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GEOLOGY

Reconstruction of Holocene Environmental Changes in North-Western Pacific in Relation to Paleorecord from Shikotan Island

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Abstract—Results of a paleolimnological investigation of a well-dated lake sediment section from Shikotan Island (Southern Kurils) showed that from ca 8.0 to 5.8 cal ka BP a warm and humid period corresponding to middle Holocene optimum took place. Cooling thereafter corresponds to Neoglacial. A reconstructed from ca 0.9 to ca 0.58 cal ka BP warm period can correspond to a Medieval Warm Period. Cooling after 0.58 cal ka BP can be correlated with the LIA. Marine regression stages were identified at ca 6.2–5.9, 5.5–5.1 and 1.07–0.36 cal ka BP. The general chronology of major climatic events of Holocene in the island is in accordance with the climate records from the North Pacific region. Revealed spatial differences in timing and magnitude of the Late Holocene climatic episodes (LIA, MWP) in the region needs further investigations.

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Kuril-Kamchatka and Aleutian Marginal Sea-Island Arc Systems stretches along a zone of intensive seismic and volcanic activity in the north-western Pacific (NWP) (Fig. 1). Neotectonic movements leading to the sea level changes alongside with the climate-born factors play a decisive role in the evolution of the region [1]. Their identification remains one of the most important questions in history of the NWP. The objective of our study is to reconstruct paleoenvironmental history of southern Kuriles based on sediment record from Shikotan Island (SI) and to compare the obtained results with the records available from the adjacent areas in NWP. We investigated biotic proxy (diatoms, chironomids, pollen) that are proven to be the most reliable for qualitative and quantitative paleoreconstructions [2, 3].

The investigated 2.94 m long sediment core spans *ca* 8.0 ka. Interpretation of variations in fossil biological assemblages with regard to their preferences in ecological conditions revealed several phases of paleoclimate, landscape and the lake development during the Holocene on SI (Table 1).

7.9–6.4 cal ka BP. The vegetation corresponded to warm mixed forest [4]. The diatom flora of the lake contained highest in the record abundance of the marine diatoms suggesting water exchange between the lake and the ocean due to a higher than at present sea level. This period corresponds to the warm and dry Holocene Climate Optimum (HCO), which occurred at similar time on the neighbouring Islands [5], at Kamchatka [6] and at Japanese Islands, where the warmer and drier than at present climate was influenced by the warm Tsushima currents [7]. At the Holocene transgression the sea-level rose up to 2.5 to 3 m above present sea level (PSL) [5, 7].

6.4–5.8 cal ka BP. The diatom communities were indicative of shallow lake with abundant water vegetation. Rheophilic and cold stenotherm chironomids

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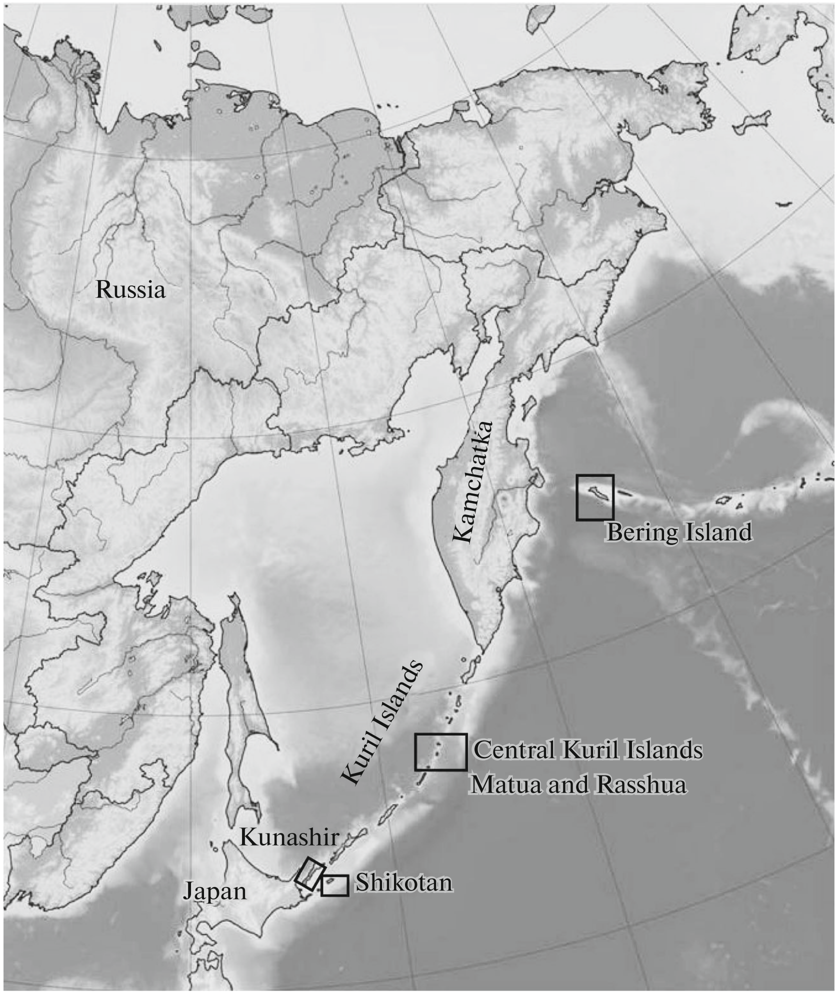

Fig. 1. Study area.

appeared after 6.1 cal ka BP indicating increase of the water flow in response to climate humidification and cooling towards the end of the HCO. The lower than in the previous period sea level corresponds to the end of the Holocene transgression [5].

5.8–5.0 cal ka BP. Cooling, related to Neoglacial, that has been identified in other sites across the NWP and in various Eurasian and North American regions [8–13] lead to changes in vegetation, taxonomic shift in chironomid communities. Diatom flora indicated that connection with the sea was interrupted. This is in accordance with the most significant Middle to Late Holocene or Jomon regression when the sea level was 4–5 m below the PSL [5, 7]. Landslides at this interval could be caused by higher precipitation and strong earthquakes, identified at other sites across the region [1].

5.0–3.5 cal ka BP. Mixed vegetation indicated temperate conditions. The diatom complex is indicative for increasing connection to the sea that caused disappearance of chironomids after 5.14 cal ka BP. This corresponds to the beginning of a low-amplitude transgression at the beginning of the Late Holocene [5, 7, 8]. Deposits of this transgression are well represented in Iturup and Kunashir Islands [4, 5], although on the other islands of the Lesser Kuriles traces of this transgression were not found, presumably due to tectonic reasons. A higher sea level can be correlated the Late Jomon transgression [7] with a sea-level rise of approximately 1.2–2.5 m above PSL. Presence of the tsunamigenic sands can correspond to strong tsunamis identified around *ca* 4.43 and 3.89 cal ka BP at other sites of the region [1].

3.5–2.0 cal ka BP. In the middle of the Late Holocene under the cool climate the area was occupied by fir-spruce forests [4]. An increase of acidophilous diatoms (15–30%) indicated influx of naturally formed coniferous acids in the lake [10] or/and the tephra deposition (2.5 cal ka BP, Tarumai Volcano, Hokkaido) that could alter the chemistry of the lake [6]. Two sand layers correspond to two small tsunamis that took place before the eruption.

Table 1. Results of biological analysis of the core from Shikotan Island and Holocene palaeoclimate stages at Bering island [8], Kamchatka [6, 13–15], Central Kuriles, islands Rasshua and Matua [1, 3, 4], Kunashir, southern Kuriles [5], and Japan [7]. All dates are given as cal ka BP; TR—transgression, RE—regression

Age, cal ka BP	Southern Kuriles (Shikotan)					TR–RE	Bering isl.	Kamchatka	Central Kuriles	Kunashir	Japan Stages
	pollen	diatoms	chironomids	climate	tsunamis						
0.43 to present	Modern coniferous forests strongly dominated by spruce and fir	Benthic taxa dominate	Semi-terrestrial cold stenotherm phytophilic taxa. No chironomids after 0.36	Cool, dry	0.34, 0.106	0.65–0.05 Edo RE	RE after ca 0.65	Cool, wet. No clear MWP	After 1.7 cold, wet: LIA. No clear MWP	After 1.6–1.2 cooling: LIA. No clear MWP	0.65–0.05 LIA
1.07–0.43	2.0–0.43: Coniferous forests. *Lysichiton* increase	Benthic taxa prevail. Planktonic - benthic taxa, flowing water, boggy and warm-water taxa rise	Before 0.89: temperate taxa of standing water. After 0.89: flowing-water taxa rise. After 0.77 only flowing-water taxa	Warm and wet from ca 0.9 to at least 0.58 (MWP)	0.95	1.14–0.65 Heian TR	After 1.7 cool. TR, sea level 2–5 m above PSL				1.14–0.65 warm Nara-Heian-Kamakura
2.0–1.07		Freshwater benthic, subaeral or terrestrial taxa	No chironomids	Cool	2.0	Low-amplitude multiple TRs at ca 5.14–1.14		wetter after 1.5	Cool	Cool	1.9–1.14: cold Kofun. TR
3.5–2.0	5.0–2.0: *Picea*, *Alnus* prevail. Oak decline	Benthic freshwater flora		Wet	3.4, 3.0		Cool. TRs at ca 3.5, 2.9, 1.75	Variable	3.05–1.9: warmer, wet. 5.3–3.05: cool,wet	After 3.8 cool	2.5–1.9: warm Yayoi
											3.5–2.5: Cold Late Jomon
5.8–3.5	Increase of spruce. Decrease of broad-leaved trees	Taxa tolerant to temporary droughts	5.5–5.1: cold stenotherm flowing-, shallow water taxa	Cool, wet. Neoglacial	4.8, 4.7, 4.3, 4.1, 3.99, 3.63. Landslides between 5.8 and 5.6	Middle Jomon RE. Sea level 4–5 m below PSL	5.3–3.5 Cooling, RE	5.2–3.4: Neoglacial. Wet	5.3–4.7 cooling. Wet	4.5–3.8 warm. 5.4–4.5 cooling.	4.7–3.5 warm Late Jomon
											5.1–4.7 cool Middle Jomon
6.4–5.8	Warm mixed forest	Marine and brackish-water diatoms decrease	Meso-euthrophic temperate taxa	Cooler, wetter		6.4–5.9 end of the Middle Holocene TR	Warm HCO. TR	HCO till 5.2, wet	Warm, dry. HCO till 5.3	HCO till 5.7	Early Jomon warm and dry stage till 5.1
7.9–6.4		Brackish-water, oceanic taxa up to 5–8%	No chironomids	Warm, dry	7.4, 7.0, 6.46	TR, 2.5–3 m above PSL					

2.0–1.07 cal ka BP. Cool climatic conditions were favourable for spreading of dark coniferous taiga dominated by spruce. The diatom complex suggested lake desiccation. Fragments of *Coscinodiscus* sp. in a sand layer at 2.0 cal ka BP indicated a tsunami event. At 1.6–1.23 cal ka BP cool conditions coinciding with the slight regression were found as well on Kunashir Island, on Central Kuriles [5] and are well correlated with the beginning of the Kofun cold stage in Japan [7].

1.07–0.4 cal ka BP. Oceanic water did not reach the lake. The gradual increase in abundance of the flowing- and warm water chironomids since 0.89 cal ka BP indicated a stronger water velocity, climate warming and transitions to a Medieval Warm Period (MWP) which could be correlated with a Nara-Heian-Kamakura warm stage. MWP was slight on Kunashir Island and not prominent at Bering and Central, Kamchatka and Central Kuril Islands apart from the island Simushir [4, 5, 8–10].

After 0.4 cal ka BP. The diatom complex is characteristic of rather dry and cold conditions. After 0.36 cal ka BP chironomids disappeared from the lake, apparently due to the lake drying. At 0.34 and 0.106 cal ka BP fragments of oceanic diatoms indicate tsunami events. The deposits of this interval were formed during the Little Ice Age (LIA), which was distinctly pronounced across Kuriles [1, 4, 5, 14], on Japanese Islands [7] and in Kamchatka [9–11, 15].

The investigation of the well dated sediment section of a coastal paleolake and comparison of our data with previous studies showed that the general chronology of major Holocene climatic events in the southern Kuriles is in accordance with the climate records from the NWP region. Revealed spatial differences in timing and magnitude of the Late Holocene climatic episodes (LIA, MWP) within region needs further investigations.

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