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GEOLOGY

The New “Voka” Key Section of Late Pleistocene Deposits on the Southern Coast of the Gulf of Finland

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Glacial deposits are widespread throughout the southern coast of the Gulf of Finland, but the thickness of the Quaternary cover there usually does not exceed 5 m and increases only within older buried valleys. Glaciolacustrine deposits, especially late Valdai supramorainic varved clays, are widespread in the preglint lowland along the shore. Their thickness is up to 3–4 m and as much as 25–27 m in some places, for instance, in Yuminda, Loksa, and Kyasmu (Estonia) [1]. Older deposits of middle Pleistocene age and Mga Interglacial transgression are known only in the eastern part of the southern coast of the Gulf of Finland in the Neva River valley mainly based on drilling data. Boreholes penetrated deposits of the Mga (Eemian) transgression and, probably, a part of the middle Pleistocene Interstadial along the southern coast of the gulf only in one region, namely Prangli Island and the adjacent region of the Estonian coast [1, 2]. Exposures of such sediments in the pre-glint lowland have not yet been discovered. A thick and extended section of mainly sandy sediments revealed by A.M. Miidel in the 1960s on the shore cliff on the eastern Estonian coast near the Settlement of Voka has thus far been ignored. Sediments exposed here were referred to the late glacial limnoglacial or glaciofluvial type [1, 3, 4]. The author of the present paper began the study of this key section in 2001 upon the suggestion and with the participation of A. Miidel. A.N. Molodkov, invited later to participate in this work, subsequently became the head of the special project of the Estonian Science Foundation.

The section extends eastward for about 2.5 km along the scarp east of the Voka Settlement and the Vasavere River mouth. The stratigraphy of the Voka area was studied in shore exposures in the marginal and central parts of the old valley. This work presents results of the detailed study of only the central part of the shore exposure located 0.5–1.0 km east of the Vasavere River mouth.

Instead of lower Paleozoic bedrock exposures (glint) that are common for the southern coast of the Gulf of Finland, this area exposes loose (mainly sandy and sandy loam) sediments with a clear (usually, parallel) bedding undoubtedly accumulated in the Quaternary. As is seen on the western and eastern edges of the exposure, Quaternary sediments are embedded into a relatively large NS-trending depression in bedrocks. According to drilling data, the depression bottom lies at a depth of approximately 100 m below the present sea level, gradually rises southward, and extends into the mainland. There is no doubt that the studied structure is a major buried old valley not expressed in the present-day relief. Such valleys are well known on the southern coast of the Gulf of Finland [3, 5].

The absolute height of the cliff terrace is about 22 m (17–21 m in some places). The height of present-day surface gradually increases southward to 30 m. Since the upper sequence is unconformably truncated by the terrace surface in some places, the surface represents the base rather than cover; i.e., the terrace should be classified as an erosion (abrasion) structure. Thick sequences of sand, sandy loam, and underlying clayey sediments (including deformed ones), commonly assigned to late Valdai glaciofluvial and glaciolacustrine deposits, are exposed at the base of the terrace and recovered by numerous strippings [1]. Preliminary results of the analysis of sediments in the valley carried out by Molodkov in 2002 by the optically stimulated luminescence method (OSL) raised the question about the assignment of the sediments in the old valley (at least, their upper part) to the Valdai interval and not to the Late Glacial. Geological arguments in favor of such a viewpoint were the following: (a) in the old Voka and the adjacent western Purtse valleys, thick sediments are observed within and not in front of the glint plateau; (b) they occur at an absolute height ranging from 0 to 30–36 m but not from 0–5 to –25–30 m; and (c) they are

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represented mainly by normal laminated sandy and sandy loams, but not by varved clays.

The walls of the Vasavere Valley incorporate narrow fragments of terraces fragments at an absolute height of 26 m (on the western wall) and 36 m (on both walls), whereas the main plateau south of the glint scarp in this coastal area occurs at an absolute height of 40–45 m. The plateau surface beyond the valley is composed of moraine with predominant Paleozoic detritus and thickness usually not exceeding 1–3 m. The upper horizon of the moraine was found within the old valley only in some boreholes beneath late glacial thin sands. A terrace as high as 36 m was cut into this moraine on the eastern wall of the old valley, whereas the same terrace is incised into parent limestones and only slightly covered with a thin sand cover (1–1.5 m) on the western wall. The moraine of certainly the Last (Weichselian) Glaciation has never been found in the region below the absolute height of 20–34 m. Shoreline pebble beds of the Baltic Glacial Lake (with subaerial sandy loam at the top in some places) are exposed at several sites on walls of the old valley. The sandy loam is crowned by a soil horizon at a depth of 0.4 m from the present-day surface in the Toila Settlement section at an absolute height of 42 m. The horizon was dated at 6970 ± 100 yr B.P. by the ^{14}C method (TA-2884).

The section on the left wall of the valley at the Vasavere River mouth, revealed and studied by the author of the present paper together with Miidel in 2001, is the most representative one among the accessible sections. In the 26-m-high terrace scarp facing the sea beneath a technogenic sediment layer, one can see two moraine horizons of clastic materials with different appearances and petrographic compositions. The horizons are separated by a thin (up to 2–8 m) layer of laminated sandy loam, loam, and sand (Fig. 1). Granite boulders occur in both horizons. The finer clastic material is mainly composed of Ordovician limestone at the base of the local section. The upper moraine horizon (about 1–1.5 m thick) of grus, debris, and boulders exposed over a small area makes up a large flat surface without any hills and cannot be regarded as deluvium or colluvium. The lower moraine horizon, which generally includes fragments of underlying Paleozoic rocks at the base, abruptly descends eastward along the slope of both old and modern valleys and gains in thickness. The lower moraine is traced in boreholes at lower levels of the buried valley.

In the central coastal part extending for about 500 m, the subaerial section consists of the following three main lithostratigraphic components (Fig. 2, from top to bottom). (i) Holocene soil layer at an absolute height of 22 m.

(ii) Fine-grained graded parallel-bedded sands with sandy loam interlayers replaced in depressions by sandy loam and loam (Sequence A).

(iii) Basal gravel horizon (with small pebbles) marking a certain erosion boundary with the absolute height

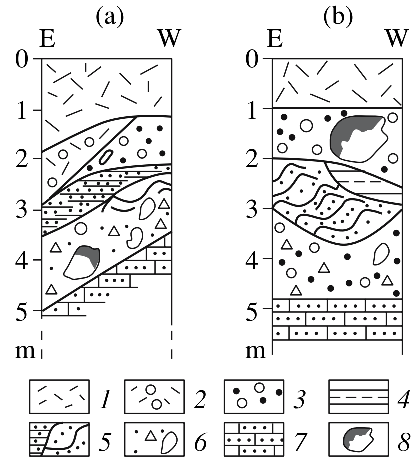

Fig. 1. Sections of loose deposits on the terrace at the absolute height of 26 m on the left bank of the Vasavere River in its mouth (southward view). Sections: (a) eastern, (b) western. (*1*) Technogenic deposits; (*2*) sandy loam–detrital deluvium; (*3*) grus–debris moraine; (*4*) basinal sandy loam and loam; (*5*) basinal variegated and whitish sands (including those with “xenoliths”); (*6*) clayey–sandy–detrital moraine; (*7*) sandstones; (*8*) granite boulders.

varying from 9 to 15 m. Judging from the parallel (mostly, horizontal) bedding with isolated horizons of inner deformations and wavy bedding, the sequence is likely to be accumulated in a remote large and calm basin. The material was drifted from the south and walls of the valley. This is reliably indicated by the presence of Dictyonema shale detritus and the increase in its concentration and size toward the land. Bedrock exposures of the shale at the Cambrian/Ordovician boundary are known only in the southern area, upper reaches of the river, and walls of the old valley.

The underlying Sequence B exposed along the whole coastal area is also composed of close- and medium-grained sand (especially in the eastern part of the study region) and coarse-grained sands (in places with sandy loam interlayers and gravel) in the western part. The sequence (mainly with parallel, partly with oblique bedding) also probably accumulated in the basin but closer to the provenance and in the southern area as well. A considerable fragment of the sequence (the middle portion) accumulated in a relatively shallow (no more than 10-m-deep) basin, as evidenced by slight wavy bedding inside generally parallel layers. The maximal exposed thickness of Sequence B is ~12 m. Its lower boundary is recognized arbitrarily in uplifted areas by some variation in the grain size composition and appearance of sediments.

The underlying Sequence C exposed only near the beach is mainly recovered by test pits down to the depth of 2–3 m. The sequence extends to a large depth below sea level and rises above sea level to the height of 5–12 m only in some places. The sequence is mainly represented by dark gray dense sandy loams (with inclusion-free sandy loam and loam interlayers) usually with thin

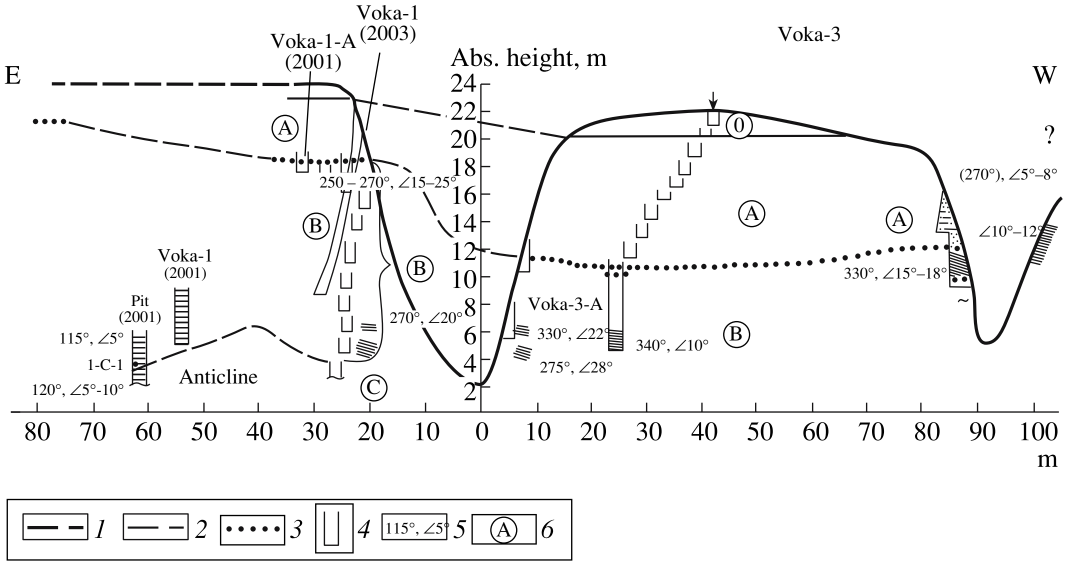

Fig. 2. Section of the coastal exposure along the sea in the central Voka region 0.5–1.0 km east of the Vasavere River mouth (southward view). Compiled by A.A. Nikonov, June 2003. (*1*) Hypsometric profile; (*2*) boundaries of sequences; (*3*) gravel–pebble basal marker horizon; (*4*) location of strippings; (*5*) strike and dip of strata; (*6*) indexes of sequences.

parallel bedding. These sediments are undoubtedly basinal (relatively deep-water) sediments accumulated under calm conditions. The analysis of two samples taken at the interval of several meters below the sequence roof in the westernmost part of the central fragment of the exposure yielded no diatom frustules (analyst E.I. Polyakova).

The analysis of samples taken from Sequence C in stripping V-1 revealed some well-preserved diatom valves represented by fresh-water *Melosira distans, Pinnularia microstauron*, *P.* sp., *Navicula* sp., *Rhopalodia parallela, Ehpitemia zebra*, and other species, including cold-water and aerophile biofoulings. According to V.S. Gunova, the sediments were accumulated in a cold lake basin. At the same time, the presence of fragments of the prevalent marine diatom species *Melosira sulcata* in samples from the upper part of Sequence C suggests their redeposition from deeper horizons of the same sequence.

Judging from boreholes 3 and GR, Sequence C plunges down to the depth of 20 m or even 60 m below sea level in the southern area off the coast. It is underlain in the old valley thalweg by a thick (up to 15 m) moraine horizon that correlates with the lower horizon on the left wall of the old valley.

To date, the upper component of the section (Sequence A) has been dated by the OSL method, and the age of the middle component (Sequence B) has been preliminarily estimated in sections V1 and V3 [6]. In the first section near the eastern wall of the local ravine (stripping V1-01 in Fig. 2), we took samples 0.7, 1.9, and 3.2 m above the sequence bottom (A-3, A-2, and A-12, respectively). In the second section (V3-03) located about 60 m westward, where the lower boundary of Sequence A in the local incision is located at a lower level and the thickness increases correspondingly, samples were taken at a depth of 2.0 m beneath the local surface of the terrace below the zone of roots and downflows of sediments (V3-4a). We also took samples from the depth of 3.2 m (V3-7) and 11.5 m (V3-19). Sequence A in both sections (V1-01 and V3-03) accumulated within the time interval from 31 to 39 (44) ka B.P. [6]. The dates show direct correlation with depth, and they are similar in all sections. These facts are also consistent with the geological correlation.

According to preliminary estimates, Sequence B is dated at 90–115 ka B.P. in section V3-03 and about 110–70 ka B.P. in section V1-01 within the depth of 16.5–7.0 m [6]. The subsidence of the basal gravel interlayer of Sequence A (probably with a sharp bend at the ravine), the location of the sequence roof at the same height, and an increase in its thickness from ~4 to 10 m suggest that Sequence A in the western section is more complete as compared to the eastern section. By contrast, Sequence B is better preserved in the eastern section V1-01. Hence, the dates obtained are consistent with each other and geological observations.

At the current stage of study, we can draw several inferences of local and regional significance. Based on both geological data and OSL datings, the upper part of the studied section (Sequence A) predated the Last or Valdai (Würm) Glaciation. The whole section exposed along the coast is represented by sediments of a large long-lived freshwater basin (or basins). A part of the less studied Sequence C could accumulate in marine conditions. We have recorded a prolonged (up to 50-ka-long near the old incised thalweg) hiatus between relicts of sequences A and B. However, the sequence lacks signs of moraine sediments within the interval of 50–70–90 ka B.P. even in the rewashed state. Within the interval of 65–45 ka B.P. during the continental regime, the river discharge within the contours of the old Voka River valley took place from the south to the north (not from the side of Scandinavia!) at an evidently low position of the Baltic Sea level. The upper moraine on the plateau and near walls of the old valley was deposited by the Last (late Valdai) Glaciation. Sequence A corresponds in time to sediments of the Leningrad Megainterstadial in the Neva Lowland (OIS 3). Sequences B and C are tentatively assigned to cold and warm intervals, respectively, of the Mikulino Interglacial (upper parts of OIS 5). The underlying moraine horizon mainly recovered by boreholes within the old valley can correspond to the Moscow Glaciation (OIS 6). Judging from sections in deep boreholes with three moraine horizons and thick sediments between them, the original downcutting of the old Voka valley took place not later than the middle Pleistocene (most likely, in the preglacial period).

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