Holocene Marine Terraces of Kunashiri Island, Kurile Islands

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Low marine terrace sequence of Kunashiri Island includes Atlantic, Subboreal and Subatlantic terraces, reflected sea level oscillations during Middle–Late Holocene. The section of Atlantic terrace (5–6 m elevation) exposes storm ridge deposits, covered lacustrine silts and peat. Pollen and diatom fossils and ¹⁴C-dates (5,450–6,070 yrs BP) correspond to development of large barrier forms with lakes in the Holocene Optimum. The paleostrata existed in the place modern Sernovodsky and Kruglovsky Isthmuses. Ocean level rose to 2.5–3 m a. m. s. l. A minor regression took place during Atlantic–Subboreal cooling. Drainage of inshore zone led to development of large dunes. Subboreal deposits record two high sea level positions: about 4,010–3,400 yrs BP and 2,950–2,620 yrs BP. Small estuarine lagoons and inlets developed in that time. The cooling and ocean level lowering at Subboreal–Subatlantic boundary accompanied by formation of dune fields and swamping of the lagoon coasts (2,220 ± 80 yrs BP, 1,440 ± 60 yrs BP, GIN-7895, GIN-7262). Subatlantic terrace (2.5 m) formed during ocean level rise to 1 m about 1,170–820 yrs BP. Dunes were formed during Little Ice Age regression. The terrace study indicates their weak tectonic deformation.

Key Words: marine terrace, Holocene, Kunashiri Is., pollen, paleoenvironment, tectonic activity

I. Introduction

Study of marine terraces gives important information for estimation of tectonic activity of the area, natural environment development, landscape changes and sea level oscillations in the Pleistocene. There are well pronounced marine terraces sequence (to 300 m elevation) in the Kurile Islands (Pryalukhina, 1964; Kulakov, 1973; Melekestsev *et al.*, 1974). Terrace deposits were almost have not been studied. There are some works, considering the age of terraces, dated by ¹⁴C and TL without bio- and tephrostratigraphy data (Polunin, 1969; Bulgakov, 1993, 1994). This paper deal with the age, pollen and diatoms records and facies of low marine terraces of Kunashiri Island (Fig. 1) for environmental and paleo-landscape reconstruction and estimation of

tectonic activity.

II. Marine Terrace Sequence

Marine terrace (elevation to 2.5–3 m) is widespread on the island. It consists of sand, supplied from Middle Holocene marine terraces and dunes. Modern abrasion processes are not active and abrasion material occurs only near capes. The terrace is leant to ancient abrasion-denudation cliffs or to Middle Holocene marine terraces. The elevation of the terrace increases in north part of the inlets due to SE storms. The height of low marine terraces can not be used for correlation. It is determined by hydrodynamic conditions. For example, there is modern accumulative form (4 m elevation) on Okhotsk Sea coast, leant to Subboreal terrace. ¹⁴C-dating of the board with hammered nail shows modern age of

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Fig. 1 Outline map of the studied area

deposits (GIN-7888). These terrace was formed due to storm-induced surge, that filled up the stream mouth by sandy material. Possibly, it was formed in 1890 (the year with anomaly low temperature and great storms) (Sakaguchi, 1983).

Ash-layers are more reliable mark for terrace correlation. ^{14}C -date of shells from the terrace with two ash-layers (South Kurile Inlet) 820 ± 80 yrs BP (GIN-7903)(Table 1) shows, that the terrace was formed during Subatlantic transgression (Taira, 1980b; Korotky and Khudyakov, 1990) and corresponds to warm climatic stage Nara-Heian-Kamakura of Ja-

pan Islands (Sakaguchi, 1983). Ash-layers are correlated with ash Ma-a, Ma-b of Mashu Volcano (Arai *et al.*, 1986).

Marine terrace (elevation of 3-4 m) is leant to 5-6 m terrace and dune field in large inlets (Golovna, Pervukhina Inlets). It is represented by storm ridges, leant to Atlantic lacustric deposits within small inlets (Kosmodemianskaya Inlet) and river mouths (Lesnaya River) (Fig. 2). This terrace occupies almost all Sernovodsky Isthmus and coastal plain in island south. The terrace is composed of eroded dunes sand, formed at Atlantic-Subboreal boundary. Pebble composition of Subboreal storm ridges indicate, that the active abrasion took place in this time. ^{14}C -dates of shells from the terrace $2,620 \pm 90$ yrs BP (GIN-7892), $2,950 \pm 100$ yrs BP (GIN-7875) conform to second warming of Subboreal (Sakaguchi, 1983; Korotky and Khudyakov, 1990).

Well-rounded pumice, covered the storm ridges tops, is marker for this age. Thick pumice layer covers lagoon terrace near Golovna (Fig. 1). Size of pumice is coarser in Pacific coast (≤ 20 cm. in Golovna Inlet) compared to Okhotsk Sea coast (3-4 cm. in Pervukhina Inlet). Supposedly, the pumice was the product of Komagatake Volcano eruption (SE Hokkaido), that took place about 3,000 yrs BP, index Ko-f (Taira, 1980a; Arai *et al.*, 1986). Pumice sands of the same age were found in Tokoro Plain, Eastern Hokkaido (Sakaguchi *et al.*, 1985).

Marsh deposits (dark-brown peaty sands with vertical-oriented concretions of Fe hydroxides at plant remains) expose within backshore of the terrace and between storm ridges. The terrace is overlaid by dunes (to 4-5 m elevation) of two generations, formed during Little Ice Age and Early Subatlantic cooling. The dunes are correlated with Little Ice Age (Kurosuna bed K₄) and Kofun Cold Stage dunes (Kuro-suna bed K₃) of Japan Islands (Taira, 1980a; Sakaguchi, 1983).

The terrace section, located in South Kurile Inlet, exposes (section 9-93, from top to bottom) :

Table 1 Radiocarbon dates of Holocene deposits of Kunashiri Island

N sample	Location	Geomorphology	Interval, m	Material	¹⁴ C-date	Labor. N
I/5732	Sernovodsky Isthmus	4 m terrace	0.45-0.50	peat	2220±80	7895
Ia/18-93	Lesnaya River Mouth	5-6m terrace	1.82-1.85	peat	4310±70	7876
I/18-93			1.6-1.7	peaty silt	6070±70	7877
II/18-93			1.4-1.6	peaty silt	5890±130	7878
III/18-93			1.0-1.2	peaty silt	5450±150	7879
IV/18-93			0.4-0.56	peaty silt	4100±80	7871
V/18-93			0.2-0.4	peaty silt	4010±70	7880
3/13/93	Pervukhina Inlet	12m dune	3.0-3.40	soil	290±60	7870
5/13/93			3.75-3.90	soil	1260±90	7871
7/13/93			4.60-4.65	soil	860±140	7872
I/5687		4 m terrace	2.0-2.10	wood	modern	7888
4/9/93	South Kurile Inlet	3-4 m terrace	0.3-0.4	peat	510±50	7873
6/9/93			0.5-0.6	peaty silt	1770±40	7874
I/5697		2 m terrace	0.4-0.5	shells	820±80	7903a
I/5676	Golovnina Inlet	20m dune	1.7-1.95	soil	190±40	7886
I/5778			2.5-2.62	soil	1460±50	7898
II/5676			3.8-3.95	soil	2130±50	7887
I/5675		12 m dune	3.75-3.78	coal	3840±100	7885
I/5674		8 m dune	2.8-2.9	peaty sand	1310±80	7884
7/3/93		3-4 m terrace	0.10-0.20	shells	2950±100	7875
I/5706	Kosmodemianskaya	5-6 m terrace	4.3-4.4	peat	4570±70	7889
II/5706	Inlet		5.5-5.7	peat	5750±70	7891
I/5777			4.95-5.0	wood	5920±50	7898
I/5708		4 m terrace	2.0-2.10	shells	2620±90	7892

Fig. 2 Geological section of 5 – 6 m marine terraces of Kosmodemianskaya Inlet
Horizontal scale is free.

Thickness, m

1. Peat with ash-layer in the bed0.45
2. Peaty silt with fine sand and ash-layer0.15
3. Grey fine well-sorting sand0.40
4. Grey moderately-sorting sand with gravel0.20
5. Grey well-sorting silty sand0.20

Three units were recognised (Fig. 3). Lower unit (0.6–1.2 m) contains marine diatom assemblage with predominance of sublittoral north-boreal *Paralia sulcata* ≤ 90%. South-boreal species are represented mainly by neritic *Acti-*

nocyclus octonarius ≤ 8%, *Actinoptychus senarius* ≤ 1% and sublittoral *Hyalodiscus obsoletus* ≤ 2 %, *Navicula marina* ≤ 4% and *Delphineis surirella* ≤ 7%. Diatom assemblage reflects shallow bay environment with sand floor and climatic condition similar to modern one (Jouze, 1962). Presence of fresh-water species, typical for flowing environments, *Tabellaria flocculosa*, *T. fenestrata*, *Stephanodiscus astrea*, indicates river flow to the bay.

Second unit, represented by peaty silt (0.5–0.6 m), contains mainly fresh-water *Frustulia rhomboides* (≤ 56%), typical for swamps.

Fig. 3 Diatom assemblages of 3 - 4 m marine terrace (N 9-93), South-Kuril Inlet

Upper unit is composed of peat with ash (0.2-0.5 m), containing rare diatoms of different ecology, and peat (0-0.2 m) with marine and fresh-water diatoms. Marine

species are represented by sublittoral north-boreal *Paralia sulcata* $\leq 10\%$, *Diploneis smithii* $\leq 35\%$ and neritic south-boreal *Actinocyclus octonarius* $\leq 13\%$ and *Actinopteryx senarius* $\leq 3\%$. Fresh-water species include coldwater *Pinnularia molaris* $\leq 7\%$, *P. brevicostata* $\leq 2\%$, *P. nobilis* $\leq 7\%$, *P. borealis* $\leq 13\%$ and moderately-warm *P. gibba* $\leq 15\%$. Marine species brought to the terrace surface by swamping during storms.

First unit was formed during second warming of Subboreal, peat-during Subatlantic. ^{14}C -date from peaty silt with ash-layer $1,770 \pm 40$ yrs BP (GIN-7874) (Table 1) shows that the ash is correlated with ash-layer Ma-d of Mashu Volcano, dated about 1,700-1,850 yrs BP, and ash-layer Tokoro II of Eastern Hokkaido coast (Taira, 1980b; Sakagushi *et al.*, 1985). ^{14}C -date from peat above upper ash-layer 510 ± 50 yrs BP (GIN-7873) allows to correlate it with ash-layer Ma-b of Mashu Volcano.

Peat units are characterized by tree pollen zones (Fig. 4). Palynozone *Picea-Abies-Betula* was obtained from peaty silt (unit 2). Conifers (*Abies* 22.5-40%, *Picea* sect. *Omorica* 25.3-26.2%, *P. sect. Eupicea* 13.8-22.7% and *Pinus* n/p *Haploxylon* 2.7-3.6%) are dominant. Fine-leaved trees pollen appear (*Betula* sect. *Albae* 2.7-5.1%, *B. sect. Costatae* 18.5%, *B. exilis* 1.3-7.6% and *Alnus* 2.5%). Pollen of *Corylus* (4%) and *Syringa* (1.3%) are found in the base.

Among herbs Compositae, *Artemisia* and *Sanguisorba* are widespread.

Second zone from peat base is composed of abundant *Myrica* (46.8%), and birch pollen (*Betula* sect. *Costatae* 8.2%, *Betula* sp. 15.2% and *B. exilis* 14.9%). Conifers decrease (*Abies* 5.5%, *Picea* sect. *Omorica* 5.8%). The assemblage reflects wet environments and development of birch-shrub vegetation on drainage coast. The peat was formed during Subatlantic cooling, corresponding to Kofun cold stage of Japan Islands (Sakaguchi, 1983).

Coniferous pollen increase in peat top (0-0.3 m): *Abies* 12.8-16.4%, *Picea* sect. *Omorica* 18.9-32.2%, *P. sect. Eupicea* 5.9-9.8% and *Pinus* n/p *Haploxylon* 1.5-2.2%. Among fine-leaved tree pollen, birch are dominant (*Betula*

Fig. 4 Pollen diagram of 3 - 4 m marine terrace (N 9-93), South-Kuril Inlet

sect. *Costatae* 17.9–18.3%, *B. sect. Albae* 2.6–5%, *B. exilis* 2.5–12.8% and *B. middendorffii* 2–3.2%), *Alnus* (1.8–6.3%), *Alnaster* (0.9%) and *Myrica* (3.6%), appear. Broad-leaved trees are represented by *Quercus* (7.3%), *Ulmus* (6.6%) and *Corylus* (0.3–0.9%). The assemblage reflects moderately warm condition and progress cooling. Dark-coniferous forests with birch, some broad-leaved trees and swamps developed in the isthmus. Among herb Gramineae ($\leq 26.2\%$), Compositae ($\leq 19\%$), *Sanguisorba* ($\leq 23.8\%$), *Thalictrum* ($\leq 9.5\%$) and Umbelliferae (7.1%) dominate. *Sphagnum* is dominant among spores (71.4%).

The terrace section was studied in Sernovodsky Isthmus, section 5732 (from top to bottom) :

Thickness, m	
1. Derno-soil with sand	0.15
2. Dark-grey, peaty sand	0.15
3. Peat with ironing ash-layer	0.40
4. Blue-grey, different-size, poor-sorting sand with abundance of pumice and water plant	0.25
5. Grey coarser silty sand with small pumice	0.15
- The deposits are divided into two units.

Lower unit (0.6–1.4 m) contains rich marine diatom complex (Fig. 5). Boreal neritic *Odontella aurita* $\leq 7\%$, *Rhabdonema arcuatum* $\leq 2\%$ and sublittoral *Cocconeis scutellum* $\leq 8\%$, *Paralia sulcata* $\leq 8\%$, *Delphineis surirella* $\leq 16\%$ and *Trachyneis aspera* $\leq 2\%$ are dominant in the base (1.0–1.4 m), whereas in the top-south-boreal neritic *Actinocyclus octonarius* $\leq 18\%$, *Actinopterychus senarius* $\leq 3\%$ and some oceanic *Coscinodiscus perforatus* and *C. oculus-iridis*. Brackish *Amphora proteus*, *Melosira juergensii*, *Navicula tuscule*, *N. peregrina* and fresh-water, typical for flowing regime, *Achnanthes lanceolata* $\leq 18\%$, *Fragilaria construens* var. *subsalina* $\leq 30\%$, *F. construens* var. *venter* $\leq 27\%$, *Opephora martyi* $\leq 10\%$ and *Stephanodiscus astra* $\leq 13\%$ appear. Diatom assemblage indicates warm condition, high sea level in this period and existence of shallow open bay near river mouth. ^{14}C -date from overlaid peat $2,220 \pm 80$ yrs BP (GIN-7895) allows to relate formation of the unit to second warming of Subboreal. The pumice is correlated with Komagatake Volcano product Ko-f of Hokkaido Island, erupted about 3,000yrs BP (Taira, 1980b; Arai et al., 1986; Machida and Arai, 1992). Clay minerals from marine deposits entail smectite (41%),

Fig. 7 Diatom assemblages of 5 – 6 m marine terrace (N 5706), Kosmodemianskaya Inlet

illite (35%), kaolinite with chlorite (24%).

The main source was surface wash.

Upper peat unit (0.1–0.6 m) contains freshwater cold diatom complex, typical for sublittoral lake zone. *Aulacosira granulata* $\leq 30\%$, *Stephanodiscus astraia* $\leq 8\%$. *Pinnularia gibba* $\leq 3\%$, *P. brevicostata* $\leq 12\%$, *P. viridis* $\leq 7\%$, *P. borealis* $\leq 18\%$ and *Hantzschia amphioxys* $\leq 9\%$ are dominant. Reobiont *Ceratoneis arcus* $\leq 5\%$ reflects river influence on lacustric flora. The unit was formed during Subatlantic (^{14}C -date $2,220 \pm 80$ yrs BP, GIN-7895). Ash-layer is correlated with ash Ma-d of Mashu Volcano.

Three pollen assemblages were obtained (Fig. 6). Marine unit contains both conifers (*Abies* $\leq 42.3\%$ and *Picea* sect. *Omorica* $\leq 23.5\%$) and broad-leaved tree pollen (*Quercus* 13.2–18.8%, *Juglans* 2.8–3.8%, *Tilia* 1.9%, *Corylus* 2.6% and *Phellodendron*). *Alnus* (10.8–13.6%) and *Salix* ($\leq 2.6\%$) appear. The assemblage reflects development of mixed coniferous-broad-leaved forests and alder groves on the coasts and coniferous forests on the mountains. The relationship between *Abies* and *Picea* is *Abies* $>$ *Picea*, that indicates climate warmer than the present, correlated with Yayoi warm stage (Sakaguchi, 1983; Sakaguchi and Okumura, 1986).

Second assemblage (0.3–0.55 m) differs by high spore contents ($\leq 69.1\%$), tree pollen

range from 30.1 to 41.1%. Among spores, Polypodiaceae is dominant ($\leq 99.7\%$), in the base-*Sphagnum* (92.6%). Among tree pollen, conifers (*Abies* 23.7–38.6%, *Picea* sect. *Omorica* $\leq 52.3\%$, *P. sect. Eupicea* $\leq 11.8\%$ and *Pinus* n/p *Haploxylon* to 5.4%) are dominant. Birch (*Betula* sect. *Costatae* 8.0%, *Betula* sp. 1.5%, *B. exilis* 2.3–5.2%), *Alnus* (4.3%) and *Alnaster* (3.2%) appear. Broad-leaved trees are represented by *Quercus* (7.1–11.7%). Among herbs, Gramineae ($\leq 36.6\%$), Compositae (7.3%), *Artemisia*, Ranunculaceae (11%) and *Sanguisorba* (25.6%) predominate. The assemblage corresponds to *Picea-Abies-Quercus* zone.

Increasing of fir, shrub birch and *Alnaster* pollen from peat, overlaid ash-layer, reflects cooling about 1,700–1,850 yrs BP. Increasing of *Abies* and *Quercus* pollen in upper part of the peat reflects Subatlantic warming, correlated with Nara-Heian-Kamakura warm stage of Japan Islands (Sakaguchi, 1983; Private Communication from Sakaguchi and Olsen).

Third pollen assemblage from peat top corresponds to *Picea-Abies* pollen zone. Conifers (*Abies* 37.1%, *Picea* sect. *Omorica* 24.7%, *P. sect. Eupicea* 22.4% and *Pinus* n/p *Haploxylon* 6.5%) are dominant. *Betula* sect. *Costatae* 2.4%, *Betula* sp. 1.8%, *B. exilis* 1.4%, *Alnus* (2.4%) and *Salix* (1.8%) are present.

Fig. 8 Pollen diagram of 5 ± 6 m marine terrace (N 5706), Kosmodemianskaya Inlet

The assemblage reflects development of dark-coniferous forests with birches and climate similar to the present. Appearance of *Potamogeton* pollen (2.9–10.7%) indicates nearness of the lake.

Marine terrace (5–6 m elevation) was found in some inlets (Kosmodemianskaya, Pervukhina, Golovnina and Lesnaya River mouth). The terrace section in Kosmodemianskaya Inlet exposes storm ridges, covered lacustric deposits (Fig. 7), section 5706 (from top to bottom):

	Thickness, m
1. Brown-grey, humus, fine, well sorting sand	0.35
2. Ash-layer.....	0.01
3. Dark-brown, fine, well-sorting sand, horizontal laminated.....	1.05
4. Ash-layer.....	0.05
5. Grey fine well-sorting sand, horizontal laminated, with concretions at plant remains	1.00
6. Pebbles and boulders with ironing coarser sand	1.80
7. Peaty silt with thin lamination and sandy silt layers	0.25
8. Blue-grey silt with ironing spots and plant remains	0.20
9. Dark-grey silt with black silt and grey sand layers with wood and plant remains	0.30
10. Interbedding of blue-grey sand, grey and peaty silts with coarser sand and gravel in the bed	0.35
11. Interbedding dark-grey and peaty silts with sandy lenses	0.55
12. Dark-grey coarser sand with gravel and pebbles	0.15

The section exposes eolian (layers 1 and 3), beach (layers 5 and 6), swamp (layer 7), lacustric (layers 8–11) and alluvial (layer 12) units.

Two diatom assemblages were divided (Fig. 7). Moderately-warm, fresh-water species occurs abundantly in lower part of the section (4.5–5.8 m): *Aulacosira granulata* $\leq 25\%$, *Epithemia zebra* $\leq 18\%$, *E. turgida* $\leq 10\%$, and moderately-cold *Cocconeis placentula* $\leq 25\%$. Some brackish species (*Nitzschia circumscuta*

$\leq 2\%$ and *Navicula peregrina* $\leq 5\%$) and rare sublittoral mezogalob *Cocconeis scutellum*, *Diplo-nis smithii* appear too. Diatom assemblage reflects sedimentation in coastal fresh-water lake with small entering of sea waters and pH 5.5–6.2. The deposits were formed during Holocene Optimum, that suggested by ^{14}C -dates of wood $5,920 \pm 50$ yrs BP (GIN-7898) and peat $5,750 \pm 70$ yrs BP (GIN-7891) (Table 1), correlated to Early Jomon of Japan Islands (Sakaguchi, 1983).

Fresh-water cold *Pinnularia brevicostata* $\leq 5\%$, *P. divergentissima* $\leq 12\%$, *P. viridis* $\leq 12\%$, *P. nobilis* $\leq 5\%$, *P. borealis* $\leq 8\%$, *Eunotia valida* $\leq 7\%$, *E. praerupta* $\leq 11\%$ and *Hantzschia amphioxys* $\leq 12\%$ are dominant in second assemblage (4.3–4.5 m), indicating swamp environment with ∂I of 4.7. The deposits were formed during cooling and regression at Atlantic-Subboreal boundary. ^{14}C -date from peat top is $4,570 \pm 70$ yrs BP (GIN-7889). This regression corresponds to Kemigawa regression of Tokyo Bay, the middle Jomon minor regression and the Middle/Late Jomon cold stage (Ota *et al.*, 1982; Sakaguchi, 1983; Sakaguchi *et al.*, 1985).

Pollen of trees ($\leq 78.6\%$) dominate in lacustric deposits, herb pollen is 1.5–13.5%, spores 7.8–36.6% (Fig. 8). Conifers (*Abies* 12.4–24.8%, *Picea* sect. *Omorica* 4.1–17.5%, *Picea* sect. *Eupicea* 3.6–10.8% and *Pinus* n/p *Haploxylon* 6.7–25.7%) and broad-leaved trees pollen (*Juglans* 4.3–22.1%, *Quercus* 7.4–19.3%, *Ulmus* $\leq 6.5\%$, *Carpinus*, *Corylus*, *Phellodendron* and *Tilia*) are dominant. The relationship of *Abies* > *Picea* is seen throughout all samples. Contents of fine-leaved trees pollen (*Betula* sect. *Albae* 1.3–8.3%, *B.* sect. *Costatae* 0.3–9.5% and *Alnus* 0.3–11.7%) are low. Pollen assemblage reflects development of mixed coniferous broad-leaved forests and warmest climate during Holocene Optimum. *Alnus* increases in the horizon with ^{14}C -date GIN-7898, that shows weak cooling during Atlantic and small lowering of sea level, drainage of the coasts and development of *Alnus* groves on coastal plain.

Pollen assemblage from buried soil on the ancient storm ridge is characterised by high

Fig. 9 Diatom assemblages of 5 – 6 m marine terrace (N 5705), Kosmodemianskaya Inlet

Fig. 10 Pollen diagram of 5 – 6 m marine terrace (N 5705), Kosmodemianskaya Inlet

Fig. 11 Diatom assemblages of 5 ± 6 m marine terrace (N 18-93), Lesnaya River Mouth

contents of broad-leaved trees pollen (*Quercus* 19.3%, *Juglans* 22.1%, *Ulmus* 1.7% and *Phe-llodendron* 0.6%). Among conifers, *Abies* (23.5%) predominates. The assemblage indicates vegetation of temperate zone, climate warmer than the present and corresponds to Early Subboreal warm stage, correlated to First Late Jomon warm stage (Sakaguchi, 1983).

Heavy mineral composition reflects facies changes. Ilmenite ($\leq 72\%$) and pyroxenes ($\leq 40\%$) are dominant in lacustric deposits. Magnetite contents are less than 3%. They increase in top of peat, their source seems to be eolian entrance. Beach sands are characterized by the dominate of magnetite ($\leq 49\%$ of sand and 80% of silt fractions). Pyroxenes ($\leq 58\%$) and magnetite ($\leq 30\%$) are main minerals of eolian sands. Leucoxene, zircon, apatite and Fe hydroxides appear in all samples, but are in small present ($\leq 2\%$). Clay minerals are represented by smectite (31–45%), illite (28–43%) and chlorite > kaolinite (16–32%). Smectite entered due to alluvium. In modern river sediments smectite reaches to 78%. Illite contents increase in peat. Zeolites appear in all section deposits.

Younger lacustric deposits are exposed in the same terrace (5705) (Fig. 2). The diatom diagram is divided into four parts (Fig. 9). Lower deposits (3.4–3.8 m) are characterized by diatom complex similar to Atlantic lacustric assemblage of 5706. The deposits of 2.75–3.6 m have some river and swamp diatoms. The deposits accumulated during Atlantic–Subboreal boundary regression. The sea level lowering led to erosion and destruction of the barrier form. The lake was drained and swamp developed. The swamp-lacustric deposits (2.4–2.75 m) contain cold freshwater diatoms: *Aulacosira granulata* $\leq 20\%$, *Synedra ulna* $\leq 4\%$ and sublittoral benthos *Cocconeis placentula* $\leq 30\%$, *Pinnularia gibba*, *P. viridis*, *P. brevicostata*, *P. nobilis*, *P. viridis* var. *sudetica*, *Eunotia praerupta* and *Hantzschia amphioxys*. High contents of rheophilous species $\leq 25\%$ (*Achnanthes lanceolata*, *A. lanceolata* var. *capitata*, *A. minutissima* and *Diatoma vulgare*) show intensive river influence. The pH of the deposits is 5.1. The peat top (1.1–

1.85 m) includes cold water swamp *Hantzschia amphioxys*, *Eunotia praerupta*, *E. arcus*, *E. praerupta* var. *bidens* and sublittoral benthos species of *Pinnularia* genus. Decreasing of rheophilous species shows that there was no river influence. The pH of peat is 5.2–5.8.

The samples are divided into five pollen zones (Fig. 10). Pollen zone *Abies–Pinus–Quercus–Juglans* (3.6–4.1 m) is similar to Atlantic lacustric deposits of 5706: tree pollen reach ≤ 70.2 –77.9%, herb $\leq 10.1\%$, spores ≤ 10.4 –17.3%. Conifers (*Abies* 28.2–30.4%, *Picea* sect. *Omorica* 17.2–18%, *P.* sect. *Eupicea* $\leq 11.6\%$ and *Pinus* s/p *Haploxylon* 16.3–26.8%) are dominant. Broad-leaved trees (*Juglans* $\leq 11.7\%$, *Quercus* $\leq 12\%$, *Ulmus* 4.2%, *Corylus* 0.8%) are abundant. Fine-leaved trees are represented by *Betula* sect. *Costatae* 0.3–0.4%, *B.* sect. *Albae* 1.2–4.2% and *Alnus* 0.9%.

Pollen zone *Betula–Alnaster* (2.6–3.6 m) is characterised by high spore content (25–60%). *Alnaster* (47.7–80%) is dominant birch pollen contents and variety increase, shrub birch appear (*Betula* sect. *Albae* $\leq 18.2\%$, *B.* sect. *Costatae* $\leq 5.4\%$, *B. exilis* $\leq 12.5\%$, *B. Middendorffii* $\leq 10.8\%$ and *B. sp.* $\leq 10.5\%$). Conifers does not exceed 6%. Pollen zone reflects climate cooler than the present at Atlantic–Subboreal boundary, sea level lowering and development of *Alnaster* groves on river valleys and coastal plain.

Pollen zone *Picea–Abies–Pinus* (2.05–2.6 m) is dominated by conifers–*Abies* ($\leq 39.2\%$), *Picea* sect. *Omorica* (26–29%), *P.* sect. *Eupicea* ($\leq 10\%$), *Pinus* n/p *Haploxylon* (18.2–36.6%). Broad-leaved trees appear (*Juglans* $\leq 11.7\%$, *Quercus* $\leq 8.4\%$ and *Ulmus* $\leq 2.1\%$). Apparently, pollen assemblage indicates first warm stage of Subboreal.

Pollen zone *Picea–Abies–Pinus* (1.1–2.05 m) entails trees pollen ($\leq 63\%$), herb ($\leq 18\%$) and spores ($\leq 44\%$). Among trees, conifers are dominant: *Abies* (6.2–17%), *Picea* sect. *Omorica* (9–17.9%), *P.* sect. *Eupicea* (8.4–30.7%) and *Pinus* n/p *Haploxylon* (25–60.6%). Fine-leaved trees are represented by *Betula* sect. *Albae* 1.2–2.7%, *B.* sect. *Costatae* 1.2–2.7% and *B. sp.* $\leq 2.4\%$. Broad-leaved trees are only sporadic and few in number (*Juglans*

$\leq 1.2\%$, *Quercus* 0.3%, *Ulmus* 2.3% and *Tilia* 0.6%). The relationship between *Abies* and *Picea* is *Abies* < *Picea*.

Pollen zone *Picea*, obtained from eolian deposits, is composed mainly of *Picea* (*Picea* sect. *Eupicea* 39% and *P.* sect. *Omorica* 12.9%) accompanied by other conifers (*Abies* 15.5%, and *Pinus* n/p *Haploxylon* 27.7%) and some fine-broad trees pollen. The pollen zone indicates that the vegetation of the northern part of temperate zone and the climate been similar to the present.

Clay minerals of lacustric deposits of this section contain higher contents of illite, reaching a maximum of 54% in peat layers. Smectite contents ($\leq 43\%$) increase in the units, formed under active river influence.

Ash-layers, located in eolian sands, are composed mainly by pumice colourless glass shards, clinopyroxenes ($\leq 52.7\%$) and Yorthopyroxenes ($\leq 23.9\%$). They are correlated to ash-layers Ma-b and Ma-d of Mashu Volcano (Arai et al., 1986; Machida and Arai, 1992).

5-6 m marine terrace was studied in detail in 250 m from Lesnaya River mouth. The section 18-93 exposes (from top to bottom):

Thickness, m

1. Soil0.07
2. Interbadding of peaty silt and sand with two ash-layers0.13
3. Dark-grey humus coarser sand0.20
4. Dark-brown ironing silt, fine laminated0.26
5. Grey well-sorting sand0.07
6. Dark-blue silt, fine laminated with clay layers with ironing bed0.17
7. Peaty silt, fine laminated with vertical ironing of plant remains0.60
8. Pink-brown silt, fine laminated, with vertical Fe-hydroxides concretions of plant remains0.20
9. Grey, dark-blue, grey-green silts, fine laminated with plant remains and Fe_2O_3 concretions0.22
10. Peaty silt0.02

11. Ash-layer with ironing layers on the contacts0.01
12. Grey different size sand with peaty lenses, debris, ironing spots, and plant remains0.28
13. Light-grey, different size, silty sand, fine laminated with gravel and plant remains0.47

Two units were divided by diatom complexes (Fig. 11). Lower unit (0.76-2.7 m) deposited in moderately-cold lake, that is suggested by rich fresh-water diatom assemblage with dominant of *Eunotia exigua* $\leq 35\%$, *E. valida* $\leq 8\%$, *E. tenella* $\leq 14\%$ and *Pinnularia interrupta* $\leq 33\%$. The pH of deposits ranges from 4.9 to 5.5.

Upper unit (0.2-0.76 m) contains more coldwater diatom complex: *Aulacosira granulata* $\leq 45\%$, *Pinnularia borealis* $\leq 25\%$, *P. brevicostata* $\leq 6\%$, *Eunotia praerupta* $\leq 18\%$, *E. praerupta* var. *bidens* $\leq 4\%$ and *Hantzschia amphioxys* $\leq 7\%$. Moderately-warm *Stephanodiscus astraea* $\leq 20\%$ and *Rhopalodia gibberula* $\leq 5\%$, typical for flowing waters, appear too. Diatom assemblage indicates swamping of the lake, existed to Subboreal.

Important fact is the presence of marine diatoms *Cocconeis scutellum*, *Diploneis smithii*, *Thalassiosara excentrica*, *Thalassionema nitzschoides* and *Coscinodiscus perforatus* in the all sections and reach a maximum in horizon 0.2-0.4 m. Marine diatoms entered into the coastal lake during storms and indicate higher sea level position than modern.

The lake was formed in Atlantic under high sea level standing due to formation of large barrier form in river mouth. The barrier form boulder deposits are exposed down-stream. Lacustric deposits were dated by ^{14}C as $6,070 \pm 70$ yrs BP (GIN-7877), $5,890 \pm 130$ yrs BP (GIN-7878) and $5,450 \pm 150$ yrs BP (GIN-7879) (Table 1). ^{14}C -date $4,310 \pm 70$ yrs BP (GIN-7876) from peaty silt, overlaid lower ash-layer is rejuvenated. ^{14}C -date from upper part are $4,100 \pm 70$ yrs BP (GIN-7871) and $4,010 \pm 70$ yrs BP (GIN-7880) show that the lake was existed to first warm stage of Subboreal.

Five pollen assemblages were divided. The

deposits of the base (1.8–2.7 m) contain mixed pollen assemblage: conifers (*Abies*, *Picea* sect. *Omorica*, *P.* sect. *Eupicea*, *Larix* and *Pinus* n/p *Haploxylon*), fine-leaved trees (*Betula* sect. *Albae*, *B.* sect. *Costatae*, *B.* sp., *B. exilis*, *Alnus* and *Alnaster*) and broad-leaved trees (*Quercus*, *Juglans*, *Ulmus* and *Phellodendron*), reflecting development of mixed forests in Atlantic.

Second pollen assemblages (0.9–1.8 m) are characterised by increasing of birch pollen (*Betula* sect. *Albae* and *B.* sect. *Costatae*) with conifers (*Abies*, *Picea* sect. *Eupicea*, *P.* sect. *Omorica*), and broad-leaved (*Quercus*, *Phellodendron* and *Corylus*) and some fine-leaved trees (*Alnus*).

In third assemblage, recorded in the top of Atlantic lacustric deposits (0.7–0.9 m), broad-leaved trees pollen predominate (*Quercus* $\leq$ 32%, *Juglans* 9.6%, *Phellodendron* 1% and *Ulmus* 1.3%), accompanied by fine-leaved trees (*Betula* sect. *Albae* 9.9%, *B.* sect. *Costatae* 16%, *Betula* sp. 4.2%, and *Alnus* 19.2%). Conifers pollen rapidly decrease (*Abies* 3.2%, *Picea* sect. *Omorica* 1.9% and *P.* sect. *Eupicea* 0.3%). The assemblage reflects development of broad-leaved with birches forests on the coasts, *Alnus* groves in river valleys and conifers forests on the mountains. The paleovegetation was similar to present oak-birch forests of south part of the island (Grabkov *et al.*, 1989).

Conifers, birches and *Quercus* are dominant in fourth pollen assemblage, obtained from Subboreal lacustric deposits (0.2–0.7 m). Conifers increase in the upper part. The paleoclimate in first warm stage of Subboreal was warmer than today.

Fifth pollen assemblages from top of the terrace (0–0.2 m) are composed mainly of conifers (*Abies* $\leq$ 9.6%, *P.* sect. *Omorica* $\leq$ 41.3%, *Picea* sect. *Eupicea* 0.8% and *Pinus* n/p *Haploxylon* 16.5%), accompanied by birch pollen (*Betula* sect. *Albae* and *B.* sect. *Costatae*), *Alnus* and *Alnaster*. It is suggested that the paleovegetation was similar to modern dark-conifer forests with some birches. The climate was similar to the modern. Presence of two ash-layers allows to relate the deposits to Subatlantic.

Ash-layer from lower part of the section is

correlated to the Ma-f ash of Mashu Volcano, erupted about 7,190–6,460 yrs BP (Taira, 1980b; Arai *et al.*, 1986; Machida and Arai, 1992). Age of the ash-layer in this section was calculated about 6,420 yrs BP, assuming rate of sedimentation about 1 mm/y. The ash-layers from terrace top (0–0.2 m) are correlated to the Ma-d ash and the Ma-b ash of Mashu Volcano.

Clay minerals are composed from smectite ($\leq$ 78%) and kaolinite > chlorite (22–35%). Kaolinite with chlorite contents increase in the base of lacustric unit (to 55%) and peaty silts ($\leq$ 61%). Apparently, kaolinization of aluminosilicates took place under influence of low temperature sulphate-waters of Lesnaya River.

Kisliy Stream from Mendelev Volcano, flowing into Lesnaya River, has acid water (pH less than 3.2). Illite appears in deposits with maximum contents of marine diatoms (45%). Pyroxenes ($\leq$ 80%) predominate in lacustric deposits, magnetite ($\leq$ 22%) in the top of section.

III Discussion and concluding remarks

Low marine terrace sequence of Kunashiri Island includes Atlantic, Subboreal and Subatlantic terraces, covered by dunes, reflected sea level oscillations during Middle-Late Holocene.

At the beginning of the Atlantic the land-bridge between Kunashiri and Hokkaido Islands was destroyed. In this time the sea level was about 25 m lower than the present (Ota *et al.*, 1982; Sakaguchi *et al.*, 1985; Korotky and Khudyakov, 1990). Intensive rise of the sea level to +2.5–3 m led to formation of the straits on the place of Serenovodsky and Kruglovsky Isthmuses. There were a large open bay on Pacific side and a large lagoon on Okhotsk Sea side of South-Kurile Isthmus. Active abrasion caused entrance of large volume of detrital material into coastal zone. Large barrier forms and separated numerous coastal lakes, were formed. Some of these lakes exist today (Aliger, Lagunnoe Lake etc.), some-only to Subboreal (paleolake near Lesnaya River mouth), some-only in Atlantic (paleolake in Kosmodemyanskaya Inlet). The section of Atlantic terrace

(5–6 m elevation) was first found on the South Kurile. The sections expose storm ridge deposits, covered lacustric silts and peat. Pollen and diatom fossil and ^{14}C -dates (5,450–6,070 yrs BP) correspond to Holocene Optimum. The deposits record weak cooling during Atlantic, dated about $5,750 \pm 70$ yrs BP (GIN-7891), that correlated to small oscillation about 5,630 yrs BP of the Holocene fluctuations curve of Japan Sea level (Korotky *et al.*, 1994). Mixed conifer-broad-leaved forests were widespread on the island, that shows warmer climate than the present. This warm climatic stage in Kunashiri Island is well correlated to Early Jomon warmest stage in Japan, accompanied by transgression. Possibly, the warming in Atlantic in Kunashiri Island was intensified by influence of warm marine currents at 5,900–4,700 yrs BP (Taira, 1992).

A minor regression took place during Atlantic-Subboreal cooling, correlated to Middle Jomon regression in Japan (Ota *et al.*, 1982; Sakaguchi, 1983; Sakaguchi *et al.*, 1985). Drainage of inshore zone led to development of large dunes (to 20 m height) due to supply of sand material from nearshore zone. Narrow landbridges were formed within Sernovodsky and Kruglovsky Isthmuses. This event was dated by ^{14}C as $4,660 \pm 15$ yrs BP (GIN-7264).

Subboreal deposits record two high sea level positions: about 4,010–3,400 yrs BP (GIN-7879), 7,038 and 2,950–2,620 yrs BP (GIN-7879, GIN-7892), correspond to Late Jomon retransgression (Funabashi Transgression) of Japan Islands (Sakaguchi, 1983). The transgression led to erosion of the dunes. Large amount of sand entered into coastal zone and wide sand beaches were formed. Fragments of these accumulative forms are wide spread on the Pacific Islands. Probably, this fact explains the opinion, that the Subboreal Transgression was even larger than Atlantic Transgression (Schofield, 1964; Yamazaki, 1983 from Private Communication from Sakaguchi and Olsen). Small estuarine lagoons and inlets developed at that time. Coniferous forests developed on northern parts of the

island, mixed coniferous with some broad-leaved trees - on the central and southern coasts. The climate was warmer than the present and conforms to First and Second Late Jomon warm stages of Japan (Sakaguchi, 1983).

The cooling and ocean level lowering at Subboreal-Subatlantic boundary accompanied by formation of dune fields and swamping of the lagoon coasts ($2,220 \pm 80$ yrs BP, $1,440 \pm 60$ yrs BP (GIN-7895, GIN-7262)). This dune generation is correlated to Kurosuna dune K₃ of Japan. The inlets within sea side of the isthmuses were closed and reduced to the lakes. The cooling of Kunashiri Island conforms to Kofun cold stage and Nakayama Regression of Japan (Sakaguchi, 1983).

Subatlantic terrace (2.5 m) formed during ocean level rise (to 1 m) about 1,170–820 yrs BP, corresponds to Heian Transgression and Nara-Heian-Kamakura warm stage of Japan (Private Communication from Sakaguchi and Olsen). Dunes, correlated with Kurosuna beds K₄, formed during Little Ice Age regression (290 ± 60 yrs BP, GIN-7870), corresponded to Edo regression in Japan (Taira, 1980a; Sakaguchi, 1983). Dark-coniferous forests with some birch occupied almost all territory of the island. The climate and landscapes were similar to the present.

It is supposed, that active tectonic uplift with rate of 2.5–2.8 mm/y of the islands began in Low Pleistocene and continues to present days (Melekestsev *et al.*, 1974). Our data of the low marine terrace study contradict traditional opinion about active tectonic uplift of Kurile Islands in the Holocene (Kulakov, 1973; Melekestev *et al.*, 1974 etc.) and another opinion, supposed, that uplift of the island changed to tectonic downlift within local plats with rate 2 mm/y during second half of the Holocene (Bulgakov, 1994). The high marine terrace sequence (elevation to 100 m) shows that the island area developed under intensive tectonic rise with rate of 0.8–0.9 mm/y during Middle Pleistocene. It was supposed that Holocene marine terrace include terrace sequence of 18–20 m elevation. But correlation of marine

deposits top in the studied terrace sections shows, that the terraces correspond to ocean-level fluctuations of small magnitude of Holocene transgression and indicate their weak tectonic deformation.

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千島列島国後島の完新世海成段丘群

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要 旨

アトランチック, サブボレアル, サブアトランチック段丘を含む国後島の低位海成段丘群は, 中・後期完新世の海水準変動を反映している. 比高 5~6m のアトランチック段丘はストームリッジ堆積物からなり, 湖成シルト層とピート層に覆われる.

この段丘の形成期は, 花粉分析や珪藻分析, ^{14}C 年代測定 (5,450~6,070 yrs BP) によって完新世オプティマムに比定される. この時期の初頭には, 海水準は 25m 程度低下しており, 北国後陸橋は繋がっていたが, その後の急激な海面上昇によって切断された. 海面上昇は最高+2.5~3m に達し, 太平洋側に広い湾が形成され, 南千島地峡のオホーツク海側には大きな潟が出現した. このため, 岸辺では急激な削剝が進行し, 沖合に巨大なバリアーが形成された. 植生は, 現在より温暖な針葉樹広葉樹混生林であった.

アトランチック-サブボレアル移行期には, 小規模な海退があり, 汀線内の河川沿いには比高 20m 程度の砂丘が形成された. セルノボドスキー地峡とクルグロブスキー地峡には小規模な陸橋が再現した. サブボレアル期の比高 2.5m の段丘堆積物からは, 4,010~3,400 yrs BP と 2,950~2,620 yrs BP の 2 回の小海進が認められる. この海進によって前期に形成された砂丘は侵食され, 中南部の海岸沿いに再び小規模な湾と潟が出現した. この時期の植生は現在よりやや温暖な, わずかに広葉樹の混じる針葉樹林である. サブボレアル-サブアトランチック移行期 (2,220~1,170 yrs BP) には寒冷期の到来とともに, 海退が進行し, 砂丘や沼沢地が形成された. サブアトランチック期 (1,170~820 yrs BP) には比高 2.5m の段丘が形成された. この時期の海水準は約+1m であった. その後, 小氷期に入り, 現在の砂丘の形成が行われた.

これらの海成段丘の形成過程から, この地域では少なくとも完新世後半以降, 顕著な構造運動は認められないことが明らかになった.

編集委員会より

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