^{14}C AGES OF TEPHRA LAYERS FROM THE HOLOCENE DEPOSITS OF KUNASHIR ISLAND (RUSSIAN FAR EAST)

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ABSTRACT. Holocene deposits from the central and southern regions of the Kunashir Island contain tephra from 12 volcanic eruptions (Kn1–12). We studied radiocarbon data, mineralogical composition, and distribution of the tephra layers in different Holocene facies. The main sources of the Holocene tephra samples were the volcanoes of Hokkaido Island. The distribution of ash layers on Kunashir Island allows us to estimate their direction. Ash layers can be reliable markers for age determination of different coastal landforms on open oceanic shores. We propose here a tephrastratigraphical scheme for different Middle-Late Holocene facies.

INTRODUCTION AND METHODS

The tephrastratigraphy of Kunashir Island (Kuril Islands, Russian Far East) was not well studied until 1990. Some studies have been published on Pleistocene catastrophic eruptions of the Great Kuril Arc Volcanoes (Braitseva *et al.* 1994; Bulgakov 1994; Melekestsev *et al.* 1988). However, they lack mineralogical study, reconstruction of the sources, and spatial distribution of the tephra layers. Tephrastratigraphical schemes were made for the adjacent territories—the Japanese Islands and the Kamchatka Peninsula (Arai *et al.* 1986; Machida 1991; Machida and Arai 1992; Braitseva *et al.* 1985; Pevzner 1994). Recent progress in the tephrastratigraphy of Hokkaido Island (Okumura 1988; Sakaguchi *et al.* 1985; Taira 1980) allows us to identify the eruption centers and to correlate the ash layers of the southern Kuril Islands (Kunashir and Iturup) with Hokkaido Island. Several Holocene tephra layers are exposed in the central and southern areas of Kunashir Island (Fig. 1). The studies of tephra containing deposits include radiocarbon and biostratigraphic (both pollen and diatoms analyses) investigations.

RESULTS AND DISCUSSION

Several layers of ash, lapilli and pumice were found in the Holocene sections of Kunashir Island. The KnIV-1 ash layer is located on the island's Pacific coast (Fig. 1). The ash is exposed in peat (depth of 1.7–1.75 m below the surface) and is represented by light-gray silt. Heavy minerals include magnetite, orthopyroxenes and clinopyroxenes. The peat unit was formed in the middle of the twentieth century. This was evident because of the presence of Japanese glassware and recent shell middens. The source of the ash layer KnI-1 was presumably the Usu Volcano, which erupted in 1943–1945 (Masao *et al.* 1968).

The KnIV-2 and KnIV-3 ash layers are exposed in the same sections, and are widely spread in the upper part of the low marine terraces, Little Ice Age eolian deposits, and the first buried soil from the Middle-Late Holocene dunes. The good preservation of the ashes in the dune deposits can be explained by a rapid accumulation of the deposits during successive phases of eolian process activities dated at *ca.* 300 BP, which correlates with the Ido Regression of Japan (Sakaguchi 1983).

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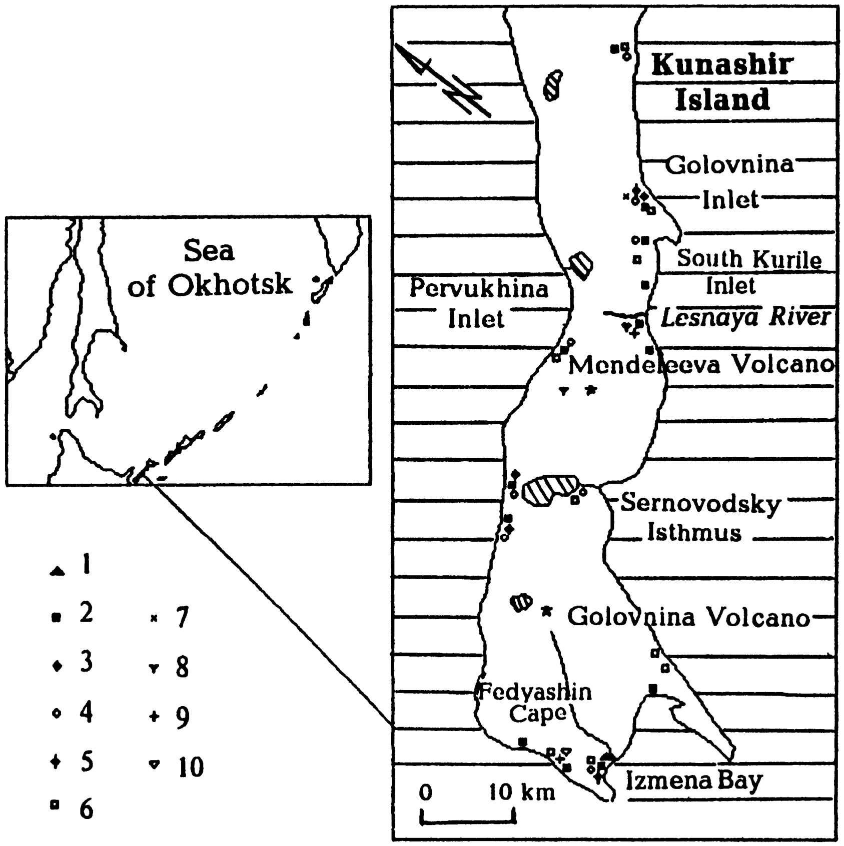

Fig. 1. Studied sections with tephra layers, Kunashir Island. Ash codes: 1 = KnIV-1; 2 = KnIV-2; 3 = KnIV-3; 4 = KnIV-5; 5 = KnIV-6; 6 = KnIV-7; 7 = KnIV-8; 8 = KnIV-9; 9 = KnIV-10; 10 = KnIV-11.

Two ash layers from the base of the first dune ridge near the Pervukhin Inlet are represented by light-gray silt. The ash layer thickness varies from 1–1.5 to 3–4 cm within the deflation basin. The thickness of the overlying eolian deposits is 5–6 m. The KnIV-2 ash layer has a dacite composition similar to the Mashu Volcano on Hokkaido Island (Ishikawa *et al.* 1963).

The Subatlantic and the Subboreal dune ridges include KnIV-2 and three ash layers (*ca.* 2 cm thick) in the first buried soil. The pollen assemblage from the buried soil consists mostly of conifers (*Abies*, *Picea* and *Pinus*), with an admixture of some fine-leaved trees (*Betula* and *Salix*). This assemblage shows a landscape structure similar to the modern one.

These ash layers are exposed at the top of the Subatlantic marine terrace. The terrace was formed during a minor transgression *ca.* 1000 BP, and correlates with the Heian Transgression and the Nara-Heian-Kamakura warm stage in Japan (Sakaguchi *et al.* 1983; Taira 1980). The Subatlantic terrace in the South Kuril Inlet includes two ash layers. The first ash layer (0.8–1 cm thick) lies under modern soil, and the second ash layer (1 cm thick) lies under buried soil. A ^{14}C date of 820 ± 80 BP (GIN-7903) was made on shell material found in the marine sand below this ash layer.

The KnIV-2 and KnIV-3 ash layers were found in the peat unit that covers the 3–4-m Subboreal marine terrace deposits and in the eolian sands covering the 5–6-m Atlantic marine terrace deposits.

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Two ^{14}C dates from the first buried soil in the dunes show for the KnIV-2 ash layer ages of 190 ± 40 BP (GIN-7886) and 290 ± 60 BP (GIN-7870). The KnIV-3 ash layer was formed before 500 BP. This was confirmed by ^{14}C dates 510 ± 50 BP (GIN-7873) from the overlying peat, and 600 ± 60 BP (GIN-8627) from the underlying peat. These ash layers are correlated with the Ma-a, Ma-b and Tokoro IV and III ash layers of the eastern and northern Hokkaido (Arai *et al.* 1986; Endo and Uesugi 1972; Machida and Arai 1992; Sakaguchi *et al.* 1985), and with the uppermost part of the ash layers from the Goryachee Lake deposits in the Golovnin Volcano caldera (Fazlullin and Batoyan 1989). The source of these ashes was the Mashu Volcano. The peat overlying the Tokoro III ash was ^{14}C dated to 620 ± 110 BP (GaK-11374) (Sakaguchi *et al.* 1985).

The KnIV-4 ash layer (5 cm thick) is located in the base of the first buried soil in the coastal dune section. The top of this buried soil includes the ash layers KnIV-2 and 3. The KnIV-4 ash layer was found in the dune fields of the Sernovodsky Isthmus (Okhotsk Sea side), and near the Pervukhin and Golovnin Inlets (Fig. 1). The ash consists of coarse pumice, sand and gravel. It is assumed that this ash layer was formed during the eruption inside the Golovnin caldera. Kipyastchee Lake was formed during this eruption. The tephra from this eruption was found in the Goryachee Lake deposits under the two ash layers. The age is calculated, based on sedimentation rate, at *ca.* 640–680 BP (Fazlullin and Batoyan 1989; Markhinin and Abdurakhmanov 1990).

The KnIV-5 ash layer is the thickest among the Holocene ash layers on Kunashir. The Kn-5 ash exposes in the buried soil of the second and third dune generations. These dunes were formed during the Early Subatlantic cooling, and the cooling at the Atlantic-Subboreal boundary (Golovnin and Pervukhin Inlets, and Sernovodsky Isthmus) (Fig. 1). The Kn-5 ash layer is well represented in the peat unit on the surface of the Subboreal terrace (South Kuril and Sernovodsky Isthmuses, and Izmena Bay). The ash thickness increases from 4 cm to 12 cm. The ash has dacite composition and is represented by light-grey silt.

The pollen assemblage from the peat is characterized by predominance of the conifers (*Abies*, *Picea* and *Pinus*) with fine-leaved species (*Betula* and *Alnus*). Such pollen is typical for the Late Holocene deposits of Kunashir (Korotky *et al.* 1995). The ^{14}C dates were obtained from dune soil in the Golovnin Inlet, from peaty silt of the 3–4-m Subboreal terrace in the South Kuril Inlet, and from the underlying peat in the South Kuril Inlet and in the Sernovodsky Isthmus: 1460 ± 50 BP (GIN-7898), 1770 ± 40 BP (GIN-7874), 1960 ± 80 BP (GIN-8430), and 2220 ± 80 BP (GIN-7895) (Fig. 2). The KnIV-5 ash layer correlates with the Ma-d ash layer of the Mashu Volcano, dated to *ca.* 1700–1800 BP, with the Tokoro II ash layer of the Northern Hokkaido coast (Endo and Yesugi 1972; Machida and Arai 1992; Sakaguchi *et al.* 1985; Taira 1980) and with the third ash layer of the Goryachee Lake in the Golovnin caldera (Fazlullin and Batoyan 1989).

Ash layer KnIV-6 was found in the peat unit of the Izmena Bay (Fig. 1). The pollen assemblage from the lower part of the peat unit consists mostly of *Quercus*, which reflects the development of the oak forests on the coast. Other broad-leaved taxa are represented by Fagus, *Ulmus*, *Juglans* and *Acer*. The increasing amount of pollen from the fine-leaved trees (*Betula* and *Alnus*) indicates climatic cooling. Ericaceae predominate among the nonarboreal pollen. A series of ^{14}C dates from the peat unit (2730 ± 60 BP (GIN-8442) below the ash layer; 2080 ± 80 BP (GIN-8441) contemporaneous with the ash, and 2070 ± 30 BP (GIN-8440) above the ash) corresponds to the second warming of the Subboreal period, and to the Subboreal-Subatlantic cooling. These data allow correlation of the KnIV-6 ash with the Eniwa I ash layer of the Hokkaido Island Eniwa Volcano, ^{14}C dated to 2060 ± 100 BP (Gak-3740) (Taira 1980), and with the third ash layer from the Goryachee Lake deposits of the Golovnin caldera (Fazlullin and Batoyan 1989).

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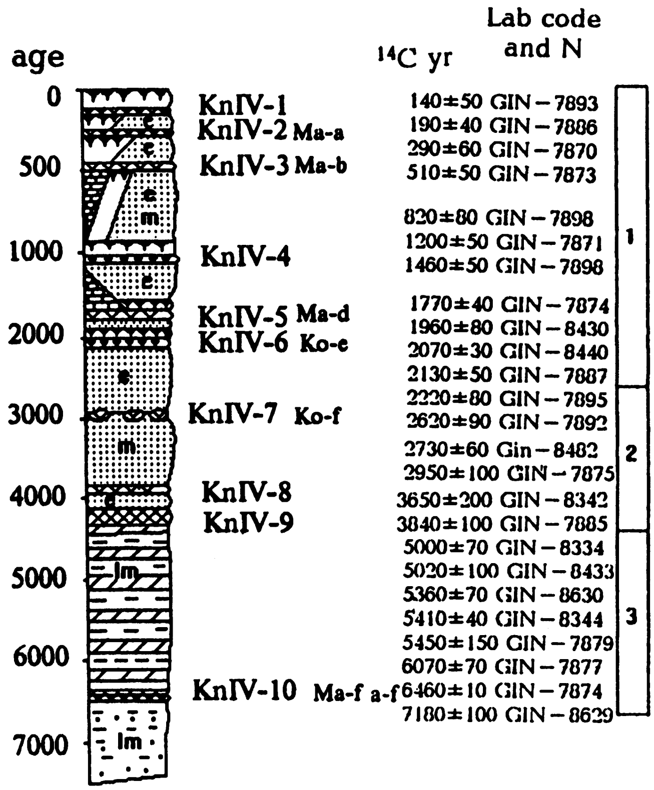

Pollen zones: 1=*Picea-Abies*; 2=*Abies-Picea-Quercus;* 3=*Abies-Quercus-Juglans* (northern part of the island), *Quercus-Betyka* (southern part). Facies: e=eolian; m=marine; lm=lacustrine.

1=ash; 2=pumice; 3=sand; 4=silt; 5=soil; 6=peat; 7=peaty silt; 8=sandy loam.

Fig. 2. Tephrastratigraphical scheme for different facies of Holocene deposits of Kunashir Island

A KnIV-7 lapilli layer with andesite composition was found in the base of the third buried soil from Late Holocene deposits in the Golovnin Inlet, and in the buried soil of the Subboreal marine terrace in the Izmena Bay. The pollen assemblage from the soil includes mostly spores. Among them Polypodiaceae, *Lycopodium* and *Sphagnum* are dominating. The nonarboreal pollen include Compositae, Umbelliferae and Ericales. The arboreal pollen include *Abies* and *Picea*. The ^{14}C date 2130 ± 50 BP (GIN-7887) is obtained from the buried soil. This layer can be correlated with the Ko-e tephra of the Komagatake Volcano, southeast Hokkaido, which erupted *ca.* 2000 BP (Taira 1980). The lapilli were transported by the marine currents to the Kunashir coast and later by the wind from the beach surface to the dunes.

KnIV-8, a light-grey pumice, occurs all over the Kunashir coast, and is located at the top of the Subboreal storm ridges. The maximum amount of pumice was found on the surface of the ancient storm ridge in the Izmena Bay. The pumice occurs on the top of a Subboreal terrace near the mouth of the

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Temnaya River, in the Pervukhina Inlet, and in the Golovnin Inlet. The single pumice sample was found on the surface of Subboreal beach ridge in the Kosmodemianskaya Inlet.

The diatom assemblage from the beach ridges reflects a warm climate and a high sea level. The pollen assemblage consists of mostly dark conifers (*Abies* and *Picea*), with abundance of broad-leaved species (*Quercus*, *Juglans*, *Tilia* and *Phellodendron*), and with an admixture of fine-leaved species (*Alnus* and *Salix*). The pollen assemblage indicates the development of coniferous, broad-leaved forests. The climate was warmer than today. The pollen assemblage from peat from the KnIV-8 ash layer (which covered the marine deposits) corresponds to the dark-coniferous forests with an admixture of birches. The climate and the landscape were similar to the present. The ^{14}C date from the peat is 2220 ± 80 BP (GIN-7895).

A ^{14}C date of 2950 ± 100 BP (GIN-7875) was obtained for shells from the layer underlying the pumice. Shells from the storm ridge (Kosmodemianskaya Inlet), are dated to 2620 ± 90 BP (GIN-7892). The distribution of the pumice on the island coasts indicates that the volcanic sources were situated south of Kunashir. The most probable source of the KnIV-8 pumice is the Komagatake Volcano, characterized by intensive pumice eruptions (Aprodov 1982). The strongest eruption of this volcano took place *ca.* 3000 BP (Taira 1980).

Ash layer KnIV-9 is found in the restricted area within the buried soil from the dune section in the Golovnin Inlet. This soil was formed at the Atlantic-Subboreal boundary (Korotky *et al.* 1995). The Kn-9 ash (2 cm thick) is characterized by brown humic silt. The charcoal ^{14}C dates 3650 ± 200 BP (GIN-8342) and 3840 ± 100 BP (GIN-7885) were for charcoal from the buried soil. This ash layer probably correlates with the Tokoro I and Ma-e ashes of the NNW Hokkaido (Masao *et al.* 1968; Sakaguchi *et al.* 1985).

The KnIV-10 volcanic scoria was found near the Mendeleev Volcano. It erupted during the Middle Holocene. The scoria is covered by the eolian sands with buried soils. The pollen assemblages from the buried soils are characterized by dominating conifers and birch (*Abies*, *Picea* and *Betula*), with relative abundance of the broad-leaved species (*Quercus*, *Ulmus*, *Juglans* and *Corylus*). These assemblages reflect the warm climate of the Middle Holocene. The ^{14}C date of 4220 ± 50 BP (GIN-160) was obtained using pine (*Pinus pumila*) remains from the underlying layer. It indicates a Subboreal eruption of the Mendeleev Volcano (Polunin 1969; Lebedev *et al.* 1980).

The KnIV-11 ash layer was found in the lacustrine terrace section near the mouth of the Lesnaya River and in the peat section near the Fedyashin Cape (Fig. 1). The KnIV-11 ash layer covered the peat layer and the Middle Holocene lacustrine silt unit. The Subboreal marine sands and the Subatlantic eolian sands are located on the top section (Korotky *et al.* 1995). The ash layer underwent strong changes under the influence of the low-temperature sulphate water of the Kisly Stream, a tributary of the Lesnaya River. The pollen assemblage from the lacustrine deposits is characterized by the abundance of broad-leaved species (*Quercus*, *Juglans*, *Phellodendron* and *Ulmus*) and birch (*Betula*). The content of conifer pollen is low. The pollen assemblage indicates that the lake existed during the Holocene climatic optimum. The ^{14}C date 4310 ± 70 BP (GIN-7876) obtained from the lacustrine deposits under the ash layer peat is probably rejuvenated because there is a series of Optimum Holocene dates from the lacustrine deposits: 6070 ± 70 BP (GIN-7877), 5890 ± 130 BP (GIN-7878) and 5450 ± 150 BP (GIN-7879) (Fig. 2). Based on the sedimentation rate of the lake (*ca.* 2 mm a^{-1}), the age of this ash layer can be calculated as *ca.* 6300 BP.

The KnIV-11 ash layer is exposed in the 2.5-m terrace section near the Fedyashin Cape. The pollen assemblage from the peat consists of broad-leaved species (*Quercus*, *Ulmus*, *Juglans* and *Phello-*

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dendron) and some fine-broad species (*Alnaster*, *Salix* and *Alnus*), with occasional pollen from *Abies*. The pollen assemblage indicates that peat silts from the KnIV-11 ash layer were deposited at the Holocene climatic optimum. The ^{14}C dates from this section are 5360 ± 70 BP (GIN-8630) and 5000 ± 70 BP (GIN-8334).

The combination of biostratigraphical and ^{14}C dates allow us to correlate the ash layer KnIV-11 with the widespread Ma-f ash of the Mashu Volcano on the eastern and northern Hokkaido, which erupted *ca.* 6400–7200 BP (Arai *et al.* 1986; Endo and Yesugi 1972; Machida and Arai 1992; Sakaguchi 1983). The ^{14}C dates from the ash-containing deposits on Hokkaido Island are 6460 ± 130 BP (GaK247), 7190 ± 230 BP (GaK248) and 7120 ± 180 BP (GaK2594) (Arai *et al.* 1986).

The dacite ash layer KnIV-12 (5 cm thick) is found in the base of peat under the ash layer KnIV-10 near the Fedyashin Cape. The source of this tephra was the Golovnin Volcano, which erupted at the beginning of Atlantic period. Possibly, this ash layer is exposed in the Holocene lacustrine section of southeastern Pacific coast of the Kunashir. The ^{14}C date from the underlying peaty silt is 7180 ± 100 BP (GIN-8629).

Conclusion

Twelve tephra layers were found in the Holocene sections of the central and southern areas of Kunashir Island. ^{14}C dates, and mineralogical and biostratigraphical studies, made it possible to determine that the main sources of these tephra layers were the Hokkaido volcanoes. It is assumed that ash layer KnIV-1 is the tephra of the Usu Volcano, which erupted in 1943–1945. The source of ash layers KnIV-2, 3, 5, 9 and 11 is the Mashu Volcano, which was active over different periods of the Holocene. The KnIV-11 ash layer was formed *ca.* 6300 BP. All of these ash layers are correlated with the ash layers Ma-a, b, d, e, and f of Hokkaido Island. The source of ash layer KnIV-6 was supposedly the Eniwa Volcano, which erupted *ca.* 2000 BP. The analogue of this ash is the Eniwa I ash layer. The KnIV-7 lapilli and KnIV-8 pumice correlate with the Komagatake Volcano tephra (Ko-c and Ko-f). Holocene tephra of the Golovnin Volcano are represented by layers KnIV-4 and KnIV-12, and the Mendeleev Volcano tephra by scoria KnIV-10. Widespread ashes KnIV-2, 3, and 5 can be used as the marker for tephrastratigraphy of the Middle-Late Holocene deposits of the southern Kuril islands. They are found in peat, soils, lacustrine deposits, coastal dunes and eolian covers.

These results allow us to construct the tephrastratigraphical scheme for different Middle-Upper Holocene facies of the Kunashir. This scheme is useful for age determination of the different units and for the correlation of the Holocene sections. The ash layers can be used as a criterion for the determination of the Subatlantic, Subboreal and Atlantic marine terraces. This is important because these coastal landforms usually have similar morphology and heights. The KnIV-8 pumice is a good marker for the Subboreal marine storm ridges.

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