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THE TSUNAMI OF 4-5 NOVEMBER 1952

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FOREWORD

At the request of the Presidium of the Academy of Sciences of the USSR, E. F. Savarensky, A. D. Dobrovol'sky, V. I. Vlodavets, L. N. Sretensky, A. E. Sviatlovsky, A. V. Zhivago, V. G. Tishchenko, and G. A. Skuridin compiled an account in April 1953 of the tsunami of 4-5 November 1952,[1] on the Pacific coast of Kamchatka and in the northern Kuril Islands, caused by an underwater earthquake. The tsunami was accompanied by severe destruction and loss of life. The report contains an analysis of the causes and consequences of the tsunami and some conclusions concerning the possibility of warning the population of the occurrence of tsunamis in future earthquakes. Parts of that account are published in the present compilation.

During the period when the Kuril Islands were a part of Japan, no studies of tsunamis in the Kuril Is. were carried out. In other countries, too, tsunamis have been inadequately investigated. Up to the present only two accounts have been published: one Japanese, of the 1933 tsunami in Sanriku, and one American, of the 1946 tsunami in the Hawaiian Islands.

In the compilation of the present report the following were utilized:

(1) data of the seismological service of the USSR on the Kamchatka earthquake of 4-5 November 1952;

(2) a preliminary report on the Kamchatka earthquake by the Sakhalin branch of the Academy of Sciences of the USSR (I. I. Katushenok, B. K. Klimov, F. I. Monakhov, and M. D. Ferchev);

(3) the results of a survey of many points on the Kamchatka-Kuril coasts carried out by A. E. Sviatlovsky and B. I. Piip of the Volcanological Laboratory of the Academy of Sciences, A. S. Ryshkova, geologist of the Lenmor Project, and V. G. Tishchenko of the Geophysical Institute of the Academy of Sciences;

(4) data of the hydrometeorological service of the USSR on the heights of the tsunami waves at several points on the Kamchatka-Kuril coasts.

The introduction and the first chapter were written by Prof. E. F. Savarensky and V. G. Tishchenko (Geophysical Institute, AS USSR), the second chapter by Candidate in Geologo-Mineralogical Sciences A. E. Sviatlovsky (Volcanological Laboratory of the AS USSR), and the third chapter by Prof. A. D. Dobrovol'sky (Institute of Oceanology of the AS USSR) and Candidate in

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[1] 4 November Moscow time, 5 November by local time.

Geographical Sciences A. V. Zhivago (Institute of Geography of the AS USSR). The map of the epicenters was prepared by Candidate in Physico-Mathematical Sciences N. A. Linden (Geophysical Institute of the AS USSR). The photographs were made by A. E. Sviatlovsky. The work was under the direction of Prof. E. F. Savarensky.

INTRODUCTION

In earthquakes and -- considerably more rarely -- in volcanic eruptions and landslides which take place on the bottom of the ocean, sea waves arise which are sometimes marked by such force that when they run upon the coast they may produce considerable destruction. These waves are usually called tsunamis (tunamis).

Destructive tsunamis are comparatively rare and, as a rule, occur only in the basin of the Pacific Ocean. This is explained by the localization in regions of the coasts of the Pacific Ocean of the overwhelming majority of catastrophic earthquakes [5]. The most notable tsunamis arise from strong earthquakes occurring in the Japan, Kuril, Aleutian, Philippine, Atacama, and other ocean deeps.

The Japanese and Hawaiian islands suffer most from tsunamis [7]. In the northern Kurils and on the east coast of Kamchatka, as well as in the Aleutian, Philippine, Sunda, and Solomon Islands and on the coasts of Chile and Ecuador, important tsunamis occur comparatively rarely.

In some cases tsunamis are accompanied by particularly severe destruction. Thus, for example, during the tsunami of 15 June 1896, seven giant waves broke on the northeast coast of the island of Honshu and the south coast of Hokkaido, taking in more than 800 km. As a result 10,000 houses were destroyed and washed away and 27,000 persons perished. At some points on the coast the waves attained a height of 30 m. [6]. Almost as strong a tsunami occurred at these places as a result of the earthquake of 2 March 1933. Less notable waves were observed all over the Pacific basin (in Australia and South America).

Huge sea waves occurred in the eruption of the volcano Krakatoa (Sunda Strait) on 26 August 1883. The eruption had the character of an underwater explosion, and the height of the waves at some points attained 36 m. That tsunami was noted in the Indian and Atlantic Oceans also. The island of Celebes and the northwest part of Java suffered severely from the tsunami (36,000 persons died).

The problem of the causes and conditions of occurrence of tsunamis has been very little studied. According to one hypothesis proposed by B. Gutenberg [4], the cause of tsunamis is landslides which occur in earthquakes. B. Gutenberg points out that the majority of earthquakes which produce tsunamis take place in Pacific Ocean trenches, on the slopes of which the formation of landslides is possible.

However, F. Shepard [10] considers this hypothesis poorly founded, as there are known to have been large landslides, for example in canyons on the Pacific coast of California, which were not accompanied by tsunamis. Furthermore, the slopes of the majority of Pacific trenches are formed, apparently, of quite solid rocks and therefore major landslides on them are hardly possible. The velocity of movement of a landslide is considerably less than that of the process of tectonic upheaval connected with earthquakes, and therefore is scarcely sufficient for the formation of tsunamis.

The following explanation seems most likely to us. It is well known that as a result of some strong earthquakes vertical and horizontal dislocations are formed on the surface of the Earth. If there is subsidence of the bottom of the ocean, then the volume of the water basin (the depth) over it increases, while nearby it decreases. These changes rarely occur singly. The subsidence occurs with a velocity close to that of sound. Waves of compression and rarefaction arise in the water, which, reaching the surface of the ocean, lead to the formation of sea waves -- tsunamis. If the earthquake occurs at great depths within the interior of the Earth, then the surface of the Earth or the floor of the ocean does not experience upheaval and in these cases very strong earthquakes are not accompanied by tsunamis.

Observations show that tsunamis arise during earthquakes as a series of several waves with a period of 10 to 30 minutes. The largest is usually the second wave. The speed of propagation of the waves in the average ocean depth of 4,000 m. is 190 m./sec. or around 690 km./hour, and the wavelength attains 100-300 km. In the open ocean such waves are imperceptible and do not cause any damage to ships.

With lessening of the depth near shore the waves lose speed. Because of the uneven change in depth of the ocean the path of propagation of the waves undergoes bending (refraction). At the moment when the height of the wave becomes comparable to the depth, the profile of the wave begins to become distorted: the steepness of the forward part increases and the wave grows higher. The wave takes on the aspect of a wall of water, which breaks on the coast with fearful force. The height and destructive force of the wave depend also on the outline of the shore. In tapering bottle-neck bays and straits the height and destructive force of the wave grow especially strongly.

On the basis of data on past tsunamis it is possible to estimate the height of the waves of hypothetical tsunamis (taking into account the peculiarities of the bottom relief and the shape of the coastline and the location of the most probable epicenters of the earthquakes). At the present time preliminary schemes for the localization of tsunamis have been set up for Japan /11/ and the Hawaiian Islands /10/. The reliability of such area classifications depends on the completeness of the results of hydrographic and topographic surveys of the coasts or islands under study.

The seismological service plays a major role in guarding against the fatal consequences of tsunamis. The speed of propagation of seismic waves is approximately 10 km./sec., while the average velocity of tsunami waves is 0.2 km./sec. Therefore the discovery of the elastic waves from an earthquake on the bottom of the ocean is the basis for reporting the possibility of occurrence of a tsunami. A regular service of this sort was set up in the Hawaiian Islands and on the coast of the USA after the Aleutian earthquake of 1 April 1946, and also in Japan.

The epicenters of earthquakes which produce tsunamis are located far from the Hawaiian Islands. Therefore tsunamis appear there only several hours after the Hawaii seismological station registers an earthquake. In that respect the Soviet Pacific coast is under less favorable conditions. On the Kuril Islands

and in Kamchatka, for example, it is ordinarily not more than 20-40 minutes from the time of occurrence of an earthquake to the appearance of the tsunami on the coastal points nearest the epicenter.

Chapter I

EARTHQUAKES AND TSUNAMIS IN THE FAR EAST OF THE USSR

Preliminary Remarks

Along the east coast of Kamchatka and the Kuril Islands extends a segment of the so-called Pacific belt of high tectonic activity (zone of faults). It is characterized by intensive deformations of the adjacent parts of the continent and depressions of the ocean floor, with an abundance of deep fractures of the Earth's crust. Along the cracks there is displacement of the mountain masses in earthquakes, and the very existence of the cracks facilitates the formation of volcanoes.

On the chart (fig. 1) are shown the epicenters of earthquakes as determined by observations of the seismological stations of the USSR (and also the epicenter of the catastrophic tsunami-generating earthquake of 1737, the epicenter of which has been determined approximately). The strongest and most catastrophic earthquakes fall along various sections of the Kuril Trench and in the region of transition to the Japan Trench on the south and to the Aleutian Trench on the north. The surface foci of the strongest earthquakes, in which there is a possibility of the occurrence of tsunamis, are situated in places where the basic longitudinal system of fractures (system of boundary surfaces between continental uplift and oceanic subsidence) apparently is transected by transverse faults.

Earthquakes in Kamchatka

The first information on earthquakes in Kamchatka is encountered in the work of the outstanding investigator of Kamchatka, S. P. Krasheninnikov,[2] where it is indicated that the earthquake of 1737 attained an intensity of 7-8 on the east coast.[3]

Subsequent known earthquakes on the east coast of Kamchatka did not exceed intensity 7. Below we present data on some earthquakes which have occurred since 1737.

15 April 1791. A strong earthquake (intensity 6-7) at Nizhne-Kamchatsk; a similar earthquake in August 1791 at Petropavlovsk, Nizhne-Kamchatsk, and Paratunka.

1807. Earthquake at Nizhne-Kamchatsk (apparently volcanic).

1809. Strong subterranean shock at Petropavlovsk.

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[2] S. P. Krasheninnikov. An account of the land of Kamchatka, composed by Stepan Krasheninnikov, Professor of the Academy of Sciences, 1755.

[3] It did not reach intensity 8, in our opinion.

1810 and 1821. Strong earthquake at Nizhne-Kamchatsk and Kl͡iuchevsky and eruption of the Kl͡iuchevsky cone.

1827. Strong earthquake (intensity 6-7) at the village of Avacha; window frames were distorted and their panes broken.

8 May 1841. Strong earthquake (6-7 intensity) at Petropavlovsk; stoves and chimneys destroyed, window glass broken; cliffs collapsed on the coast near the port.

1851, 1902, 1904, and 1911. Rather intense earthquakes (intensity 5-6) at Petropavlovsk.

23 February 1923. Earthquake (of no more than intensity 6) on the east coast.

13-14 April 1923. Earthquake (intensity 6-7) at Ust'-Kamchatsk and southward.

1931 (autumn). Earthquake (up to intensity 6) at Kl͡iuchi.

September 1936. Earthquake (intensity 6-7) at Ust'-Kamchatsk.

October-November 1948. Earthquake (up to intensity 6) at Kl͡iuchi.

4-5 November 1952. Strong earthquake (intensity 6-7) in Kamchatka.

General Information on the Kamchatka Earthquake of 4-5 November 1952

The earthquake of 4-5 November 1952, in Kamchatka was preceded by a no less intense earthquake on the east coast of Hokkaido on 4 March 1952. According to data from USSR seismological stations, the coordinates of the epicenter of this earthquake were 41.8°N. and 143.8°E.

The amplitude of the oscillations of the ground at Moscow produced by this earthquake (the distance is about 7,000 km.) exceeded 2,000 μ. The earthquake was accompanied by numerous secondary shocks. It should be noted that toward July 1952 the epicenters of many secondary shocks had shifted northward, to the central part of the Kuril Trench, although for a time shocks occurred farther to the north and south. There is information concerning a destructive tsunami produced by the earthquake of 4 March 1952.

The epicenter of the Kamchatka earthquake of 4-5 November 1952, as determined from the data of 51 USSR seismological stations, was located at the point 52.3°N. and 161°E. (northern end of the Kuril Trench). The position of the epicenter was determined with an error not greater than 50 km.

The earthquake occurred at 19 hours 58 minutes 20 seconds on 4 November by Moscow time or at 3 hours 58 minutes 20 seconds on 5 November by Petropavlovsk time. The maximal amplitude of the ground oscillations at Moscow reached

2,300 μ. In the amount of energy expended the earthquake exceeded by many times the Ashkhabad earthquake of 1948.

Judging from the character of the oscillations registered by the seismological stations, the focus of the earthquake was located at a depth not greater than 20-30 km. The exceptionally high intensity of the earthquake and the tsunami formed by it testify to the considerable destruction of the relief of the ocean floor in the epicentral zone.

The point on the coast nearest to the epicenter (Kamchatka, Cape Shipunsky) is 140 km. distant. The distance to Petropavlovsk-on-Kamchatka is 200 km. and to Severo-Kuril'sk about 350 km. Thanks to the distance of the epicenter from the coast and the shallow depth of the focus, the earthquake was not accompanied by significant destruction. As a result of a survey of damage to buildings and installations it was established that on the Kuril-Kamchatka coasts the force of the earthquake did not exceed intensity 7; for Petropavlovsk the force of the quake reached intensity 6; farther south it was somewhat greater (intensity 7). North of Petropavlovsk the intensity of the earthquake was weaker. At Ust'-Kamchatsk the force of the quake was of intensity 5. From the Kronotsky Peninsula to the northern Kuril Islands there was damage to structures, destruction of stoves and chimneys, and so on. Buildings and structures in Petropavlovsk and its surroundings suffered comparatively little.

The considerable extent of the epicentral zone along the Kamchatka coast is testified to by the fact that the force of the earthquake of 4-5 November varied comparatively little over an extent of almost 700 km., with a shallow depth of focus.

The earthquake was accompanied by a large number of secondary shocks, the frequency and force of which gradually lessened. From 4-10 November the Petropavlovsk seismological station detected 507 secondary shocks; many of them were also detected by the majority of seismological station of the USSR.

The greatest destruction and suffering of 4-5 November were caused by the tsunami which arose as a result of the earthquake and which took in about 700 km. of the east coasts of Kamchatka and the Kuril Is. On the average the height of the waves on the coast reached 6-7 m.

Weaker waves were detected all over the Pacific basin. At the Hawaiian Is. the waves attained a height of several feet [8], but thanks to a timely notification of the tsunami, damage and suffering were prevented. On the coast of New Zealand the height of the wave reached 1 m. maximum (at Wellington, for example, the rise caused by the tsunami was about 0.25 m.).

In Kamchatka and on the Kuril Is. destructive sea waves appeared 30-40 minutes after the earthquake. At most points the beginning phase of the waves was accompanied by a lowering of the level of the ocean. Hence it follows that the actual moment of appearance of the waves on the coast occurred half a period earlier.

It is well known that earthquakes stimulate the activity of local volcanoes.

Below we will present data of A. E. Sviatlovsky and B. I. Piip on the volcanic activity after the earthquake of 5 November.

In the first week after the earthquake there was no change in the usual condition of the volcanoes, except for the Karpinsky Volcano (Paramushir I.). The inhabitants of the settlement at Cape Vasil'eva affirm that this volcano, several hours after the earthquake, threw out from its crater a dense column of dark vapor, but the activity of the volcano did not develop further on subsequent days.

The Krenitsyna Volcano (Onekotan I.), which had been considered dead, began to erupt on 12 November. The Avachinsky and Koriaksky volcanoes, situated north of Petropavlovsk, intensified their fumarole activity. In the Krenitsyna Volcano at first there were gaseous explosions, which were followed by a strong eruption of ash and lava. On 14 November huge white clouds of steam rose over the caldera lake surrounding the active cone of the volcano, testifying to the emission of lava into the lake. On the evening of 15 November a fiery glow, visible from afar, appeared over the volcano. A great cloud of ash hung over the ocean, and at night bright flashes of lightning cut through it. On 16 November the eruption began to weaken, and on 18 November it ceased.

On the morning of 12 November there appeared over the Avachinsky Volcano a large cloud composed of two columns of gases -- a thick central column up to 2 km. high and a slenderer lateral column at the northeastern part of the volcano's summit. Two streams of gas from fumaroles which were usually inconspicuous were observed over the summit of the almost extinct Koriaksky Volcano. On 13 November the Avachinsky and Koriaksky volcanoes returned to their usual condition, but over the Mutnovsky Volcano (80 km. south of Avachinsky Bay) a dark gray column of steam, gas, and ash with a height up to 2-3 km. was observed for many days. The Gorelyi Volcano, situated alongside Mutnovsky, according to information from the local hydrologist I. M. Iakovlev temporarily increased, after the earthquake, its fumarole activity, which had almost ceased after the eruption of 1931. The Karymsky Volcano, located in the Kronotsky region, put out a dark column of ash and other ejecta for several days after 5 November; the Semliachik Volcano also intensified its fumarole activity. On 15 November Kliuchevskoĭ Volcano unexpectedly threw up a column of steam and gas, dark with ash.

It should be kept in view that in terms of seismological area classification Petropavlovsk and much of the east coast of Kamchatka can have earthquakes of up to intensity 8, and in some places to intensity 9 (south tip of Kamchatka, Kuril Is.). This calls for study of the consequences of the earthquake of 4 November 1952, and attention to the possibility of more serious consequences from stronger earthquakes in the future.

In particular the results of study of the effects of the earthquake of 4-5 November 1952 have revealed a relatively nonuniform distribution of the force of the quake within the limits of Petropavlovsk in dependence on geological and soil conditions.

Thus, in the central part of the city houses built of cinder blocks did not receive damage. Here and there chimneys were completely destroyed and stoves were

damaged; deformation of foundation walls was observed only in an occasional building.

At the same time in the Kirpichny settlement, situated on loose alluvial marine deposits in the area of Rakovaia Bay, the chimneys and the inner walls contiguous to the stoves were destroyed in almost all houses. The oscillations of the ground appeared here with greater force than in the central part of town. The same thing was observed in the Elizovsky area and generally in all cases where buildings were situated on loose (alluvial) soils.

There are many sections of Petropavlovsk where stronger earthquakes could be very dangerous. In this connection we should take into consideration the very uneven relief of the city's territory: the streets are located on various levels along the rather steep sides of a cone, which requires that in the construction of buildings retaining walls be employed to protect the buildings from slips and slides.

In the earthquake of 4-5 November 1952, cracks appeared in some supporting walls. In stronger earthquakes, in a number of places in the city, there is a possibility of landslides and slippages of the surface mass of the ground, which could have dangerous consequences.

In Kamchatka there is a great deal of construction on coastal sites, which are prepared by dredging or filling with soil. In spite of the fact that such substrates are seismologically very unfavorable, the yard of the tin can plant in Petropavlovsk was enlarged by artificial filling and dredging of the inshore part of the bay. Ten meters from the water's edge, on dredged ground across from the new can factory there is situated a block of subsidiary shops. Because of the shifting of the ground in the earthquake, large cracks formed here (fig. 2, 3), and part of the walls and foundations were made unserviceable. Similar damage was observed in the old part of the factory building and in shop No. 10 of the shipyard (fig. 4, 5).

Unfortunately, no on-the-spot geological-engineering and hydrogeological investigations were carried out in Petropavlovsk, such as could reveal the most seismically dangerous sectors, first of all those exposed to landslides. Such work is definitely essential.

It should be noted that anti-seismic measures are often given insufficient attention. Thus, in the construction of wooden log and squared timber houses measures are not taken to insure the rigidity of the corners and the securing of the lower wall framing to the foundation; in stone (block) buildings anti-earthquake belts are not set up on each floor but on every other floor; due attention is not given to decreasing the number of floors of buildings, to the quality of the construction when exposed to freezing, the selection of types of cinder blocks, and so on.

Tsunamis in the Far East of the USSR

The first information on tsunamis in Kamchatka and the Kuril Islands is also met with in the work of S. P. Krasheninnikov.[4] He described the earthquake in Kamchatka and the Kurile Is. in 1737.

Presented below are data on tsunamis in Kamchatka and the Kuril Is. beginning from 1737, borrowed from the materials at our disposal.

17 October 1737 (according to S. P. Krasheninnikov's account). A very strong earthquake in the northern Kurils and southern Kamchatka with catastrophic tsunamis. Many Kamchatkan yurts and huts were destroyed. At first on the shore a wave about 5 m. high was observed. After that the sea retreated a great distance. The second wave was larger than the first. Then the sea withdrew so far that no water could be seen in the straits. After a quarter of an hour even greater waves followed and the water rose to 60 m.[5] The oscillation of the water continued for a long time. The earthquake and tsunami caused great suffering.

Secondary shocks were observed until the spring of 1738.

17 December 1737. A tsunami on Paramushir and adjacent islands. Sea waves up to 6-7 m. All ships carried away to sea. Some coastal cliffs collapsed into the sea.

19 January 1780. A strong earthquake in the northern Kurils and southern Kamchatka. Intense waves. A ship lying in a harbor in Kamchatka was thrown ashore.

29 June 1780. A very strong earthquake, accompanied by a tsunami, was noted at Urup I.

12 August 1792. A strong earthquake, accompanied by a catastrophic tsunami, occurred on the east coasts of Kamchatka and the northern Kurils.

17 May 1841. As a result of an earthquake in the region of Kamchatka, a tsunami arose which was also observed in the Hawaiian Is.

25 April 1843. Two subterranean shocks and tsunamis were noted at Urup I.

25 April 1904. An earthquake (epicenter unknown) and tsunami. Several ships were thrown ashore at Petropavlovsk.

7 September 1918. As the result of a strong earthquake at 45.5°N., 151.4°E., there was a tsunami which brought great destruction to Urup I. The tsunami was also detected at Hawaii.

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[4] S. P. Krasheninnikov. An account of the land of Kamchatka, composed by Stepan Krasheninnikov, Professor of the Academy of Sciences, 1755.

[5] Exaggerated, probably.

3 February 1923. A strong earthquake on the east coast of Kamchatka (epicenter 53°N., 161°E.) caused a tsunami which was also observed at the Hawaiian Is.

13-14 April 1923. A strong earthquake in northeastern Kamchatka, particularly at Ust'-Kamchatsk (epicenter 55°4'N., 162°8'E.) produced a catastrophic tsunami.[6] The shore structures of a fish cannery were razed to the foundations, apparently by the broken masses of ice carried by the waves. On the coasts of the northern Kuril Is. the height of the waves reached 3 m. *[2]*. The tsunami was also observed at the Hawaiian Is. and even there caused insignificant damage.

28 December 1927. A strong earthquake on the east coast of Kamchatka (epicenter 53°8'N., 161°4'E.). There was a tsunami which was also observed in the Hawaiian Is. There is no information about this tsunami in Kamchatka.

13-14 November 1936. A strong earthquake (epicenter about 55.2°N., 164°E.), which was felt at Ust'-Kamchatsk (intensity 7) and was accompanied by a tsunami.

1 August 1940. A strong earthquake on the west coast of Hokkaido (epicenter 44°2'N., 139°1'E.). It produced a tsunami in the Sea of Japan. There was destruction at Olga Bay (Maritime Province).

4-5 November 1952. (Epicenter of the earthquake 52°3'N., 161°0'E.). There was a very strong tsunami which, judging from descriptions, was similar to the tsunami of 1737.

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[6] We present the story of the event told by V. I. Ivanova, a teacher of Ust'-Kamchatsk, as written by A. E. Sviatlovsky.

"At 2 o'clock in the morning of 14 April strong shocks began, as a result of which stoves collapsed, crockery was shattered, and objects moved. Then a loud noise was heard from the direction of the ocean. There all was black and the terrible roar drowned out the cries of the people. The Kamchatka River freed itself from the ice, which had a thickness of more than a meter. Part of the ice was thrown on the bank and part was carried away into the ocean. Five houses on the edge of the settlement of Ust'-Kamchatsk next to the Kamchatka River were carried away by the ice. From the sandspit where the Dembo fish cannery was located, all of the structures were washed away by the waves and the machines were torn from their bases. A cannery farther up the Kamchatka River was not destroyed, but its shore structures were damaged by the ice.

It may be supposed that if it had not been for the heavy ice covering the ocean and the Kamchatka River the wave would have been destructive to Ust'-Kamchatsk also."

Chapter 2

EFFECTS OF THE TSUNAMI OF 4-5 NOVEMBER 1952 IN KAMCHATKA AND THE KURIL ISLANDS

General Information

The waves of the tsunami of 4-5 November 1952 were noted from Iturup I. on the south (height of wave 2.5 m.) to the village of Shubertovo near Ust'-Kamchatsk (wave height 0.5-1 m.) and had destructive force over an extent of more than 700 km. of the Pacific coast -- from Onekotan I. on the south to the Kronotsky Peninsula (Kamchatka) on the north.

The morphology of the shores and the relief of the bottoms of bays and straits played an important role in the heightening of the waves upon their arrival at the coast; waves which were imperceptible to ships on the open ocean, at the coast transformed themselves into terrible battering rams, which not only destroyed installations but changed the coastal relief, washing away sandy soils and causing landslides.

For investigation of the damage produced by the tsunami and determination of the height of the waves, a special expedition was organized under the leadership of I. P. Kucherov and A. E. Abaev. The expedition visited a number of points on the coast where the tsunami had been observed and carried out a geodesic survey. The author of this chapter also took part in the expedition.

From the analysis of the material collected and interviews with eye-witnesses it can be concluded that it is necessary to differentiate between the height of the tsunami wave at the moment of its appearance at the coast and the highest marks on the shore reached by the wave (the wash of the wave, the zone of flooding). The height of the wave was most accurately determined from isolated cliffs (at Cape Shipunsky) or from isolated structures and objects which somehow survived. In the accounts of eye-witnesses the height of the wave was usually somewhat exaggerated.

The heights of the waves on the east coasts of the Kuril Is. and Kamchatka are given in table 1, compiled on the basis of data from the survey and interrogations.

Paramushir Island

City of Severo-Kuril'sk

The largest place which suffered from the tsunami was the city of Severo-Kuril'sk, where the heaviest destruction and the most numerous losses of life were noted.

Severo-Kuril'sk is situated on the west coast of the Second Kuril Strait, on Paramushir I., across from the settlements of Kozyrevsk and Baikovo, which are on the eastern shore of the Strait on Shumshu I.

The tsunami of 5 November moved from the east, entering first into the broad part of the Second Kuril Strait. Farther north the Strait narrows. Here the shores of the Strait are low and winding, and the above-mentioned inhabited places are located on bends in the coasts. All of this necessarily caused an increase in the height of the tsunami and strengthened its destructive action.

The territory of the city (fig. 6) is a lowland gradually rising toward the slopes of the mountains (height above sea level 1-5 m.), bounded by terraces more than 10 m. high lying on the slopes of the mountains surrounding the city. The low ground is traversed by a creek which empties into the Strait.

On its southwest side the area of the city is bounded by a rocky cape ending at the Strait in a hill, at the foot of which the port is situated. Behind the port area, 200-300 m. from the shore, an ancient sand ridge several hundred meters long adjoins the port, and on its slopes were located store houses and auxiliary structures (fig. 7). Behind the ridge, south of the town, is a flat which is partly swampy ; and has no buildings on it. On the south this low ground is bounded by a terrace which is connected to the slopes of the mountains. The central streets of the town were laid out along the shore right up to the stadium near which were situated the administrative buildings of the city. On the shore of the Strait north of town were canneries and reduction plants; just beyond the area of these factories high ground begins.

On the terraces and sides of the mountains which bound the flat there are many dwellings.

On the night from 4-5 November 1952, at about 4 o'clock local time, the inhabitants of Severo-Kuril'sk were awakened by an earthquake of intensity 7. Stoves were destroyed; stovepipes fell; dishes and other domestic utensils fell from the shelves; water splashed out of buckets; chandeliers swung violently. The startled people ran out of their houses.

After cessation of the shocks, which continued for several minutes, most of the populace began to return to their homes; only those who had previous acquaintance with tsunamis, among them the Korean fishermen, hastened toward the hills after the first shock, despite the calmness of the sea.

About 45 minutes after the beginning of the earthquake a loud roar was heard from the direction of the ocean and just a few seconds later a huge wave broke on the town, moving with great speed and having its greatest height in the central part of the town, where it rolled up the valley of the creek.

After a few minutes the wave rushed back to the sea, carrying with it all that it had destroyed. The retreat of the first wave was so great that the bottom of the strait was exposed to the extent of several hundred meters. Silence fell.

After 15-20 minutes, a second, even larger wave, reaching a height of 10 meters, broke on the town. This wave caused especially severe destruction, washing away every structure in its path. All that remained in place behind the wave were the concrete foundations of houses.

Table 1

Heights reached by the tsunami of 5 November 1952

Points	Max. rise of water accord. to data of I. P. Kucherov and A. E. Abaev	Max. rise of water accord. to interview data (m.)	No. of waves causing destruction	Highest wave	Time for arrival of the first wave, from moment of earthquake (min.)
		Kuril Islands			
Iturup I.	--	2.5	--	--	--
Matsuwa I.	--	3-5	--	--	--
Shiashkotan I.	--	8	--	--	--
Onekotan I., Mussel'Bay	9.5-10	9	--	--	--
Paramushir I. (east coast of Cape Vasil'eva)	6.2	--	--	--	30
Paramushir I. (west coast of Cape Vasil'eva)	4-5	--	2	first	30
Paramushir I. (south of Kitovaia Bay)	--	14	--	--	--
Paramushir I. (Kitovaia Bay, valley of Tukharka R.)	18.4	--	3	second	20
Paramushir I. (Okeanskaia Bay)	8.3	--	2	second	--
Paramushir I. (Cape Ozerny in the Second Kuril Strait)	6-7	--	--	--	--
Paramushir I. Severo-Kuril'sk	9-10	12-15	3	second	35-40
Paramushir I., west coast, Shelekhova village	5.5	3-4	--	--	--
Shumshu I., Kozyrevsk settlement	7	6	3	second	--
Shumshu I., Baikovo village	9	--	3	second	30
Alaid I.	1.5	--	--	--	--
		Kamchatka			
Cape Lopatka (east coast)	9.5	--	--	second	20
Cape Lopatka (west coast)	--	5	--	second	--
Utashud I.	8.6	--	--	--	--
Piratkova Bay	--	10-15	3	second	30

Table 1 (continued)

Heights reached by the tsunami of 5 November 1952

Points	Max. rise of water accord. to date of I. P. Kucherov and A. E. Abaev	Max. rise of water accord. to interview data (m.)	No. of waves causing destruction	Highest wave	Time for arrival of the first wave, from moment of earthquake (min.)
		Kamchatka			
Khodutka Bay	--	cutter thrown 500 m. up from shore	--	--	--
Asacha Bay (northern cape)	7	--	--	--	--
Cape Povorotny	--	10	--	--	--
Akhomten Bay	--	7	--	--	--
Zhirovaia Bay	7	8	2	second	20-25
Sarannaia Bay	7	--	--	--	--
Viliui settlement	--	6-8	--	--	--
Cape Izmenny	5	--	--	--	--
Petropavlovsk City	1.2 (by tide recorder)	--	--	--	30
Rakovaia Bay, Kirpichny settlement	--	3	--	--	--
Tar'ia Bay	1.8	--	--	--	--
Khalakhtyrka settlement	4.5-5	6	--	--	--
Malychevo settlement	--	6-7	--	second	--
Cape Shipunsky (southern tip)	--	8-9 (by tide marker)	--	--	15
Cape Shipunsky, Morzhovaia Bay	--	7-8	2	second	--
Zhupanovo	--	4-5	--	third	--
Cl'ga Bay	--	10-13	--	third	40
Shubertovo settlement	--	0.5-1	--	--	--
Ust'-Kamchatsk	--	5-10 cm.(!)	--	--	--
Ozernoe settlement	--	3-5	--	--	--
		Other areas of the Far East			
Komandorsky Is.	--	small wave	--	--	--
Okhotsk coast (Magadan)	2 (by tide recorder)	--	--	--	120
Sakhalin, Korsakov	1 (by tide recorder)	--	--	--	--

Passing through the town, the wave reached the slopes of the surrounding hills, after which it began to roll back into the depression near the center of the town. Here was formed a great whirlpool in which revolved with great speed all sorts of fragments of buildings and small boats. In the course of a few minutes many people perished in this whirlpool. Rolling back, the wave struck from the rear the beach ridge in front of the port area, on which several houses and the warehouse of the Kuriltorg trading organization survived, and running around the high ground, rushed into the Kurile Strait. Part of the beach ridge and the hill became an island for several minutes. On the path between this island and the hill the wave heaped up a mountain of timbers, boxes, and so forth and even brought there two houses from the town (figs. 8, 9).

A few minutes after the second wave, the weaker third wave came, bringing much debris to shore (fig. 10). This was scattered all over the area of the town and along the shores of the Strait. At 9 o'clock in the morning there was a strong fluctuation of the ocean's level, which was repeated more and more weakly during the whole day of 5 November.

In the Strait, when the waves came and during the following day, there were formed whirlpools and current rips -- standing waves and vertical spoutings formed as the result of the meeting of currents running against one another from the Pacific and from the Sea of Okhotsk.

After the tsunami houses, roofs, wreckage, casks, and all sorts of implements were floating in the Strait between Severo-Kuril'sk and Kozyrevsk and in the Pacific Ocean. On some of the roofs were people, who were rescued by the crews of launches.

The main part of the town was completely annihilated. Only an insignificant part of the houses survived, mainly in the western part of town, at altitudes above 10 m. On the low ground in the center of the town, only the walls of the small stone radio station remained. The bridges and the cobble paving of the main streets were torn out.

Old Japanese pill-boxes and the monument and gate of the stadium, located 1 km. from the shore, survived although they were twisted out of the ground by the wave (fig. 11). The whole waterfront of the fishing port, except for the breakwater and the loading platform, was completely destroyed. Only the concrete slipway partially survived. The walls of the pier in the boat basin were broken out in two places and thrown over on the side toward the Strait. The waves, leaving the town, carried into the Strait the wreckage of houses, barges, and boats which, striking the pier, prepared the way for its destruction. The loading area in the boat basin was covered with the debris of buildings, barrels, and automobiles (fig. 12). A concrete mixer placed on the shore side of the cargo-handling platform was thrown by the wave clear across the platform and was only stopped by the wall of the pier from being thrown into the Strait. The machines in the repair shops of the port were torn up, together with their bases, and scattered over the port area. An 800-ton fuel tank was tilted as a result of the washing out of the sandy foundation from under it (fig. 13).

The tsunami also caused great destruction in the areas of the fish plant and the fish reduction plant (figs. 14-17).

The structures of the cannery, situated in the northern part of the factory area, however, survived.

Water craft of the fishing port which were at their moorings or drawn up on shore for repairs were thrown hundreds of meters inland and badly damaged. The wave threw a large powered barge 2 km. up the valley of the creek. Small boats moored in the boat basin were thrown across the breakwater into the Strait by the ebb of the first wave. They were carried through the Strait from the Sea of Okhotsk to the Pacific. Houses on the high ground of the beach ridge at the end of the port area were spared. Only part of the houses, standing on the slopes of the ridge, received damage.

At the foot of the hill, on the sandy beach ridge, a storehouse covered with corrugated iron survived. It was saved from destruction by piles of boxes stacked around it, which received the blow of the outrushing water.

The crews of the fishing boats which had been carried into the Strait at the time of the catastrophe strove valiantly to pick up the drowning. These crews rescued people during the course of 48 hours and then, without rest, evacuated the people from the island to steamers.

A considerable part of the population saved themselves by taking to the hills, where they had to remain for 12 hours.

On the day following the catastrophe airplanes and steamers, trawlers, and other vessels from many points took part in rescuing the people.

Cape Vasil'ev

Narrow, low Cape Vasil'ev, 6 km. long, is the southern end of Paramushir I. The height above sea level in the central parts of the cape is 5-6 m., and 3-4 m. in the coastal parts.

The wave approached the cape from the northeast 30 minutes after the earthquake. It washed away all structures in the coastal zone (about 1 km. wide) of the eastern shore. The settlement, which was situated inland from the coast, did not suffer. That happened because on the east coast of Cape Vasil'ev there are many reefs scattered among the shallows, thanks to which the wall of water broke before it reached dry land and the wave was widely dissipated over the flat shore. Nevertheless, the height of the wave reached 4-5 m., and according to some data 6-7 m.

Entering the Fourth Kurile Strait, the wave took in also the western shore of Cape Vasil'ev, however, here it was considerably weaker. According to the accounts of the inhabitants, before the first wave they observed an ebb which exposed the bottom of the sea 500 m. out. Alongside the breakwater on the western shore of the cape the wave threw ashore small vessels (kungases, skiffs, launches) and rose to 5-6 m. but did not reach the settlement. The only damage was partial destruction of the boiler house, a small wooden building situated 100 m. from the shore (at a height of about 3 m. above sea level). The water broke in the doors

and filled the boiler room almost to the ceiling. Then the water retreated, laying bare the breakwaters and the bottom for 200-250 m. When the water ran out, it carried to sea a barge, on which there were several persons.

The second wave hit the west coast of the cape after 10-15 minutes and was weaker and 0.5 m. lower than the first.

The Whaling Station at Kitovaia Bay

Kitovaia Bay is on the southern part of the east coast of Paramushir I. It is a small bay, open to the southeast, bounded on the southwest and northeast by two steep rocky points. The bay is shallow and there are many reefs in it. A small creek, flowing down a valley 200-300 m. wide, empties into the bay. The gradual northeastern slopes of the valley come out on a flat water divide, the height of which in its western part reaches 20 m. above sea level. In the river valley was a settlement of some twenty houses. Some houses stood on the flanks of the valley. The whale processing plant was built on the northeastern slope of the valley at the shores of the bay. The first section of the plant was at a height of 4 m. and at a distance of 10 m. from the shore. From it a concrete slipway ran down to the ocean for hauling out whales. The other parts of the plant were located above the cutting platform, farther from the shore.

At a point 50-60 m. up the valley, at an altitude of 7-8 m., was the electric generating plant (a one-story cinder block structure). Farther up the valley stood a store, two cinder block dwellings, and about 20 other houses.

The first wave reached this area approximately 20 minutes after the earthquake and caused comparatively slight damage to the settlement. After its retreat, in 10-15 minutes, a second, stronger wave came. This wave struck the rocky shores of the points at the ends of the bay and rebounding from them rushed into the narrow valley of the creek, along which the settlement was situated. Passing up the valley for 2 km., the second wave reached an altitude of 20 m. (greater than at all other points on the coast). In its withdrawal to the ocean the wave had no less force than in its movement to the shore.

The plant and the settlement suffered very severely from the tsunami. Only the highest of the houses standing on the southwest slope of the depression survived. The houses located 1-1.5 m. lower on the slope were torn away by the wave and rolled up the valley. The concrete base to which the three winches of the slipway were fastened was torn up together with its stone foundation and thrown 20 m. toward the ocean. Oil-extracting furnaces 10 m. long, which were at a height of 5-6 m. above sea level, were knocked off their foundations and carried along the flat valley floor. On the slope above the furnaces there were whale oil cisterns dug into the ground. They were torn out of the earth and thrown 200-300 m. inland. After the tsunami the whole valley was littered with debris, kungases, iron pots, and barrels.

At the highest place reached by the water, in the northwestern part of the settlement, was a radio station (altitude about 19 m.). Its tower survived, but the building was completely destroyed and the roof was carried 150-200 m. toward

the ocean. The rest of the structures of the settlement were all carried into the ocean. After the catastrophe there remained here the walls of the cinder block building of the electric power plant, and the generator remained on its concrete foundation.

A motor launch was thrown against a house which stood at a distance of about 0.5 km. from the shore at an altitude of 12-13 m. above sea level. From the blow of the wave and the launch the house buckled and its walls fell apart. The tsunami tore away from the reefs a ship which had stranded there several years before.

There were losses of life in the settlement at Kitovaia Bay as a result of the catastrophe.

Okeanskaia Bay

Okeanskaia Bay is also on the southern part of the east coast of Paramushir I., 4 km. north of Kitovaia Bay. This bay is open to the south and is surrounded by a flat sandy shore. On the northeast it was protected by a concrete breakwater 120 m. long, 6 m. broad, and 7 m. high. Southwest of the breakwater was a concrete pier, covered with slabs of reinforced concrete. The depth of the bay at a distance of several hundred meters from shore is 7-10 m.; there are fewer reefs in this bay than in Kitovaia.

The settlement was situated 300-400 m. from the sea on a low shore formed of marine deposits at the foot of a small isolated conical hill.

The inhabitants of the settlement were awakened by the earthquake, which continued with short interruptions until 4 h. 30 min. The wooden houses creaked and dishes fell.

According to the account of the watchman who was on the pier, shortly after the earthquake he noticed through the pre-dawn mist a great wave rolling in from the ocean, moving with great speed and with a roar.

The wave rolled from the northeast along the shore and struck a groin of reinforced concrete blocks (7 x 7 x 7 m.), which did not withstand the pressure of the water and were scattered in a radius of 20-50 m.

After that the wave broke on the workshops of a large cannery which was situated at the very water's edge (fig. 18) and also on the shoreward houses of the settlement. The cannery was completely destroyed and its fragments were carried off into the ocean. Many oil-extracting boilers and machine were scattered along the shore when the wave went out. Part of the inhabitants of the settlement saved themselves by fleeing to the hill, but the wave caught others in their houses and these perished. At 10 o'clock in the morning the oscillations of the water level were still continuing and the waves reached a height of 2-3 m.

Shumshu Island

Settlement of Baĭkovo

The settlement of Baĭkovo is located northeast of Severo-Kuril'sk, on Shumshu I. The dwelling area is situated comparatively high up, but the main trading and working structures were located in a steep-sided gulch about 500 m. wide and more than 1 km. long. A fishing port had been installed right on the shore of the Strait.

Before the wave struck, the water rushed away from the shore for 500 m. on the Okhotsk Sea side. A steamer which had sunk in 1949 at a distance of 500 m. from shore appeared above water. After that the gigantic wave dashed on the shore. The approach of the wave, as at Severo-Kuril'sk, was accompanied by a roar. The wave caused great destruction to the buildings of the settlement.

After the retreat of the first wave calm ensued. The second wave broke on Baĭkovo 10-15 minutes later. It came with even greater speed and height. After its passage there remained of the fishing port only the pier, deformed by the waves. The wrecked buildings were carried off by the ebbing wave into the Strait and thence into the Pacific Ocean. Later, weaker waves threw ashore roofs, timbers, and debris that had been carried away by the first waves (fig. 19).

There were few lives lost in the Baĭkovo settlement, as it was mainly working structures that were located on the low coastal area.

Kozyrevsk Settlement

The settlement of Kozyrevsk is 2.5 km. southwest of Baĭkovo. It is separated from Severo-Kuril'sk by the Second Kuril Strait. On the shore, on low ground, there were a cannery and other workshops (fig. 20), which were completely wiped out by the tsunami. Of the cannery only the concrete floor of one shop, a part of the foundation, and some boilers remained (figs. 21, 22).

After the tsunami the shore was covered over a distance of several kilometers with fragments of buildings, boxes, canned fish, and barrels (fig. 23). Part of the debris on the shore had been carried from Severo-Kuril'sk on the opposite side of the strait. The old Japanese pier, which had been considerably damaged at the time of the war, was completely destroyed by the wave. Thanks to the fact that the dwellings of the settlement were situated on high coastal slopes, there were few human lives lost at Kozyrevsk.

Onekotan Island

Mussel' Bay

This is a small sickle-shaped bay with a great number of reefs and with rocky points. A stony surf-beaten strip is surrounded by the steep bluffs of a lava plateau which is cut through by a narrow gulch. The settlement here is

situated high and far from the shore, and therefore did not suffer from the wave, the height of which reached 7 m. Only houses located on a low sandy shore about 100 m. wide were destroyed by the wave.

Kamchatka

Avachinskaĭa Bay and Petropavlovsk City

The entrance to Avachinskaĭa Bay is flanked by narrow, rocky heads, protecting the bay from tsunamis. The tsunami penetrated the bay on a narrow front and then dissipated itself over the whole breadth of the bay, causing only a slight rise in the water level. For this reason the inhabited points on the shores of the bay did not experience the catastrophic effect of the tsunami.

At Petropavlovsk a slight oscillation of the water level was noted 30 minutes after the earthquake. The wave, with a height of about 1 m., did not cause any damage. Small vessels, lying at moorings, received only insignificant damage to their gunwales from striking against one another. The electric power station at Seroglazka was partially flooded, but its equipment was only slightly damaged. The minor damage caused by the earthquake was here more considerable than that from the tsunami.

In the settlement of the Avachinsky Combine on Avachinskaĭa Bay the residents were awakened by the quakes, which caused brick chimneys and plaster to fall in some houses.

The oscillation of the sea level began an hour after the earthquake. In Tar'inskaĭa Bay, situated in the southwestern part of Avachinsky Gulf, the rising of the water began from the side toward Ĭagodnaĭa Bay and at the head of the bay reached 3 m. Water from Tar'inskaĭa Bay poured across a sandspit into a small lake, from which it went through a sandbar into Avachinskaĭa Bay. The rise was gradual. Oscillations of the water level in the bay were observed all day, the greatest rise (1.8 m.) being around 8:00 a.m. The water carried a launch and a barge ashore, scattered barrels along the beach, and partially flooded the warehouse and workshop of the Avachinsky Combine. Sacks of flour, firewood, timbers, and other property that were on the landing were carried away into the water.

At Rakovaĭa Bay the boiler-house of the tin can factory was built 10 m. from the shore on filled land. The ground alongside the plant was washed away, which resulted in a landslip that broke the north wall of the plant in two places. There were landslides and washouts of the shore along fissures which appeared as a result of the earthquake (see figs. 2, 3). Some buildings on the shore were partially flooded and some were thrown out of shape as a result of the landslides.

In all of the creeks emptying into Rakovaĭa Bay the water rose to a height of 3 m. and poured over the banks, flooding low sections.

At Izmenny Point, at the entrance to Avachinskaĭa Bay, two barracks were carried away. There were losses of life. On the cliffs on the side toward the ocean, after the wave receded, icing was observed up to a height of 5 m. Probably the spray reached that height.

In Petropavlovsk city and in the area of Rakovaia Bay there were no losses of life.

Khalakhtyrka Settlement

East of Petropavlovsk, at the foot of the Avachinsky Volcano, there is a broad valley opening to the ocean toward the southeast. Near the ocean it has the character of a swampy lowland, in the middle of which is Lake Khalakhtyrskoe, separated from Petropavlovsk by a line of volcanic cones which reach a height of 200 m.

The settlement of Khalakhtyrka is situated on the shores of the ocean, 15 km. east of Petropavlovsk, on ancient beach ridges which are cut through on the northwest by the valley of the Khalakhtyrka River.

At 4 o'clock in the morning the inhabitants, startled by the earthquake, rushed out of their houses. After a few minutes the shocks ceased and the people all began to disperse to their homes. In 15-20 minutes a deafening noise was heard from the direction of the ocean.

The inhabitants saw a high wave, with a foaming, phosphorescent crest, moving rapidly on the settlement. The wave rolled up the bed of the river, through the southern part of the settlement, and rushed up the valley. The water flowed out of the river valley and poured into the low ground which lay along the settlement, reaching several houses. The caviar factory and smoke house which stood at the southern edge of the settlement were completely destroyed. The concrete floor of the caviar plant was torn up and concrete slabs 10-15 cm. thick were broken up and scattered about. The blow of the wave broke out the walls of two log houses on the edge of the village. The house which stood between them was carried away, and its roof was later found, together with a bridge, at a distance of a kilometer up the valley.

The sand bar and delta deposits of the river were washed away, and the bed of the river was displaced 100 m. to the south.

The water which rushed in from the direction of the river, along the tundra at the edge of the village, passed over the low ground along the main row of houses and again joined the water that was running up the river. Part of the houses were destroyed and part were flooded. Inside the cabins the walls of which were broken in, the water reached a height of one meter. The main wave did not reach the settlement, as the sandy shore here has a height of 7-8 m. above sea level. Three persons perished.

Nalychevo Settlement

The settlement is located 40 km. northeast of Petropavlovsk. It did not suffer from the earthquake, but the wave damaged it greatly. Of 15 log houses standing at a height of 5-6 m. above the ocean level, only one survived. The first wave did not destroy the houses, but only shifted and turned them. The

second wave washed the houses away and carried some of them into the ocean. The height of the wave at Nalychevo was 6-7 m. Four persons died.

Vilíuchinskaía Bay (Bol'shaía Zhirovaía)

The settlement of the Combine at Bol'shaía Zhirovaía Bay was situated on a flat sand bar at the head of the fjord-like bay. The grounds of the settlement are at a height of 5 m. and have an area of 1 km^2. Its northern edge adjoins the rocky slope surrounding the bay. The site, with its low, sandy shores, is surrounded on three sides by water. The settlement was in the southwestern part of the flat site and away from the steep side of the bay, which is dangerous in winter because of snow slides (fig. 24). In all there were about two dozen small wooden houses and one large eight-room house on a concrete foundation. After the tsunami there remained, of all the wooden structures, only one roof, which was carried onto the slope of a hill in the higher northeast part of the site.

In the eastern part of the area, nearer to the channel which separates the site from the south shore of the bay, the concrete foundation of the eight-apartment building (fig. 25) remained, the wooden part having been completely washed away. The wave struck from the east, along the long wall of the building, which was 10 m. from the water at a height of about 2 m. above sea level. Where the bakery had been, a half-destroyed oven remained.

The outline of the flat sandspit on which the settlement had been situated changed as a result of the tsunami. The part of the site on the side toward Vilíuchik, where there were a pier, a landing platform, and a sorting shed, was washed away together with its structures. At that place now there are only scattered wooden pilings sticking out of the water. The edge of the shore now runs 20-30 m. farther to the east along a sandy beach ridge, which forms a cut-bank 2-3 m. high above the water. There is now no sandbar along the shore -- it was washed away. In the shallows of the surf zone lies a broken iron cart which was carried by the wave from the saltery across the whole settlement site. The small hill by the cliffs at the northeastern part of the site was littered with debris deposited there by the wave in its return to the ocean.

In the neighboring bay near the sandbar, on a small flat area at the mouth of a creek which empties into the bay, there was a settlement of fishermen. Half a dozen houses which stood there were washed away. All that remained was the cow barn.

There were losses of life in the region of these two bays as a result of the tsunami.

Cape Shipunsky

The steeply rising rocky shores of the cape are surrounded at their foot by a narrow sand and gravel beach, interrupted by steep bluffs which drop off into the ocean. The floor of the ocean at Cape Shipunsky is characterized by sharp changes from shallow to deep sections.

The description of the consequences of the tsunami is based on the data of G. A. Ptachek of the Hydrometeorological Service.

The meteorological station at Cape Shipunsky is at the southeast end of the Shipunsky Peninsula and is high above the ocean on a steep bank over a narrow shore zone of sand and gravel beach ridges. The bluffs, rising steeply above the ocean, reach a height of 120 m.

The workers of the meteorological station, awakened by the earthquake, ran out of their creaking wooden house. The underground rumbling which accompanied the shocks of the quake was replaced in a few seconds by the roar of collapsing cliffs and rocks rolling into the ocean. A cloud of dust rose above the ocean and covered the shore. After 10-15 minutes the dust hanging over the shore settled, and great piles of fallen earth with masses of soil up to a ton in weight became visible. The beams of the station building were bent, and the walls were cracked. When the earthquake ended, all returned to the house.

The arrival of the first wave was not noted. The wave was not large and barely reached the crest of the beach ridge, which had heights of up to 5 m. Then the wave retreated, exposing the bottom and the underwater reefs for about 50 m. out (to a depth of 6-10 m.).

Several minutes after the ebb of the first wave everyone saw a broad dark band approaching from oceanwards. At a distance of 20-250 m. they made out that it was a wave which, as it swiftly drew near to the shore, became ever higher and was crested with white foam. The wave came quickly and picked up everything that was on the shore (barrels, boxes, timbers, etc.). The wave immediately began to roll back, again exposing the bottom and the reefs along shore. That time the bottom was uncovered out to 100-120 m. from shore. In its return to the ocean the wave carried away the property of the meteorological station that had been lying on the sandy beach (batteries, bricks, lumber, motors weighing 500 kg. and containers weighing 1.5 tons, barrels, antenna poles, and radio apparatus). After the second wave there were two more noticeable but weaker waves. The height of the second wave was measured by its traces on the coastal cliffs and found to be 8-9 m. At the time of the tsunami it was high tide and the actual rise of the water due to the wave may be considered about 7-8 m. According to other reports, the splash of the wave reached 12 m. at Cape Shipunsky.

The contour of the shore and its relief were somewhat changed after the catastrophe. The beach ridge was partly washed away and flattened. New talus heaps appeared, formed by the slides in the earthquake. Along the shore behind the ridge there was a small lagoon, connecting with the ocean by a small channel about 2 m. wide. The wave broadened that channel and in its return to the ocean it broke a new channel through the beach ridge, which had a height of 5-6 m., at the western part of the lake.

Ol'ga Bay

Ol'ga Bay is southwest of the Kronotsky Peninsula, in the northern part of the Gulf of Kronotsky. It is surrounded on the northeast by cliffs and is bounded on the south by a chain of reefs.

The description of the effects of the tsunami is based on data furnished by Comrade Oshmetko.

The settlement of Kronoki is situated at an altitude of 12-13 m. and the meteorological station at 15 m. Near the settlement was a suspension bridge 5 m. long. East of the settlement were storage facilities.

The earthquake awakened the inhabitants of the settlement. It caused some destruction -- in several houses the stoves collapsed. The arrival of the wave was preceded by a small retreat of the water from the shore. The rise of the water, which took place rather slowly, began 40-45 minutes after the earthquake stopped. The tent of the geologists, which was on the beach, appeared in the water, and that made the people flee to the adjacent higher slopes. After a few minutes the water went back, exposing the rocks near shore. Then the second wave came, as gradually as the first. The first wave did not have great force and was like a rapid flood of the tide. The second wave was higher and reached a height of 6-7 m. Many houses were in the water but there was no destruction.

After some time a dull sound was heard from the direction of the ocean, like the roar of a large number of motors, and the third wave rolled with great speed to the shore, its crest, covered with white foam, visible from a distance of about 0.5 km. The wave, which looked like a wall of water, noticeably lost speed on the gradually sloping shore, but at the same time its height increased.

Most of the population of the settlement went to the higher slopes after the first waves. Only a few persons failed to save themselves.

The third wave came 30 minutes after the second and caused the greatest destruction. Houses collapsed with a crash, roofs and timbers were carried away by the foaming wave. The wave knocked out the walls from some houses which stood 50-70 m. from the shore at a height of 5-6 m. It was difficult to recognize the place which one had left just a few minutes before the catastrophe. The shore was littered with the debris of buildings, boxes, bags, all sorts of goods from the wrecked warehouses, scattered along the beach over a distance of 16 km. A 400-ton barge which had been lying 15 m. from shore at a height of about 4 m. and which was drifted over with sand, was carried away and thrown on the rocks 4 km. east of the settlement; a 3-ton truck and a tractor were moved from their places and damaged; a crane weighing 19 tons was moved 2 m. and bent out of shape; a 15-ton pump was moved and overturned; a diesel engine was torn from its bed and moved 1 m.; motors standing at a height of 3 m. above the ocean and weighing about 3 tons each were shifted distances up to 20 m. Drill pipes were swept along the beach.

The seismological field station was inundated and knocked out of commission.

Among the reefs, which form a line of underwater cliffs with sandy shallows at the entrance to the bay, the waves washed out deep channels. The waves did not reach the meteorological station.

At points north of Ol'ga Bay the wave did not cause any damage and its height was insignificant.

Piratkova Bay

Piratkova Bay, in southern Kamchatka, opens to the east and is quite well protected. In front of the entrance to the bay there is an underwater sill 5-6 km. wide with depths of 33-47 m. In the northern part of the bay there is a line of reefs. The north shore of the bay is high and precipitous, reaching a height of 15 m. To the southwest the coast gradually rises even higher. A creek flows into the bay from the west.

The description of the effects of the tsunami are based on data of G. A. Ptachek of the Hydrometeorological Service.

The house of the meteorological station is situated on the west coast of the bay at a distance of 100 m. from the shore and at a height of 4-5 m. above sea level; the observation platform is at a height of 6-7 m. Before dawn all of the people living in the station were awakened by the earthquake and ran outside, but they then came back in. Approximately half an hour later the staff again went out of the house and saw a high wall of water rolling from the northeast toward the house. They ran away from the bay. Behind them the wave broke with a roar on the house, but did not destroy it. That first wave had a height of about 7-8 m. After some time the second, higher wave came, 10-14 m. high. The station house, of log construction on a wooden foundation, was destroyed by the wave, but a motor which stood on the foundation in the entry way was saved.

At the weather observation platform, situated north of the river valley at a height of 6-7 m., only two wind signal hoists survived. By the bay, at the base of the steep bank, much timber was lying; it was thrown by the onslaught of the second wave up to a height of about 10 m. Here there were also pipes, chains, bricks, anchors, whaling harpoons, a coil of heavy galvanized cable -- all were thrown about by the wave: the cable was unwound and tossed onto the high bank, harpoons weighing 50-60 kg. were thrown several hundred meters away, bricks and pipes were washed away.

Trees and bushes growing along the river valley were torn up along a band 150 m. wide. The very relief of the bay shore was changed. The bed of the river became wider; bluffs were exposed along the sides of the valley and heaps of slide material were formed. The bar on the bay shore at the mouth of the river was washed out.

During the course of several hours after the tsunami there were repeated fluctuations of the sea level, of which two or three reached 4-5 m.

Zhupanovo Settlement

The settlement of Zhupanovo is situated south of the Semlachinsky Lagoon on the high shore of the Gulf of Kronotsky. After the earthquake three waves came, at intervals of up to 30 minutes. The height of the waves was 4-5 m. The waves did not reach the settlement, and only the pier, which was at the foot of the steep bluff, was washed away. There were no lives lost.

Akhomten Bay

This is a narrow bay like a fjord opening into the mountainous rocky shore of the east coast of Kamchatka. Several houses which stood low on the shore of the bay were carried away by the tsunami. The wave height reached 7 m. Lives were lost.

Sarannaia Bay

There is on the shore of the bay a lake, which at rising tide motor launches enter through its outlet. On the sandspit separating the lake from the ocean there are two fish salteries and some warehouses of corrugated iron. The wave washed out the sandspit and scattered the salteries. Only the pillars of the warehouses, with the roof boards, remained. Wooden tanks were broken out of the sand and concrete tanks and a windmill were thrown about by the tsunami. The wave washed away several structures and changed the bed of the lake outlet.

According to the topographers' data, the wave reached a height of 6 m.; according to the inhabitants it was 8 m.

Asacha Bay

At the northern point of the bay, 20-30 m. from the sandy beach strip, bushes and trees were growing; all of them were torn up by the roots by the water. The height of the wave at the northern headland of the bay reached 6-7 m.

Khodutka Bay

In Khodutka Bay the tsunami was observed 20 minutes after the earthquake. The wave threw a launch 500 m. in from the shore. There are no other reports concerning the tsunami.

Cape Lopatka

On the shores of Cape Lopatka the height of the wave, according to data from topographic surveys, reached 9.5 m. According to local inhabitants, two waves were observed here, of which the first was considerably the weaker. It came 20 minutes after the earthquake. Thanks to its high situation, the settlement remained beyond the reach of the waves.

Ozernoe Fishing Base

The earthquake was felt quite weakly at the Ozernoe base, located in the southern part of the west coast of Kamchatka. The rise of the water was gradual and reminiscent of a rapidly flooding tide (the maximum rise was 3-5 m.). The

water reached only the southernmost fish plant. There was almost no damage. The water level was higher than ordinary for two days and the character of the tides was disrupted.

Farther north on the west coast the height of the wave was smaller. Thus, at the village of Kolpakovo (on the latitude of Ol'ga Bay) the rise of the water did not exceed 0.5 m.

Other Areas of the Far East

On Sakhalin, at Magadan, and at Vladivostok the earthquake was not felt, and the rise of the water in the Sea of Okhotsk was slight. For instance, in Terpeniia Bay on the east coast of Sakhalin ships lying in the roadstead were only slightly rocked by a small swell. Only later did their crews associate that phenomenon with events in the Kuril Islands. At Magadan a rise of 2 m. was registered by the mareograph.

In the Komandorsky Is. the shocks of the earthquake were felt at the village of Nikol'skoe on Bering I. After earthquakes old settlers always observe the ocean from the high shores to see whether there will be a tsunami and warn the inhabitants of danger. On 5 November the rise of the water was insignificant. Exact data are not available.

Reports of Eye-Witnesses

A record of the accounts of eye-witnesses is presented below in order to give a fuller idea of the character of the tsunami and the scale of the destruction.

> L. I. Dymchenko, chief of the exploratory party of the Kamchatka branch of the Giproryba, related the following:
>
> In mid-September 1952 I led an exploratory party to the Malaia Zhirovaia fishing base of the Avachinsky Fishery Combine to do topographo-geological and geological engineering work in the area of the fish plant, the workers' settlement, and the industrial installations. Our party worked there from September 20 to November 4, 1952.
>
> On the night of November 5 I was awakened by a strong shaking. Once awake, I realized that the shaking was an earthquake, and I began to awaken my comrades; the shaking continued for 3 to 5 minutes. While we got up, dressed, and lit the lamp the earthquake ceased. All of my comrades and I had a feeling of anxiety. We went to look at the fissures caused by the earthquake. These fissures (30-40 cm. wide) began at our tent and ran in the direction of the oil-extraction plant, approximately paralleling the contour of the shore, passed under the oil plant and continued on. The oil-extraction plant was the only building which the earthquake left damaged to its foundations. The cracks in it were over a meter wide.

Not far from the oil boiler in the direction of the pier was the saltery, a large wooden shed 25 or 30 m. long. This shed was moved into the sea by the earthquake, and under the pressure of a light west wind it was drifting out of the bay to sea.

After the earthquake ended, 10-12 minutes passed and suddenly we saw that that same saltery which had just been carried out to sea was floating right back toward us, but now it was drifting with great speed and against the wind. Only then did I realize that the saltery was drifting under the action of a tsunami. There was no time to think, we had to save ourselves. I was 700 meters away from the volcano and the sea was right beside me. About 70 meters from me was a cargo lighter pulled up on shore. I ran to the boat and reached it already up to my knees in water. I had just managed to spring into the boat when the wave picked it up and carried it toward the volcanic cone. Then the wave passed the boat, leaving me approximately at the place where the lake had been before. After some time the wave rushed back and washed off from the sandspit, where the fish plant was located, the boat with me and a mass of the most miscellaneous floating objects beginning with timbers, roofs, floors, and bundles of hay and ending with various boxes of canned fish, bags of flour, assorted clothing, etc.

This first wave was of comparatively small height, about 4-5 m., and, the main thing, of low velocity. In front of the wave there was a rapid rise of the water and right after it the wave itself rushed in. The wave destroyed almost all of the houses of the settlement and then, rushing back to the sea, washed away almost everything. My boat was half filled with water. Grabbing a piece of a plank, I began to paddle toward the volcano, northward, but a light breeze was blowing from the northwest. The boat was large (capacity more than a ton) and I could not move it against the wind with a piece of a board.

A little later, when things had calmed down somewhat after the first wave, a motor launch of the Avachinsky Fishery Combine passed not far off but they did not see me from the launch. Paddling the lighter with my broken board in a heavy swell (a swell appeared in the bay after the first wave, apparently because the wave was subsequently reflected by the high shores of the bay), I thought that the catastrophe was all over and I was figuring how I might get to the cone (northward), where three bonfires, lit by the people who had taken refuge there, were burning. About 10-15 minutes after the first wave I noticed that a huge ice field, covered with snow, was moving into the bay from the ocean. But what I took to be an ice field turned out to be a second wave of much greater height (roughly up to 10 m.) and much higher speed, with a mass of foam and spray. The wave rushed on me with fearful force (I even felt pain from the blow of the water), picked up my boat, lifted it high on the crest, and capsized it. The wave carried me with it for some time; I was under water so long that

I ran out of air. Finally the wave passed me, I came to the surface, and clung to a floating timber.

The second wave of the tsunami, the one that covered me, consisted in its upper part of gigantic whitecaps (similar to the whitecaps in a storm at sea, but of much greater dimensions), and these whitecaps and the spaces between them were full of very fine water droplets and spray.

My encounter in the bay with this second wave was the most terrifying thing that I have ever lived through. I sighted my boat and made my way to it, but I could not move from the spot where I was. I began to freeze, but there was nowhere to look for help.

When the sun rose, I saw that the cutters which had gone out to sea from the bay in the night at the time of the first wave were coming back. I began to shout to them with all my strength. One of the boats passed near me, but they did not notice me and went on. Then I decided that they could not hear me on the cutter because of the noise of the engine. I ceased paddling, raised my paddle over my head, and began to wave it from side to side. I did not stop waving until the cutter came back to me. They pulled me aboard, and I could not stand up, because my legs were stiffened and had no feeling. It took three sailors to draw my rubber boots off, as my ankles would not bend at all; then I began to shiver, and I did not warm up for an hour. In all I had been drifting on the icy sea for 4 hours.

The crew of the boat of the Avacha Fishery Combine which took me aboard, together with the crew of another cutter, picked up all of the people who had taken refuge on the volcano, after which the cutters proceeded to Petropavlovsk. We went first to the fishing base of the Bolshaîa Zhrovaîa cannery, where we saw the same kind of scene as at our own place. Halfway to Petropavlovsk we met a steamer, which took us aboard and delivered us at 1700 at the city of Petropavlovsk-Kamchatsky.

Major Sinitsyn reports that on November 5, 1952, at approximately 3 h. 55 min. there was an earthquake which continued for about 2 minutes with gradually strengthening shocks separated by unequal periods of time. Shortly afterwards the tsunami came.

In the town the highest crest of the wave passed up the creek which cuts through the middle of town. The first wave rushed into the houses but did not carry them away, although it turned some of them around on their foundations. The second wave caused total destruction to the low-lying part of the town.

Comrade Semenov, a resident of the Kozyrevsk settlement, related that the earthquake destroyed the stoves in houses situated on the shore. Fissures up to 25 cm. wide were formed in the sand of the

beach area. The first wave came while it was still dark. That wave twisted houses around, tearing them loose from their foundation, and breaking in the walls of some of them. The second wave came at dawn. Before its arrival the water ran out 200-300 m. from the breakwater, exposing rocks covered with seaweeds, the sharp odor of which was perceived by the people who were wandering about on the exposed sea bottom. Thanks to the situation of the Kozyrevsk settlement on the slopes high above the sandy shore, the wave reached only the fish cannery and some other structures in the beach area. The low shore has a breadth of 100-200 m. When, after the ebb of the water, the second wave came, it was with a roar, and the people ran for the hills. Almost all of them managed to save themselves, as the high ground was near at hand. The second wave wiped out the fish cannery and all structures on the low shore. Only the concrete foundations of the cannery survived. The water did not calm down for a long time, but carried past Kozyrevsk through the strait much debris, roofs, floating houses, and small vessels.

Chapter 3

FORMATION OF THE TSUNAMI ON THE EAST COAST OF KAMCHATKA AND THE NORTHERN KURIL ISLANDS

Propagation of the Wave of the Tsunami of 4-5 November 1952

The velocity c of propagation of a tsunami having a length of wave considerably greater than the depth is determined by the formula of Lagrange-Airy:

$$c = \sqrt{gH}$$

where g is the acceleration of the force of gravity and H is the depth. This formula is widely used for calculating the speed of propagation of waves when the depth is known. It is also used for figuring out the mean depth in the path of a wave where the velocity is known. The speed is determined from the interval of time between the moment of the earthquake (the moment of origin of the tsunami) and the moment of the wave's arrival at a given point and from the distance between this point and the epicenter of the earthquake. There is a view that the actual speed of propagation of a wave is less than the calculated value, but still the calculated and actual values are very close in an overwhelming majority of cases. For example, according to the calculations of Zelter {Zetler (translator)} [12], the disagreement on the average is 1.2% (in 20 cases). Using the formula of Lagrange-Airy and a bathymetric chart of the Pacific Ocean, he charted the times required for tsunamis to reach the Hawaiian Islands from various areas of origin. This chart shows the time for spread of the waves directly by means of isolines and greatly facilitates tsunami warning work. However, as was stated earlier, the Hawaiian Islands are very advantageously located in this connection, as they are distant from all possible epicenters. Kamchatka and the Kurils lie in the immediate vicinity of several areas of potential epicenters. Whereas the time of propagation of tsunamis from the nearest epicenters to the Hawaiian Is. is reckoned in hours, for Kamchatka and the Kurils that time is reckoned in tens of minutes.

It must be emphasized that this unfavorable situation is made even worse by the fact that here tsunamis reach the continental slope and shelf very soon after they originate. Consequently the velocity and length of the waves rapidly decrease, preceding crests travel slower than the following ones, the symmetry of the profile breaks down, the application of the Lagrange-Airy formula becomes less and less feasible, and calculation of the velocity becomes more difficult. When the depth is equal to the height of the wave, the velocity of the crest becomes greater than that of the trough of the wave, and calculation must be carried out with the formula of Scott and Russell

$$c = \sqrt{g\left(H \pm \frac{A}{2}\right)}$$

where A is the height of the wave.[7] The asymmetry of the wave increases as the

[7] The plus sign refers to the crest, the minus sign to the trough.

steepness of the forward slope sharply grows owing both to the lessening of the wave's length and to the increase in its height.

The height of a wave increases especially greatly when it enters a narrow place with a rising bottom. Here the energy of a large mass of water (great in depth and broad in section) is transferred to a smaller mass (less in depth and narrower in section), which produces an increase in the speed and height of the wave. If we consider that the energy is transferred without any loss to friction, the height in the second section will change according to the law

$$h_1 = h_0\sqrt{\frac{B_0}{B_1}\sqrt{\frac{H_0}{H_1}}}$$

where h_0, B_0, and H_0 are respectively the height, breadth, and depth of the initial section; h_1, B_1, and H_1 are the same for the second, narrower and smaller, section.

When the tsunami reaches dry land, there is reflection of the wave, more significantly where the water is deeper and the slope of the bottom and the beach is steeper. This reflection leads to interference between waves and may further increase their height; furthermore, this effect appears more strongly in narrows, and in such places waves may reach heights twice as great as in the open sea.

Finally, when the wave (the "wave trajectory") reaches shore it undergoes refraction, inclining to the side of lesser depth, i.e., converging on capes. For this reason, under conditions of a comparatively small extent of shallows, i.e., when the absorption of energy by friction, leading to a decrease in wave height, is insignificantly small, we can observe at capes a growth in wave height through coincidence of phases and a decrease in height due to opposed phases of waves coming in from different sides.

When the height of the wave becomes equal to the depth, the wave breaks down and is transformed into a wave of translation (wave of displacement) of the breaker type. This "breaker" can also cause considerable destruction. To this must be added the kinetic energy into which the potential energy stored up in the water is transformed when it runs onto the dry land. This energy goes mainly into the formation of an extraordinarily strong reverse (seaward) flow, washing away soil and undermining foundations. It is necessary also to take into account the role of the force which causes bodies to decrease in weight (according to the law of Archimedes) and causes objects lighter than water to float on the surface of the sea in the flooded parts of the land. At present there is no possibility of giving any precise numerical evaluation of the energy of a tsunami. It is also difficult to give an adequate account of the other most important elements of a tsunami -- the height of the wave, time for its spread, direction of the wave's movement, speed of propagation, deformation of the profile, and so on.

Where abundant data are available, it is possible to give a very detailed description of the phenomenon, as can be seen, for example, from the chart of tsunami characteristics for the Hawaiian Islands (fig. 26), taken from cited work [10]. However, for the tsunami of 4-5 November 1952, it is impossible to make

such an analysis because of the limited nature and imprecision of the information about the elements of the tsunami (time of arrival of the wave, its height, the direction of the crest, the fluctuations of level in the area of propagation of the wave, and so on), which is related to the great dearth of points of observation of the sea level, especially mareographic ones, and the low degree to which the relief of the bottom and the coasts has been studied. Concerning the relief, data are particularly scarce for depths greater than 200 m. and altitudes on land below 24 m. In this case we have to limit ourselves to selected descriptions which can be derived from the available material.

The most circumstantial information about the wave is available for Petropavlovsk, where there is a tide gauge. From analysis of the mareograms (fig. 27) it is apparent that on 5 November at 4 h. 24 m. local time there began an unusual fall in level -- a phenomenon characteristic of the majority of tsunamis -- but this drop was slight -- 5 cm. in the course of 10 minutes. After this a sharp rise in level began (95 cm. in 5 min.), and then another fall (of 100 cm.) and another rise (of 110 cm. in 5 min.). This was the highest position of the level, 280 cm. above the zero mark for the station and 100 cm. above the tide level for that moment; the latter value is close to the highest position of high water. It should be noted that the wave arrived at Petropavlovsk at the time of the incoming tide (rise in level), which means that the absolute value of the highest level recorded includes in part the tidal level. The highest position at the time of the wave could have been lower, if it had coincided with low tide, or higher, if it had coincided with high tide (the range of tide at Petropavlovsk on that day was more than 1.5 m. and generally is as great as 2 m.). In passing it should be noted that the height of the tsunami at Severo-Kuril'sk and a number of other points came just around the monent of high water, which magnified the destructive force of the phenomenon.

The first change in level occurred 26 minutes after the earthquake (at 3 h. 58 m. Petropavlovsk time). This datum made it possible to determine the speed of propagation of the wave as about 130 cm./sec. or about 470 km./hr. (the distance to the epicenter was 200 km.).

The mean depth of the sea on the profile between the epicenter and Petropavlovsk, determined from this velocity, was 1,670 m. The mean depth determined from the profile taken from the 1:2,500,000 map of the USSR (1950) is 1,500 m., which gives a speed of 430 km./hr. (fig. 28). This disagreement must be explained by the fact that the relief is not truly shown on the chart, and in the area of the Avacha Gulf great ocean depths approach the coast closer than is shown in the charts. The results of soundings by the Vitiaz in recent years lead to the same conclusion.

After the arrival of the first waves of the tsunami at Petropavlovsk the mareograph recorded fluctuations of the level which have some similarity to seiches (standing waves in a closed basin). Some doubt concerning their origin is raised by the lack of correspondence (particularly at first) between the actually observed periods of oscillation of 5-10 minutes and the periods calculated by the formula of Merian

$$\tau = \frac{2L}{\sqrt{gH}}$$

where τ is the period of the wave and L the size (diameter) of the basin. For the whole of Avachinskaia Inlet one gets a period of about 3/4 hour, (L = 20 km., H = 20 m.) and for the harbor of Petropavlovsk 1.5 minutes. Because of this lack of correspondence between the calculated and observed periods it may be concluded apparently that the fluctuations of the level in the bay were caused by a subsequent series of tsunami waves. Furthermore, the earthquake itself gave a whole series of shocks (after-shocks), each of which could have given rise to a weak wave appearing at many points in the form of disturbance of the sea level. It is true that one must also take into account the possibility of reflection of waves inside the bay and interference, but we do not have any data other than this mareogram for a more precise analysis of the course of sea level changes at Petropavlovsk.

The second mareogram which is available -- from Korsakov on Sakhalin -- is considerably less revealing (fig. 29). It shows sharp fluctuations in level with a general downward tendency beginning at 8 hr. Petropavlovsk time. However, it is quite difficult to establish the time of propagation of the wave from this mareogram because of the lack of any clear cut trace of the arrival of the wave on it. It can be assumed that it corresponds approximately with the highest level (125 cm. above the minimum), as this assumption gives calculated results that appear very reasonable. Actually the difference between the time of the earthquake and that of the rise in level (4 h. 58 m. and 12 h. 18 m. by Petropavlovsk time) is 7 h. 20 min., while the shortest distance from the epicenter to Korsakov is about 2,300 km.; this gives a velocity of about 320 km./hr. (90 m./sec.) and a mean depth of about 800 m. If we take the minimal level as the time of arrival of the tsunami, the time for the run will be 5 h. 32 min., the velocity 415 km./hr., and the mean depth about 1,350 m. It must be pointed out that these second values can also not be called unlikely, as the depth of the southern part of the Sea of Okhotsk is over 3,000 m. However, the wave enters this deep basin through the barrier of the Kuril Chain, in which only two passes have depths of around 2,000 m. and the rest considerably lesser depths (from 600 to several dozen meters). Therefore, the first alternative should be considered the more likely, the more so as more than an hour passed between the minimum and maximum water levels, whereas for tsunamis that interval of time is figured at 10-20 minutes.

We should add that in a preliminary estimate by the Sakhalin branch of the USSR Academy of Sciences [1] a wave velocity of 350 km./hr. is given. This velocity is greater than the velocity in the direction of Paramushir I., which is 300 km./hr., but in this estimate the moment of arrival of the wave is not established with sufficient precision.

To calculate the speed with which the wave spread in the direction of other points is meaningless, as the moment of arrival of the tsunami was noted very roughly, with a precision of less than 5-10 or even 15 minutes.

The height of the wave is better known, but still with far from adequate precision or completeness (fig. 30). Separate charts were also compiled for the most important areas.

The summary chart clearly shows that the number of points of observation is

very small. This provides no possibility of getting a more complete general picture.

Thus, for example, one could have expected the highest waves heights in areas closest to the epicenter, i.e., at Cape Shipunsky (140 km.), at Cape Povorotny (175 km.), and at Akhomten Bay (165 km.), but the heights here (8, 10, and 8 m. respectively) are by no means the highest but rather average. On the other hand, the greatest heights were observed at a considerable distance: Cape Lopatka -- 330 km. (9 m.), Kitovaia Bay on Paramushir I. -- 440 km. (20 m.). At the same time, smaller waves were observed at nearer points: at Cape Izmenny 5 m. (200 km.), at Khalakhtyrka 4.5 m. (180 km.). The unevenness with which the height of the wave declined with distance is further emphasized by the fact that at Matsuwa I., situated 700 km. from the epicenter, the wave still had a height of 4 m., while at Bering I. (480 km.) it was about 2 m.

Another circumstance which can have an effect on the height of the wave is the presence of a screen, that is, any shore standing in the path of propagation of the wave. However, there is no such screen before any of these points, with the exception of the western shores of Kamchatka and the Kurils, where the wave actually was considerably smaller. But the screening effect appeared comparatively weak, because tsunamis, thanks to the great length of the wave, easily diffract around obstacles.

Undoubtedly the character of the earthquake (shock) itself must have a substantial effect on the diffusion of the wave. Depending on the character of the earthquake, the wave may be circular, spreading evenly along radii from the epicenter, or a directional wave going primarily to certain sectors.

The second phenomenon can be caused by a dipolar shock. The tsunami of 4-5 November gives some hints of just such a phenomenon: toward the northwest, west, and southwest the amplitude had very great values, but to the north (Ust'-Kamchatsk) and northeast (Komandorsky Is.) it had very small ones.

Finally, the bottom relief and the outline of the shore are significant -- obviously they determine the height of the wave at each particular point. The general character of the influence of these factors has been discussed above, the concrete conditions of passage of the wave in particular small areas are considered in what follows.

Geomorphological Characteristics of the Kuril-Kamchatka Coasts and their Influence on Changes in the Height of the Wave

Observations on the wave at different points on the coasts of Kamchatka and the Kuril Is. show that the basic cause influencing the height of the wave was the characteristics of the relief of the bottom and the coast. Distance from the epicenter played a subordinate role. Thus, the maximum height of the wave, caused by peculiarities of the bottom relief, was observed in the Kurils, separated from the epicenter by a distance four times exceeding that to Cape Shipunsky in Kamchatka. A heightening of the wave at the shore was especially pronounced where the bottom rises gently from the edge of the shelf to the

shoreline. The maximum effect of the breaking wave could be observed where these conditions coincided with the presence of low-lying ground inshore of the beach (fig. 31).

Underwater Relief of the Pacific Ocean in the Area of the Earthquake

The waters of the Pacific Ocean east of the Kuril Chain and Kamchatka cover a region of extraordinarily complex relief with great differences of depth. This relief, unfortunately, has not yet been adequately studied and is far from being accurately depicted on existing charts, especially in the deepwater parts of the ocean floor; it is known, however, that in a comparatively narrow strip of the bottom, 100-150 km. wide, all of the basic types of ocean floor relief are represented.

Most significant for the propagation of tsunamis is the underwater relief of the strip of bottom closest to shore, the continental shelf, particularly its width. To the south, in the region of Paramushir I., it reaches a width of 50 km., with separate underwater heights lying parallel to the coast on the gently sloping bottom.

Northward the breadth of the continental shallows at first increases slightly (it is 60 km. at Cape Lopatka) and then begins gradually to lessen, and at the entrance to Avachinskaĭa Inlet it is only 10-12 km. As the shelf narrows it also steepens. The steepest section is off the Avachinskaĭa Inlet and the peninsula lying to the north of it. North of Cape Maĭachny the continental shelf again broadens. The whole expanse from Cape Shipunsky to the entrance to Avachinskaĭa Inlet is shallow, and the edge of the shelf here lies 50 km. from the shore. Along the coast of the Gulf of Kronotsky the zone of shallow water is nowhere wider than 30 km. At Cape Kozlov on the Kronotsky Peninsula the continental slope comes right up to the shore line, from which it is separated only by a narrow abrasion platform. Along the shores of the Gulf of Kamchatka the continental shelf is quite narrow (8-15 km.) and has a complex outer contour, because of the deeply cut underwater valleys, the upper ends of which closely approach the shore. Near Ust'-Kamchatsk the continental shelf fades out completely. The steep continental slope is a direct continuation under water of the mountains of Cape Kamchatsky. Finally farther east, opposite the tip of Cape Kamchatsky, the shelf forms a protrusion to the south for 18-20 km.

The continental slope, which bounds the zone of coastal shallows along the whole extent of the coast, represents a third type of underwater relief. The upper part of the slope, within the depth range of 200-1,000 m., is characterized by great steepness and strongly dissected underwater canyons. The relief at these depths affects tsunamis. Especially steep sections lie opposite the Second Kuril Strait, off the fjord-type coast south of Avachinskaĭa Inlet, east of Cape Shipunsky, and opposite the Kronotsky and Kamchatsky peninsulas. At the Kronotsky Peninsula the continental slope, maintaining great steepness, penetrates strongly into the region of the ocean floor.

We should note as a general morphological characteristic of the continental

slope, besides the considerable steepness of its upper part, the rather sharp change from a steep slope to a gradually falling floor at depths of 1,000-2,000 m. Dissection of the lower portion of the slope is considerably less than of the upper part.

The transition from the continental slope to the region of the ocean floor is so gradual that it is very difficult here to draw the boundary between the morphological types of the bottom. We note that within the area of the floor, at depths of around 4,000 m., lies the epicenter of the earthquake.

Farther east the ocean floor also gradually gives way to the deep-water Kuril Trench, with depths in the region of the Kuril Islands greater than 10,000 m. and off Kamchatka of 7,000-8,000 m. This narrow trench-like depression extends even farther to the northeast, penetrating the Kamchatka Strait with depths of about 5,000 m. The bathymetric charts which show a submarine sill here are, apparently, erroneous.

a. Geomorphology of the Coast of the Northern Part of the Greater Kuril Chain. The action of the tsunami was especially severe on the islands of Paramushir and Shumshu.

Paramushir is one of the larger islands of the Kuril Chain. It extends from southwest to northeast for 102 km. The island is mountainous, and its volcanic peaks rise in places to 1,800 m. The Pacific coast of the island is lower and less steep than the Okhotsk Sea coast. The submarine coastal slope on the Pacific Ocean side is also considerably more gradual. Here underwater reefs extend more than 2 km. offshore, scattered among sandy and rocky flat areas (the shelf). The southern tip of the island -- the low-lying Cape Vasil'eva -- is a wave-deposited sandspit, extending 6 km. from the high primary coast of volcanic material. Rocky reefs lie scattered at the end of the sandspit. The degree of the tsunami's action on the cape is related to the origin of the latter. The formation of Cape Vasil'eva is conditioned by the combined action of two wave-actuated sand-depositing currents which meet in the area of the cape. One of them moves in from the direction of the Sea of Okhotsk, from Cape Kapar'toward the head of Vasil'ev Bay and farther south; the other, directed south-southwest, comes from the direction of the Pacific coast, and is loaded with fragments of the rock forming the eroded cliffs of the Karpinsky Range and with material brought down by the rivers which cut across the slopes of that volcano. The two directions of the flow of deposits to the point are emphasized by the vestigial lakes which lie in the base of the point.

The underwater coastal slope in the area of Cape Vasil'eva is distinguished by its strongly worked character and relative flatness. The flows of deposits, meeting near the tip of the cape, have formed to the south of it an eminence on the bottom which is well shown by the isobaths and isohypses on the charts. The relatively weak effect of the tsunami on the cape was conditioned by the peculiarities of the underwater and above-water relief of the coast. The broad protrusion of the bottom to the south of the cape caused the front of the tsunami to bend long before it reached the shore. The forms of the horizontal dissection of the cape itself also did not favor the rise of the water. The broad, even shore without any significant indentations or protrusions made possible an

extensive and quiet spreading out of the water close to the shore line. There was no important damage on Cape Vasil'eva.

Northward from Cape Vasil'eva, as has already been pointed out, the Pacific coast is bounded by the elevated flanks of the Karpinsky Range. The shore line here is slightly curved, and rocky reefs extend along it. About 15 km. from the cape the coast begins to trend gradually eastward, forming a broad bay at the head of which is the mouth of the Tukharka River. West of the river mouth is the small Kitovaia Bay, the high shores of which, gradually closing together, penetrate for 1 km. into the island. The triangular form of this bay and the nearness of the high primary shores set the conditions here for the tsunami to rise to 19-20 m., which is the highest mark of the tsunami on the whole coast. It should be noted also that the attainment of such a great height by the wave was undoubtedly made possible by the situation of Kitovaia Bay within the broad gulf lying between capes Vasil'eva and Okeansky. The converging shores of this gulf caused a piling up of a mass of water in its head, which consequently led to the rise of the water level in the smaller bay.

On the right shore of the gulf, in the area of Okeanskaia Bay, the height of the tsunami did not exceed 7 m., as here the wave which entered the gulf only brushed the shore with its right flank on its way to the head of the gulf. In contrast to Kitovaia Bay, its action appeared here as a parallel rather than a frontal displacement of water mass. Correspondingly, the dynamic action of the tsunami also was weaker. The only structures which suffered were those located directly at the water-side, but there was heavy damage to a mole which extended perpendicularly out from shore and thus received a frontal blow from the tsunami.

From Cape Okeansky the coast, forming several gentle curves, extends northeast to Cape Tomarisaki. It also has a mountainous character.

The degree to which the tsunami affected the shore of this whole section is unknown. It may be supposed that in the broad bay of Asakiwan, which is similar in form to the more southern bay already described, the wave was quite high. The zone of coastal shallows off Asaki-wan presents all of the conditions for a rise of the wave as it approached shore. We should note, however, the lesser area of this bay in comparison with the one to the south of it, a factor which should have affected the height of the wave.

About 5 km. northeast of Cape Tomarisaki, Cape Arahatasaki extends out to sea, serving as the left-hand headland of the Second Kuril Strait. The breadth of the zone of coastal shallows here attains 35 km., and off the Strait lies the upper part of a broad submarine depression which drops down along the continental slope.

The outline of the Second Kuril Strait in plan is reminiscent of a triangle with its apex between Severo-Kuril'sk and Baikovo settlement. Here the converging coasts of the islands of Paramushir and Shumshu are only 1.5 km. apart, and the strait between them continues narrow as it extends on straight north. This circumstance, as will be seen in what follows, was the cause of the catastrophe which occurred here.

The coast of Paramushir I. in the Second Kuril Strait runs in general meridionally, forming gradual curves. Numerous short rivers flowing from spurs of the Vernadsky Range have formed on the shore of the Strait a strip of low sedimentary land. Only here and there do spurs of the mountains reach the shore, and in those places the sea has formed low rocky cliffs. The coast of Shumshu I. on the Strait presents approximately the same morphological aspect. At Cape Ozerny on the Paramushir side, on a low stony shore surrounded by hills, there was a fish cannery which was damaged by the tsunami. The wave, coming from the southeast, reached a height of 7 m.

As it moved westward the wave gradually increased in height, and around Cape Kabutoyama it reached 10 m. The south shore of this cape directly faced the front of the wave as it came in from the ocean and consequently underwent the heaviest flooding.

Immediately north of the cape the wave entered a broader part of the Strait, formed by Kashiwabara Bay, with the town of Severo-Kuril'sk strung out along its shores. The rise of the water in this bay, caused by the narrowing of the Strait farther to the north, led to the almost complete destruction of the town. Only a few houses that were built on ancient beach ridge 4-5 m. high remained (see fig. 5).

Farther on, the vertical bluffs of the plateau on which the old airfield was located caused a deflection of the wave to the east, toward the settlement of Baĭkovo, situated on the low delta of a small creek on Shumshu I. At Baĭkovo the water rose 6 m. Apparently the wave attained its greatest size at the steep bluffs in the area of the airfield, as the Strait is narrowest here. Precise data on the height of the water are lacking for this part of the Strait.

The underwater relief of the Second Kuril Strait is quite complex. The depths at first decrease somewhat toward the northwest, to 11-16 m., but farther on, in the narrowest portion, they again increase to 25-40 m. In cross-section the Strait resembles a trench. At Severo-Kuril'sk the 5-m. isobath is at a distance of 200-500 m. from shore. Nevertheless, the principal role in the increase in height of the wave as it proceeded north was probably played by the outlines of the coasts of the Second Kuril Strait and not by the bottom relief.

Information on the height of the tsunami at other sections of the shores of Shumshu I. are lacking. Judging from geomorphological data, it was not very great, because of the eastward convexity of the Pacific coast and the development everywhere of rocky coastal cliffs. The height of these cliffs commonly exceeds 50 m.

Shumshu is the northernmost island of the Kuril Chain. It is separated from Cape Lopatka on Kamchatka by the First Kuril Strait, with a width of about 12 km., abounding in rocky reefs, sand banks, and isolated, irregular depressions. Because of strong tidal currents, the relief here is highly changeable.

b. Geomorphology of the East Coast of Kamchatka from Cape Lopatka to Ust'-Kamchatsk. The coast of Kamchatka washed by the waters of the Pacific Ocean extends from southwest to northeast over a distance of about 900 km. Within this

range the coast shows various forms of relief, permitting us to divide it into several geomorphological sectors.

1. The Complex (Erosional-Depositional) Coast of Southern Kamchatka from Cape Lopatka to Cape Povorotny. The structure of this sector of the coast attracts attention by its frequent alternation of erosional and depositional sections. In places where small capes enter the sea -- spurs of the highlands of the southern tip of Kamchatka -- the waves have formed erosional cliffs with wave-cut concavities at their bases, small remnant pinnacles, and reefs. Between these capes there are bays, not penetrating deeply into the land, with shores laid down by deposition of material washed down by the numerous creeks and brooks. Here the relief of the bottom in the coastal zone is characterized by great complexity. The continental shelf extends more than 50 km. from shore and in most places has an uneven surface, covered with stony and sandy ground. Usually off the capes there are elevations of the bottom, covered with growths of kelp; near shore reefs rise above the water.

At one kilometer from shore the depths sharply vary from 10 to 25 m. Areas of bottom with greater depths are located off bays with accumulative shores, which means that they, like the latter, are predetermined tectonically. The deepening of the bottom corresponds to sandy ground.

At Cape Lopatka the tsunami wave reached a height of 9 m. However, the Lopatka Peninsula was not washed over, as the coastal bluffs here have approximately that height. The water covered only the strip of gravel beach and the low sand and gravel ridges at the base of the bluffs. The high rise of the water at Cape Lopatka was facilitated by the chain of rocky reefs running from the Cape toward the middle of the First Kuril Strait. This chain, oriented parallel to the front of the wave, caused a brief damming up of the water, while at the same time there was a sharp deformation of the tsunami. Passing the narrow part of the Strait, formed by Cape Lopatka, the wave sharply decreased its height, and on the western side of the peninsula it took the form of a wash up to a height of about 5 m.

North of Cape Lopatka on the east coast of Kamchatka, on the shores of the broadly open bight, no observations of the height of the tsunami were made. On the basis of morphological data (the gentle inshore slope of the bottom, low coastal dunes, beaches), it may be supposed that the rise was considerable. On the island of Utashud, lying on an extensive stony shoal off the entrance to Vestnik Bay, the wave left traces at a height of 9 m. above sea level (fig. 32).

In Piratkova Bay, surrounded by high cliffs, the rise was even greater (to 14.5 m.), judging from interview data. It must be pointed out that off this bay there is a submarine trench which facilitated the movement of a great mass of water to the head of the bay.

The broad bay of Asacha, bounded by capes Siamo and Asacha, has an extensive depression in its bottom. The depth of the bay regularly and gradually decreases toward the low-lying depositional shore. This shore appeared to have been inundated to a great extent. The low sandbar cutting off the bed of the Asacha River from the sea was completely covered by the water. The water level in the bay rose 7 m.

2. The Fjord-type Coast of Kamchatka from Cape Povorotny to Avachinskaia Inlet. At Cape Povorotny the coast sharply changes its morphological aspect. Here the land is penetrated by deep, long fjords, the rocky walls of which have been smoothed by ancient glaciers. In this section the coastal heights increase to 800-1,000 m. The relief is dominated by steep or precipitous slopes with a talus of rock fragments. Traces of glaciation are shown very clearly. In the upper parts of the fjord valleys huge accumulations of moraine material can be traced. The trough-like valleys have characteristic bends in their sides, leading in their upper parts to their abrupt broadening. On the slopes of the high mountains cirques remain. The glacial origin of the relief is shown also in the forms of the underwater coastal slope. The drowned valleys have smoothed, trough-like bottoms (Akhomten and Zhirovaia Bays), divided in places by underwater sills -- the ancient riegels of the glacial troughs (Viliuchinskaia Bay).

As in the bays of southern Kamchatka, here the principal factors affecting the height of the tsunami were the relief of the underwater coastal slope and the outlines of the bay. The greatest heights (8 m.) of the tsunami (fig. 33) in this geomorphological section have been located at Viliuchinskaia and Sarannaia bays. In both cases the bays are formed where two neighboring valleys join together (Bol'shaia Sarannaia and Malaia Sarannaia, Viliuchinskaia and Zhirovaia), which gave them a considerably greater breadth of entrance than the other narrow fjords of the coast (Akhomten Bay, etc.).

The eastern part of Sarannaia Bay, between the headlands of capes Opasny and Saranny, has a width of about 10 km. With a gradually rising bottom, its shores, surrounded by vertical, step-like cliffs, gradually converge and at the head of the bay give way to low-lying river mouths (the Bol'shaia and Malaia Sarannaia) with a complex of depositional forms such as sandspits, bars, beach ridges, and delta islands. Naturally, the bottom relief and the character of the shores of the bay tended to magnify the tsunami from the time it entered the bay. The water could not pour off to the sides because of the steep converging shores. On the other hand, at the head of the bay it did not meet any substantial obstacle to its spreading deep into the land.

The same sort of picture, but with division of the water into two parts, was observed in Viliuchinskaia Bay. The breadth of the entrance to this bay, between capes Krutoi and La Perouse, is 7 km. Farther west the width gradually diminishes until 5 km. from the entrance it is 5 km. wide. Here the bay is divided in two -- Viliuchinskaia proper and Zhirovaia -- by the long narrow Razdel'ny Peninsula.

Viliuchinskaia Bay does not narrow deep in the land, but on the contrary widens slightly. Two kilometers from Cape Razdel'ny it is cut across by a high underwater sill, formerly a riegel of the glacier. This peculiarity of the relief probably somewhat weakened the tsunami, but its effect here was nevertheless destructive.

In Zhirovaia Bay the shores converge rather rapidly, and this bay is almost three times shorter than Viliuchinskaia. The mighty wave completely destroyed the fishery installations here and passed deep into the valley of the Zhirovaia River, covering the broad, low delta of the river, with its lakes and extensive swamps. Exact data on the height of the wave in Zhirovaia Bay are lacking.

North of Viliuchinskaia and Sarannaia bays the coastline as far as the entrance to Avachinskaia Inlet is finely dissected by small bays, some of which have been cut off by water-transported deposits and converted into lakes. There is no information available concerning the height of the tsunami in this section. Judging from geomorphological indications, the greatest height of the wave here must have been in Bezymiannaia Bay at the entrance to Avachinskaia Inlet.

Avachinskaia Inlet experienced strong action of the tsunami only near its entrance (fig. 34). At Cape Izmenny the wave had a height of about 5 m., but to the northwest the mass of water, spreading out as the inlet broadened to a greater area, caused only a minor rise in water level at the delta of the Avacha River and a rise of 1.2 m. at the city of Petropavlovsk. In Tar'ia Bay the rise was 1.8 m. The diminution of the height of the wave was also made possible by the character of the bottom of Avachinskaia Inlet, with its depths increasing to the north.

3. Coast of Central Kamchatka, With Low-lying Depositional Forms in Large Bays and High Eroded Peninsula (from Avachinskaia Inlet to Ust'-Kamchatsk). The characteristic morphological trait of this sector is an alternation of broad bays and comparatively narrow elevated peninsulas. The bays penetrate only slightly into the land, forming gently curved arcs as long as 150 km. The shores inside the bays are low and composed primarily of gravel and sand alluvium of the river, shifted and redeposited by sea waves. Behind the broad beach there is usually a high (up to 5 m.) contemporary storm beach, not anchored by vegetation. Farther inland a whole series of more ancient beach ridges can be traced, separated by shallow, slightly swampy depressions. The heights of the beach ridges gradually decrease and usually at 1.5-2 km. from the shore their crests are hidden under the plant cover of the swamps. The landscape begins gradually to rise 4-6 km. from the coast, giving way to the slopes of the mountains. This is the sort of aspect presented by the coast southwest of Cape Malychev, in Kronotsky and Kamchatsky bays.

The absence of high beach ridges on the landward side seen everywhere on Kamchatka testifies to the general submergence of the peninsula, which is continuing at present. The tempo of the sinking, as estimated by V. P. Zenkovich, is rapid, approximately 1 meter in 250 years. With this sinking process is linked in part the formation of major features of the coastal relief, i. e., the bays and the peninsulas separating them. The latter extend out into the ocean 30-50 km.

In contrast to the bays, the peninsulas in their coastal portions are undergoing erosional development. The steep rocky cliffs reach heights here of 400-500 m. At the foot of the cliffs there usually lies a band of reefs.

The Shipunsky Peninsula is characterized by the forms of a deep ingression of the sea into narrow mountain valleys (fig. 35). Here Bechevinskaia and Morzhovaia bays penetrate 7-10 km. into the land. Depositional forms of relief are poorly developed here or completely lacking, as for example, in Morzhovaia Bay.

The Kronotsky Peninsula, which has a greater absolute height than the

Shipunsky Peninsula, is more weakly dissected, however, the processes of erosion are manifested more intensively here, in connection with the nearness of the edge of the shelf to the water's edge. The area of Cape Kozlov, at the southeast tip of the peninsula, undergoes particularly severe destruction. There are also erosional sectors in northern Kamchatksky Bay, in the area of Shubertovo settlement.

On the shores of this geomorphological sector measurements of the height of the tsunami were made only at two points on the Shipunsky Peninsula. On the south coast of the peninsula, at Cape Shipunsky, the height of the wave was 8 m. It should be noted that Cape Shipunsky is the point on Kamchatka closest to the epicenter of the earthquake. The extensive continental shallows surrounding the cape also doubtless facilitated the increase in height of the wave as it approached the shore, however, the horizontal dissection of the shore, which caused a great rise of the water in other, much more distant sectors, is here of a different character. At Cape Shipunsky there is no narrowing bay which might have magnified the wave in its movement toward the bay-head, but on the contrary, there is an elevated, narrow crest, dividing it into two parts. The band of reefs stretching from the tip of the cape toward greater depths was also conducive to weakening of the wave.

In Morzhovaia Bay, on the northeastern shore of the peninsula, the height of the tsunami was 5-8 m. On the southeast, i.e., in the direction of the epicenter, this bay is completely closed by mountains, and the crest of the wave passed by the entrance to the bay, headed toward the end of the Gulf of Kronotsky. The water marks on the high shores here are explained by the general rise following the passage of the crest. A second rise of the water in the bay was the result of reflection of the tsunami from the shores of the Gulf of Kronotsky.

According to interview data, the greatest height of the tsunami was observed at the settlement of Nalychevo and at Cape Ol'ga, situated south of the Shipunsky and Kronotsky peninsulas, respectively. At Nalychevo the water rose 7 m., and at Cape Ol'ga (fig. 36) 8-10 m. Both points lie on open shores inside broad bays. The area of Cape Ol'ga was, in addition, a place of concentration for that part of the tsunami which had passed along the whole coast of the Gulf of Kronotsky. It may be supposed that at the settlement of Kronoki, for which no information is available, the height to which the wave washed was even greater.

North of Cape Kronotsky, in the Gulf of Kamchatka, the tsunami wave acted very weakly on the coast. The cause, apparently, was the projection of the Kronotsky Peninsula, which created a wave shadow for the whole extent of the Gulf. Thus, at Shubertovo settlement and at Ust'-Kamchatsk the rise of the water was only a few centimeters, although the geomorphological conditions there are like those of the Cape Ol'ga area.

The geomorphological analysis of the coast and the offshore zone of the bottom permits us to draw certain conclusions about the patterns of propagation of tsunamis.

Distance from the earthquake epicenter affects the height of the wave only in far distant areas, where the energy of the wave has already considerably

weakened. On nearby coasts the geomorphological factor takes on the greatest significance. The peculiarities of the relief of the underwater part of the coastal slope and the shore determine the possibility of a growth in height of tsunami waves as they approach shore.

The bottom relief at the shore strongly influences the degree of deformation of the tsunami wave, which may differ depending on the breadth and the slope of the continental shelf and the off shore zone. Our observations have shown that the greatest heights of tsunamis occur in those cases where the continental shelf has a width no greater than 30-50 km. and rises gently toward the shore, unbroken by underwater elevations, depressions, or reefs. The latter, where they screen bays, may however promote growth of the tsunami in shoal water.

Trench-like depressions in the bottom at the entrances of bays or in the bays themselves are favorable for the growth of tsunamis, as they facilitate the approach to the shore of large masses of water.

The influence of the shore relief on the tsunami is seen mainly in the character of the horizontal dissection of the shore zone. Off capes there is diffraction of the wave and a weakening of its action on the shore. On the other hand, where the outline of the coast is composed of a number of bays with converging shores, the growth in height of the crest proceeds very intensively toward the heads of the bays.

In the character of the vertical dissection, most important is the relationship of high, steep shores and broad, low shores within the bays. Where there are high, precipitous shores at the heads of bays, tsunamis do not reach great heights, since around such places, as a rule, there are considerable depths of water. At the same time, the same kind of shore, when it lies along the converging sides of a bay, conduces to a raising of the water level.

The maximum heights and the greatest spread of tsunamis to landward are seen on low-lying coasts at the heads of bays in those cases where steep coastal bluffs extend along the sides of the bay.

The conclusions which have been drawn permit us to consider the converging heads of bays which are open to the ocean as most dangerous with regard to tsunamis. This danger is intensified where the bay is situated in the head of a broad gulf like those of the east coast of Paramushir I., Kamchatsky, Kronotsky, and so on.

Least dangerous are capes with elevated shores, surrounded by cliffs and reefs.

CONCLUSIONS

1. From the results of the tsunami observations generalized in this report, and in view of the possibility that more severe earthquakes may occur in the Kuril-Kamchatka seismic zone, the possibility of occurrence of higher tsunamis should be kept in mind. The greatest tsunami wave known reached a height of 30 m. (at Tokachi and Mayori on Hokkaido in 1896). Hereafter, in setting up a scheme of tsunami regionalization, this height should be taken as a possible maximum for the gulfs, bays, and straits of the Kuril-Kamchatka coast of the Pacific Ocean.

2. The action of a tsunami on the shore can be both hydrodynamic and hydrostatic. In the first case the destructive effect is due to the kinetic energy of the onrushing wave (Sarannaia Bay, Viliuchinskaia Bay). In the second case, which takes place on coasts protected from the direct action of the wave, there is a rapid rise of the water which causes flooding (Morzhovaia Bay).

3. Most dangerous with respect to tsunamis are bays and straits with converging (narrowing) shores and gradually diminishing depths. Especially strong wave action is seen under these circumstances where the shores at the entrance to the bay are precipitous but are low-lying at the head of the bay (Zhirovaia, Kitovaia, and Ol'ga bays and the Second Kuril Strait).

4. It is proper to build industrial installations which have to be located in direct proximity to the shoreline in bays which have a narrow entrance and a broader central portion (the town of Petropavlovsk on Avachinskaia Inlet).

5. In locating populated points and in further construction on the coast, the actions of tsunamis should be taken into account, using the present study as a guide.

6. For estimation of the interval of time between an earthquake and the appearance of a sea wave caused by the quake, one may use the data in table 2, which were calculated on the basis of the formula of Lagrange-Airy and the mean ocean depths between the coastal points listed and the places of potential occurrence of earthquakes in regions of epicenters: 1952 -- the northern end of the Kuril Deep; 1923 -- near the Komandorsky Islands. (It is assumed that at the initial phase of the wave a rise in level takes place.)

This interval of time in case the epicenter is in the area of Urup I. (1918) will be approximately 50 minutes for Severo-Kuril'sk and IUzhno-Kuril'sk.

Table 2

Time intervals between the arrivals of longitudinal seismic and sea waves (given with a precision of 5 min.).

Point	1952	1923
Severo-Kuril'sk	0 h. 45 min.	1 h. 35 min.
Entrance to Avachinskaia Inlet (Petropavlovsk)	0 " 15 "	0 " 55 "
Ust'-Kamchatsk	0 " 45 "	0 " 25 "

7. In view of the great seismic activity of the Kuril-Kamchatka zone, it is necessary to take into account, along with tsunamis, the possibility of occurrence here of severe earthquakes. This requires serious consideration of anti-seismic construction, first of all in the city of Petropavlovsk. Special attention should be given to sectors of potential landslides and avalanches, which in case of an earthquake of intensity 8-9 could have catastrophic consequences.

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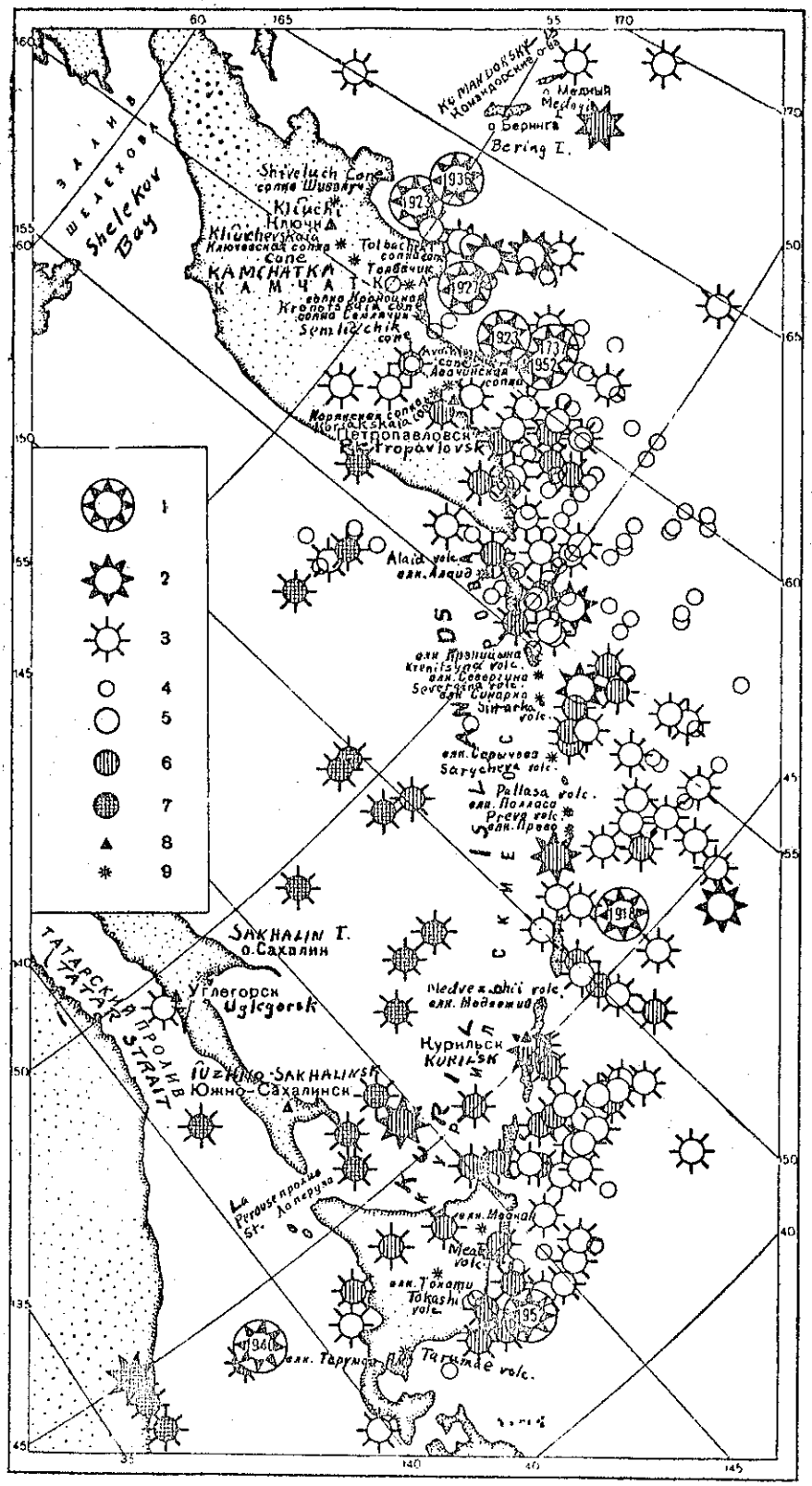

Fig. 1. Map of epicenters of earthquakes, according to data from Soviet seismological stations, 1910-1952.

1-4 are characteristics of earthquakes: 1 - catastrophic earthquakes accompanied by tsunamis; 2 - catastrophic earthquakes not accompanied by earthquakes (intensity 9-10); 3 - destructive earthquakes (over intensity 8); 4 - secondary shocks of the 1952 earthquake; 5 - 7 depth of foci: 5 - in the earth's crust; 6 - under the crust ($h < 300$ km.); 7 - under the crust ($h \leq 300$ km.); 8 - seismological stations; 9 - active volcanoes.

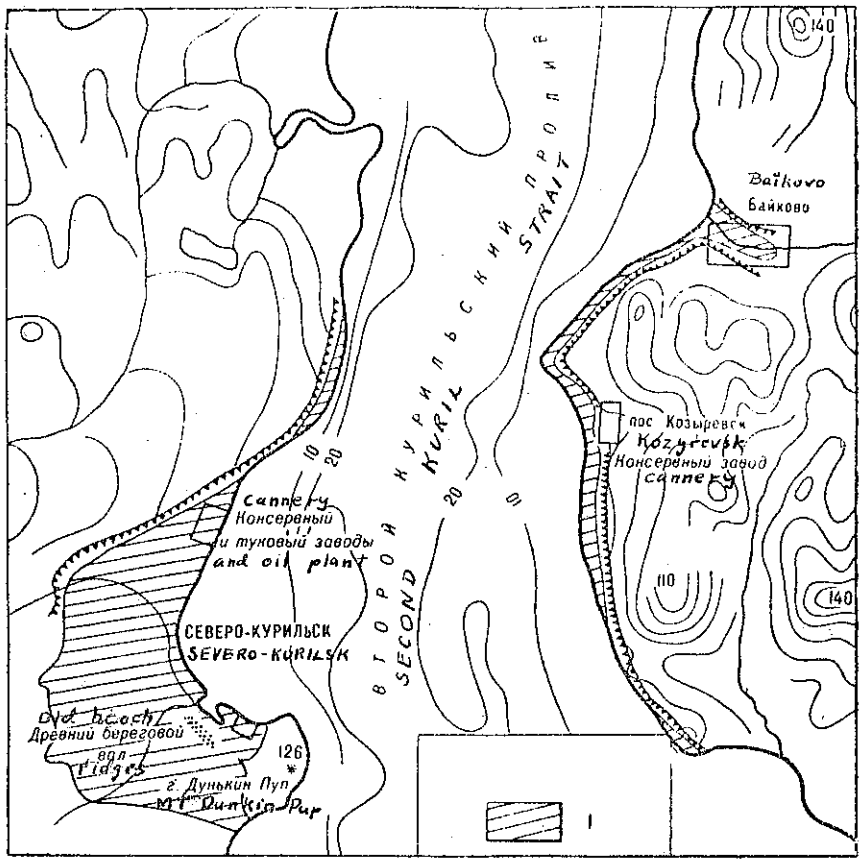

Fig. 6. Locations of the inhabited points which suffered from the tsunami in the Second Kuril Strait. Shaded areas were inundated in the tsunami of 6 November 1952.

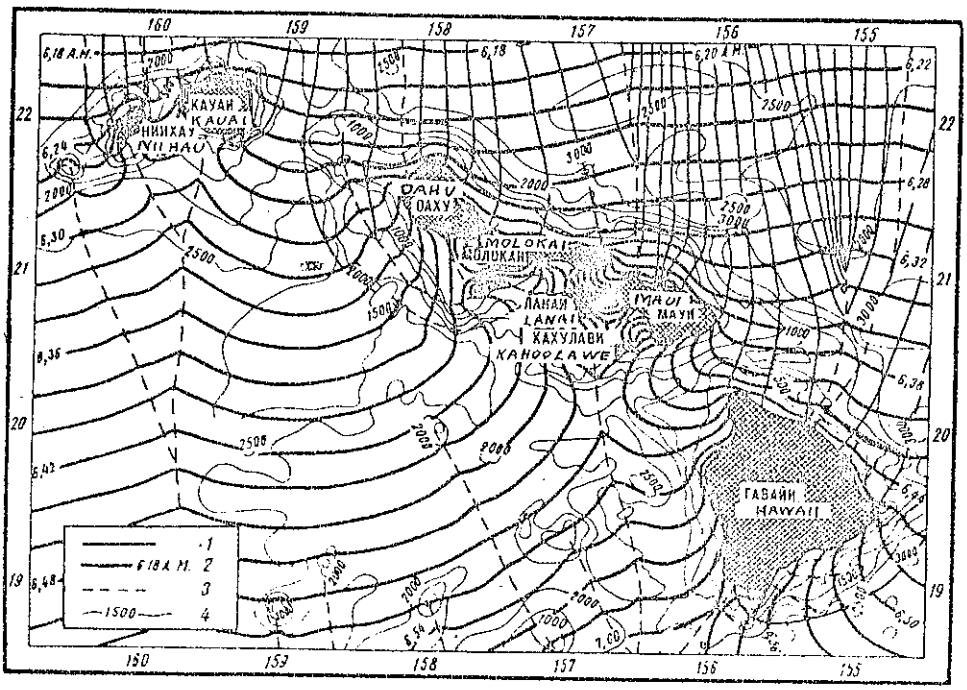

Fig. 26. Chart of the region of the Hawaiian Islands showing the bottom topography and the successive positions of the front of the tsunami wave of 1 April 1946, for every 2 minutes, and the wave trajectories. 1 - wave trajectories (orthogonals); 2 - successive positions of the front of the wave (figures show time in hours and minutes); 3 - lines of convergence of waves; 4 - isobaths (in fathoms).

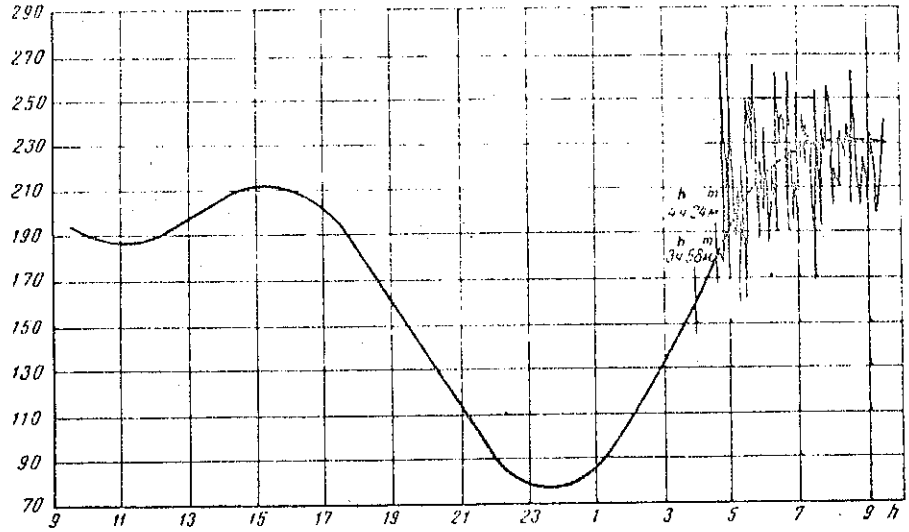

Fig. 27. Mareogram of the mareograph at Petropavlovsk-na-Kamchatka for 4-5 Nov. 1952 (Petropavlovsk time). The mareogram was started on 4 Nov. at 9 h. 30 m., cycle 201, column 289, tide marker 195. The mareogram was taken off on 5 Nov. at 9 h. 25 m., cycle 257, column 326, tide marker 240.

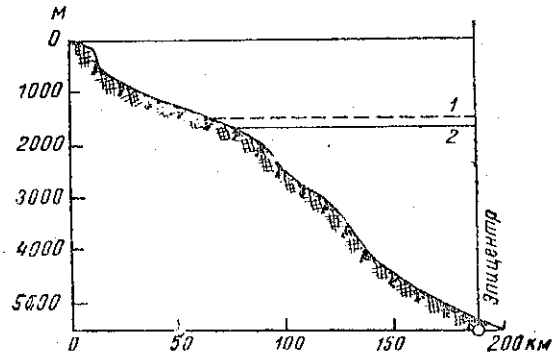

Fig. 28. Profile of the bottom from the entrance to Avachinskaia Inlet (Cape Bezymianny) to the epicenter (according to the 1 : 2,500,000 chart). 1 - mean depth over the area of the profile, 1,500 m. (c = 120 m./sec. = sec. = 430 km./hr.); 2 - mean depth by the formula $c = \sqrt{gH}$, 1,670 m. (c = 130 m./sec. = 470 km./hr.)

	Calculated $c = \sqrt{gH}$	Observed
Velocity	430 km./hr.	470 km./hr.
Mean depth ...	1,670 m.	1,500 m.

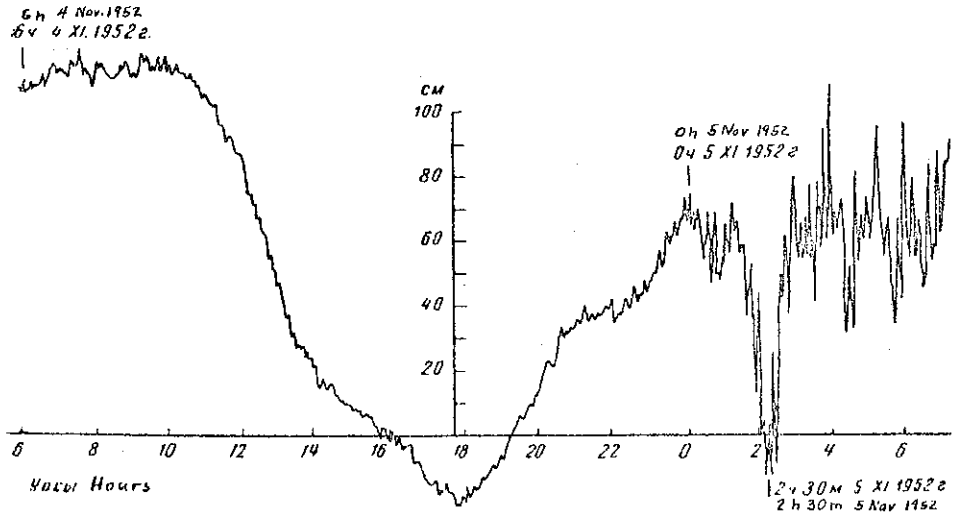

Fig. 29. Mareogram from the Korsakov tide gauge for 4-5 November 1952 (Moscow time)

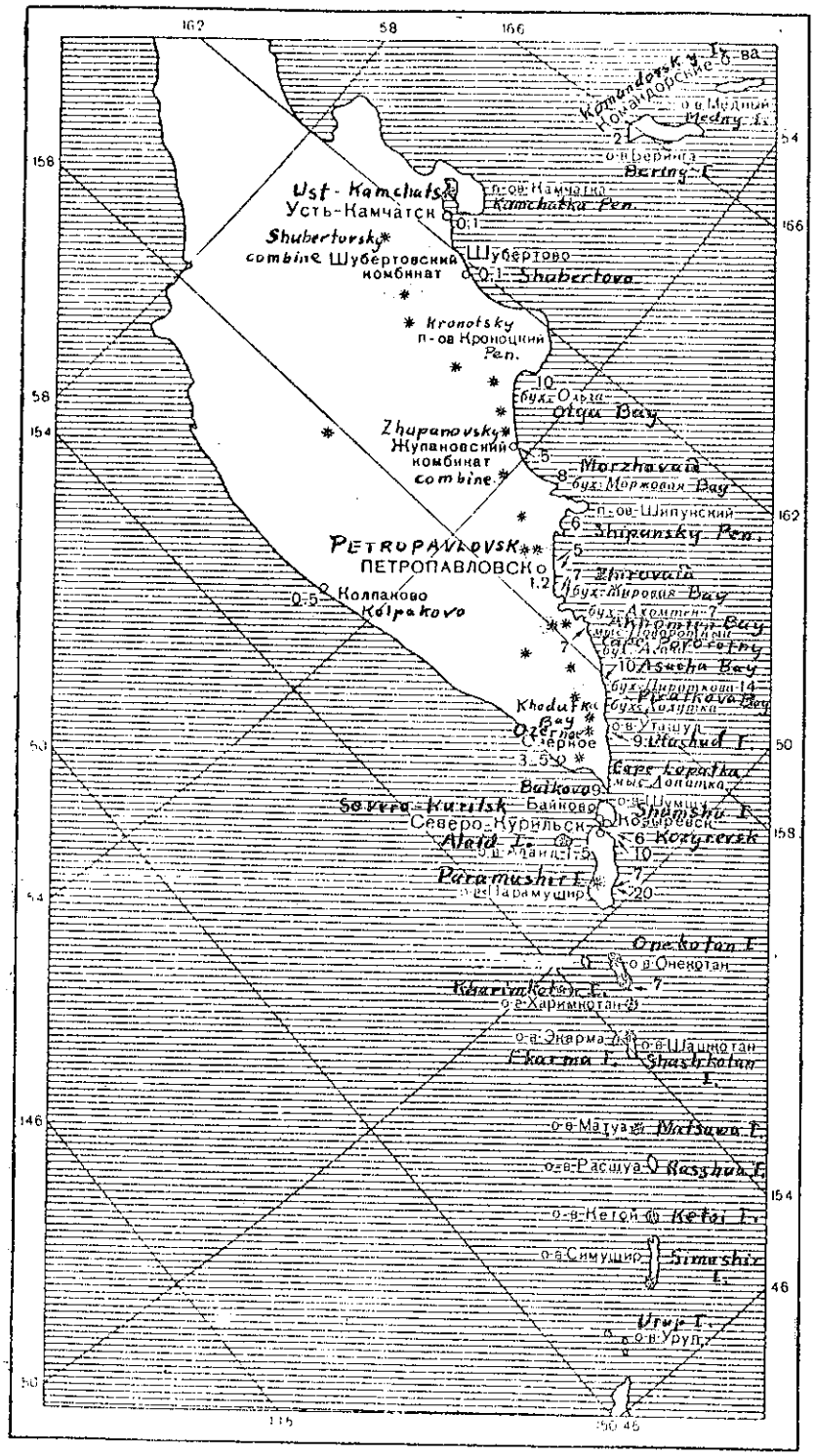

Fig. 30. Map of the area of the tsunami of 4-5 November 1952. The numbers show the height of the tsunami wave (in m.), the stippling areas exposed to danger from volcanic eruptions, and the stars show active volcanoes.

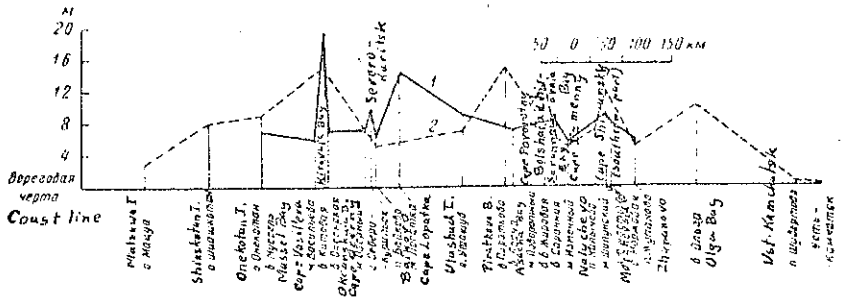

Fig. 31. Graph of the height to which the water rose at various points on the coasts of the Kurils and east Kamchatka (compiled by A. V. Zhivago from materials of A. E. Sviatlovsky). 1 -- height of the rise from geodesic data; 2 -- height of the rise from interview data. Note: the points on the abcissa represent a projection of geographical points on a straight line drawn along the shore. [Translator's note: the words at the lower left corner of the graph appear to say "Coast line" and the writing under the horizontal axis is a list of places running from south (at the left) to north (at the right) as follows: Matsuwa I., Shiashkotan I., Onekotan I., Mussel' Bay, Cape Vasil'eva, Kitovaia Bay, Okeanskaia Bay, Cape Ozerny, town of Severo-Kuril'sk, Baikovo settlement, Cape Lopatka, Utashud I., Piratkova Bay, Asacha Bay, Cape Povorotny, Bol'shaia Zhirovaia Bay, Sarannaia Bay, Cape Izmenny, Nalycheve settlement, Cape Shipunsky (southern part), Morzhovaia Bay, Zhupanovo settlement, Ol'ga Bay, Shubertovo settlement, Ust'-Kamchatsk.]

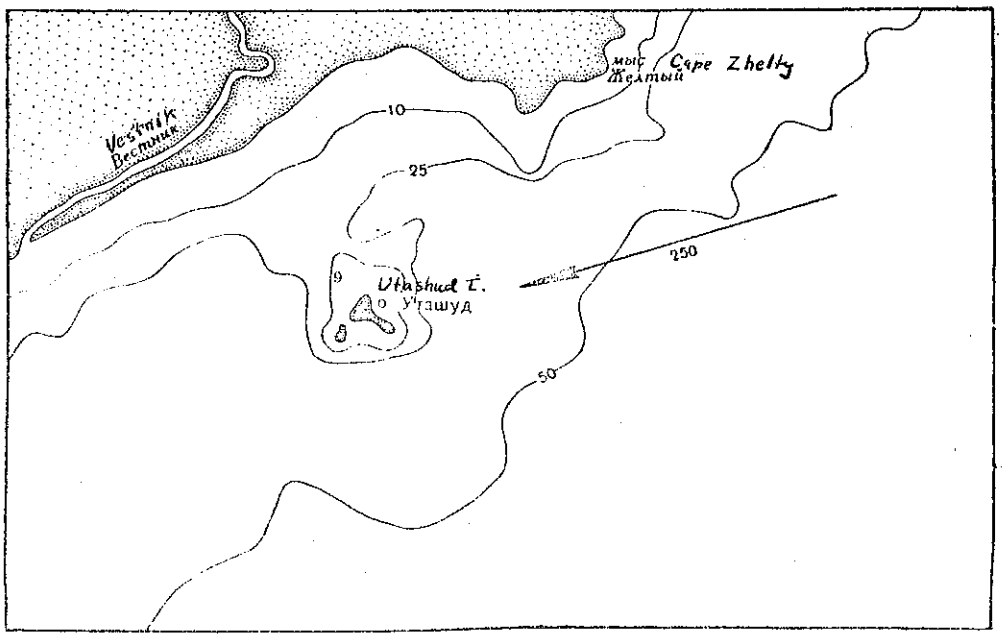

Fig. 32. The tsunami at Utashud I. Legend: on figs. 32-36 the arrows indicate the direction of propagation of the tsunami from the epicenter; the figures by the arrows are the distance from the epicenter (in km.); the figures on land indicate the height washed by the tsunami; the fine lines are isobaths.

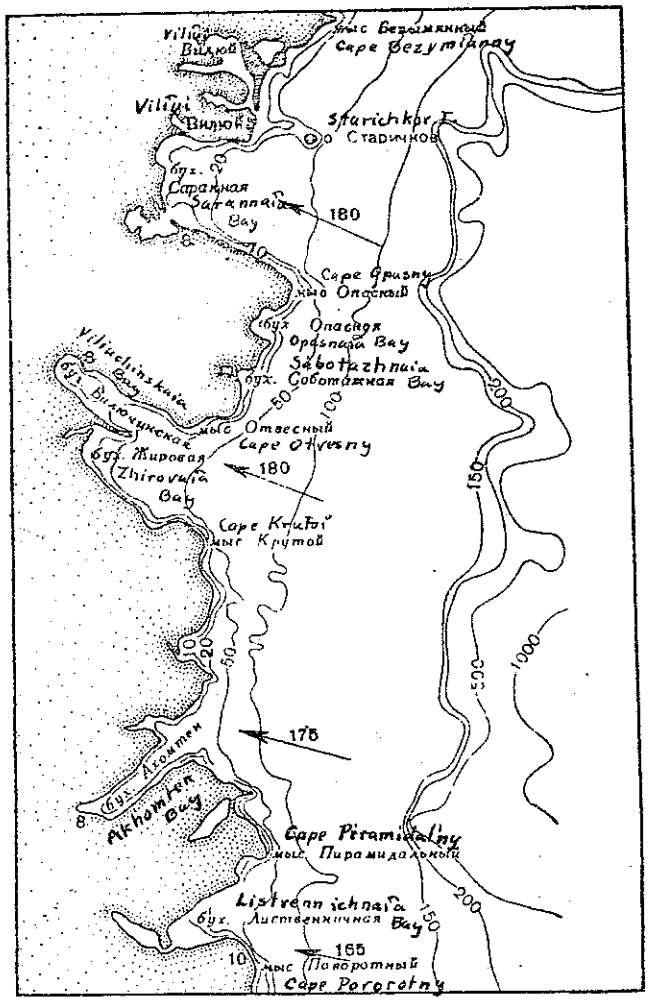

Fig. 33. Plan of the coast of Kamchatka from Cape Povorotny to Cape Bezymianny

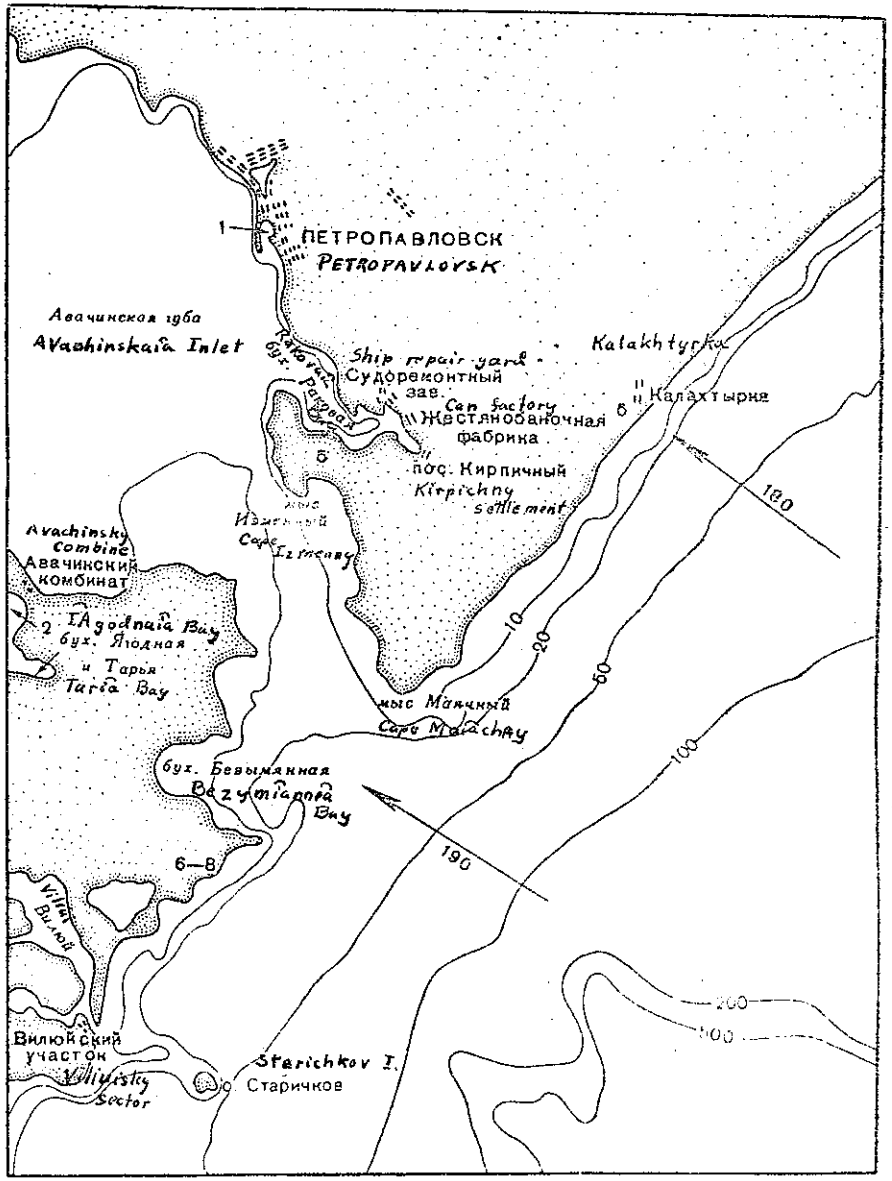

Fig. 34. Plan of the Kamchatka coast in the region of Avachinskaia Inlet.

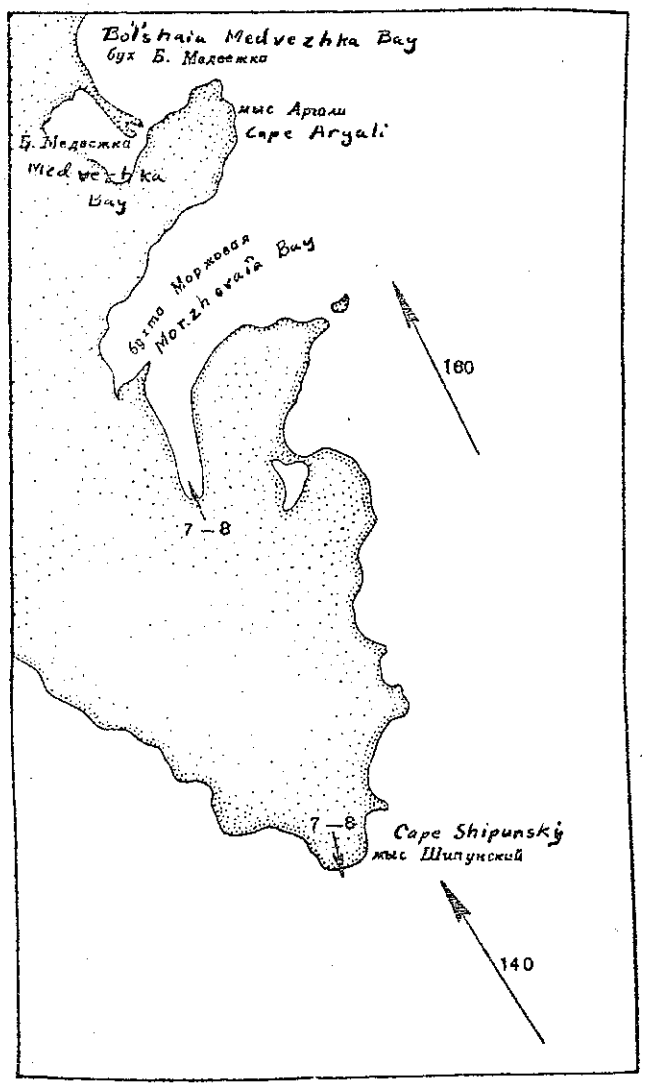

Fig. 35. Plan of the Kamchatka coast in the region of the Shipunsky Peninsula

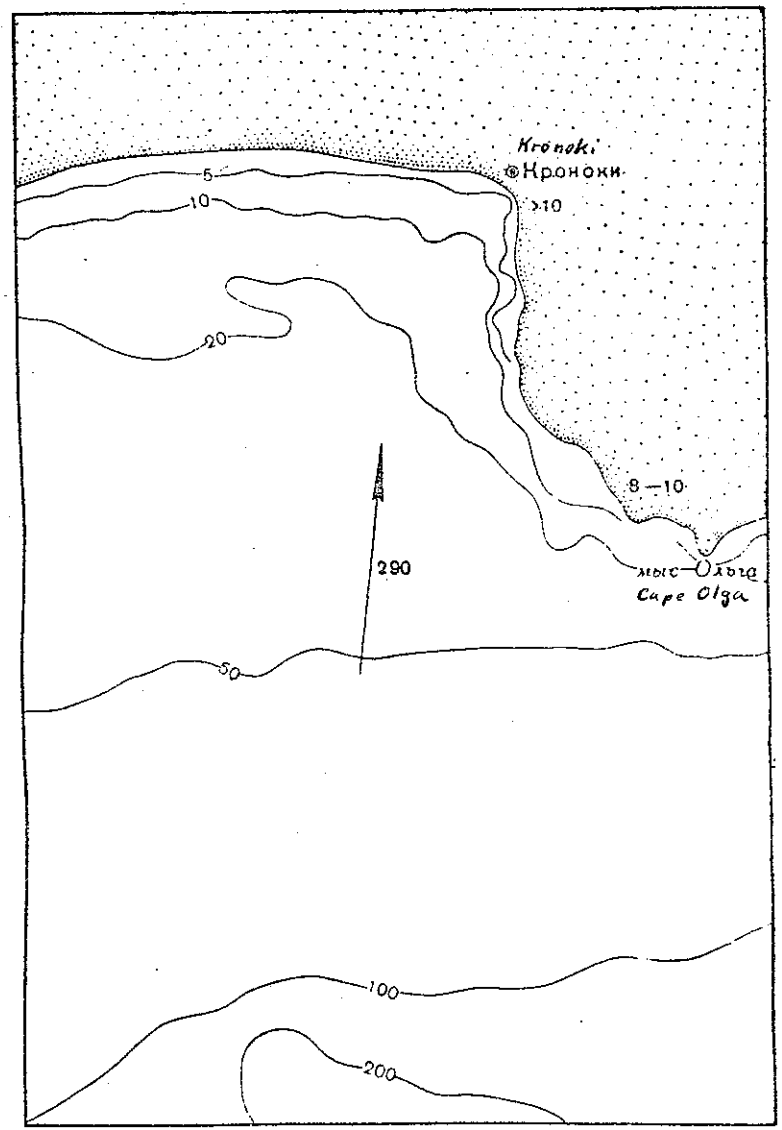

Fig. 36. The tsunami in the area of Cape Ol'ga