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GEOLOGY

Identification of Marker Horizon in Bottom Sediments of the Onega Periglacial Lake

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Degradation of the Scandinavian late Valdai Glaciation in the Onega Lake depression and on adjacent lowlands resulted in the formation of the large Onega periglacial lake (OPL). Its area, depth, and outflow threshold changed time and again during deglaciation (Fig. 1a). Bottom sediments of the OPL are mainly represented by gray varved clay, more than 7 m thick, deposition of which proceeded from 12.4 to 10.4 ka ago (according to ^{14}C data) [1] (Fig. 1b, 1c). Almost black (shungite-rich), pinkish gray (carbonate), and pinkish brown (varved) clays are also found [2, 3]. Although varved clays are the most informative sediments of periglacial basins and successfully applied in varvometric, paleomagnetic, and palynological methods, the identification of reliable marker horizons is an important component in stratigraphic, geochronological, and paleogeographic investigations, as well as in correlation of sections during a geological survey.

The analysis of the results of sedimentological, geochemical, and geochronological studies of varved clays from the OPL, and their correlation with new and available data on the structure of shore deposits and outflow thresholds, allowed us to distinguish pinkish brown varved clays as a marker (reference) horizon formed as the result of diagenesis of sediments due to a sharp decrease in the water level of the ancient Lake Onega.

The horizon of pinkish brown, pale yellow clays (pink horizon, PH), 10–30 cm thick, was penetrated by nine boreholes within Lake Onega and nine other lakes (previously part of the OPL) at an absolute height of –28 to +80 masl (Fig. 1a–1c) [1–4]. The content of oxides in the PH (Fe_2O_3 2.81–8.03%, FeO 0.36–3.61%, and MnO 0.075–0.12%) are usually 8–20% higher relative to that in the PH-hosting gray varved clays [2–4]. It was inferred previously that this horizon had formed due to glacial water transport of Fe-rich material of Proterozoic hematite-bearing shales from the Onega–Segozero watershed into the Onega Lake depression [2, 3]. However, the subsequent findings of the PH in the spacious OPL area and the study of its structure made it possible to suggest that the PH formation was related to sharp changes in hydrochemical conditions of the OPL, which caused diagenesis of deposited sediments.

The number of annual varves in the PH varies from 40 to 120 (average 90). The PH occurs in all the boreholes at the boundary between distal-type laminated clays and underlying proximal-type varved clays (Figs. 1b, 1c). The number of varves in overlying gray clays reaches 486 and depends, as a rule, on preservation of the varved clay top from erosion [1]. Varves inside the PH and in overlying gray clays are laminated and up to 2–3 mm thick. They are usually composed of two laminae. The thickness of the winter, clayey lamina makes up 3/4 or 4/5 of the entire varve thickness. More sandy laminated varved clays were deposited above the PH during 100–150 yr [4, 5] (Fig. 1b). The thickness of varves in proximal gray and pinkish gray varved clays underlying the PH varies within 5–40 mm (14–21 cm at the base of the sequence). As a rule, the summer, sandy lamina is thicker than the winter, clayey lamina.

The redox potential (*Eh*) was measured in the borehole drilled in the central part of Lake Onega. The Eh value varies from +10 to –10 mV in the PH and from +170 to +175 mV in overlying and underlying clays [4].

Contact between differently colored, varved clay horizons of the OPL, whose original color is inherited from the color of underlying rocks, is usually gradual. The transitional zone (up to 20–50 cm thick) is represented as an alternation of differently colored laminae of overlying and underlying clays. The lower contact of PH is always distinct and sharp but without washout,

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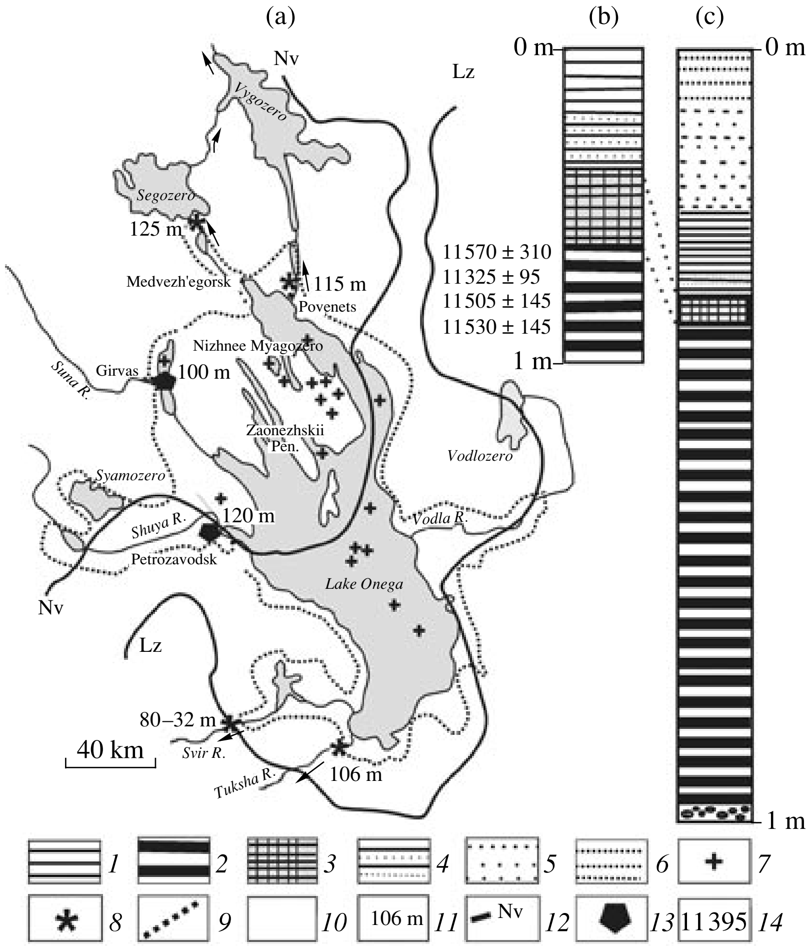

Fig. 1. (a) Location of boreholes that penetrated the pinkish brown horizon of varved clays in the Onega periglacial lake. (b, c) Structure of bottom sediments in Lake Onega. (*1–4*) Varved clays: (*1*) gray laminated distal-type, (*2*) gray proximal-type, (*3*) pinkish brown laminated (pink horizon) (PH), (*4*) sandy laminated; (*5*) homogeneous silt; (*6*) mud; (*7*) location of boreholes that penetrated the PH of varved clays; (*8*) position of ancient outflow thresholds of Lake Onega; (*9*) maximal boundaries of the Onega periglacial lake; (*10*) outflow direction; (*11*) absolute height of outflow thresholds and fluvioglacial deltas; (*12*) inferred positions of the glacier margin during the Luza (Lz, 13 ka ago) and Neva (Nv, 12 ka ago) glaciation stages [10]; (*13*) fluvioglacial deltas; (*14*) absolute age of sediments [1].

whereas the upper contact is gradual. Such contacts are more characteristic of a secondary color acquired after sedimentation and of geochemical barriers, especially in layered sediments.

On the other hand, black shungite-rich and pinkish gray carbonate varved clays up to 1.65 m thick are locally developed on the Onezhskii Peninsula near exposures of relevant bedrocks and moraines developed on them [2, 3]. At the same time, a thin (up to 30 cm) PH is found everywhere in the vast area of Lake Onega (Fig. 1a), although hematite-bearing shales are subordinate on the Onega–Segozero watershed.

Brown or pale yellow clay horizons—similar in structure and thickness, variations of the redox potential, and the content of ferromanganese oxides—were time and again found in pelagic turbidites of the Atlantic Ocean at the Pleistocene/Holocene boundary [6]. Their formation is related to the progressive oxidation front developed at a sharp change of redox conditions in surface layers of sediments, which represent an initially nonequilibrium, unstable physicochemical system. Such sharp changes may be caused by the organic material (OM) input by a turbidite stream, a sharp decrease in the OM deposition rate, or intense inflow of oxygen to bottom water layers [6]. As a result, oxidants (free oxygen or nitrate ion), which oxidize bivalent iron and manganese of sediment, diffuse deep into sediments. On the other hand, bivalent iron and manganese ions concentrated in lower horizons of interstitial water slowly diffuse upward. The oxidation front advances downward until equilibrium between the upper horizon of oxic interstitial water and the slightly reductive lower horizon. The transition from the oxic interstitial water to the reductive interstitial water is very abrupt. Consequently, the thin horizon of sediments is enriched in Fe and Mn, as well as in Ni and Co in some places [6]. Although the formation of metalliferous pale yellow horizons in the Atlantic remains to be studied, it is evident that a sharp change in redox conditions at the water/sediment boundary provokes diagenesis of sediments.

What events could sharply change hydrochemical conditions at the OPL bottom? Under cold conditions of the late glacial period, the lake was covered with drift ice for the majority of the year and was constantly supplied with the oxygen-poor glacial water. Bottom water horizons were depleted in oxygen, because water exchange and contact with the atmosphere were hampered. A significant quantity of iron (including the bivalent variety) entered the basin with sandy–clayey fractions from the Onezhskii Peninsula dominated by gabbro-dolerites. The sedimentation rate varied from 5 to 40 mm/yr. The varved clay was deposited in a low-alkaline (pH 6.95–7.95) and weakly oxidizing (*Eh* from +55 to +175 mV) environment [4].

The glacier margin retreated from the Onega–White Sea watershed in the late Allerød, and the OPL acquired a new, lower outflow threshold to the northern White Sea depression. Saarnisto [7] studied bottom sediments of small lakes at the outflow threshold on the Onega–Vygozero watershed and concluded that this event took place about 11 ka ago. The OPL material was transported via the present-day White Sea–Baltic Sea channel and the Kumsin–Ostes depression located between Medvezh'egorsk and Lake Segozero (Fig. 1a). When the glacier dam, which controlled the Onega water level, was destroyed, the lake water level rapidly dropped by 20–25 m. The maximum level of OPL in the northern and western Onega region was ~120 m. Shore deposits are observed at the height of 114–125 masl in the Medvezh'egorsk region [8]. The absolute height of the surface of a large delta near Petrozavodsk, through which glacial water discharged from the Shuya River basin to the OPL during the Neva Glaciation and the beginning of the Allerød, is also ~120 m (Fig. 1a). The water level drop and stabilization promoted the formation of shorelines, which are well defined from Medvezh'egorsk to Povenets at 95–96 masl [8], and a thick delta near the settlement of Girvas at 95–100 masl (Fig. 1a). As a result of sharp water level drop in the lake and cardinal change in the direction of its outflow (from the southward direction along the Svir River to the northward direction to the White Sea), the oxic surface water mixed with the anoxic bottom water. The redox potential at the water/sediment boundary abruptly changed. The oxic water oxidized the sediment and the bivalent iron gave way to the trivalent variety. Consequently, a horizon of pinkish brown varved clays formed according to the Wilson model [6]. The lake level drop resulted in incision of rivers and transport of sandy material to the basin, where sandy varves were accumulated above the PH (Fig. 1b) [4, 5].

On the other hand, since that time the OPL lost direct connection with the margin of the retreating glacier and passed from the proglacial evolution stage to the periglacial stage, this was reflected in a sharp decrease in sedimentation rates. Distal-type laminated varved clays began to form in the lake. Thaw water and sediments from the glacier margin entered the lake only via the Suna River system. An extramarginal delta, the largest in Karelia (~25 km^2), formed near the Girvas Settlement at the estuary of this river system (Fig. 1a).

The AMS analysis of organic remains in varved clays of the OPL underlying the PH in Lake Nizhnee Myagozero yielded four dates (Figs. 1a, 1b) [1]. The youngest date (11 570 yr) falls out of the trend of other dates, because it is probably related to a redeposited OM. The second (from the top) date (11 325 ± 95) was obtained within the interval of 70–80 annual varves below the PH base. Therefore, the age of the PH base is estimated at ~11 250 yr, whereas the age of the PH top is estimated at 11 150 yr. Hence, the timing of the PH coincides with the opening of the northward outflow threshold approximately 11 000 yr ago [7].

Based on measurements of diatom spectra in sediments of the northern OPL, Davydova [9] also assumed a considerable drop in the lake level in the second half of the Allerød.

Thus, at the end of the Allerød, approximately 11.25 ka ago (^{14}C dating), the OPL lost direct contact with the margin of the northwestward retreating glacier and acquired a new outflow to the White Sea depression. The water level drop of 20–25 m resulted in a substantial enrichment of bottom water with oxygen. A sharp decrease in sedimentation rates and OM input fostered the oxidation of bottom sediments. This is reflected in the formation of the pinkish brown, iron oxide-rich, 30-cm-thick horizon of varved clays over the entire vast area of the Onega periglacial lake.

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REFERENCES

1. M. Saarnisto and T. Saarinen, Global Planet. Changes, **31**, 333 (2001).
2. I. N. Demidov, in *Problems of Precambrian Geology of Karelia* (Karel. Nauchn. Tsentr Ross. Akad. Nauk, Petrozavodsk, 1993), pp. 127–151 [in Russian].
3. I. N. Demidov, in *Contribution to the Origin of Quaternary Deposits and Their Resources in Finland and Northwestern*

Part of the Russian Federation (GSF, Espoo, 1997), pp. 57–65.
4. A. A. Kurochkina, in *Paleolimnology of Lake Onega* (Nauka, Leningrad, 1976), pp. 74–127 [in Russian].
5. S. A. Vyakhirev, in *Problems of Precambrian Geology of Karelia* (Karel. Nauchn. Tsentr Ross. Akad. Nauk, Petrozavodsk, 1993), pp. 151–160 [in Russian].
6. T. R. S. Wilson, J. Thomson, D. J. Hydes, et al., Science **232**, 972 (1986).
7. M. Saarnisto, T. Gronlund, and I. Ekman, Quatern. Int. **27**, 111 (1995).
8. G. S. Biske, G. Ts. Lak, A. D. Lukashov, et al., *Structure and Evolution History of the Onega Lake Depression* (Karelia, Petrozavodsk, 1971) [in Russian].
9. N. N. Davydova, in *Paleolimnology of Lake Onega* (Nauka, Leningrad, 1976), pp. 130–191 [in Russian].
10. I. M. Ekman, in *Geology of Karelia* (Nauka, Leningrad, 1987), pp. 79–93 [in Russian].