PALEOTSUNAMI DEPOSITS ON THE COAST OF KUNASHIR ISLAND*

Alexander Ya. Iliev [1], Nadezhda G. Razjigaeva [2], Victor M. Kaistrenko [1], Elena V. Gretskaya [1], Elena A. Tikhonchuk [1], Andrey A. Kharlamov [3]

[1] Institute of Marine Geology and Geophysics FEB RAS, Yuzhno-Sakhalinsk, Russia
[2] Pacific Institute of Geography FEB RAS, Vladivostok, Russia
[3] P. P. Shirshov Institute of Oceanology RAS, Moscow, Russia

E-mail: **tsunami@imgg.ptcom.ru**

INTRODUCTION

Kunashir Island is located in the region of high tsunami activity. Tsunami waves produced by the Great October 4, 1994 Shikotan Earthquake had heights up to 8.7 m on the eastern coast of Kunashir Island [Korolev *et al.*, 1997]. In spite of this, the existing catalogues contain the tsunami data for the coast of Kunashir Island only since 1958. Such short tsunami history of this region does not allow the creation of a good model to describe the tsunami activity. The necessary tsunami data can be found in the coastal sediments. Evidence of strong tsunamis and pre-historic earthquakes in this region has been found on the coast of Iturup Island [Bulgakov *et al.*, 1995] and Eastern Hokkaido [Nanayama *et al.*, 2000; Sawai, *in press*]. The present paper describes the results of the first attempt to examine the geological traces of paleotsunamis on the Pacific coast of Kunashir.

MATERIAL AND METHODS

During the field investigations of August-September 2001 many tsunami traces associated with the October 4, 1994 event and other old events were found on the Pacific coast of Kunashir Island as sandy layers inside the peat on the terraces near the sandy coast. Mainly, the tsunami traces are the layers of well-sorted sand between peat and lacustrine silt-pelitic sediments and diatomites. Several tsunami traces are the pumice layers. For discrimination of tsunami deposits, we have used the criteria suggested by Pinegina and Bourgeois [2001]. To evaluate the paleotsunami heights, the geomorphologic profiles were created for all examples of the tsunami traces. More than 90 sections (excavated trenches or outcrops) in the peat areas and paleolakes along the coast of Kunashir Island were carefully investigated (Figure 1) and materials for further analysis (radiocarbon dating, chemical analysis of tephra, grain-size and mineralogical analysis of tsunami sands, biostatigraphy) were prepared. Now and then, inside these layers we could find wood scraps, which were analyzed by radiocarbon method to evaluate the layer age. Many tephra examples were used to estimate the tsunami layer age. The time period related to the found tsunami deposits is about 6000-7000 years. The reconstruction of some tsunami parameters (tsunami runup and maximum inundation) was based on the presence and elevation of interpreted tsunami deposits and distance from the modern shoreline.

RESULTS AND DISCUSSION

The terrestrial and coastal records on the island are usually discontinuous and it is necessary to study the stratigraphy of a number of sections composed of different facies for reliable palaeogeographic reconstruction. The studied sections are located on a coastal plain and low marine terrace sequences, 3-5 m and more above the present sea level. Tsunami deposits are

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Figure 1. Location of the explored area.

represented by very thin sand sheets (with thickness of 1-5 mm, rarely up to 3 cm) that could be found beyond storm-wave influence. Significant age correlation of such sand layers measured at different sites of the coast is one of the substantial evidence proving the tsunami origin of the deposits. Most of the peatlands of Kunashir Island were formed at the late Holocene. They contain the traces of paleotsunami that took place during the last 2500-3000 years. At this time the configuration of the coastline was similar to modern time [Korotky *et al.*, 2000].

In the northern part of the island the coast is represented by the late Holocene low marine terrace adjacent to the ancient overgrown cliff. Accumulative landforms are usually non-extensive. Soils or peat from the upper part of the sections usually include some sand layers but it is difficult to define their exact origin and to differ tsunami deposits from storm surge sands. Sand layers could not be found in the soil profiles on flat surfaces with elevation more than 10 m. The deposits, which we identified as tsunami traces, were found in peat bogs in low current of the Rogachevka River (Figure 2). The peat formed on the places of the former meanders and located behind storm ridges with dunes (elevation up to 7 m amsl).

The peat includes up to five thin (3-5 mm) layers of well-sorted medium to fine sands with modal fractions of 0.25-0.315 mm and 0.16-0.25 mm. The source of the material was possibly beach and dune sands. The marine origin of the deposits was confirmed by the diatom data. The base of the section exposes ash layer dated about 2350 cal. yr BP (^{14}C-date from underlying peat 2360±40 BP, GIN-11908), the upper part three andesite-basalt ash layers from Tyatya Volcano erupted approximately 1000 BP and in 1973. One of the large eruptions of Tyatya was dated

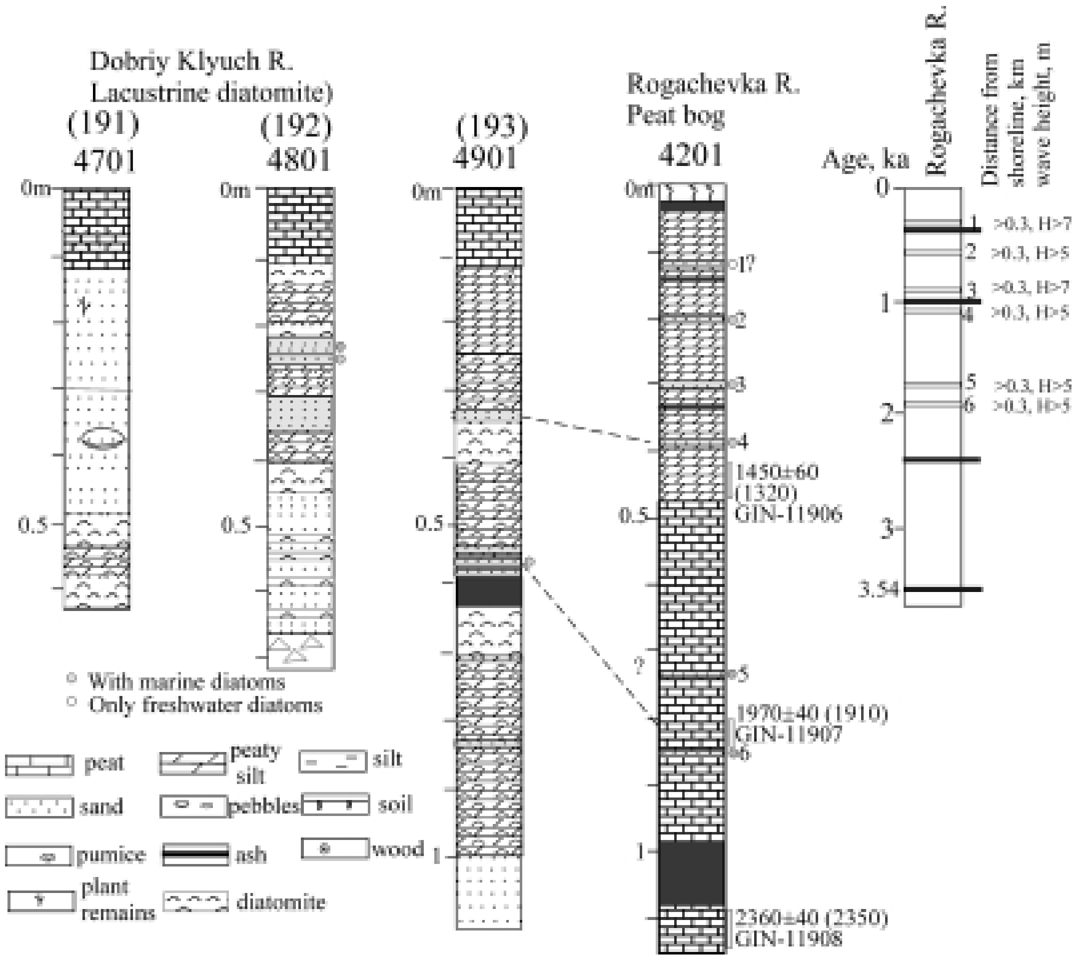


Figure 2. Tsunami deposits from late Holocene sections of northern Kunashir.

about 500 yr BP (^{14}C-date obtained from the paleosol with scoria is 510±90 BP, GIN-11947 from soil profile within 10 m abrasion terrace near the Tyatin River mouth). The runup of paleotsunami must exceed storm ridge height and possibly reached 5-7 m. Two lower tsunami layers were deposited during the beginning of cooling, accompanied by a fall of sea level [Sakaguchi, 1983; Korotky *et al.*, 2000] and these estimations are considered as minimal.

Coastal plane in low river flow of the Dobriy Klyuch Stream is represented by a lacustrine terrace separated by series of ancient storm ridges from the modern beach. The terrace is composed of diatomites with several sand layers (Figure 2). Sand sheets are well observed landward, the deposits include rare marine diatoms and are interpreted as tsunami deposits. Thickness of sand sheets reaches 2 cm, penetration inland is more than 0.5 km. The sand is characterized by unimodal fine-tailed distribution. The sandy layers are composed of medium and coarse sands in peripheral part of the paleolake. Mean grain size of the deposits decreased landward, where fine sands with modal fraction of 0.10-0.16 mm dominated. Dacite ash layers exposed to base of the section allow correlating some tsunami layers with those from peat bog section of the Rogachevka River.

On central Kunashir the traces of the late Holocene tsunami were found within extensive peatland located on the Pacific side of South Kurile Isthmus near settlement Yuzhno-Kurilsk. The coastal plane is composed of peat covering the late Holocene marine deposits. Active progradation of the coast with formation of storm ridges took place about 3000-4000 years ago during a relative stabilization of sea level, which was higher than the present sea level [Korotky *et al.*, 2000]. Swamping of the coastal plane began in the second half of the late

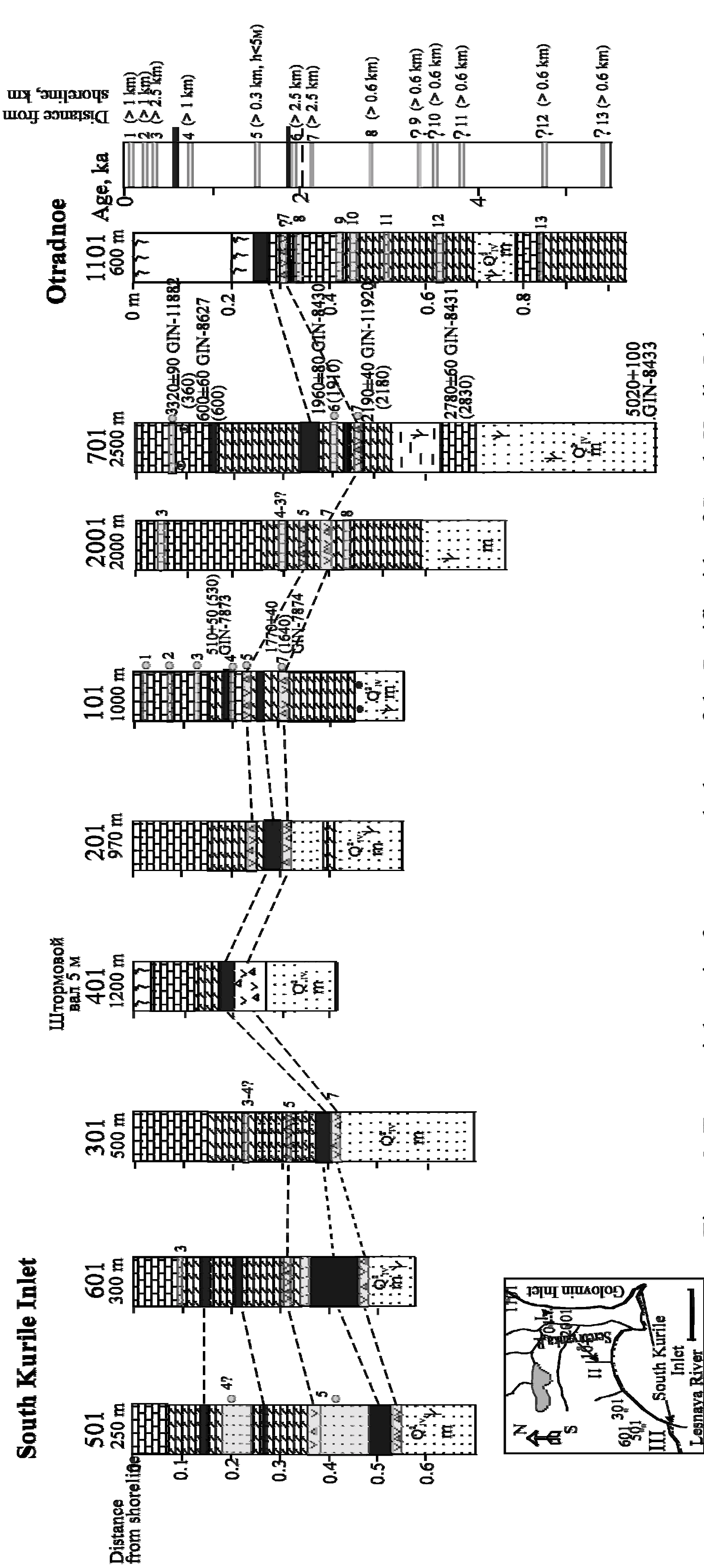


Figure 3. Tsunami deposits from coastal plane of the Pacific side of South-Kurile Isthmut.

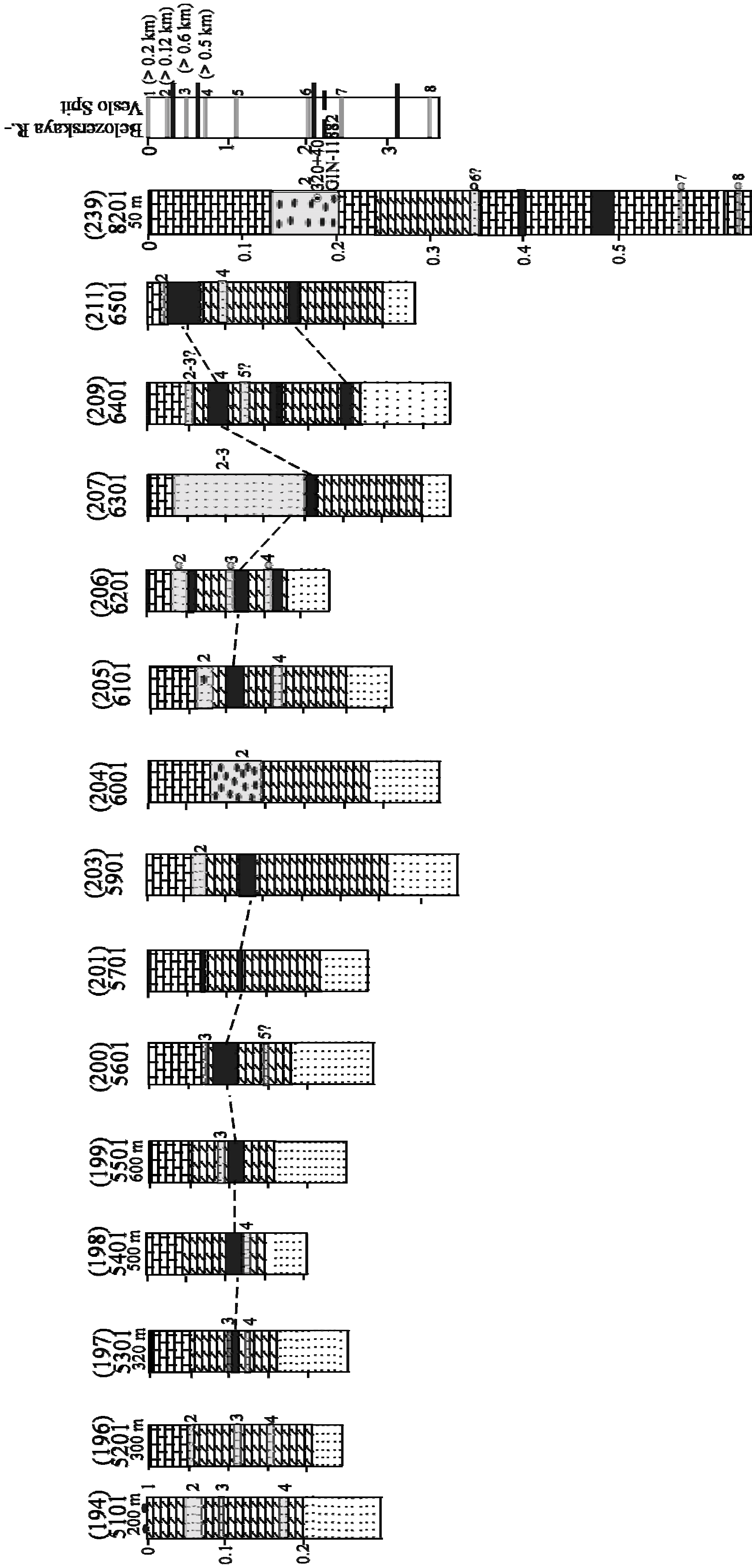


Figure 4. Tsunami deposits from peatland near the Belozerskaya River mouth.

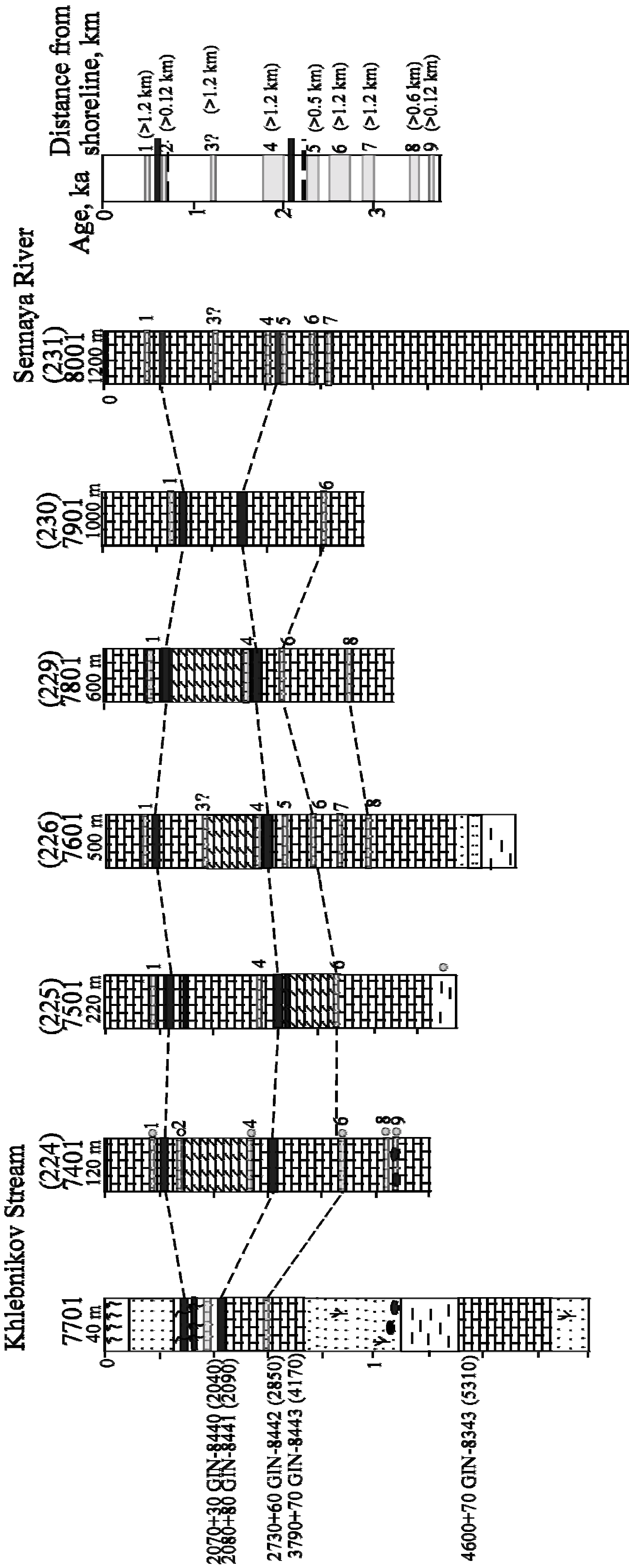


Figure 5. Tsunami deposits from peatlands of Izmena Bay coast.

Holocene and the peat accumulated at least 2000-2500 years ago. The peat unit includes 8 sand layers observed up to 2.5 km inland. Thickness of the layers changes from 6-10 cm to 1-3 mm, decreasing inland. One of the sedimentary features of the deposits is deformation structures found at the sand/ash interfaces. The structures are interpreted to have resulted from the sinking of sand into underlying soft and wet material [Minoura and Nakata, 1994]. The distribution pattern of sediment facies implies that the sand layer was deposited in a swamp pond located near the former coastline. Such flame structure is observed in the site located 250 m inland from the modern coastline. The deposits are composed of medium to fine sand and include some amount of silt (up to 22%). Sorting of the tsunami sand is lower than underlying marine sands deposited during the transgression. The sections include three ash layers of Mashu Volcano (Hokkaido Island), erupted about 1700 BP and last 500 yr. Two sand layers with coarser volcanic material were also used to examine the correlation of the sites. The age of these layers was about 1500 and 2100 BP (^{14}C-date from underlying soil is 2130±50 BP, GIN-7887). The source of tephra was the Mendeleev Volcano apparently erupted during a tsunami event. Marine origin of the deposits is based on diatom data. This tsunami was very intensive and penetrated inland up to 2-2.5 km.

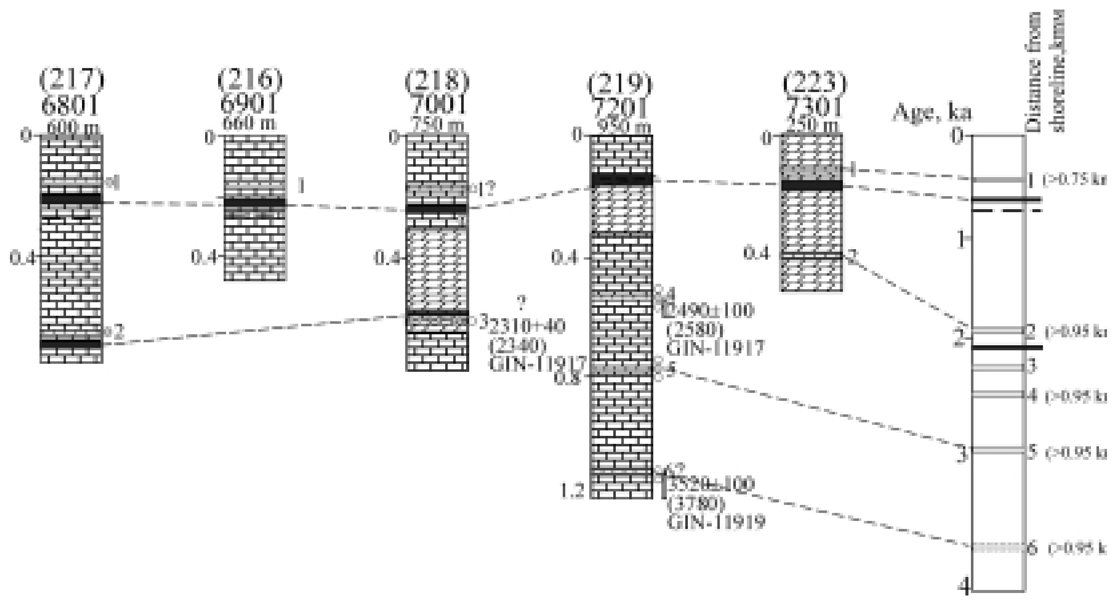
More ancient tsunami traces may be reconstructed from peat unit from Site 1101 located within the coastal plane near Otradnoe (Figure 3). The peat includes seven sandy layers, which composed of well-sorted fine sand. Sorting of this sand is higher than tsunami deposits of coastal plane of Yuzhno-Kurilsk Bay. The sources of this sand were the sand beach of open Golovnin Bay and extensive dunes developed in this place. We cannot confirm that these sand layers were deposited by a tsunami because they were located behind a storm ridge and the former shoreline was deeper inland during the transgression, which took place at the time of the deposit formation. But high correlation of these sand layers with Eastern Hokkaido paleotsunami data [Nanayama et al., 2000] may be the base for the suggestion about its tsunami origin.

Extensive peatland is located in the southern part of Kunashir near the Belozerskaya River mouth. The main part of this swamp is very young. Thickness of the peat, underlying storm ridges and an inter-ridge depression, reaches only 15-20 cm and increases toward the river mouth (more than 1 m), where there is more ancient peat bog. The age correlation of the sections was made by tephrochronology. Three dacite marker ash layers are spread in the late Holocene deposits on South Kunashir: two of them are correlated to the eruption of Mashu Volcano of 1485 and 1535 [Faziullin and Batoyan, 1989] and the third was formed about 2060 cal. yr BP and correlated to the regional tephra Ta-c2 of Eastern Hokkaido [Nanayama *et al.*, 2000; Sawai, 2001]. The main part of the peat bog includes four sand layers (up to 1 cm) located up to 600 m inland from the beach (Figure 4). Pumice gravel found in the peat surface 200 m inland is the possible evidence of the 1994 tsunami. Other layers of medium to fine sand were deposited about 1000 BP. Tsunami deposits have a single-mode distribution but sorting of the material is poorer than underlying peat marine deposits. The study of grain size composition of the deposits has revealed that the sands are of marine origin and transported from the littoral environment by a great flooding of seawater. More ancient sand layers from a peat bog near the Belozerskaya River mouth are considered in preliminary way as tsunami deposits based on high correlation with other sites in Kunashir and Eastern Hokkaido. These layers were found in the site located about 50 m from the modern coastal line. Their origin must be determined by future investigations.

Evidence of tsunami penetration into the Izmena Bay coast may be obtained from the sections of peat bogs stretching up the valley of numerous rivers. Deposits of the middle Holocene and the first transgression of the late Holocene are highly correlated to those of the middle and late Jomon transgressions of the Japan Islands [Sakaguchi, 1983]. During these periods semi-open bays and estuaries were formed at the places of modern swamps. Marine deposits of this age underlay the peat [Korotky *et al.*, 2000]. The late Holocene peat unit includes up to 9 thin (≤ 2 cm) medium to fine sand layers (Figure 5) located up to 1 km inland. Amount of sand layers decrease in peatlands located farther inland from the Pacific coast. The presence of pumice and large pieces of wood marks the maximum inundation of tsunami waves. Tsunami deposits contain silt fractions (up to 32%), which were transported inland from the littoral environment of the semi-open bay. More ancient peat bog was found near the Golovnin River mouth. The peat includes middle Holocene tsunami traces (Figure 6).

The middle Holocene tsunami deposits were also found in the lacustrine sequences. During this Holocene stage, the sea-level rise led to active abrasion, causing a large volume of detrital material to enter the coastal zone. The active formation of barrier forms led to the separation of numerous coastal lakes. The deposits of such paleolake compose a 5-6 m terrace in the low flow of the Lesnaya River. Lacustrine deposits consisting mostly of clay or peaty silt contain eight intercalated thin beds (up to 5 cm) of well-sorted medium-to-fine sand (Figure 6). Deposition of thin, laterally persistent sand layers in the barrier lake can be attributed to a catastrophic seawater invasion upon low-lying coastal land. The sands are characterized by the unimodal distribution with fine-tails. Two lower layers are characterized by low heavy fraction content and by domination of pyroxenes among heavy minerals. The sand was deposited during a tsunami penetration into a relatively extensive coastal lake. Four upper sand layers were formed at the final stage of paleolake development. The deposits are distinguished by high heavy mineral content with magnetite predominance. Six thin layers of well-sorted medium-to-fine sand were found in the Kosmodemianskaya Bay middle Holocene lacustrine terrace (Figure 7). A lower sand layer is correlated to the one of the Lesnaya River lacustrine sequences. The evidence of possible tsunami origin of the upper sand layers is their high correlation with the Eastern Hokkaido paleotsunami data [Nanayama *et al.*, 2000]. Interred correlation of tsunami deposits from various places of the Pacific side of Kunashir coast is shown in Figure 7.

Seventeen isochronal layers can be traced among the coast. Tephrochronological and ^{14}C-dating gave the following ages of the most distinct tsunami layers (with their standard deviations): 470±60, 740±60, 1100±50, 1400±140, 1800±230, 2500±100, 2850±100, 3340±240, 3650±170 years. Some of them are well correlated to the Eastern Hokkaido [Nanayama *et al.*, 2000] and



Iturup [Bulgakov *et al.*, 1995] paleotsunami reconstructions. Sand on the surface of peatland may correspond to the 1994 Tsunami (M = 8.0). The trace of a tsunami of the 19th century was found only in Yuzhno-Kurilsk Bay, 1 km inland from the modern shoreline. It is probably related to Ts 1 on Eastern Hokkaido associated with the1843 Tempo Tokachi-oki Tsunami (M = 8.4). Several historical tsunami events of the 17th century (Edo Era) were very intensive, traces of these tsunamis were found in many places of Eastern Hokkaido [Nanayama *et al.*, 2000; Sawai, in press]. Kunashir Island coastal sequences possibly record the trace of the tsunami event Ts 3 on Eastern Hokkaido associated with the 1611 Kaicho Samriku-oki Tsunami (M = 8.1) [Nanayama *et al.*, 2000]. Possibly, the trace of this event was found in the Kasatka Bay pet bog of Iturup Island [Bulgakov *et al.*, 1995]. A tsunami of the 13th century that is correlated to Ts 4 of Eastern Hokkaido was mainly detected on the coast of South Kunashir. A tsunami dated 9th century, which was recorded in the central and northern parts of Kunashir, is apparently related to the 869 Jogan Sanriku-oki Tsunami (M = 8.3) [Nanayama *et al.*, 2000]. This means that most of the prehistorical tsunami events observed on the coast of Kunashir are highly correlated to the Eastern Hokkaido data. Two late Holocene paleotsunami traces, which were found in central and northern Kunashir, have possibly been also observed on the coast of central Iturup. The sources of these tsunamis were apparently located northward from these islands. The general view of the tsunami deposit correlation for the large region of Iturup-Kunashir-Eastern Hokkaido is shown in Figure 8.

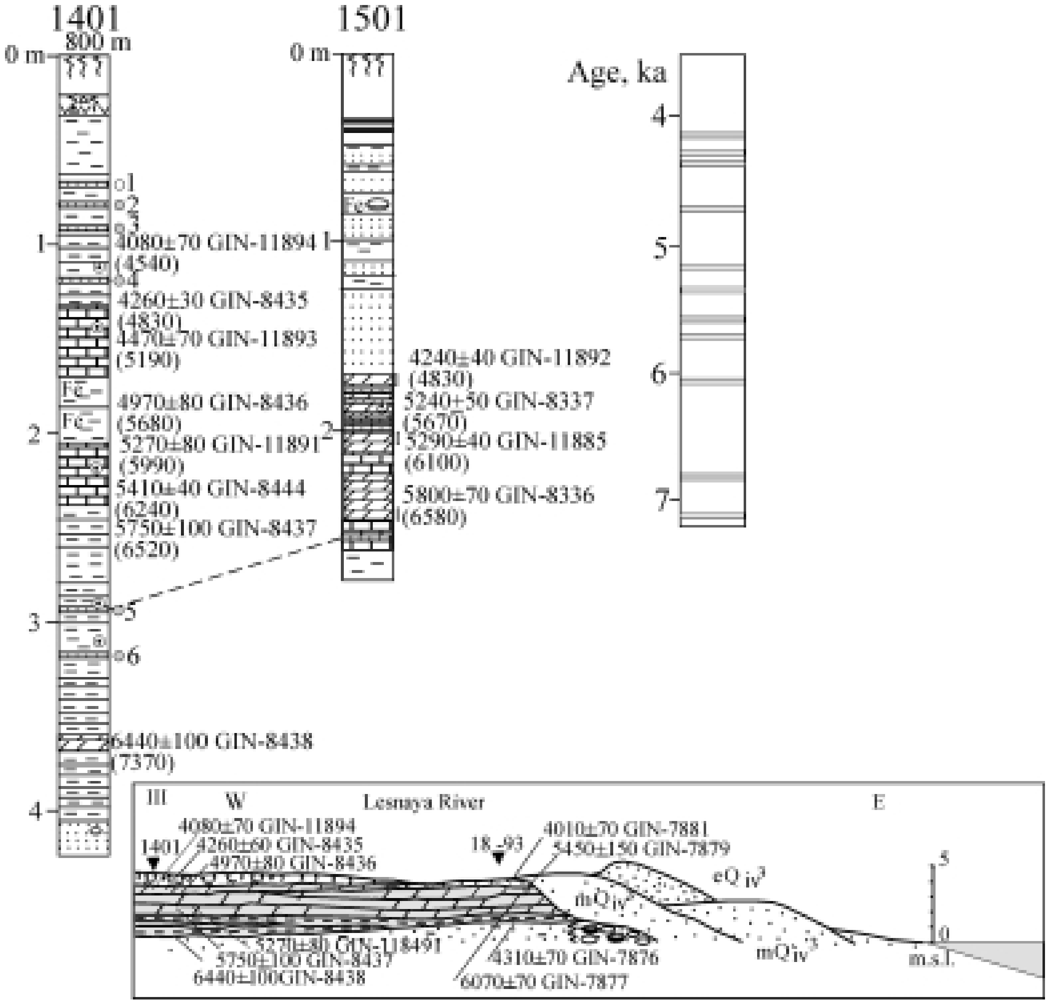


Figure 7. The comparison between tsunami deposits near the Lesnaya River (1401) and Kosmodemyanskoye Village (1501)

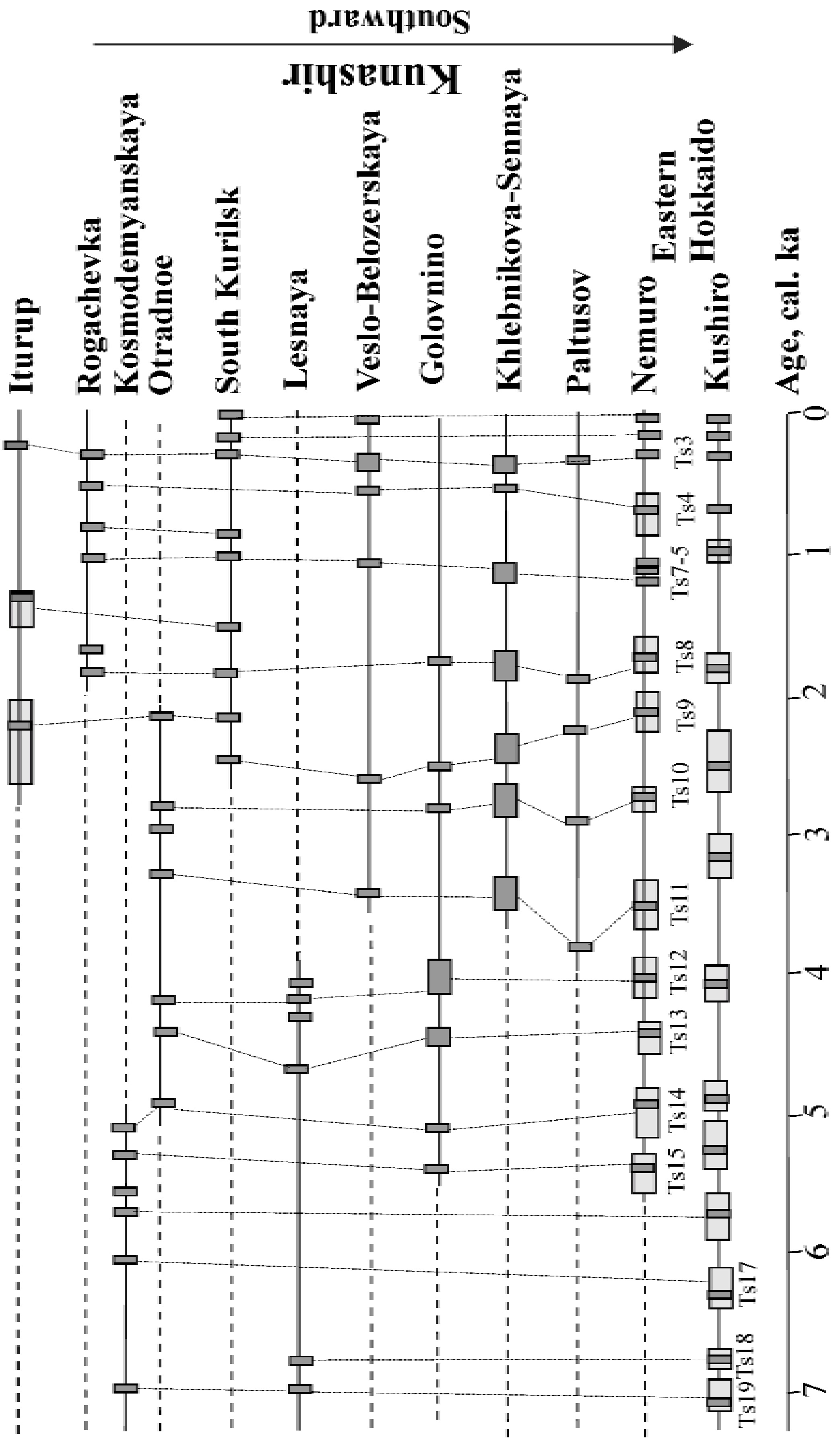


Figure 8. Correlation of tsunami events on the Pacific coast of Kunashir Island with those on the coasts of Iturup Island [*Bulgakov et al.*, 1995] and Eastern Hokkaido [*Nanayama et al.*, 2000].

CONCLUSIONS

Seventeen thin sand layers were found to be intercalated within peat of lacustrine deposits on the Pacific coast of Kunashir Island. Field data, grain-size composition and biostratigraphical data enable us to interpret them as paleotsunami traces. The sand layers were deposited by tsunamis with a maximum run-up of more than 7 m and inundation inland for more than 2.5 km. The time period related to the found tsunami deposits is about 6000 – 7000 years. Tsunamis which inundated an extensive area along the Pacific coast of Kunashir Island were generated by large earthquakes (M > 8) in the Kurile subduction zone. These events are correlated with historical and prehistorical tsunamis of Eastern Hokkaido and Iturup Island.

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