ISSN 1028-334X, Doklady Earth Sciences, 2012, Vol. 442, Part 2, pp. 242–246. © Pleiades Publishing, Ltd., 2012.
Original Russian Text © F.A. Romanenko, O.S. Shilova, 2012, published in Doklady Akademii Nauk, 2012, Vol. 442, No. 4, pp. 544–548.

GEOGRAPHY

The Postglacial Uplift of the Karelian Coast of the White Sea according to Radiocarbon and Diatom Analyses of Lacustrine-Boggy Deposits of Kindo Peninsula

F. A. Romanenko and O. S. Shilova

Presented by Academician A.P. Lisitsyn June 16, 2011

Received June 20, 2011

DOI: 10.1134/S1028334X12020079

Beginning with P.A. Kropotkin's works, it was believed that the modern Fennoscandian relief formed mainly during the Late Weichselian Glaciation. In this region, high and nonuniform isostatic uplift rates of the coast [2, 6, 7] and significant evidence of associated seismic events are traditionally noted [1, 13]. However, many events of the geological history of the Karelian Coast and Kandalaksha Coast in the Late Pleistocene and Holocene are still under discussion.

The main objective of our work was to reconstruct in detail the geological history of the formation of the relief of the southern coast of Rugozerskaya Bay and the Great Salma Strait (Karelian Coast of the White Sea) (Fig. 1) in the area of the White Sea Biological Station (WSBS)of Moscow State University.

MATERIALS AND METHODS

During the period of 2003–2006, lacustrine-boggy deposits were drilled with a Hiller peat borer and their geomorphology was studied.

As a result of our work, the bog massifs on the Kindo Peninsula and nearby Kastyan Island were studied for the first time in 19 wells with a total depth of about 40 meters.

The sampled core drill columns were dated using the radiocarbon method in the isotopic laboratories of the Geological Institute, Russian Academy of Sciences, and the Institute of Geography, Russian Academy of Sciences. In total, 35 dates were obtained (table); they were calibrated with the program OxCal 3.10 (Bronk Ramsey, 2005) [14]. In order to trace the vertical distribution of marine sediments and reconstruct the Holocene sea-level changes, the lower layers of lacustrine-boggy and underlying sediments were studied using diatom analysis in six cores. The wellheads were 3–87 m above sea level.

GEOLOGICAL STRUCTURES AND MAJOR CHARACTERISTICS OF RELIEF

The northern part of the Karelian Coast of the White Sea is represented by structural-denudation pediment plains and low hills of up to 120–150 m, with fiord-skerry shores. The isolated rock massif of Mt. Rugozerskaya with the maximum height of 103.8 m covers the greater part of the Kindo Peninsula. The massif is made of garnet, biotite gneisses, and amphibole–plagioclase crystalline schists belonging to the Late Archean White Sea complex, containing amphibolite bodies, dykes of gabbro, gabbro-norites, and pyroxenites of Proterozoic–Paleozoic age [3, 10].

The central part of the massif is a gently undulating exaration–denudation plateau with a height of 70–105 m, formed by subparallel ridges with rounded tops up to 100 m in width. The ridges are separated by deep ravines of 15–25 m deep with a thin (1 m) peat cover. A significant part of the top surface is not covered by sediments. The relative steepness of the mountain slopes, complicated by fault scarps, ranges from 10° to 40°. The grabenlike troughs within this massif comprise rounded depressions 500 m in diameter, occupied by dead lakes with a depth of up to 4 m. The thickness of lacustrine-boggy deposits in these depressions is over 5 m.

At heights of 25–90 m, accumulations of boulders were found on stepped slopes and bottoms of the depressions. As a rule, boulders are well-rounded and sorted by size, which may indicate their coastal–marine genesis.

The massif of Mt. Rugozerskaya is surrounded by a series of subhorizontal and gentle dipping marine terraces, reaching a maximum width at the base of the Kindo Peninsula (the Ershovskie Lakes area). The compound marine terrace with a thickness of 18–26 m

*Faculty of Geography, Moscow State University, Leninskie gory 1, Moscow, 119992 Russia
e-mail: faromanenko@mail.ru*

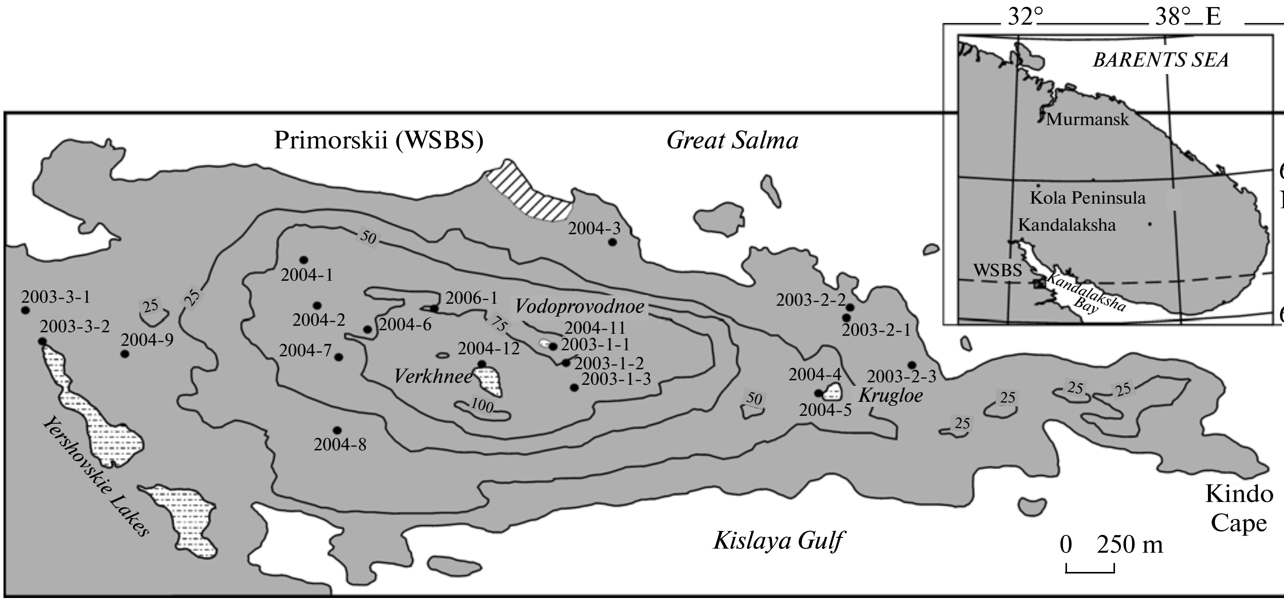

Fig. 1. Hypsometric scheme of Kindo Peninsula and location of the sections of lacustrine-boggy deposits sampled for the radiocarbon age dating. The structure of sections and sampling sites are shown in Fig. 2.

is often adjacent to steep rocky scarps of the fault planes and the sides of the faults, smoothed by abrasion. The terrace sequence is represented by sandy clays with abundant fauna of bivalves, gastropods, brachiopods, foraminifera, and barnacles overlying well-sorted sands [4].

The age of shells corresponds to the Tapes transgression (table). At a height of 14–18 and 8–12 m, fragments of two more levels of marine terraces, composed of pebble–gravel–sandy deposits, can be traced. The first marine terrace is 3–6 m thick, and the modern marine terraces (up to 2 m thick) are separated by visible scarps from each other and from the tidal marshes. The scarps are made of pebble–sandy–clay deposits with boulders and complicated by sickle-shaped ridges up to 3–4 m in height.

STRUCTURE AND RADIOCARBON AGE OF LACUSTRINE-BOGGY DEPOSITS

Peatbogs of the Kindo Peninsula are low-lying and aapa mire complexes. The maximum thickness of lacustrine-boggy deposits is noted in closed depressions of Verkhnee Lake (altitude 87 m), Vodoprovodnoe Lake (72 m), and Krugloe (27.5 m) Lake. The sequence of the deposits is as follows (from top to bottom):

peat 1.5–3.5 m, a sapropel (up to 2.5 m), and sandy with gravel and pebbles or thick silt deposits (Fig. 2).

Towards the sides of the depressions, the thickness of lacustrine-boggy deposits is reduced to 2 m; sapropels disappear; and the substrate is represented by gneiss and amphibolite eluvial deposits. Moreover, peat and (rarely) sapropel fill numerous ravines, open and closed depressions with a relative depth of 2–3 m on the gentle slopes of Mt. Rugozerskaya at a height of 14–75 m above sea level. The sedimentary cover here does not exceed 2.5 m in thickness.

The boggy deposit cover on low (3–6 m) marine terraces is represented by weakly decomposed peat deposits that are altered facially by sandy silt deposits in depressions. The maximum thickness (0.8 m) of the boggy deposits is noted in the vicinity of the Ershovskie Lakes formed at the site of the former strait, which separated the massif of Mt. Rugozerskaya from the mainland shore. Here peat deposits overlie boulder deposits with sandy–gravel–pebble and silt–muddy filling.

COMPOSITION OF DIATOM ASSOCIATIONS IN LACUSTRINE-BOGGY AND UNDERLYING DEPOSITS

Diatom assemblages were studied in six wells (Figs. 1, 2): 2004–12 (87 m asl), 2003–1–1/2004–11 (72 m asl), 2004–2 (64 m asl), 2004–4 (27.5 m asl), 2004–9 (13–14 m asl), and 2004–3–1 (4 m asl). At the bottom of all the studied sections of the Kindo Peninsula, the diatom assemblages in sands and sandy silts underlying lacustrine-boggy deposits contain brackish and marine species. The predominant species in the diatom complex are *Paralia sulcata, Hyalodiscus scoticus, Cocconeis scutellum*, species of the genus *Diploneis* (especially in sandy sediments), *Achnanthes brevipes,* and other species widespread on the desalinated littoral area in modern seas. The bottom of peat and peaty sapropel, as a rule, contains diatom assemblages characterized by a high number of halophilic species. There is a predominance of *Stauroneis anceps,* List of radiocarbon age data for the area of the White Sea Biological Station (WSBS)

Ser. No.	Laboratory number	Number of well, location	Wellhead elevation	Depth, m	Material	Radiocarbon age, years	Calibrated (chronological) age, years
1	GIN-12640	2003-5-1, Kastyan Island	5	0.55–0.70	Peat	160 ± 60	1720–1820
2	GIN-12641			0.70–0.80	The same	460 ± 60	1400–1490
3	GIN-12654	2003-2-3, Vonyuchee Lake (Vonyuchaya Gubka)	3	0.03–0.35	″	220 ± 60	1720–1810
4	GIN-12653	2003-2-2, Vonyuchee Lake (Vonyuchaya Gubka)	3	0.25–0.30	″	270 ± 70	1490–1670
5	GIN-12652	2003-2-1, Vonyuchee Lake (Vonyuchaya Gubka)	5	0.40–0.45	″	390 ± 40	1430–1530 1540–1640
6	GIN-12655	2003-3-1, Ershovskie Lakes	4	0.40–0.50	″	810 ± 40	1205–1270
7	IGAN-3972/GIN-13115	2004-9, Marine terrace to the east of the Ershovskie Lakes	14	2.80–3.00	Sapropel	2100 ± 90	210–10 BC
8	MGU-1473	Section of Paleontological object	20	2.60	Sea shells	5400 ± 60	4340–4080 BC
9	GIN-9062			2.60		7160 ± 90	6230–5840 BC
10	IGAN-3970	2004-5, Krugloe Lake	27.5	3.20–3.45	Sapropel	3000 ± 90	1390–1120 BC
11	GIN-13097	2004-4, Krugloe Lake	27.5	0.30–0.40	Peat	610 ± 60	1280–1430
12	GIN-13098			0.95–1.05	The same	2570 ± 70	810–740 BC
13	GIN-13102			1.75–1.85	″	2990 ± 60	1320–1120 BC
14	GIN-13105			2.20–2.30	Peaty sapropel	3970 ± 40	2570–2460 BC
15	GIN-13106			2.30–2.40	Sapropel	4380 ± 80	3110–2900 BC
16	IGAN-3971	2004-8, southwestern slope of Mt. Rugozerskaya	37	1.70–1.80	Peat	4020 ± 80	2680–2450 BC
17	IGAN-3969/GIN-13094	2004-2, northwestern slope of Mt. Rugozerskaya	64	2.05–2.15	The same	6620 ± 110	5640–5470 BC
18	GIN-13116	2003-1-1/2004-11, Vodoprovodnoe Lake	72	0.50–0.60	″	2310 ± 60	420–200 BC
19	GIN-13117			1.00–1.10	″	2970 ± 70	1310–1180 BC
20	GIN-12626			1.30–1.45	″	3570 ± 70	2030–1870 BC
21	GIN-13118			1.70–1.80	″	4470 ± 70	3360–3000 BC
22	GIN-12627			2.20–2.35	″	3810 ± 90	2350–2130 BC
23	GIN-12628			2.35–2.50	″	4260 ± 90	3020–2840 BC
24	GIN-12629			2.55–2.70	″	3620 ± 90	2140–1880 BC
25	GIN-12630			2.70–2.85	″	4250 ± 80	2930–2670 BC
26	GIN-12632			3.35–3.50	″	5370 ± 70	4330–4070 BC
27	GIN-12633			3.50–3.65	Sapropel	5460 ± 100	4450–4170 BC
28	GIN-13121			3.80–3.90	The same	6670 ± 70	5650–5530 BC
29	GIN-12634			4.05–4.20	″	7170 ± 80	6100–5980 BC
30	IGAN-3973			4.20–4.35	″	7090 ± 80	6050–5890 BC
31	GIN-12635			4.70–4.85	″	8350 ± 60	7500–7350 BC
32	GIN-12637	2003-1-2, Vodoprovodnoe Lake basin	73	1.90–2.00	Peat	6950 ± 70	5900–5740 BC
33	GIN-13783	2006-1, A trough on Mt. Rugozerskaya slope	80	0.80–0.90	Sapropel	2690 ± 60	895–805 BC
34	GIN-13784			0.70–0.80	Peat	3250 ± 40	1620–1430 BC
35	GIN-13124	2004-12, Verkhnee Lake	87	4.45–4.60	Sapropel	7780 ± 110	6760–6460 BC

Note: The table shows the author’s data, except for the data in the 8th row [5], and the 9th row [12]..

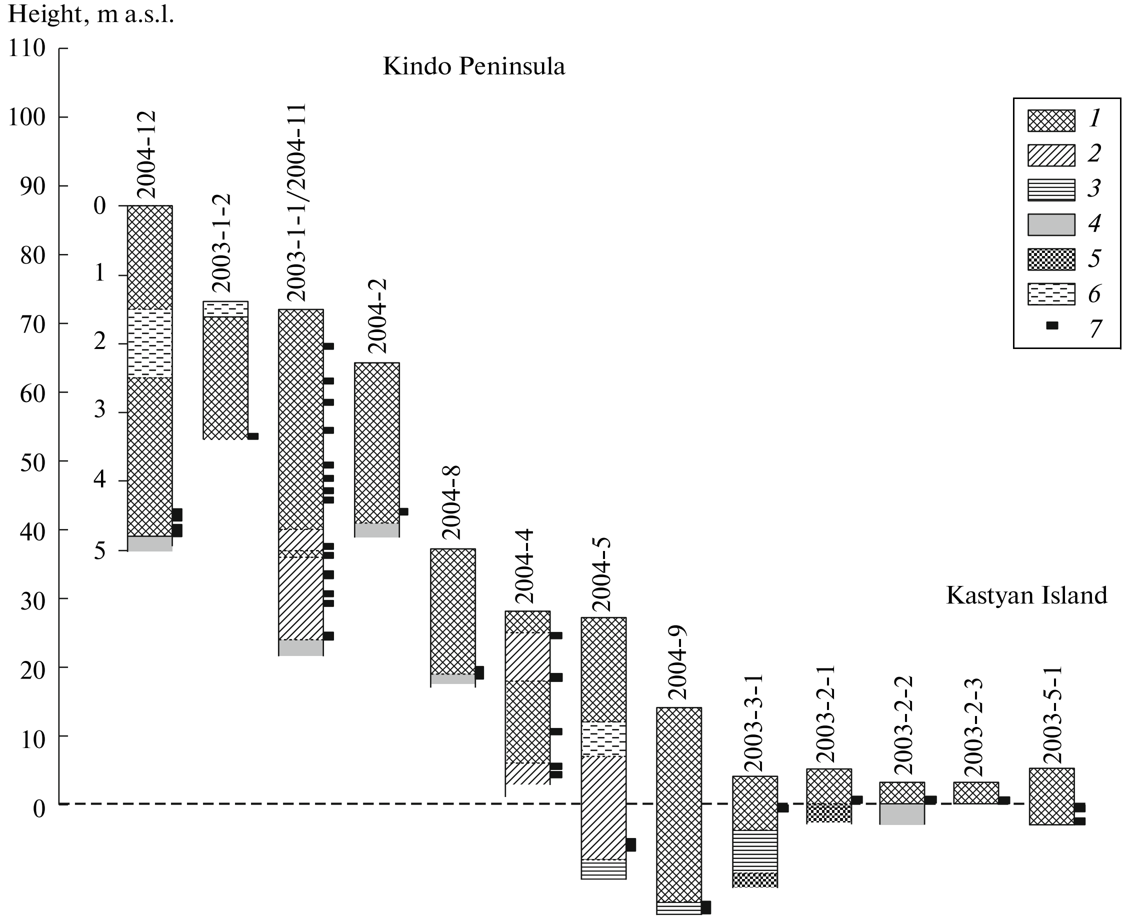

Fig. 2. The structure of lacustrine-boggy deposits of Kindo Peninsula and Kastyan Island (location of the sections is shown in Fig. 1): (*1*) peat, (*2*) sapropel, (*3*) sandy silt, (*4*) boulders, (*6*) water, (*7*) radiocarbon dates.

S. phoenicenteron, Sellaphora pupula, Aneumastus tusculus, and *Anomoeoneis shaerophorum*. In addition, this horizon is characterized by species of the diatom genera *Pinnularia* and *Cymbella* with very large valves. This may be associated with favorable nutritional conditions (the intermediate mineralized soils are enriched in nutrients (mainly silica)) in low-lying boggy biocenoses.

Above the transition horizon, typical lacustrine-boggy diatom assemblages dominate. They are halophobous and indifferent species of the genera *Pinnularia, Eunotia, Brachysira, Frustulia, Cymbopleura*, etc. Thus, diatom assemblages show a gradual change in the marine conditions of sedimentation under lacustrine-boggy conditions.

BASIC TENDENCIES IN HOLOCENE RELIEF DEVELOPMENT

The series of radiocarbon dates obtained and no evidence of a significant break in sedimentation during the transition from the sandy-silt deposits, containing brackish-marine diatom species, to the overlying peat and sapropel deposits allow us to calculate the relative (without considering the eustatic rise in sea level during the Holocene) rates of uplift of the Kindo Peninsula during the last 9500 years (Fig. 3). During the existence of the marine basin in the White Sea depression, the uplift level of the Kindo Peninsula was greater than 90 m. According to our data, the boulder deposits on the Kindo Peninsula spreading up to this height mark are ancient shorelines. For the Early Holocene (9500–5000 years), the rate of uplift is end of estimated to be 9–13 mm/year. At the early stages (the end of Late Weichselian Glaciation period and Early Holocene), it may have been greater. From the Middle Holocene, the uplift was uneven and less intensive, about 5–5.5 mm/year. The rate of uplift slowed down in the Atlantic (the Tapes transgression), then increased in the Subboreal period, and slowed down again in the sub-Atlantic time up to modern uplift rates of about 4 mm/year.

A similar pattern was reconstructed in [6] based on comprehensive study of cores of lacustrine-boggy deposits in adjacent areas (the settlement of Lesozavodsk, about 20–25 km to the north of the Kindo Pen-

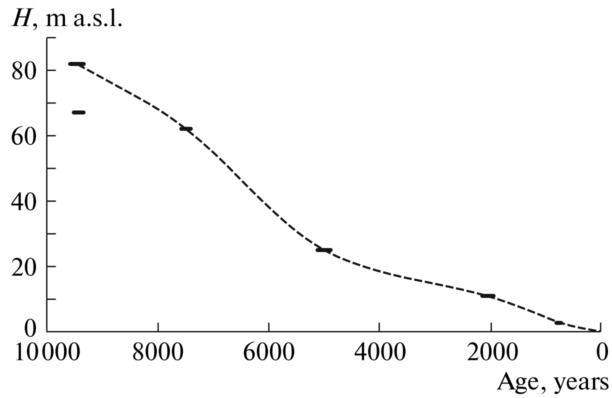

Fig. 3. Location scheme of dated terraces of Kindo Peninsula and the sea level change curve during the Holocene. The abscissa shows the approximate time when Kindo Peninsula was uplifted above sea level.

insula, and the settlement of Chupa, 30 km to south of the Kindo Peninsula). Our data confirm that in the apex part of Kandalaksha Bay, the amplitude of postglacial uplift was greatest on the White Sea coast, up to 150 m or more [7–9, 11].

Such high rates of uplifting in the Holocene could not lead to significant tectonic stresses in the Earth's crust, the discharge of which occurred as a result of earthquakes and activization of faults of different orientation and gravitational processes. In the Kindo Peninsula, these events can be traced in the form of numerous rocky ledges with height of 15–40 m (as an example, in Biofilters Bay) and by terracelike steps on the slopes, deep (up to 2–3 m) fractures and ditches, as well as stone chaos in the marginal parts of the rocky massif formed by heaps of fallen rock blocks.

Thus, the early stages of postglacial development of the relief of the southern coast of Kandalaksha Bay are characterized by the following:

an absence of accumulative forms composed of glacial and water–glacial deposits;

a high rate of uplifting in the first half of the Holocene due to isostatic postglacial uplift and subsequent uneven reduction;

significant tectonic and seismotectonic activity, which led to widespread manifestation of steep slopes, ditches and shrinkage cracks, landslides, and chaotic tumble of seismic and landslide bodies. At the later stages of the relief formation, the role of abrasion and accumulation, the glacial erosion impact on the coastal zone, and biogenic and weathering processes increased.

ACKNOWLEDGMENTS

This work was supported by the Russian Foundation for Basic Research (project nos. 08-05-00932 and 11-05-01044).

We are sincerely grateful to E.I. Ignatov, E.I. Polyakova, and N.V. Shevchenko for useful discussion and assistance in organizing the field work.

REFERENCES

1. I. G. Avenarius, A. D. Vital', and V. V. Frol', in *Theory and Practice Of Complex Marine Researches of Strategic Importance for National Security and Economy of the Russian North* (KNTs RAN, Apatity, 2005), pp. 9–10 [in Russian].
2. A. D. Armand and L. Ya. Samsonova, in *The Principal Problems of Geomorphology and Stratigraphy of the Anthropogene of the Kola Peninsula* (Nauka, Leningrad, 1969), pp. 96–111 [in Russian].
3. *Geology of the USSR. Vol. 37. Karel'skaya ASSR* (Gosgeoltekhizdat, Moscow, 1960), Part 1 [in Russian].
4. I. S. Zyuganova, Vestn. Mosk. Univ., Ser. 4: Geol., (3), 47 (1999).
5. E. I. Ignatov, E. G. Maev, V. I. Myslivets, and N. V. Shevchenko, in *The Main Results of Study of Quarternary Stratigraphy and the Main Research Trends in XXI Century* (St. Petersburg, 1998), pp. 316–317 [in Russian].
6. V. V. Kol'ka, V. Ya. Evzerov, Ya. Meller, and D. V. Korner, in *New Data about Geology and Mineral Resources of the Kola Peninsula* (KNTs RAN, Apatity, 2005) [in Russian].
7. B. I. Koshechkin, *Holocene Tectonics in the Eastern Part of the Baltic Shield* (Nauka, Leningrad, 1979) [in Russian].
8. M. A. Lavrova, *Quarternary Geology of the Kola Peninsula* (AN SSSR, Moscow, 1960) [in Russian].
9. N. I. Nikolaev, *Modern Tectonics and Geodynamics of the Lithosphere* (Nedra, Moscow, 1988) [in Russian].
10. *Early Precambrian of the Baltic Schield*, Ed. by V.A. Glebovitskii, (Nauka, St. Petersburg, 2005) [in Russian].
11. S. A. Strelkov, V. Ya. Evzerov, B. I. Koshechkin, et al., *History of Formation of the Topography and Accummulation of Loose Deposits in the Northeastern Part of the Baltic Schield* (Nauka, Leningrad, 1976) [in Russian].
12. N. V. Shevchenko, Candidate's Dissertation in Geography (MGU, Moscow, 1999).
13. N. V. Shevchenko, D. E. Kuznetsov, and A. A. Ermolov, Vestn. Mosk. Univ., Ser. 5: Geogr., No. 3, 47 (1999).
14. M. Stuiver and P. J. Reimer, Radiocarbon **35**, 215 (1993).