# DIATOM DATA AS AN INDICATOR OF THE PALAEO-TSUNAMI DEPOSITS

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## INTRODUCTION

The problem of paleotsunami study is connected not only with search of their traces during field work but their following identification. The origin of paleotsunami deposits can be proved by methods of marine micropaleontology [Fujiwara *et al.*, 2000]. One of valuable method for this aim is diatom analysis [Minoura, Nakata, 1994; Hemphill-Haley, 1996; Nanayama *et al.*, 2000; Nitshimura *et al.*, 2000; Sawai, *in press*]. The discussion of diatom data to clearly show that diatom analysis may add valuable information to identification of tsunami deposits. Other methods such as forams analysis can't be used for underwater outcrops study in these regions**,** because carbonate fossil poorly preserved in acid environments common for volcanic islands. At contrast, these environments are favorable for diatoms development. Diatoms are single-cell algal with siliceous valves and are almost present in fine-grained deposits along North Pacific coast. They are particularly useful in studies of paleotsunami deposits because different species are found in freshwater than in brackish-marine environments, and therefore can be used to identify past marine incursion including those associated with tsunami.

The presence of marine diatoms in the deposits show marine influence, that may resulted by different causes: marine transgression, strong storm surges and tsunami. Diatom assemblages formed during marine transgressions are characterized by high abundance and diversity of marine species, well preservation of the valves and ecological parameters typical for climatic warming stages during high sea level position. Thickness of these marine units is as a rule significant. The presence of marine and brackish diatoms among freshwater assemblages in thin sand layers indicates short time marine influence, which can be connected to such events as storm surge or tsunami. In this cases marine diatoms are very rare and most valves are fragmented [Sawai, *in press*]. Although it is generally difficult to distinguish tsunami from storm surge deposits by diatom data.

In this study we would like to demonstrate how the diatom content of prehistoric tsunami deposits can be used in support of their origin. The diatom analysis has been used for identifying Holocene palaeo-tsunami traces on Pacific side of Kunashir Island and Izmena Bay coast (Fig. 1).

## MATERIAL AND METHODS

Diatoms were collected from sand layers of peat bogs and barrier palaeo-lake deposits and from overlying and underlying deposits. Thickness of these sand layers range from 1 mm to 1-2 cm. The studied sections are located on different distance from coastal line (up to 2.5 km). Diatom samples were analyzed at these sand layers and overlaying and underlaying deposits. One site 101, located in the swamp near South Kurilsk in 1 km from shoreline, was sampled at 2 cm, interval. Age of the deposits was determined by tephrostratigraphy and $^{14}$C-dating. The samples were treated with standard acid and alkali solution. $^{14}$C dates were produced by liquid scintillation counting in the Geological Institute, Russian Academy of Sciences Moscow. The age calibrations were made using the calibration programme Calib 3.0 [Stuiver and Reimer, 1993].

Diatoms was studied in 16 key sections. Diatom processing method follow this of Gleiser *et al.* [1974: 55-79]. The samples were treated with a solution of hydrogen peroxide and washed with distilled water. For certain diatom preparation heavy-liquid (mixture of $H_2O$:$CdJ_2$:KI=1:1.5:2.25, density 2.4 g/sm$^3$) was used. Permanent preparation were made with 18×18 mm cover glasses and Elyashev aniline-formaldehyde resin with refraction indices n = 1.66-1.68. Diatoms were identified at magnification ×1000. When possible, 200-300 valves were counted per sample. The ecological significance of diatoms species was taken from de Wolf [1982], Kramer and Lange Bertalot [1986; 1988; 1991a, 1991b]. The ecological Data provided by the above-mentioned authors has enable most taxa to be grouped into the three categories marine, brackish and freshwater, and then marine species were divided into oceanic, neritic and sublittoral species, freshwater – into planktonic and benthic forms. Palaeo-tsunami traces are identified by appearance of marine diatoms among fresh-water assemblages, typical for lacustrine-swamp environments.


Figure 1. Location of the study area.

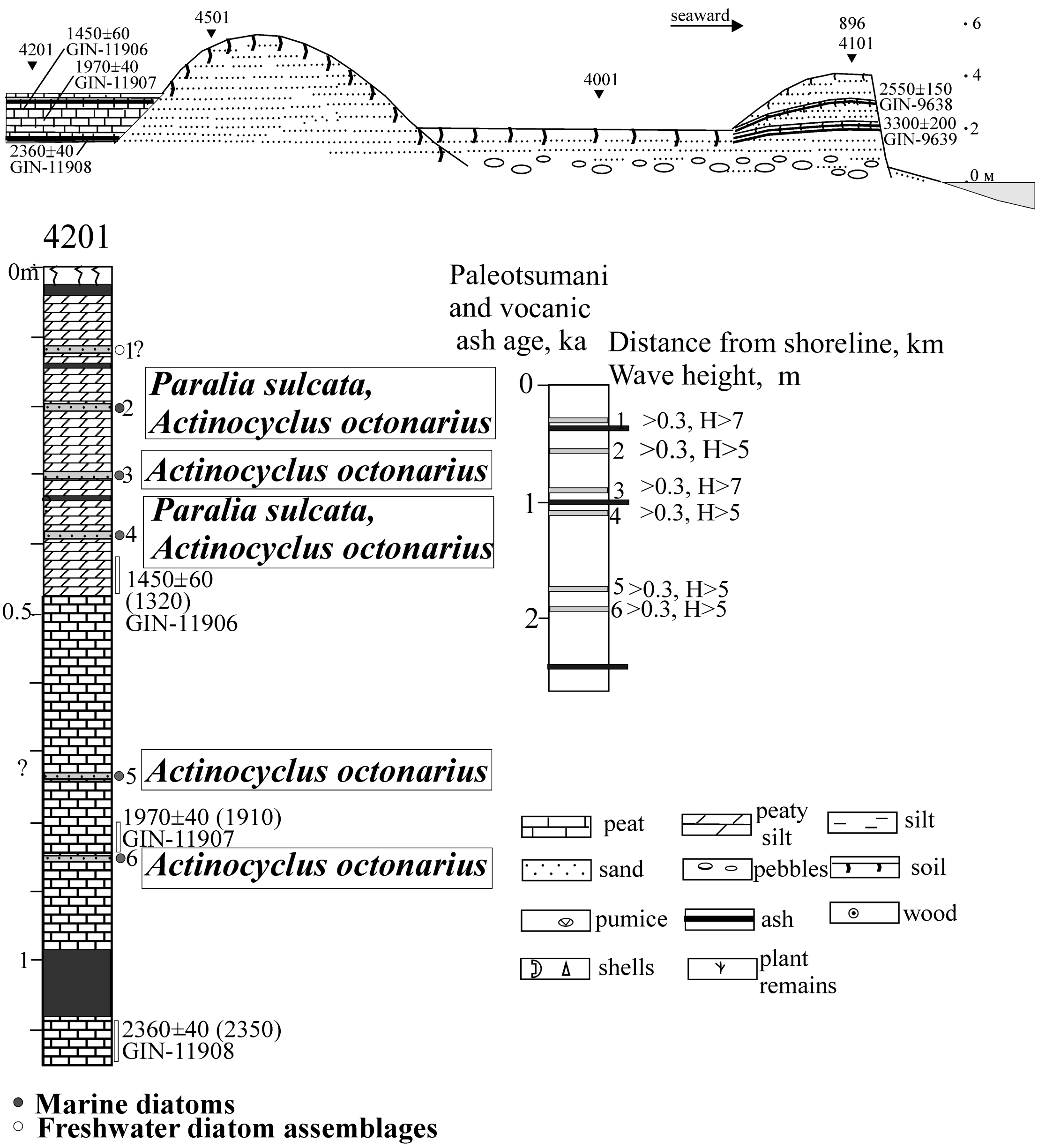


Figure 2. Cross-section of coastal lowland in low current of Rogachevka River and marine diatoms from site 4201.

## RESULTS AND DISCUSSION

The most north site was studied within coastal lowland of Rogachevka River low current (Fig. 2). The peatbog with paleotsunami traces is located behind ancient mid-Holocene storm ridge with dune fields, elevation of which is about 5 m. The peat was formed at late-Holocene. The section includes 6 sand layers. Among rich freshwater diatom assemblages we found rare marine diatoms: sublittoral *Paralia sulcata* and neritic *Actinocyclus octonarius.* The presence of marine species indicates that tsunami inundated area more that 300 m landward. The peat bog was formed during the past 2.5 ka the sea level was similar to modern or lower than present position for two lower sands. We suggest that paleotsunami runup was more than 5 m.

Upper sand layer don't contain marine diatoms but by our opinion this layer is paleotsunami trace. The layer don't include marine species because the dunes and broad beach could have provided main source of sand. This sand layer deposited during cooling and minor regression of Little Ace Age. At this time sea level fall led to development of extensive dune fields [Korotky *et al.*, 2000], that was crossed by tsunami only on this place. Age analog of this sand layer wide distributed in other sites includes marine diatoms.

In the middle part of the island we studied the coastal lowland on Pacific side of South Kurilsk Ithmus (Fig. 3). The main object was the swamp located on the place of ancient inlet. Peatbog overlies mid-late Holocene marine deposits and storm ridges. Peat was formed at the end of Subboreal-Subatlantic and has thickness less than 0.6 m. Diatoms were studied in three sections on the different distances from modern shoreline. More detail results were received for the site 101, located about 1 km from shoreline. Fossil diatom assemblages were divided into two diatom zones. Zone 1 from sand unit and lower part of peaty silt contains abundance of marine species and indicates marine environment. The units were deposited during last Subboreal transgressive phase, correlated with Late Jomon transgression of Japanese Islands [Korotky *et al.*, 2000; Sakaguchi, 1983]. Zone 2 from upper peat includes mainly fresh-water diatoms. Relative abundances of well-preserved marine species increase in the sand as compared to the underlying and overlying peat. Along with freshwater species the assemblage contains rare marine species. Contents of marine diatoms increase in 6 intervals. Occurrences of some marine species in upper part of the peat bog where a sandy interval is not recognizable suggest that the tsunami extended farther lowland than was previously inferred from the field stratigraphy.

Diatom assemblages in sand consist of different dominant taxa, but both indicate that the sand units originate from South Kurile Inlet. Among marine diatoms in tsunami deposits sublittoral species (*Paralia sulcata, Cocconeis scutelum, Diplneis smithii, Odontella aurita, Hyalodiscus obsoletus* etc) dominate. Rare valves of the large specimens of *Arachnoidiscus ehrenbergii*, which lives attached to seaweed, were also recovered from the sand. High content of neritic (*Actinocyclus octonarius, A. divisus, Actinoptychus senarius, Thalassiosira gravida, T. leptopa, Thalassionema nitzschioides* etc.) and oceanic (*Coscinodiscus perforatus, C. radiatus, C. marginatus, Rhizosolenia hebetata*) species are found. Content of these species is higher in tsunami layers compare to marine deposits of Holocene transgressive phase (Fig. 4). Appearance and high percent content of deep-sea species is connected to strong marine water flow, penetrated far landward and brought large amount these forms as compared with storm-induced surge. Possibly this fact can serve as informative sign of palaeo-tsunami. It should be noted that some of the marine taxa found under the sand layers may be due to infiltration of marine water into peat.

Sand layers with marine diatoms were formed at past 2 ka. The configuration of shore line was similar to the present [Korotky *et al.*, 2000]. Two of lower sand layers contain volcanic coarser debrises (up to 8 mm). This fact indicates that tsunami accompanied by volcanic events may be explosions and formation of hydrothermal fields on Mendeleev Volcano slopes.

shwater diatom assemblage from tsunami layers and overlaying deposits indicates that palaeo-tsunami had an influence on environment pH (Fig. 4). After tsunami diatom assemblage common for acid swamp environments (acidophilous and acidobiontic) changed by diatom flora of neutral and alkaline environments. Circumneutral, alkaliphilous and alkalibiontic forms dominate in diatom assemblage, these species continued their development after tsunami event during some period. Thus, palaeo-tsunami influence to environment results in changes of development tendency of swamp system, that could have effect to landscape development.

Analogues of paleotsunami traces from middle part of peat are two sand layers from the section located at a shorter distance from modern shoreline (Fig. 3). Thickness of the layers increases and they composed of well-sorted fine sand. The deposits includes fresh-water diatom assemblages with rare marine sublittoral species *Cocconeis scutellum, Odontella aurita*

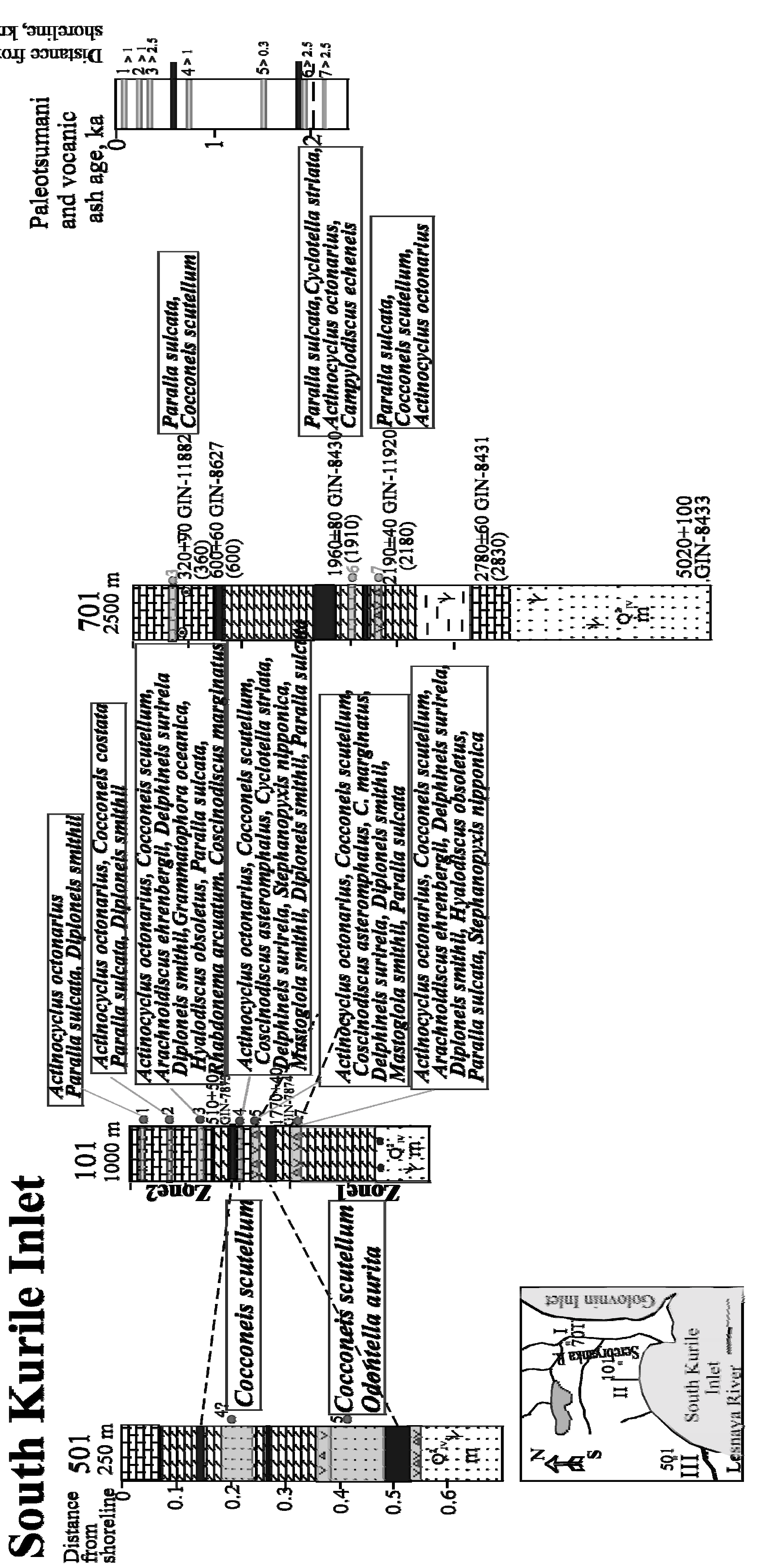


Figure 3. Marine diatoms from the sites 101, 501, 701 the swamp near South Kurilsk.

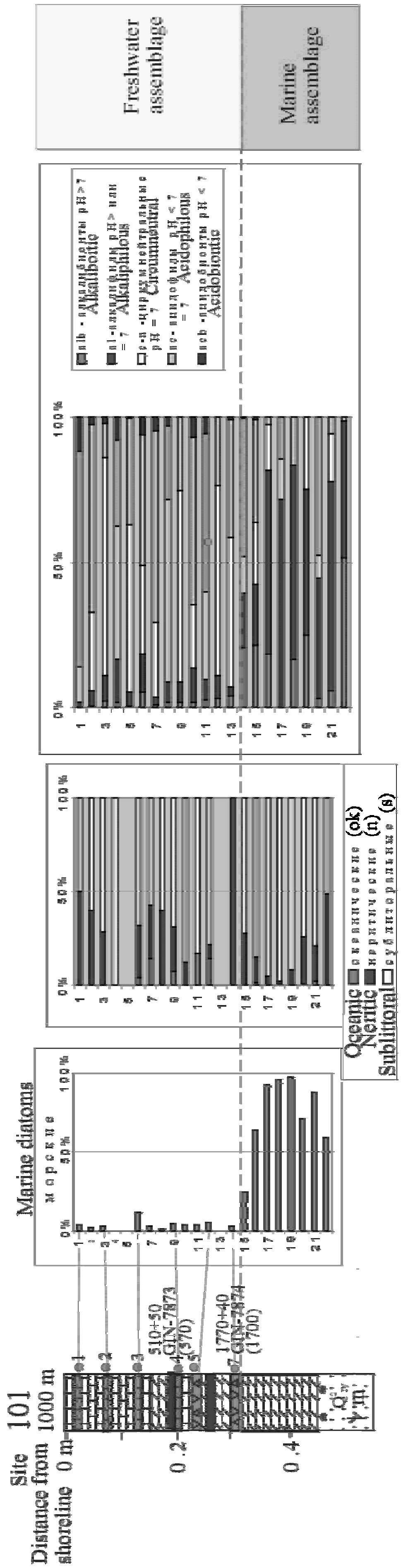


Figure 4. Ecological groups of marine and freshwater diatoms from site 101.

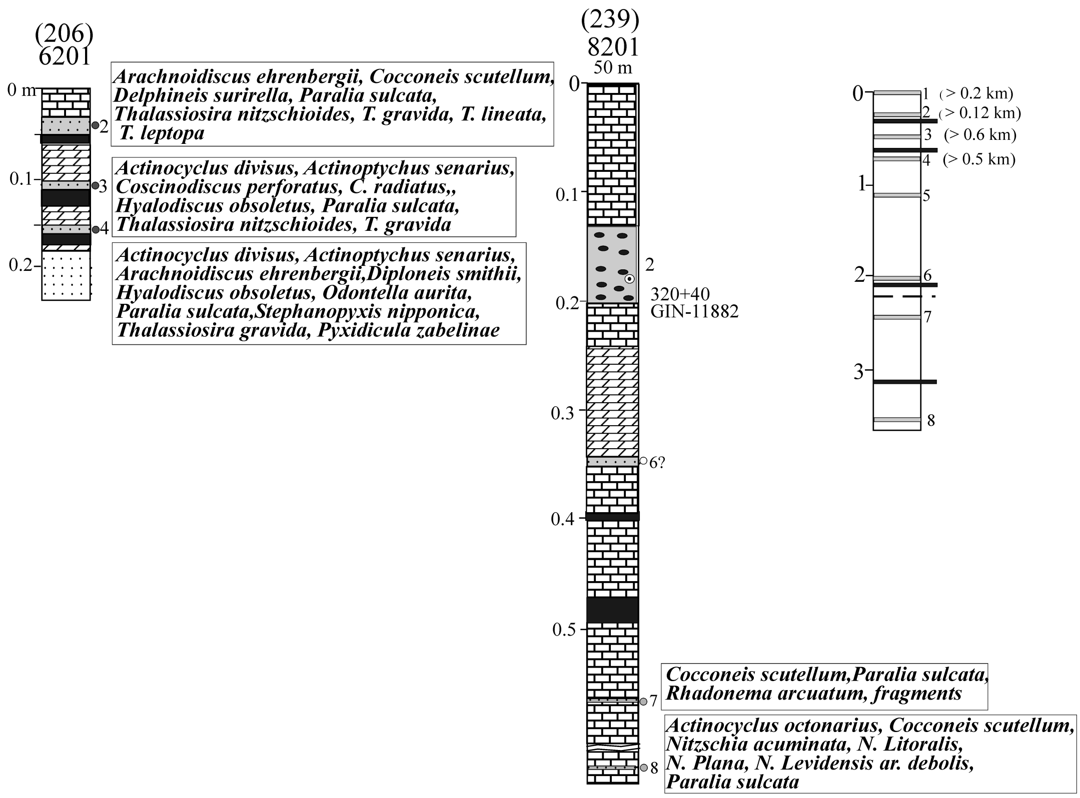


Figure 5. Marine diatoms from the sites 8201and 6201, the swamp near Belozerskaya River mouth.

Along the Serebryanka River the landward limit of sand layers within peat bog is 2.5 km from mouth of the river. Three sand layers with marine diatoms are found in section located landward at Serebryanka River middle current. Sand layers exposed in peat bog section with the same ash layers. Lower layer contains coarser volcanic material. Content of marine diatoms in sand layers is higher than in the section near the shoreline. Diatoms add to stratigraphic evidence that tsunamis flooded this part of lowland three times during the past 2 ka. Marine assemblages includes mainly sublittoral species and neritic *Actinocyclus octonarius.* Tsunami at this site were probably generate by great earthquakes. We suppose that these sand layers were deposited by largest tsunami.

The tsunami deposits are late Holocene that explains predominance of south- and north-boreal diatoms, typical for modern sublittoral environment of this region. At this time shoreline configuration was similar to the present [Korotky *et al.*, 2000].

In southern part of the island we investigated peatland between Belozerskaya River mouth and Veslovsky Spit (Fig. 5). Most part of peatland was formed at late-Holocene and show young age of this accumulative form. More ancient mid-Holocene peat bog is located only near Belozerskaya River. Diatoms from the sand layers consist of marine and brackish species that indicate their tsunami origin. Diatom assemblages well reflect configuration of ancient coastal line during palaeo-tsunami event. Presence of species which usually live in lagoon and closed inlet such as *Nitzschia acuminala, N. levidensis, N. litoralis, N. plana, Rhabdonema arcuatum, Thalassiosira bramaputra, Navicula glasialis, Lyrela forcipata* etc. reflects that the coast was more irregular at Subboreal. Diatom analysis shows the tsunami deposits most likely originated from the lagoon water, and good preservation supposed that the diatoms were deposited and buried rapidly. Diatom flora from upper Subatlantic layers with the species commonly live in inlets and bays record open coast environment.

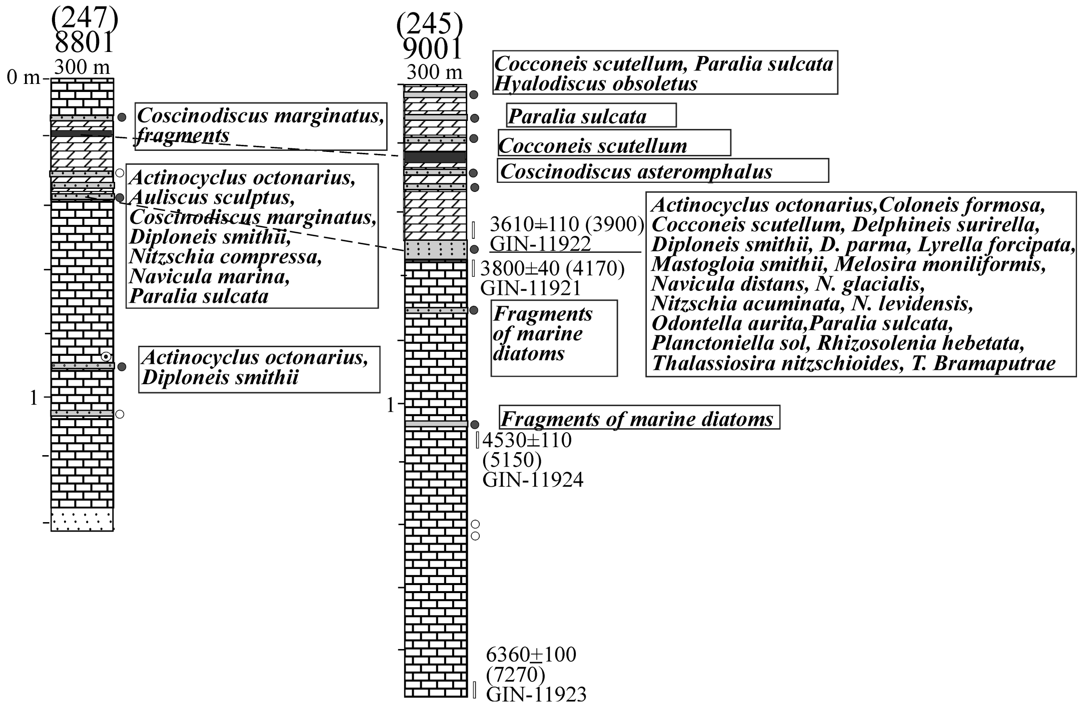


Figure 6. Marine diatoms from the sites 8801and 9001, the swamp near Golovnin River mouth.

On Izmena Bay coasts we studied peatlands extended upward river valleys. Most ancient peat bog was founded in low current of Golovnin River (Fig. 6). The lower part of the section deposited about 5-6 ka ago. Peat includes rich freshwater diatom flora, commonly live in small flood lakes. Two lower sand layers contain fragments of marine diatoms, identifying a bay-ward source of the sand. Lower sand was deposited during the cooling about 4.5 ka ago [Sakaguchi, 1983; Korotky *et al.*, 2000]. Sea-level position was lower than the present, and we suppose that the sand was formed by tsunami. Second sand layer possibly has the same origin.

Next upper sand layer have relatively large thickness (up to 7 cm). This layer includes high content and diversity of marine and brackish diatoms (17%). Marine assemblage reflects semi-open inlet environment. Presence of warm-water neritic species such as *Planctoniella sol* and *Thalassiosira nitzschioides* indicates influence of Kuroshio current. Fresh-water species are common for river input. Radiocarbon dates indicate that the sand was deposited at first half of the Sibboreal. Diatom analysis suggests that the sand originated from sandy shallow subtidal deposits of Izmena Bay. The sand may be formed by extensive tsunami, trace of which was recorded on Eastern Hokkaido coast near Nemuro [Nanayama *et al.*, 2000]. However, we cannot exclude that the unit was formed during short-time transgression at fist phase of Subboreal that correlated to peak of Late Jomon transgression of Japanese Islands.

Late Holocene peaty silt from upper part of the site includes freshwater species which usually live on soil. Rare marine diatoms from sandy intervals consist of species observed on modern tidal flats of the open bay, identifying a bay-ward source of the sand. The same results were received for site from other side of the river.

Beat bog from Khlebnikov Stream low current has late Holocene age (Fig. 7). Rich and diverse marine assemblage from lower sand layer with pumice possibly record storm surges within ancient coastal line of second phase of Subboreal transgression. Similar marine diatom assemblage was found in deposits of this transgressive phase exposed near the modern coast

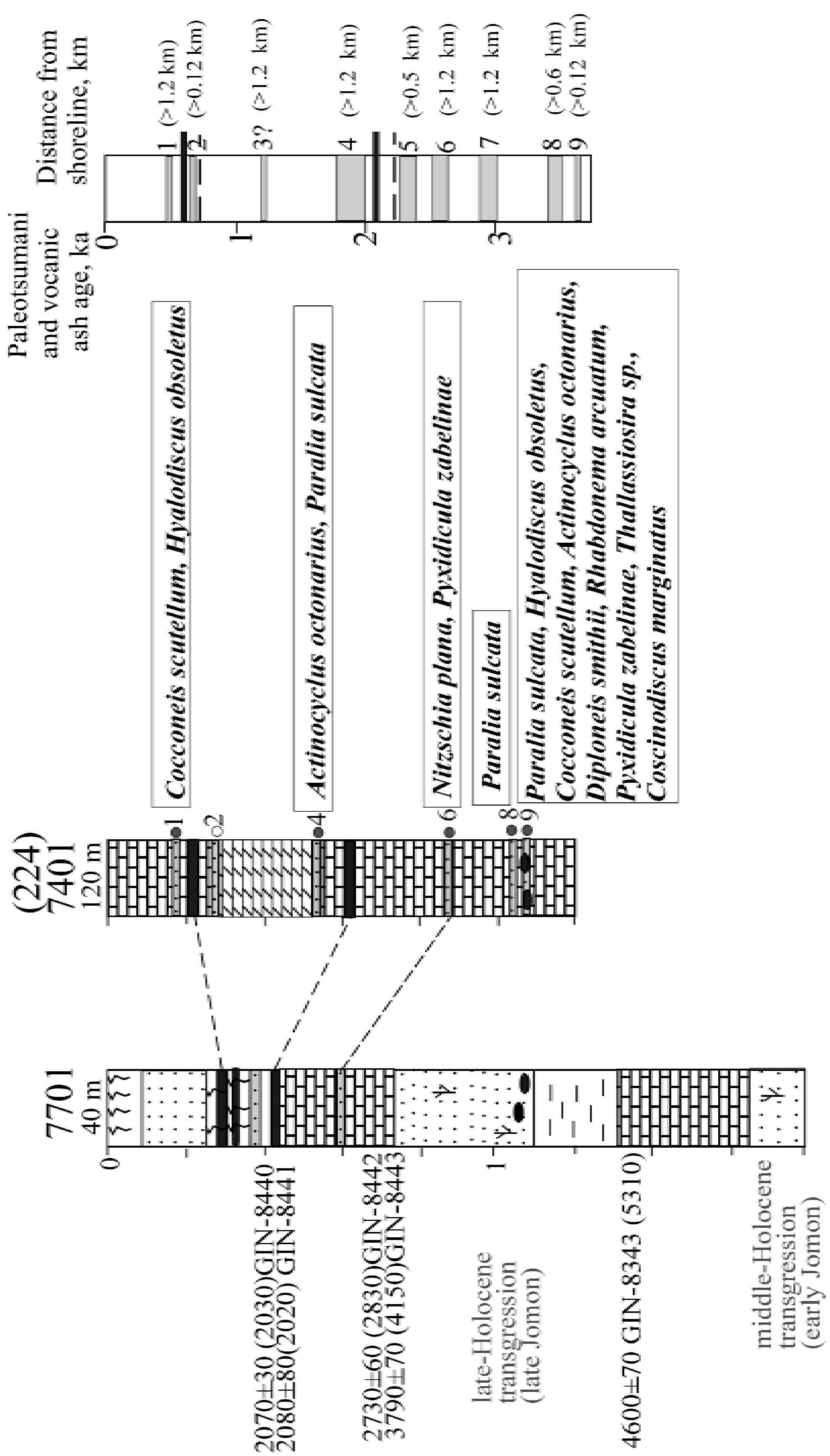


Figure 7. Marine diatoms from the sites 8201 and 6201, the swamp near Khlebnikov Stream mouth.

[Korotky *et al.*, 2000]. While the peat from upper part of the section typically contains divers assemblages of freshwater diatoms, the sand layers includes a few marine species. In addition

the tsunami sand contain rare specimens of the marine extinct diatoms such as *Pyxidicula zabelinae* which redeposited from Pliocene Golovnin Formation exposed on the coast cliffs. The diatom evidence suggests, that the Subatlantic tsunami sand most likely originated from shallow subtidal marine deposits.

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The most remote peat bog from Pacific side is located near Paltusov Cape in the valley without stream). The peat contains freshwater species that live on moss and on soil. Marine taxa are observed in sand layers as fragments. Rare marine species were found in upper sand. Poorly preservation of specimens may be indicate input transport by largest tsunami during the past 4 ka. The traces of these tsunami are wide distributed even along the Izmena Bay coast, separated from direct Pacific influence. It should be noted that Veslovsky Spit was formed only last 1-2 ka and earlier Pacific influence to Izmena bay coast was more intensive.

Another approach to studding the record of paleotsunami inundation is to look for evidence from incursion of marine water into coastal freshwater lakes. Evidence for tsunami inundation to lakes might include anomalous sand layers in lacustrine deposits with freshwater microfossil. Good example for this evidence is barrier paleolake deposits composed 5-6 m terrace in low current of Lesnaya River. Palaeo-lake deposits contain mostly laminated mud with abundant freshwater diatoms, but include some anomalous sand layers. The lake was formed at maximum of Holocene transgression about 6 ka ago. During this time, 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.

Marine diatoms in two lower sand layers are very rare and fragmentated, which suggests that they were deposited by strong currents. Second sand layer includes oceanic *Coscinodiscus marginatus* and sublitoral *Diploneis smithii.* Possibly the sands were deposited by middle-Holocene tsunami penetrated to relatively extensive barrier lake. We cannot exclude that these layers are a downriver flood deposits because freshwater assemblage contains abundant river species (*Rhoicosphenia abbreviate, Diatoma mesodon, Cymbella genus* etc.). These sands are also characterized by low heavy mineral fraction.

Upper part of the section was formed at beginning of Subboreal. Lacustrine clay includes four sand layers with marine diatoms, identifying a bay-ward source of the sand. Rich freshwater and marine assemblages were found in lower layer. Warm-water species such as oceanic *Coscinodiscus perforatus, C. asteromphalus,* neritic *Thalassionema nitzschioides* and subtropical oceanic *Rhoperia tesselata* were found in this sand which formed by tsunami incursion to freshwater lake during first half Subboreal. At this time warming was accompanied by Kuroshio current system shift northward. Upper deposits contain poor freshwater diatom assemblage. The lake strongly decreased the size and active filled by clay deposits. Upper sand layers include rare marine species and possibly are the traces of Subboreal paleotsnami too.

Late-Holocene lacustrine deposits were studied in low terrace section of Dobry Kluych low current. There was small short-time flood paleolake with mineral spring. At this environment diatomite was deposited. The deposits include some sandy layers and ash, correlated to ash of Rogachevka site formed about 2.4 ka. While the diatomite typically contains divers assemblages of freshwater diatoms, the sands include a few marine species. Diatoms from these intervals consist of species observed on modern sublittoral *Cocconeis scutellum, Paralia sulcata, Arachnoidiscus ehrenbergii,* neritic *Actonoptychus sena*rius and oceanic *Thalassiosira eccentrica.* In addition the tsunami sand contain rare speciments of the marine tychoplantton species *Odontella aurita.*

## CONCLUSION

1. Diatoms analysis can provide valuable evidence for the validity of proposed tsunami deposits. Presence of marine and brackish species in sandy layers suggest a seaward source for the sand, as opposed to a downriver flood deposits and reflect configuration of ancient coastal line.

2. Diatom analysis suggests that the tsunami may have deposited finer-graned sediments and diatoms at last distance farther upland where sand layers have not been observed.

3. Content of marine species and their diversity depend as by distance from sea coast as sand layer thickness that possibly is connected with tsunami intensity. The rarity and poor preservation of diatom valves indicate long-distance transport during a high-energy event.

4. The most palaeo-tsunami deposits are late Holocene that explains predominance of south- and north-boreal diatoms, typical for modern sublittoral environment of this region. Warm-water species were found in middle-Holocene palaeo-tsumani deposits that was connected with Kuroshio current system shift northward.

5. The results of this study show the usefulness of diatom palaeoeclogy as a tool for reconstructing the ecological effect of tsunami on swamp geosystems.

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