teun	6.9	129.2	P	0
1953	VI	27	(underwater)	2.4	147.4	L	1
1888	III	13	Sakar (Ritter)	5.5	148.1	D	3.5
1937	V	28/29	Raluan and Tawurwur	4.2	152.2	L	1.5
1958	X	7	(underwater)	16.8	168.5	Q	0

Gravity waves, caused by slumps, landslides and suspension currents.

Date			Site of Occurrence	Cause of Slump	Authenticity of Tsunami	Tsunami Intensity i_o
Year	Month	Date				
1602	I	-	Japan, Boso Peninsula	-	P	1
1699	III	-	Japan, west Kyushu Island	-	Q	-
1700	IV	1	Japan, west Kyushu Island	-	P	2
1815	XI	22	Indonesia, Bali Island	earthquake	P	1.5
1880	VII	18	Philippines, east Luzon Island	earthquake	L	0
1899	IX	30	Indonesia, south Ceram Island	earthquake	D	3
1924	IV	15	Philippines, Mati	earthquake	P	1.5
1964	IV	2	Indonesia, Atjeh region	earthquake	P	0

Tsunami-type oscillations in sea level of meteorological or unknown origin and isolated waves in open sea (for some zones).

Date			Site of Occurrence	Authenticity of Tsunami	Tsunami Intensity i_o
Year	Month	Date			
Japanese Island Arc. Coast of Pacific Ocean.					
799?	IX	19	Ibaraki Prefecture, Hitachi, etc.	L	1
855?	VI?	-	Mie Prefecture, Kumano	P	0
1420	IX	6	Ibaraki Prefecture	L	1
1510	X	10(1)	Sizuoka Prefecture, Totomi Nada	L	1
1512	X?	-	Tokushima Prefecture	P	1.5
1562	VII	26(25)	Kumamoto Prefecture, Yatsushiro	P	0.5
1585	VI	11	Miyagi Prefecture, Motoyoshi	Q	0.5
1603	-	-	Mie Prefecture, Kumano	P	0
1651	-	-	Miyagi Prefecture, Watari	P	0.5
1670	IX	-	Osaka Bay	P	0
1676	XI	-	Ibaraki Prefecture, Fukushima, Aomori	Q	1.5
1689	-	-	Iwate Prefecture	Q	1
1696	VII	25	Fukushima Prefecture, Onahama	P	2
1696	XI	25	Miyagi Prefecture, Ishinomaki	P	2
1697	II	26	Iwate Prefecture	E	0.5
1698	XII	22	Oita Prefecture, Bungo Strait	Q	0
1699	IX	8	Shizuoka Prefecture, Suruga Bay	P	0.5
1700	I	27	Iwate Prefecture, Kii Peninsula, Ozuchi	P	1
1704	I?	-	Shizuoka Prefecture, Suruga Bay	Q	0
1704	-	-	Iwate Prefecture, Kii Peninsula, Nachikatsu'ura	P	0
1718	X	5	Mie Prefecture	L	0
1722	IX	24	Aichi Prefecture, Iwate, Ise Bay, Kii Peninsula	P	1.5
1732	-	-	Izu Peninsula, Hachijo Island	P	0.5
1747	III?	-	Izu Peninsula, Hachijo Island	P	0.5
1751	VII	24	Miyagi Prefecture, Ojika Peninsula, Kesennuma Bay	Q	0

Date			Site of Occurrence	Authenticity of Tsunami	Tsunami Intensity i_o
Year	Month	Date			
1773	VII?	-	Kumamoto	P	0
1787	-	-	Iwate Prefecture	P	1
1808	VII	4	Kii Peninsula, Kumano	Q	0
1816	XII?	-	Izu Peninsula, Matsuzaki	Q	0
1847	VIII	27	Iwate Pref., Miyagi, Kesennuma, Motoyoshi, Ojika, Mono	L	1.5
1856	IX	-	Tokyo Bay	P	0
1884	XI	15	Okayama Prefecture, Tamashima, Kasaoka	P	0
1928	V	30	Sapporo	E	-
Coast of Sea of Japan and Sea of Okhotsk.					
1650	XII	13	Fukui Prefecture	P	1
1687	VII	26	Wakasa Bay	P	0
Coast of Asian Continent.					
1076	X	31	China, Kwangtung Province	Q	1
1407	VIII	23	Korea, Haeju Coast	P	0
1434	VIII	6	Korea, Inch'on (Chemulpo)	P	0.5
1519	IX	24	Korea, coast of Chedzhudo Island*	P	0
1556	X	21?	Kyonggi, Ch'ungch'ong Provinces	P	0.5
1636	VII	31	Korea, Pusan	P	0
1923	VIII	-	Korea	Q	1.5
1926	VII	-	Korea, south	Q	1.5
Nampo, Mariana, Caroline, Marshall Islands.					
1747?	III	-	Hachijo Island	P	0.5
1837	X	-	Guam Island, Caroline Islands	P	1.5
1906	VII	1	Marshall Islands	Q	-
1925	XII	22	Caroline Islands, west	P	1.5

Date			Site of Occurrence	Authenticity of Tsunami	Tsunami Intensity i_o
Year	Month	Date			
Philippine Archipelago.					
1830	IX	16	Manila	P	1
1887	IX	23	Tiburon, Jeremie	E	-
1897	X	12	Tacloban	L	1.5
Indonesian Archipelago.					
1608	VII	1	Makian Island	L	1.5
1771	XI	9	Ternate Island	Q	0.5
1851	V	4	Sumatra Island, Telukbetung	L	1.5
1855	IV	14	Flores Island	L	1
1859	XII	25/26	Sulawesi Island, Kema	L	1
1861	III	-	Ambon Island	P	1
1861	VI	5	Java Island, Pakis	P	1
1883	V	20	Horn Islands	Q	1
1883	V	31	Banka Island, Belinju	Q	0
1883	X	10	Java Island, Djikawung	P	0
1885	VIII	3/4	Sulawesi Island, Boijong	L	0
1889	VIII	16/17	Java Island, Anjer Lor	Q	1
1891	VI	10	Batjan Island	L	0.5
1891	VI	20	Ambon, Saparua, Banda Islands	L	0
1904	II	2	Sulawesi Island, Tolitoli	P	0.5
1904	VII	5	Saparua Island	Q	1
1914	XII	3	Ambon Island	P	0
1915	VIII	2/3	Java Island, Genteng, Tjisolok	D	2.5
1917	I	9	1° 34' N., 122° 43' E.	Q	2
1917	I	-	Linga Archipelago	Q	1.5
1917	III	16	Sambergelap Islands	P	1
1917	VIII	23	Saparua Island	P	0.5
1919	II	13	Timor Island	P	1.5

Date			Site of Occurrence	Authenticity of Tsunami	Tsunami Intensity i_o
Year	Month	Date			
1927	VIII	23	Djakarta (Batavia)	Q	1.5
1929	XI	9	Sumatra Island, Tjalang	P	1
Solomon Islands, Santa Cruz, New Hebrides.					
1892	VIII	-	Espiritu Santo Island	P	1.5
1893	VIII	27	Efate Island	P	0
1968	XI	28	Santa Cruz Islands	P	-0.5

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 m (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 AND TRANSLATIONS OF JAPANESE LITERATURE SOURCES

Zishin (Earthquake)
Kagagu yomiuri (Popular science)
KD - Kenshin jiho (Journal of earthquakes)
KYo - Kisho Yoran (Meteorological survey)
KK - Kaiyo no kagaku (Oceanography)
SITKh - Shinsai iobo tesakai hokoku (Reports of the Committee for the investigation and prevention of earthquakes)
TD - Tigaku zassi (Geographic Journal)
Toyo gakugei zassi (Journal of Eastern Culture)
Umi to sora (The sea and the sky)

ABBREVIATED NAMES OF LITERATURE SOURCES

ACERM - Annales de la Commission pour l'etude des raz de maree
AJSA - American Journal of Science and Art
ASEV - Annales de la Societe des emulateurs des Vosges
ASIND - Annual Summary of Information on Natural Disasters, UNESCO
BASLB - Bulletin de l'Academie Royale des sciences, des lettres et des beaux-arts de Belgique
BCIS - Bureau central international seismologique
BERI - Bulletin of the Earthquake Research Institute, Tokyo University
BHVO - Bulletin of the Hawaiian Volcano Observatory
BSSA - Bulletin of the Seismological Society of America
BV - Bulletin volcanologique
CAVW - Catalogue of the Active Volcanoes of the World Including Solfatara Fields
CRAS - Comptes rendus de l'Academie des sciences
CSI - Committee on Seismological Investigations
EN - Earthquake Notes, Eastern Section of the Seismological Society of America
GBG - Gerlands Beitrage zur Geophysik
CJ - Geographical Journal
GSJSR - Geological Survey of Japan, Special Report
IDG - International Dictionary of Geophysics
ISS - International Seismological Summary
JBGR - Jahrbuch der Geologischen Reichsanstalt
JES - Journal of Earth's Sciences, Nagoya University
JOSJ - Journal of Oceanographycal Society of Japan
MASAB - Memoires de l'Academie des sciences, arts et belles-lettres de Dijon, section des sciences
MCAB - Memoires couronnes et autres memoires publies par l'Academie Royal de Belgique
MEC - Materiaux pour l'etude des calamites
MKMO - Memoires of the Imperial Kobe Marine Observatory
MM - Mineralogische Mitteilungen
MPM - Mineralogische und petrographische Mitteilungen, Neue Folge
NGWG - Nachrichten der Kaiserlichen Gesellschaft der Wissenschaften zu Gottingen. Mathematische-physikalische Klasse

NJMGP - Neues Jahrbuch fur Mineralogie, Geologie und Palaontologie
NL - News Letter, International Tsunami Information Center, Honolulu
NTNI - Natuurkunding tijdschrift voor Nederlandisch Indie
NZJST - New Zealand Journal of Science and Technology
OM - Oceanographical Magazine, Central Meteorological Observatory, Tokyo
PBCSI - Publications du Bureau central seismologique international, ser. B, Catalogues, Strassbourg
PGM - Petermann's geographische Mitteilungen
PTM - Proceedings of Tsunami Meetings, Associated with Tenth Pacific Science Congress, UGGI, Monographie, N 24, Paris
QJGS - Quarterly Journal of the Geological Society of London
QJS - Quarterly Journal of Seismology, Central Meteorological Observatory, Japan Meteorological Agency, Tokyo
REC - Revue pour l'etude des calamites
REIC - Reports of the Imperial Earthquake Investigation Committee, Tokyo
RUIS - Revue de l'Union international des secours
SBMCO - Seismological Bulletin, Manila Central Observatory
SN - Seismological notes, BSSA
SNL - Science News Letter
SRTU - Science Reports, Tohoku University, Serie 5, Geophysics, Sendai
TNGGB - Territory of New Guinea Geological Bulletin
UGGI - Union geodesique et geophysique international
USCGS - United States Coast and Geodetic Survey
USE - United States Earthquakes
VL - Volcano Letter, United States Geological Survey
VMMOB - Verhandelingen voor Koninklijk magnetisch en meteorologisch observatorium te Batavia
WBMCO - Weather Bureau, Manila Central Observatory
ZV - Zeitschrift fur Vulkanologie

ABBREVIATED NAMES OF LIBRARIES

BAN - Library of the Academy of Sciences of the USSR, Leningrad
BKhL - Library of Chemical Literature of the Academy of Sciences of the USSR, Moscow
VGB - All-Union Geological Library, Leningrad
VGO - All-Union Geographic Society, Leningrad
VINITI - All-Union Institute of Scientific and Technical Information, Moscow
VSEGEI - All-Union Geological Institute
GBL - State Library im. V. I. Lenin, Moscow
GBS - Main Botanical Garden of the Academy of Sciences of the USSR, Moscow
GGO - Main Geophysical Observatory im. Voeikov, Leningrad
GPNTB - State Public Scientific and Technical Library, Moscow
IG - Institute of Geography of the Academy of Sciences of the USSR, Moscow
IGEM - Institute of Geology of Ore Deposits, Petrography and Geochemistry, Moscow

IO	-	Institute of Oceanology of the Academy of Sciences of the USSR, Moscow
IFZ	-	Institute of Earth Physics im. O. Yu. Schmidt of the Academy of Sciences of the USSR, Moscow
L'v.Gu	-	L'vov State University
MBAN	-	Library of the Academy of Sciences of the USSR, Moscow
MGU	-	Moscow State University im. M. V. Lomonosov, Moscow
MOIP	-	Moscow Naturalists' Society
MTsD	-	World Geophysical Data Center, Moscow
ONZ	-	Earth Sciences Branch of the Academy of Sciences of the USSR, Moscow
S-Shch	-	State Public Library im. Saltykov-Shchedrin Leningrad
SakhKNII	-	Sakhalin Integrated Scientific Research Institute of the Academy of Sciences of the USSR
Tartu	-	Library of Tartu University
TsVMB	-	Central Naval Library, Leningrad
TsSO	-	Central Seismic Observatory of IFZ, Obninsk
Zurich	-	State Library of Zurich
YaMA	-	Japanese Meteorological Agency, Tokyo