TWO GREAT KAMCHATKA TSUNAMIS, 1737 AND 1952

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Abstract. The paper is devoted to the comparative study of the two most destructive tsunamis occurred in Kuril-Kamchatka area – October 16, 1737 and November 4, 1952. The Kuril-Kamchatka region is characterized by a very high level of seismic and volcanic activities and it is one of the main tsunami-prone areas in the Pacific. Great earthquakes here are associated with the subduction of the Pacific plate under the Eurasian plate, that occurs along the narrow zone between the axis of the deep-water trench and the island chain. The historical tsunami catalog for the Kuril-Kamchatka region covers the period of 260 years and lists 115 tsunamigenic events with 10 of them resulting in the perceptible damage and loss of lives. Among these destructive tsunamis there are two events which considerably surpass all others in terms of their intensity and the magnitude of damage. They are the October 16, 1737 and the November 4, 1952 tsunamis associated with two most severe and damageable earthquakes whenever occurred in this area. While the 1952 tsunami was the most damageable event in the area for this century, the 1737 tsunami was obviously the strongest event in the Kuril-Kamchatka region whenever observed and one of the largest tsunamis in the Pacific historically known. Such an event, should it happens in the present days, would result in the heavy catastrophe for the Northern Kuriles and the whole eastern coast of Kamchatka. The study of these mega-tsunamis is very important, because they give essential input in the long-term tsunami risk for almost all the parts of the Pacific coast.

The Kuril-Kamchatka region is characterized by a very high level of seismic and volcanic activities and it is one of the main tsunami-prone areas in the Pacific. Great earthquakes here are associated with the subduction of the Pacific plate under the Eurasian plate, that occurs along the narrow zone between the axis of the deep-water trench and the island chain. The historical tsunami catalog for the Kuril-Kamchatka region covers the period of 260 years and lists 115 tsunamigenic events with 10 of them resulting in the perceptible damage and loss of lives.

Among these destructive tsunamigenic events there are two tsunamis which considerably surpass all others in terms of their intensity and magnitude of impact on the coastal population. They are the October 16, 1737 and the November 4, 1952 tsunamis associated with two most severe and damageable earthquakes whenever occurred in this area.

The most important geodynamic process, which determines all the tectonic and geomorphologic features of the Kuril-Kamchatka region, is the subduction of the Pacific plate under the overthrusting Eurasian plate. Fig.1 shows the shaded relief of the area near the Kamchatka east coast calculated on the basis of 30-sec land and 1-min bottom digital relief model of this area. The main feature of this relief is the deep-water trench with depths of 7000-7500 meters extending in the northeastern direction at the distance of 150-180 km from the coast. Another prominent bottom feature is large deep-water terraces associated with the three main Kamchatka bays. The steep continental slope is cut in many places by the submarine canyons, some of them being clearly connected with mousses of the main Kamchatka rivers. The chain of active volcanoes extends within the Eastern Kamchatka Ridge at the distance from 20 to 100 km from the coast.

The shallow depth seismicity of Kamchatka fills in a wide strip located between the axis of the deep-water trench and the volcanic chain with the major events associated with the steep continental slope (Fig.2). The middle and the deep focus seismicity clearly marks the subducting oceanic plates (see the vertical crossection in Fig.2). In the analysis of the seismicity map, one should take into account that the deployment of the regional seismic stations began in Kamchatka since the beginning of the fifties, so that clouds of aftershocks in Fig.2 reflect the regional events occurred only during the last 40-45 years.

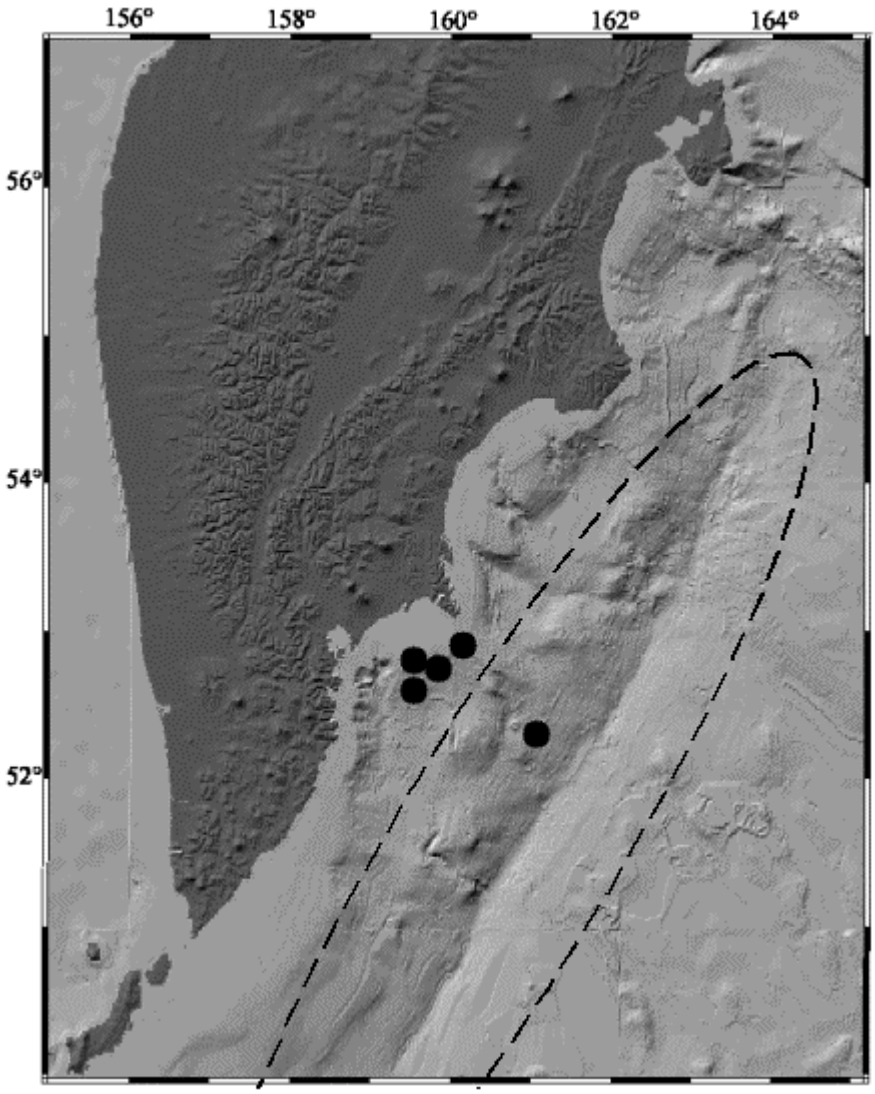

Fig.1. Shaded relief of the Kamchatka Peninsula and the nearby areas of the north-western Pacific. Black circles show the positions of the epicenter of the 1952 earthquake as provided by different seismological catalogs. Dashed ellipse outlines the source area of the 1737 earthquake.

The map of historical tsunamigenic earthquakes for this area is shown in Fig.3. The historical tsunami catalog for Kamchatka starts since 1737, and it is rather short comparatively with some other tsunamigenic regions in the Pacific. Its duration is only 260 years that hardly covers the main seismic cycle for the Kuril-Kamchatka area estimated to be 140±50 years (Fedotov, 1968). But even for this period the historical tsunami catalog is obvious incomplete (that can be seen from the I(t) diagram shown in Fig.3). Sources of almost all the tsunamigenic

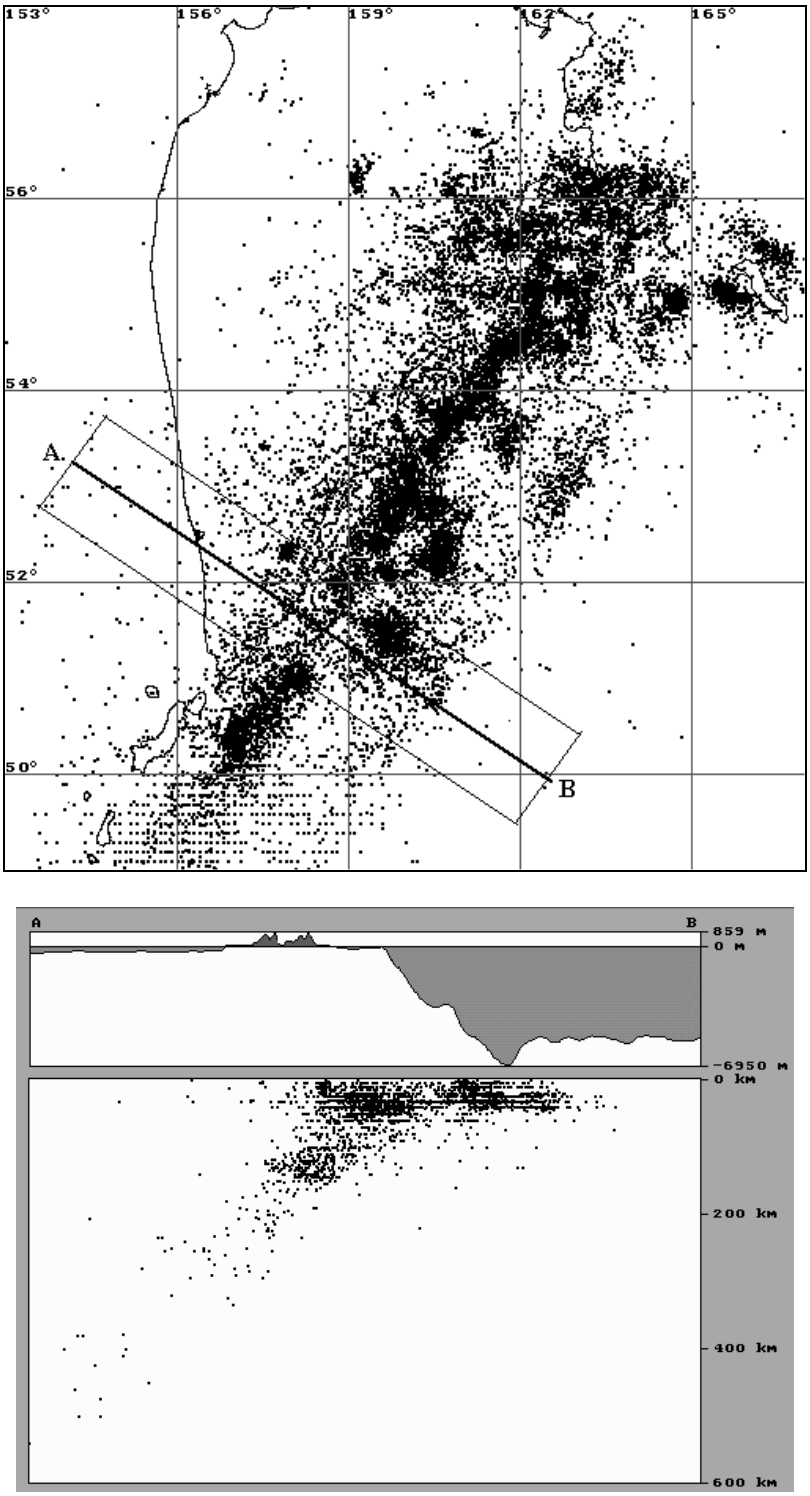

Fig.2. A map of historical seismicity of Kamchatka and North Kuriles for the period from 1737 to 1992 (above) and the vertical cross-section along the line A-B (below). Note the difference in the number off events and in the accuracy of epicenter determination for the north Kuriles and Kamchatka areas resulted from the difference in the density of seismic network

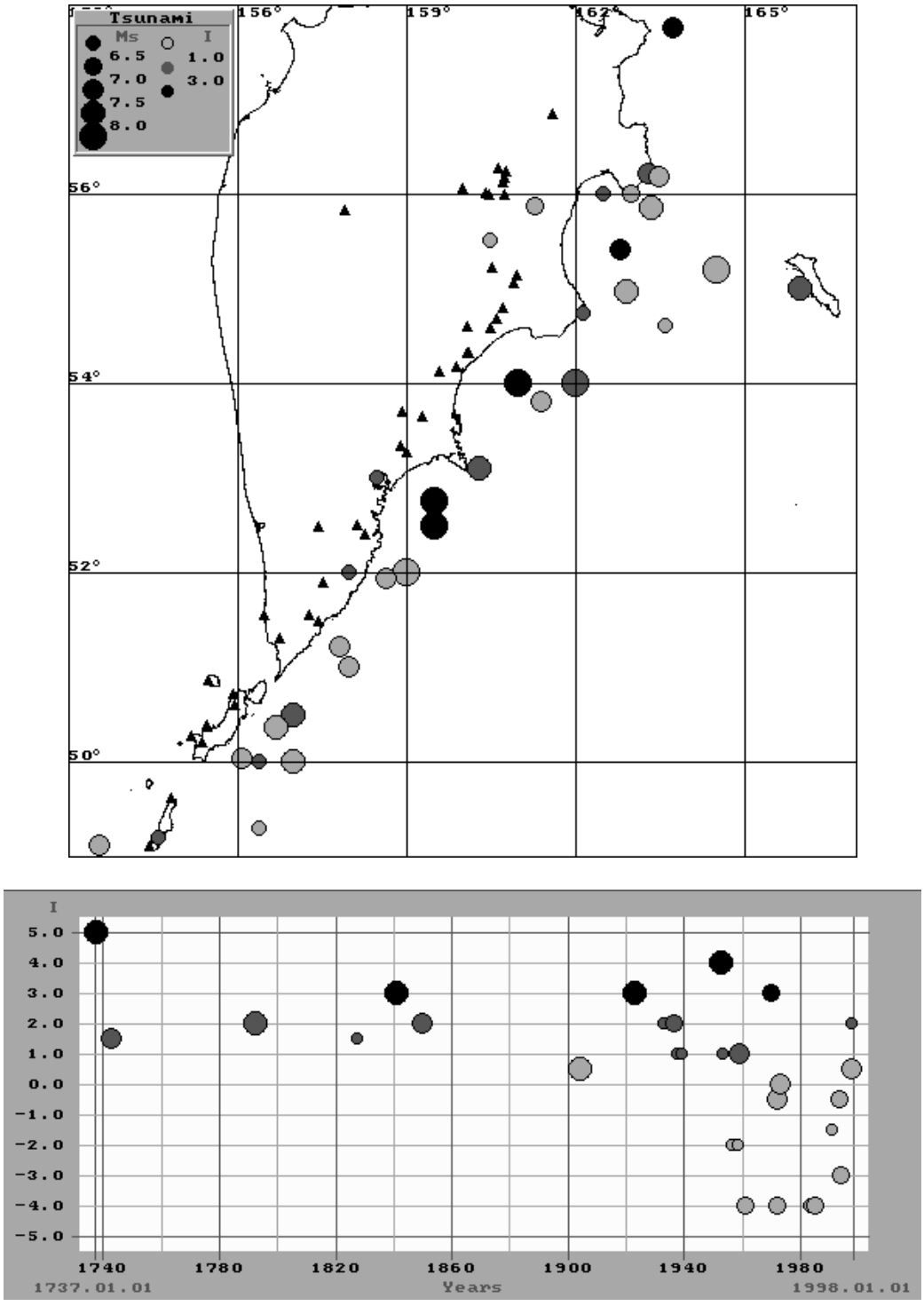

Fig.3. Historical tsunamigenic earthquakes of Kamchatka and North Kuriles for the period from 1737 to 1999 (above) and **I(t)** diagram (tsunami intensity versus time) (below). The size of the circles is proportional to the magnitude **Ms**, the density of the gray scale – to the tsunami intensity **I**. Black triangles in the upper figure show the positions of active volcanoes.

events are associated with the steep continental slope and typically located at the distance of 50-70 km from the coast. The area to the north of the junction of the Kuril-Kamchatka and Aleutian trenches was considered as inactive in terms of tsunami generation until 1969 when a strong submarine earthquake resulted in 10-15 meter tsunami that flooded the coast near the Ozernoy Cape.

The present paper is devoted to the comparative study of the two most destructive tsunamis occurred in this area – October 16, 1737 and November 4, 1952.

The November 4, 1952 earthquake hit the northern Kuril Islands and almost the whole eastern coast of the Kamchatka Peninsula from the Lopatka Cape in the south to the Kronotskiy Cape in the north. It was the strongest shallow earthquake in this area recorded instrumentally. The "New catalog …" (Kondorskaya, Shebalin, 1982) gives the following set of parameters for this event: position of the epicenter at 52.75°N and 159.5°E, the source depth of 30 km, magnitude $\mathbf{M_S}$ 8.2. The earthquake has generated a destructive tsunami, that destroyed several coastal villages in the northern Kuriles and the southern Kamchatka and was observed almost everywhere in the Pacific. It took the waves 20-21 hours to cross the entire Pacific and to reach the coast of South America (Fig.4). The tsunami source area estimated by the reverse travel-time diagrams and by the aftershock distribution was delineated as a 600-km strip lying between the outer edge of the shelf and the deep water trench. Such a great size of the source area is also confirmed by the isoseist map showing the 8-grade zone of intensive shaking stretching along 600 km of the eastern coast of Kamchatka.

Tsunami waves have seriously damaged the village of Severo-Kurilsk on the Paramushir Island that was almost completely destroyed. The exact number of victims is unknown, but it is estimated to be more than one thousand. The highest run-up of 18 meters was observed at the

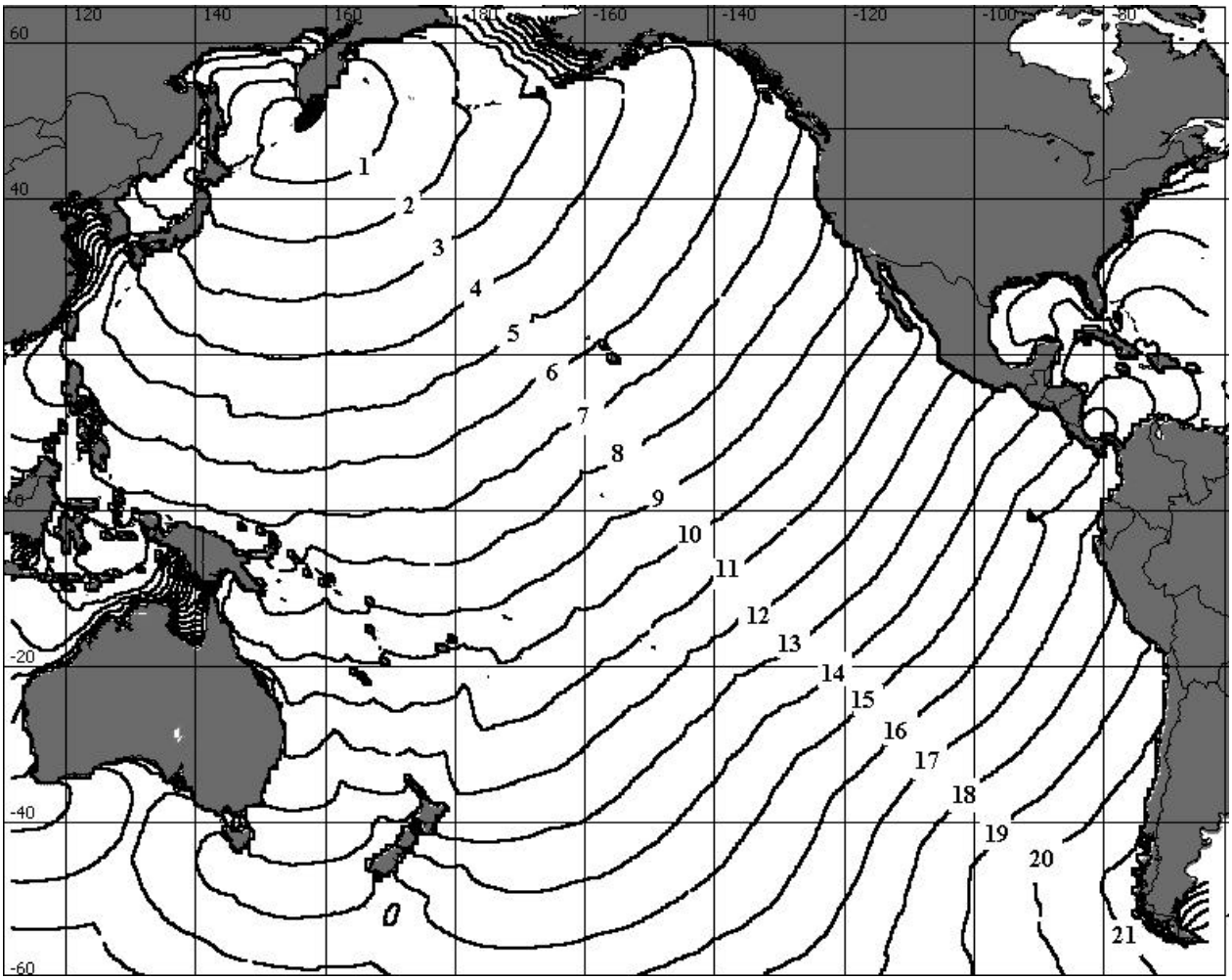

Fig.4. A calculated travel time chart for the 1952 tsunami. Isochrons show the position of the front wave in one-hour intervals. The solid ellipse shows the position of the tsunami source

Kitovaya Bay, located in the southeastern part of the Paramushir Island (Fig.5). The average (over a distance of 700 kilometers along the eastern coast of Kamchatka) run-up height was 6-7 meters. Fig.6 illustrates the widespread effects of the 1952 tsunami. Tsunami waves came to the Hawaiian Islands with height up to 6-8 meters. Property damage caused by this tsunami in Hawaii was estimated at $800,000. The waves beached boats, destroyed piers and houses, moved road pavement, etc. The highest far-field run-up of 9.1 meters was reported from Kaena Point, Oahu Island (Lander, Lockridge, 1989). For the 1952 Kamchatka tsunami, the Historical Tsunami Database for the Pacific (Gusiakov et al., 1997) contains 339 records of tsunami run-ups

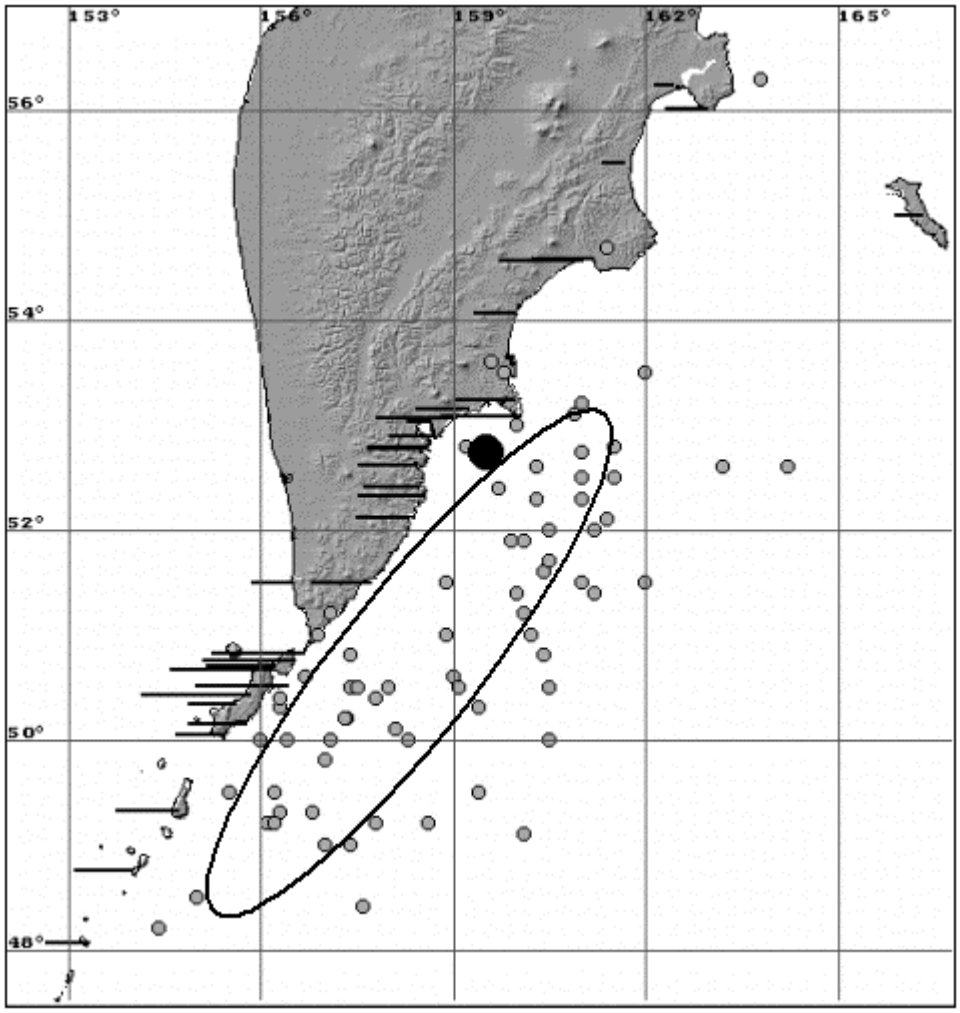

Fig.5 Tsunami run-up heights, position of tsunami sources and epicenters of one-month aftershocks for the 1952 earthquake.

and tide measurements and by this parameter it is the fourth largest Pacific tsunami (after the 1960 Chile, the 1946 Aleutians and the 1964 Alaska events). At the Chilean coast, the tsunami was recorded by tide-gauges at Arica (2.3m), Antofagasta (1.4m), Caldera (2.8m), Valparaiso (1.8m) and Talcahuano (3.6m). The observed travel time of the first wave was 19h 48m at Arica, 19h 58m at Antofagasta, 20h 27m at Caldera and 20h 40m at Valparaiso (The tsunami of November 4, 1952 …, 1953).

Nearly 200 years prior to this event, another great earthquake hit exactly in the same area on October 16, 1737. For this event, the “New Catalog …” (Kondorskaya, Shebalin, 1982) gives

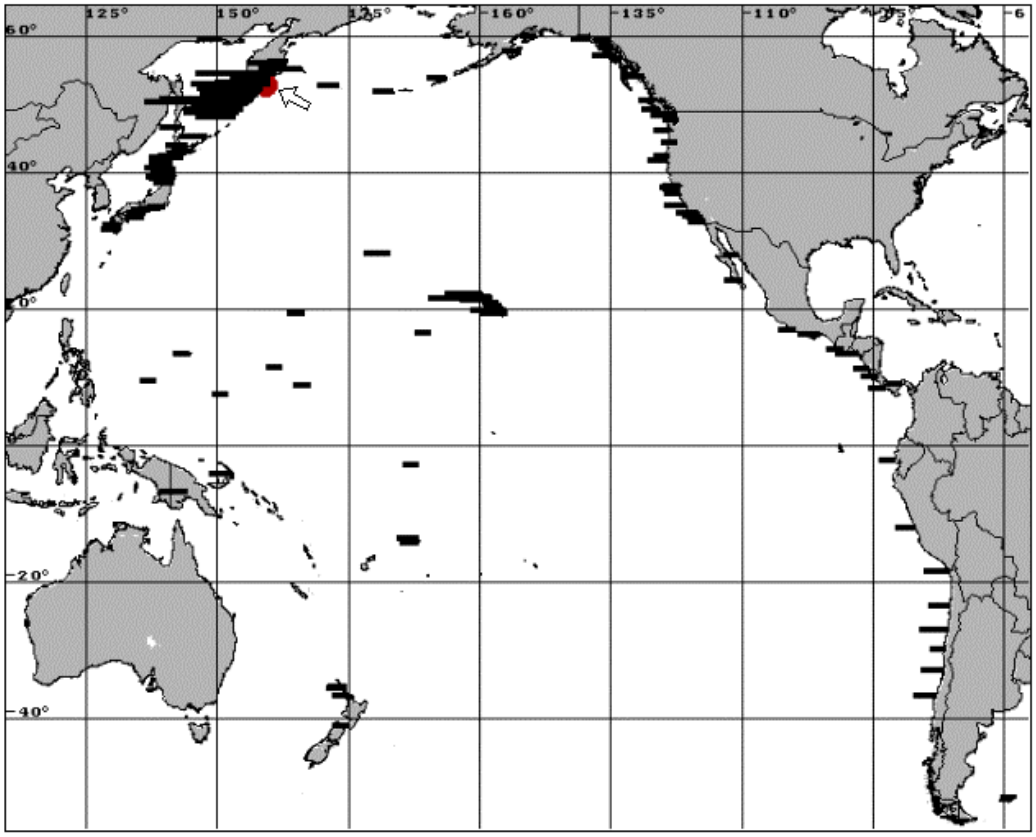

Fig.6 Far-field observations of the run-up heights for the 1952 tsunami. The length of the black lines is proportional to the actual run-up measurements. The white arrow shows the position of the earthquake epicenter.

almost the same set of the source parameters as for the 1952 event: position of the epicenter at 52.5°N and 159.5°E, the source depth of 40 km, magnitude Ms 8.3. This event occurred in the very beginning of the Russian conquest of Kamchatka, when the whole area was sparsely populated. The main source of information for this earthquake and tsunami is the report by Stepan Krasheninnikov, a member of the Russian research expedition, who is thought by many to be a pioneer of scientific studies in Russia. He set off to the western coast of Kamchatka on October 25, 1737, just eight days after the event, and soon (on November 25, 1737) prepared the detailed report on its manifestation. Later this report was included in his famous book "Description of Kamchatka Land" (1755), that is considered to be the first academic monograph written and printed in Russia.

Krasheninnikov's report on this event gives the excellent description of tsunami manifestation and it is worth to be cited here. Three paragraphs below are taken from the English translation of his original book published in 1972 by the Oregon Historical Society.

"The earthquake began on the sixth of October [local date according to the old Russian calendar], at about three o'clock in the morning, and lasted approximately **fifteen minutes**. The shocks were so violent that a number of Kamchadal iurts and balagans [native's homes made of wood and skins] were completely destroyed. All the while, the ocean shuddered with dreadful roaring sounds, passes its usual limits, and a tidal wave swept up over the earth to a depth of **three sazhens [**Russian sazhen is 2.1m], then it immediately retreated and rushed out a considerable distance. The earth shuddered a second time, and sea rose as violently as before. As it receded this time, it moved out so far that one could not even see the water. It was on this occasion that down in the depths of the water in the strait between the first and second Kurile Islands people could see a mountainous ridge which had never been seen before, although there had previously been severe earthquakes and floods. At the end of a quarter of an hour, frightful shocks were felt, much worse than before. The sea rose **thirty sazhens** and flooded the entire coast; the water remained as briefly as the first time. The sea was in a state of great agitation for a long while, rising and falling. Each temblor was by a terrifying rumble, like underground booming. The natives lost everything and many died horribly. There were places where meadows became hills, and fields became lakes and bays".

"The earthquake was not felt as violently on the western coast of Kamchatka [Sea of Okhotsk] as along the eastern coast [Pacific ocean]. At least, the natives at Bolsheretsk noticed nothing extraordinary, and they did not know whether or not the mouth of the river had been flooded. No one there could give an account of it. Probably the flood, if indeed there was one,

was much less noticeable on the Bolshaya River, for the balagans on the sand banks were not affected, and no one of them was tipped over".

"At that time we were sailing from Okhotsk to the mouth of the Bolshaya River. As we landed on the fourteens of October [i.e. eight days after the main shock], we could felt earth tremor that at times was so violent that we could scarcely keep out footing. Earth tremors continued until the spring of 1738. These were much stronger on the islands and at the tip of Cape Lopatka and on the shores of the Pacific than they were in areas more distant from the sea. The Bolsheretsk Cossacks who were then in the Kurile Islands told me that at the first shock, they fled with islanders to the mountains and abandoned all their possessions which were completely lost. They said that all the Kurile dwellings on the islands were destroyed".

According to Krasheninnikov's report, there were three destructive waves that hit the coast soon after the severe seismic shaking started at about 3 a.m. on October 17 (October 16 in GMT), 1737. The water run-off between the first and the second waves was so strong that the bottom rocks in the Second Kurile Strait (between the Paramushir and the Shumshu Islands), that were never exposed before, could be seen above the water. The navigation charts for this strait show the depths in the middle of the strait to be up to 30 meters that can give us a rough estimate of the wave amplitude. Krasheninnikov says that when the water retreated, the natives living in the north Kuriles and the south-eastern coast of Kamchatka could not even recognize the locations of their dwellings because "meadows became hills, and fields became lakes and bays". So large-scale co-seismic deformations, associated with this event, have been never observed in Kamchatka afterwards. They can be considered as the direct evidence for the extraordinary large moment release in the earthquake source.

Krasheninnikov's report gives only three quantitative indications to the wave heights – 30 fathoms (63 meters) for the north coast of the Paramushir Island, and 15 fathoms (31 meters) for the Lopatka Cape (the southernmost tip of the Kamchatka Peninsula) and 15 fathoms (31 meters) at some point near the Avacha Bay (Fig.7). The reported 63 meter run-up looks incredibly high, however, it is confirmed by another evidence written by I.Gmelin in 1740 in the diary of his travel over Siberia (Gmelin, 1752).

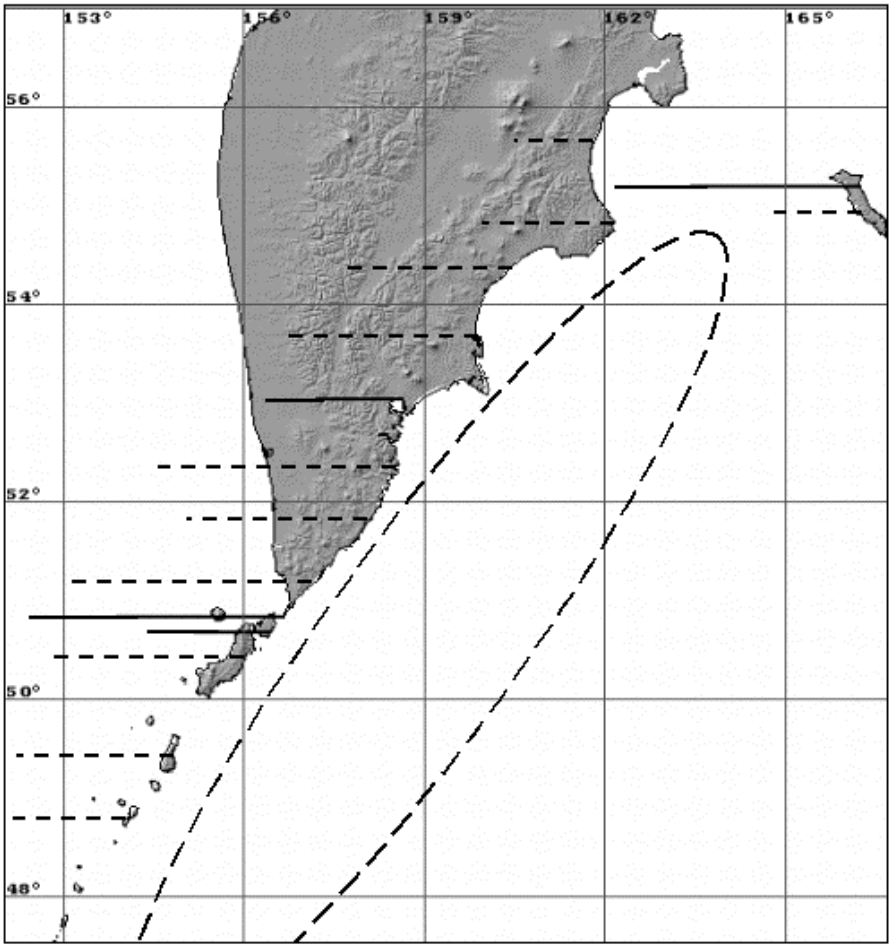

Fig.7. An assumed position of the source area of the 1737 tsunami (dashed ellipse), run-up heights reported by Krasheninnikov (black solid lines) and obtained as a result of numerical modeling (dashed lines).

One more indication to the large-scale destructive effect of the 1737 tsunami comes from the report by G.Steller (1774), a scientist traveling with Commander Vitus Bering in his famous

expedition to the North America. The expedition spent the winter of 1740-1741 on the island later named the Bering Island (in the group of the Komandorskiy Islands), where the great explorer died. G.Steller wrote in his journal that great changes on the island might have resulted from earthquakes and high-sea tides. In several places on the island he found driftwood and sea mammal bones high up on the hills, some of them located as high as 30 fathoms (63 meters) above the watermark. He also found trees buried upright in the new sand dunes which he attributed to the 1737 Kuril earthquake.

Both 1737 and 1952 earthquakes have been preceded and accompanied by the splash of volcanic activity, however, in 1737 volcanic eruptions were much more intensive. Almost all the Kamchatka volcanoes were activated, and in some of them (like the Klyuchevskaya Sopka) the eruptions were among the strongest in the written history of Kamchatka.

Soloviev and Ferchev (1961) see the 1737 tsunami as similar to that of the November 4, 1952 event, however, the earthquake and tsunami effects reported by S.Krasheninnikov, I.Gmelin and G.Steller describe it as a much greater event. Such a great tsunami in the Kuril-Kamchatka region would have an effect on the whole Pacific, however, these effects in the areas other than Kamchatka and the Komandorskiy Islands have not been investigated yet. The only indication to the tsunami run-up outside of the source area is cited by J.Lander (1996). On page 33 of his catalog “Tsunamis affecting Alaska, 1737 – 1996”, he quotes Tebenkov’s (1825) report telling us that “Half-rotten driftwood is piled up on the shore of Amchitka Island in some places forty and fifty feet above the water mark. The circumstances and the large quantity of driftwood on the shores of Alaska and Norton Sound, are attributed by natives to the terrible earthquake of 1737, which shook Kamchatka and Kuril Island”. We believe that the careful search for

geological traces of this tsunami in the western Aleutian and Hawaiian Islands as well as at the coast of South America would give some direct evidence of its wide-Pacific impact.

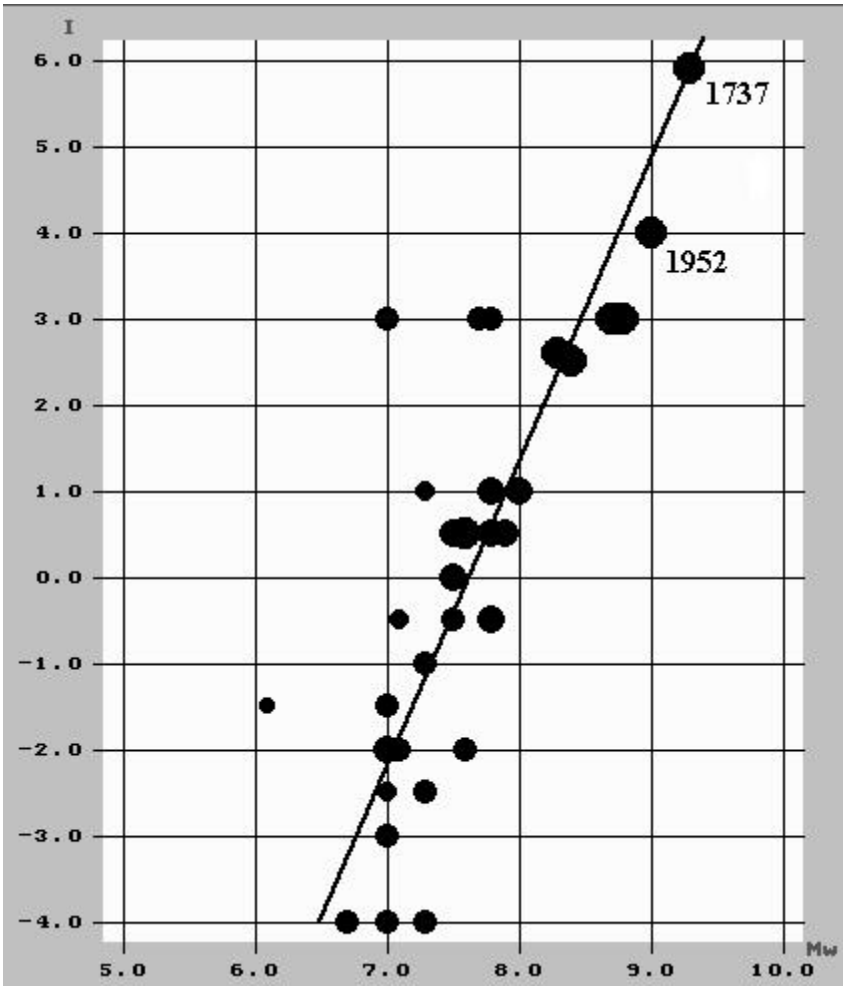

Fig.8. Dependence of the tsunami intensity **I** on the moment magnitude $\mathbf{M_w}$ for the historical Kurile-Kamchatka events occurred from 1900 to 1999. The solid line shows theoretical dependence $\mathbf{I=3.55M_w-27.1}$ obtained in (Chubarov, Gusiakov, 1985).

In the paper (Vikulin, Gusiakov, Titov, 1992) an attempt was made to make a numerical simulation of the 1737 tsunami in order to fill in the gaps in the actual run-up observation of this event. Krasheninnikov's data on the tsunami run-up were used as a benchmark to select the source parameters (mainly, the length of the fault plane and the amount of dislocation) to fit these run-up values. The resulted run-up heights along the Kamchatka east coast are shown as dashed lines in Fig.7. The overall distribution of the run-up height gives us a possibility to calculate the

average wave height $\mathbf{H_{av}}$ over the whole east Kamchatka coast and then calculate the tsunami intensity on the Soloviev-Imamura scale by the formula $\mathbf{I=1/2+\log_2 H_{av}}$. This calculation gives us the intensity **I = 5.9** for the 1737 tsunami. Using the relation between **I** and **Mw**

$$\mathbf{I=3.55M_w - 27.1}$$

obtained in (Chubarov, Gusiakov, 1985) we can estimate the **Mw** value for the 1737 earthquake that turns out to be **9.3** (Fig.8).

By this parameter, the 1737 earthquake is an event of the mega-scale similar to the 1960 Chilean earthquake (**Mw =9.5**). For sure, such an event should be observed in many places over the Pacific, including Hawaii and the coast of South America. There is little hope to find the direct witness reports on manifestation of this event in the remote areas, however, the goal-oriented search for the geological traces of this tsunami could be successful and could give invaluable additional data for evaluation of the wide-spread effect of the 1737 tsunami..

The 1737 tsunami was obviously the strongest event in the Kuril-Kamchatka region whenever observed and one of the largest tsunamis in the Pacific. Such an event, should it happens in the present days, would result in the heavy disaster for the Northern Kuriles and the whole eastern coast of Kamchatka. The study of these mega-tsunamis is very important, because they give essential input in the long-term tsunami risk for almost all the parts of the Pacific coast.

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