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Disturbed Stratification in Late Pleistocene Sediments of the Khibiny Pluton (Kola Peninsula)

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Abstract—The paper presents a description of three Late Pleistocene sections within the Khibiny pluton, outcropping on the proximal slope of the Kukisvum morainic ridge, a fluvioglacial terrain in the valley of the Kukisiok River, and a glacial complex in the valley of the Vuonnemiok River. Various small disturbances of the primary stratification were found in the first two sections. These structures do not form horizons sustained along the strike and are associated with the top of sand–silt sediments with horizontal or wavy bedding of shallow lacustrine genesis. They form small wavy bends, 'tongues", ovoids, and flexural microfolds that could not be preserved at the bottom of the basin and, consequently, formed after overlapping deposits accumulation. Analysis of the cross bedding of the coarse clastic deposits of the fluvioglacial terrace has allowed us to relate its formation to north-to-south glacial water discharge along the trough valley of the Kukisiok River. In the glaciolacustrine varve clays of the third section (the Koashva open pit), extended horizons of plicative disturbances 0.5–2 m in thickness and 300 m in length were studied. The soft-sediment deformations are covered with an unstructured horizon composed of coarse grains dispersed in sand–silt matrix, which means that the deformation was caused by either a glacial flood or a mudflow. The study has revealed no signs of seismic liquefaction during the formation of the folded structures.

The relevance of the performed study is determined by the fact that it has become possible not only to clarify the formation conditions of the Quaternary Khibiny deposits but also to develop the objective criteria for determination of the soft-sediment deformation structures associated with thixotropic effects in weakly consolidated sediments. Similar structures are sometimes regarded as seismic convolutions, which can lead to unjustified overestimation of the regional seismic hazard level.

Keywords: deformation structures, wavy stratification, seismic liquefaction, mudflow, glaciolacustrine deposits, Khibiny, Kola Peninsula

INTRODUCTION

Soft-sediment sections often contain local (nonregular) or extended (regular) primary—bedding disturbances of different morphology that occur primarily in unconsolidated water-saturated deposits. Such structures have been attracting researchers' attention with ever increasing frequency due to their importance for understanding of sedimentation conditions. In English-language publications, different deformed structures occurring in weakly consolidated sediments are often marked as *soft-sediment deformation structures* (SSDS) (Moretti, 2000; Moretti and Sabato, 2007; Van Loon, 2009, 2014) that are widely spread in lacustrine, glacial-lacustrine and marine sediments.

The last-decade publications describing the geological environments of NW Russia have a tendency for a univocal identification of different bedding disturbances as paleoearthquake consequences disregarding their morphology, host sediments, and sedimentation conditions (Verzilin and Sevast'yanov, 2001; Nikolaeva, 2003, 2009, 2014; Nikonov, 2003, 2007; Spiridonov, 2005; Biske at al., 2009; and others). However, in most of cases, the authors are not able to provide sufficient evidence to confirm the seismogenic origin of these structures following such generally accepted criteria (Bowman et al., 2004; Chunga, 2007; Korzhenkov et al., 2014) as exclusion of the gravity mechanisms of sediments deformation; systematic lateral repetition of deformed structures and their abundance; simultaneous formation and cyclicity.

When considering the genesis of deformed bedding in the territory of the Baltic Shield it should be taken into account that in the late Quaternary this region was strongly affected by glaciation and cryogenic processes that by themselves, produce dislocations in soft sediments (Gruszka and van Loon, 2011). Additionally, powerful water and mud flows that occurred due to glacial melting could have resulted in intensive deformation of earlier deposited sediments (Grigor'ev, 1986; Deev et al., 2012). Moreover, the weakly consolidated sediments could have deformed being affected by their own weight or by dynamic sedimentation condi-

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tions, i.e., without any additional external factor to mention. These sedimentation and early-diagenetic disturbances may have included landslides, load casts, inflow and maceration structures, etc. (Botvinkina, 1962).

The objective of the presented study was a complex analysis of the sedimentation and deformation conditions of Quaternary sediments within the Khibiny pluton; identification of possible mechanisms of primary-bedding disturbances in sediments of different genetic types and their estimation as paleoseismicity indicators.

Consideration of deformed structures in the sediments of the Khibiny glacial lakes is regarded as important for solving the issue of strong Late Pleistocene paleoearthquakes that might have affected the area, for this type of sediments are susceptible to seismic effects due to their increased capability for vibrational liquification. This capability of fine-grained lacustrine sediments is underlined by finding in them a variety of the deformed structures proved to be of seismic origin such as seismogenic convolutions in varve clays in Eastern Canada, Northern Italy and some other seismically active periglacial regions (Obermeier, 1996; Moretti and Sabato, 2007; Chunga et al., 2007).

STUDY REGION

The Khibiny alkali pluton located the central part of the Kola Peninsula is a concentric zonal Hercynian intrusion (350–300 Ma), whose relief is subdued mountains with the plateau-like tops located at the heights of 1000–1191 m (Bilibina, 1980). The Khibiny structure is a result of the block uplift and denudation of the late Paleozoic pluton, while all the surrounding adjusted lowland experienced compensational sinking that manifested itself in the relief of the submeridionally extended Big Imandra and Umbozero Lakes (Strelkov, 1973; Nikolaeva, 2014).

The Khibiny soft sediments are represented by Late Pleistocene glacial, glacial-lacustrine and fluvioglacial sediments as well as by Holocene eluvial, colluvial, alluvial, lacustrine, boggy and technogenic deposits (Fig. 1). The glacial sediments are widely presented in the through valleys open south- and westward to the glaciation center and reached by the Late Valdai glacier (Fig. 1), whose tongues were as high as 600 m (Lavrova, 1960). Long (stadial) stops of glacier margins are marked by a series (up to 5–6) lateral moraines. The most complete lithologic-stratigraphic Quaternary complexes up to 210 m in thickness form a bedrock depression of, most probably, pre-Pliocene age are penetrated by the wells drilled in the hollows of the Bol'shoi and Malyi Vud'yavr Lakes (Anan'ev, 1998c).

In the upper reaches of the through valleys, where a part of a flowing tongue got occluded, the glacier-dammed lakes formed, their bottoms accumulating the glacial-lacustrine sediments being a sequence of varve clays, silt and sands. The shores of periglacial lakes were affected by melted-water discharges (including outburst floods) bringing big amounts of detrital materials. Its further accumulation and erosion on the valleys' slopes resulted in formation of fluvioglacial terraces.

The Khibiny and its adjacent areas are territories with a moderate level of modern seismic activity. For instance, since 1956, a seismic station of Apatity town has been registering earthquakes whose magnitudes do not exceed 4–5 points in the MSK-64 scale. Most of the registered earthquakes are of technogenic nature, so their epicenters are localized at the depth up to 1 km in the regions of massive mining activity (Godzikovskaya et al., 2010). Only a few dozens of events with the epicenter depth of 15–20 km and the magnitudes of 2–3 have been classified as of natural origin so far, but their intensity is too weak to cause any seismic dislocation in the relief, bedrock or soft sediments.

Within the Khibiny pluton some researchers have indicated a complex of seismotectonic Late Pleistocene and Holocene dislocations that suggest the territory in the past had experienced the seismic quakes reaching magnitudes 11–12 in the MSK-64 scale (Avenarius, 1989; Nikolaeva, 2003, 2014). In our opinion (Gorbatov and Kolesnikov, 2016; Gorbatov et al., 2017) the issue of seismogenic origin of these deformations (gorges, fractures, benches, etc.) remains debatable since one cannot exclude their formation due to selective denudation of the structural inhomogeneities of solid rock. In this respect, complex genetic studies of heterochronous deformation structures may foster objective resolution of the issue of this region's seismic potential.

During field surveys (2015 and 2017) our team investigated three sections penetrating the inner composition of a moraine, fluvioglacial terrace and through-valley Quaternary complex (see their locations in Fig. 1). All the three sections exposed primary-bedding deformations, and almost always these deformations formed in the fine-grained sands and silt accumulated in either stagnant or low-flow basins. Describing the sediments' textures in the next section we relied on the classification formulated by L.N. Botvinkina (1962).

SECTIONS DESCRIPTION

Kukisvum moraine ridge. The earthworks performed in the territory of the Tirvas resort made it possible to study the composition of the eastern (proximal) slope of the Kukisvum moraine formed in the Late Pleistocene due to long-term stop of a glacier tongue that had come from the south into the intermountain through. The absolute age of surface boulder-pebble deposits in the middle part of the moraine comprises 64 ± 16 ka. The age was determined using the radiothermoluminescent method (analysis was performed by O.A. Kulikov (Anan'ev, 1998a)) and corresponds to that of the early Valdai glaciation.

The examined ridge extends from the southwestern spur of the Kukis Mountain and to the Vud''yavrchorr Mountain and divides the hollows of the two biggest Khibiny lakes—

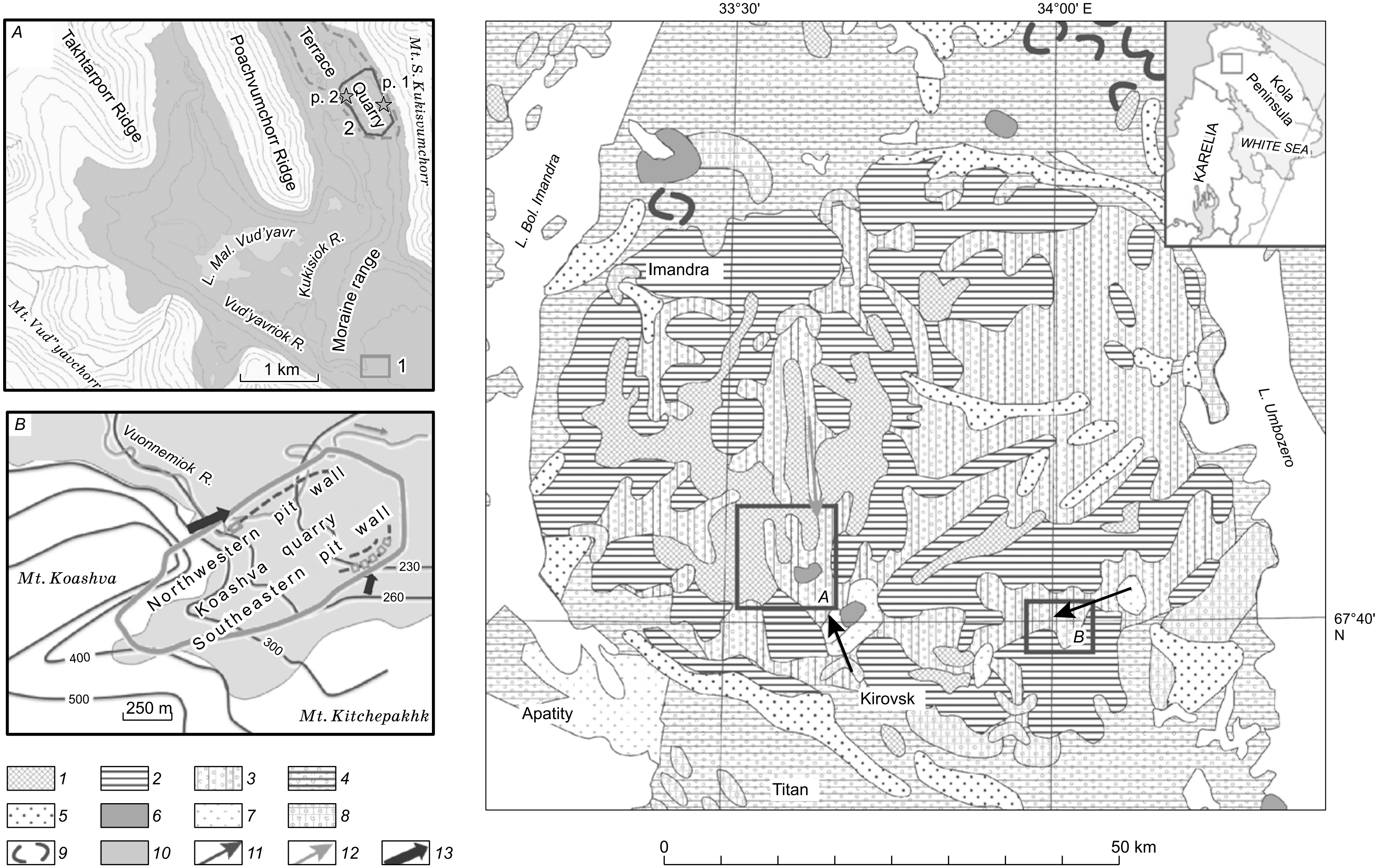

Fig. 1. Map of Quaternary sediments of the Khibiny pluton (according to (Kalinina and Pezhemskaya, 2003)) and location of the investigated sections (see the sidebars and the corresponding framed areas in the main map). *1*, pre-Quaternary primary rocks: *2*, Late Pleistocene–Holocene alluvial–diluvial sediments. Boulders, gravel, grus, sands; *3–6*, Late Pleistocene glacial sediments: *3*, main mountain-glacier moraine, silted boulders; *4*, main covering-glacier moraine, sanded boulders, silts, loams, *5*, fluvioglacial sediments, sands, gravelly sands with pebble lenses, *6*, glacial-lacustrine sands, silt, loams, clays; *7*, Holocene technogenic sediments; boulder and gravel banks; tailing-dump sands and clays; *8*, separated boulder trains and margin moraines; *9*, circular dead-ice meltings; *10*, glacial sediments (see the side bars); *11*, late Valdai glacier's valley ice-tongues movement direction; *12*, glacial–water discharge direction during formation of the top of fluvio-glacial terrace in the Kukisiok River valley (reconstructed from observations of the oblique stratification); *13*, movement direction of the underwater detrital flow while forming folds in the Koashva quarry varve clays (reconstructed from structural observations). Numbers 1, 2 in sidebar *A* mark the survey areas in the Central Khybiny: 1, Kukisvum moraine; 2, actual quarry at the bottom of the Southern Kukisvumchorr mountain.

the Malii and Bol'shoi Vud'yavr. The moraine is sawn by the v-shaped Vud'yavriok river valley that has no natural outcrops due to the taluses of coarse-grained material that present everywhere in the valley. The ridge's cross-section is abruptly asymmetrical, so its eastern (proximal) slopes are smooth, and the western ones (distal) are steeper.

Our team has documented outcrops found in trenches, extracted soil in the slope, and basement pits. The moraine's top is a partly rewashed and sanded with gradual transition into slated fluvioglacial and glacial-lacustrine deposits at the bottom of the section. The material selected in the five outcrops has allowed for summary section of the eastern slope (top to bottom):

Thickness, m

Stratum 1. Boulders of 20–50 cm in diameter (some reaching 1.5 m) "suspended" in unlayered gravel-pebble material of gray color. The stratum also has lenses of coarse-grained dust sand of light gray color. The petrographic composition of the material is mainly allochthonous granites 0–3.5

Stratum 2. This stratum is a coarsely-stratified bench of sanded gravel with competent interlayers (up to 60–80 cm) of large gravel and boulders (up to 20 cm). The layers dip to the NNE 11–25° 3.5–5.5

Stratum 3. This stratum is iron-rich cemented brown sand with interlayers (3–7 cm) of fine gravel and grus, and rare pebble and boulder inclusions. The layers are subhorizontal with rhythmical sorting. The stratum embraces a single flexure of a 0.8 m amplitude 5.5–10.7

Stratum 4. Grey and warm-gray horizontally-slated loams 10.7–11.0

Stratum 5. Horizontal interbedding of boulders, coarse sand and grus 11.0–13.5

Stratum 6. Sandy gravel-pebble sediments with interlayers and sand lenses (Fig. 2, Strata 1–2) 13.5–14.5

Stratum 7. It is a rhythmic interlaying of fine-grained sands and silt with displaced convolute bedding (current ripples) transforming down the stratum into the low-angle wavy cross bedding formed by dropdown sediments redistributed by weak vibrations (Fig. 2, Strata 3–4). Below, the sand-aleurite sediments are replaced by varve loams with boulder (dropstone) inclusions. The stratum's subface deepens to the NNW 14.5–16.2

Considering the lithological composition and the inner textures of the strata opened on the eastern slope of the Kukisvum moraine ridge, Stratum 1 represents a typical moraine (coarsely-fragmented material with significant amounts of fine earth without sorting and bedding); Stratum 2—a partially rewashed moraine (the material is still coarse, but certain degree of bedding can be observed); Strata 3–6—the fluvioglacial sediments formed by the moraine materials rewashed by melted water (stratified and sorted sand-gravel-

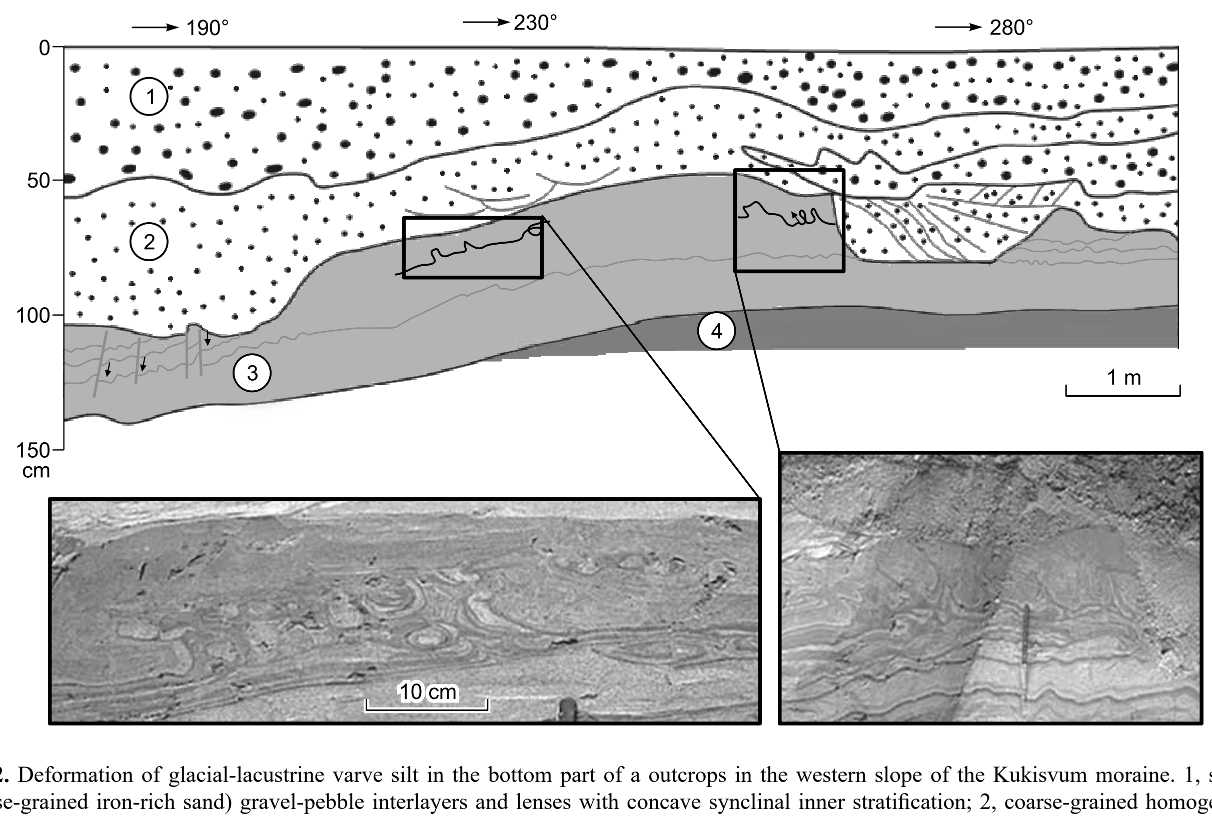

Fig. 2. Deformation of glacial-lacustrine varve silt in the bottom part of a outcrops in the western slope of the Kukisvum moraine. 1, sanded (coarse-grained iron-rich sand) gravel-pebble interlayers and lenses with concave synclinal inner stratification; 2, coarse-grained homogeneous sand with weak oblique wavy stratification. Bottom layer 3 includes a coarse-grained sand lens with oblique stratification, marking melt-water flow; 3, cross-bedding of fine-grained well-sorted sand with wavy stratifications (ripple marks), and of gray silt. The wave length is 10–20 cm, amplitude is 2–4 cm. The top embraces deformation structures and microthrusts; 4, dense and vaguely stratified aleurite with fine-grained interlayers.

pebble sediments), and Strata 4 and 7—glacial-lacustrine formations (fine-grained sand-aleurite and loamy sediments with dropstones).

Deformation structures were found in the top of Stratum 7 composed of the rhythmically interlaying sands and silt of glacial-lacustrine genesis. The traces of thin-layer sediment redistribution are thin "tongues" of 8–10 cm in length inclined eastward (Fig. 2, right photo). The intersections between these ridges have synformal folds and closed turbations of round shape. Probably, the periodicity of the tongues had been inherited from the primary (sedimentational) convolute bedding of the sediments. From the east, along the strike, the convolution horizon wedges out, and from the west it is cut off by a sand lens of 150 cm wide, and 30 cm thick.

Northeastward from the first deformation area (Fig. 2, left photo) in the same stratum the structures shaped as isolated ovals, drops and other rounded and often doubled fragments of 5–9 cm in size were found. These structures are characterized by inner concentric bedding (3–5 layers). The inclusions are surrounded by either the layers making them twist and bend or by a homogeneous material. The long axes of extended inclusions are directed along the strike.

In the most northern sector (left end of the drawing in Fig. 2) the layers of varve silt are fragmented by the reverse shear microdiscontinuities (2–5 cm), which cross the whole stratum and manifest themselves as scarps in its top (partially washed out), but have no clear continuation into the overlaying stratum.

Fluvioglacial terrace in the Kukisiok River valley. In the valley we performed a detailed study of Quaternary sediments opened by an actual sand-and-gravel quarry located at the bottom of the Southern Kukisvumchorr Mountain on a flat fluvioglacial terrace in the submeridional valley of the Kukisiok River. Down the creek stream, the valley cuts into a low moraine that extends to the southeast from the Poachvumchorr Ridge. Behind the moraine is a small lake called Seites'yavr. The quarry is 300 × 800 m. The absolute heights of the terrace elements are 440–450 m (edges), and 460 m (back suture).

The upper parts of the section are large cross-bedded structures of sand-gravel-pebble sediments (Fig. 3).

Point 1 (terrace back suture). The most complete section of the cross-bedded formation could be seen in a washout in the eastern wall of the quarry (Fig. 1, Point 1 and Fig. 4). The section has the following structure (from top to bottom)

	Thickness, m
Stratum 1. Unstratified boulder-gravel material with inequigranular sand. The stratum is of dark-brown color and contains a significant amount of peat	0–1.1
Stratum 2. The stratum is unstratified grus and sand mixed with poorly-rounded gravel of gray color	1.1–1.8
Stratum 3. This stratum is coarsely stratified sandy boulder-pebble material. The large fragments are properly rounded. The boulder size varies from 15 to 20 cm. The stratum has heterogeneous thickness (20–100 cm) and pinch-outs	1.8–2.4
Stratum 4. This cross-bedded semigravel formation contains up to 4 levels of 30–40 cm each, interlaid by thick (1–2 m) layers of gravel-pebble sediments. The layers are subparallel with straight boundaries. Thanks to their stability, the sand layers could be observed as those forming bench-like structures. In bottom-top direction the layers become thicker and the material's sorting decreases. In the bottom of the formation is a thick sandy layer of well-rounded pebbles and small boulders (12–18 cm) with a characteristic direct waste sorting. In the side of the washout (perpendicular to the quarry side) the stratum layers incline at 10°–15°, and in the quarry wall (parallel to the slope)—at 5°–10°	2.4–10.3
Stratum 5. The stratum consists of light gray, middle- and coarse—grained well-sorted sand. Its inner stratification is well expressed and of parallel-inclined, wavy and oblique wavy types. The layers are either homogeneous or binary.	

Fig. 3. Large cross-bedding sequence (break-through flow facies) stripped in the central part of the quarry at the bottom of the Southern Kukisvumchorr mountain. The sequence analogous to Stratum 4 in Fig. 4 is composed of slated gravel sands and gravel and include big boulders and unstratified pebble-boulder sediments with inverse sorting (the material gets coarser towards the top) The sand layers are of close foliation. The interlayers are parallel, weakly cut and strength-lined to the south at 15°–20°. The boulder's long-axis inclination is parallel to the oblique stratification (the detrital material was dragged to the anterior slope of the accumulation dump). The flow direction in the figure in from left to right.

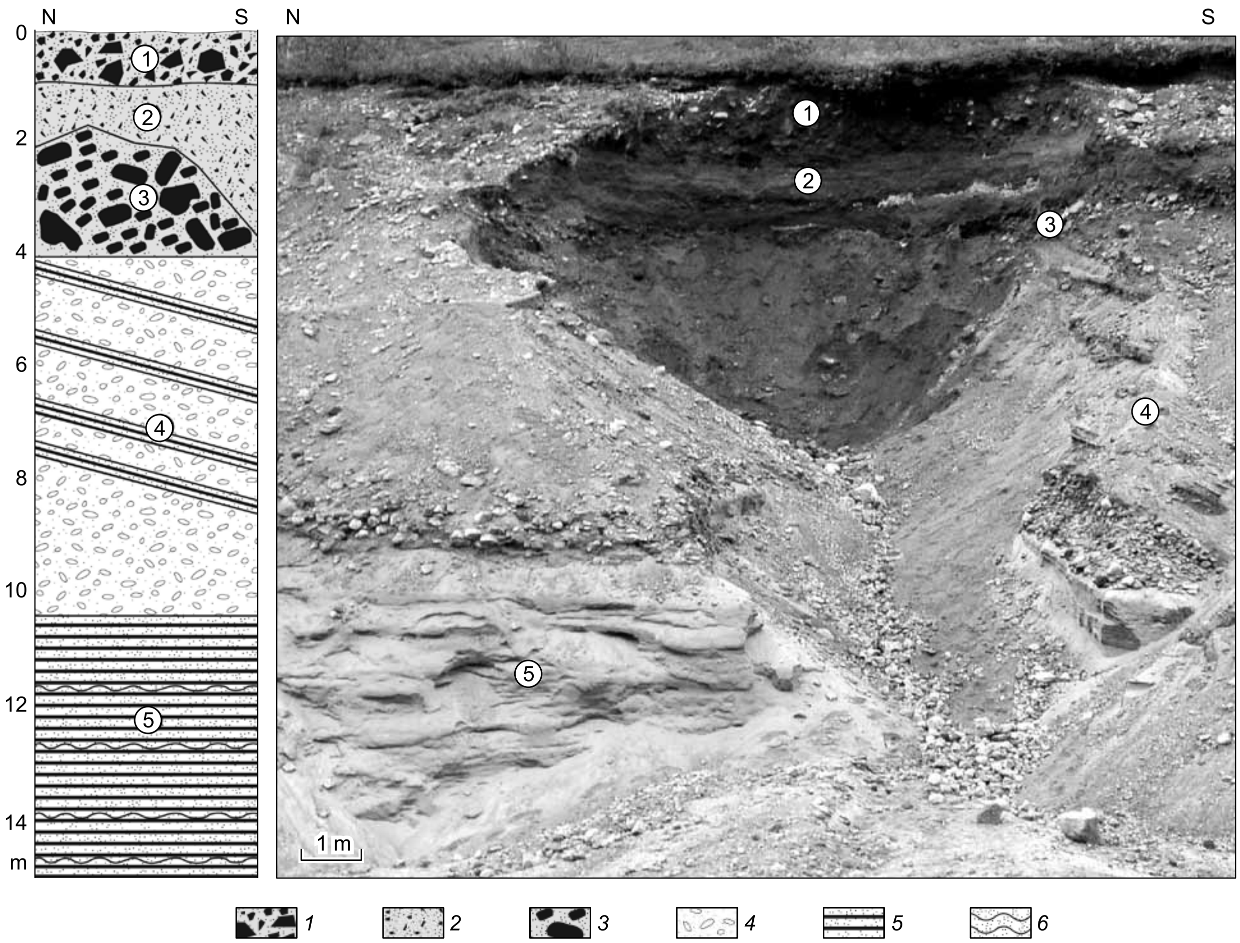

Fig. 4. Outcrops of fluvioglacial and lacustrine sediments in the washout formed in the eastern wall (Point 1) of the quarry at the bottom of the Southern Kukisvumchorr mountain: *1*, unstratified boulder-gravel peaty colluvial deposits; *2*, unstratified grus sand with gravel; *3*, unstratified silty boulder-pebble fluvioglacial material; *4*, gravel-pebble sediments of a large obliquely stratified fluvioglacial sequence with the layers directed south-westward; *5*, uneven-grained sands of inclined stratification in a obliquely stratified sequence; *6*, uneven-grained sands of lacustrine genesis with wavy stratification and the deformation structures shown in Fig. 6. The circled numbers (1–5) mark the strata in the way they are described in the paper.

Thickness, m

The stratum deepens westward at the angle of 13°–15°. It has an abrupt upper boundary with deflected layers under the boulders, classified as denting deformations (Fig. 5*a, b*) 10.3–14.9

Strata 1 and 2 are typically contain a lot of angular waste rock of different sizes, have a complete absence of sorting and inner stratification, which allowed us to classify them as colluvial accumulations that had come from the western slope of the Southern Kukisvumchorr mountain as a talus blanket. Despite being unsorted, colluvial formations are still easy to distinguish from moraine ones by their brown color, and by their composition that includes a plentiful of angular waste rock and is dominated by local alkali rocks from the Khibiny pluton.

Stratum 3 is a lens that pinches out laterally and is composed of well-rounded coarse-grained material with traces of exposure to water, i.e., it was accumulated by melted glacial water.

Stratum 4 forms a thick formation of sand-gravel-pebble sediments with large cross-edded stratification that is analogous to the formation in Fig. 3 that is nonconformably overlaid by colluvial deposits. These deposits have different granulometric composition and are accumulated by a unidirectional fluvioglacial flow, whose velocity underwent strong periodical changes. The layer inclination in the formation that is parallel to the slope adjusting the quarry seems to be determined by depositing of the material on the anterior slope of a big accumulative pile migrating in the direction of the fluvioglacial flow (from the north to the south), and in the perpendicular section—by the inclination of the deposition surface due to enveloping the bedrock slope by the layers formed within the ajacent area of the fluvioglacial terrace. The observed sorting decreasing up the section is an evidence of the gradual attenuation of flow velocity pulsation intensity.

The bottom part of the section of the fluvioglacial terrace is composed of sand or sand-alluvial sediments of lacustrine

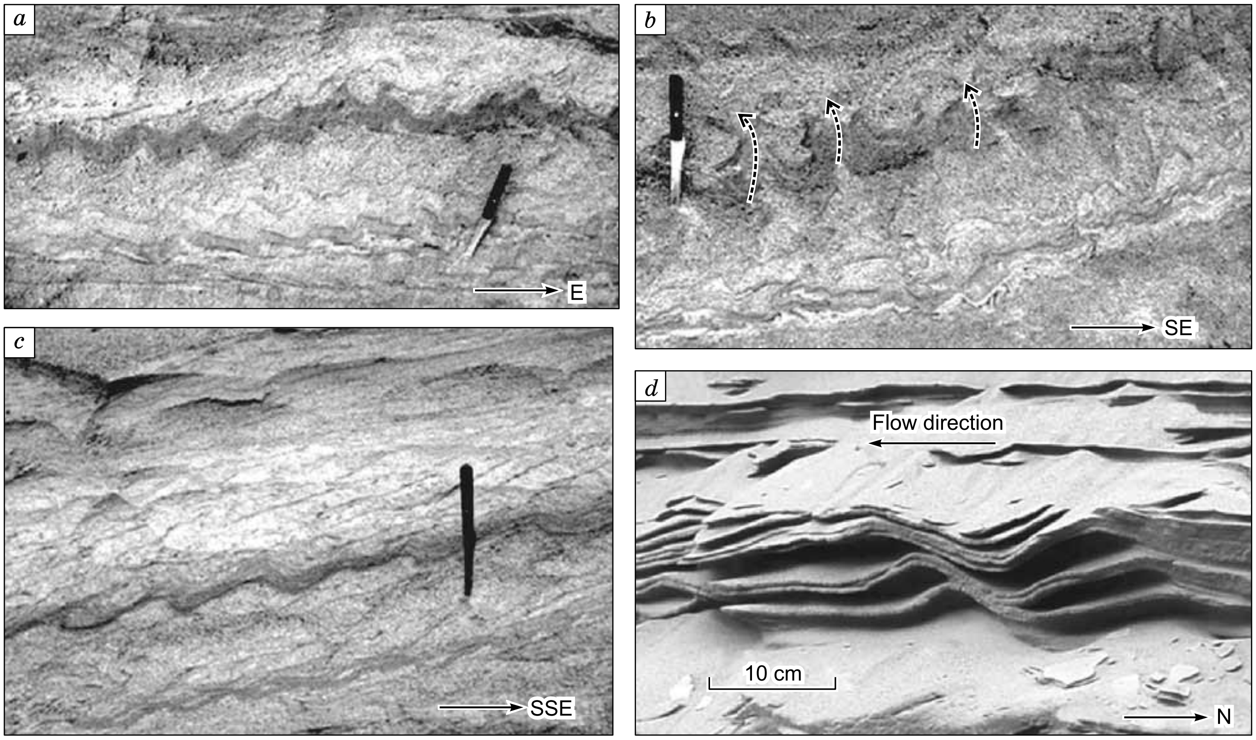

Fig. 5. Disturbed-stratification structures and primary structures in the bed of wavy and oblique wavy sands of shallow lacustrine genesis, opened by the quarry at the bottom of the Southern Kukisvumchorr mountain. *a*, deformed current ripple; *b*, thrust series (marked with arrows) in which sand material bursts the aleurite interlayers formed in the sands with developed oblique wavy stratification; *c*, medium-grained sand with asymmetric wavy stratification; *d*, exhumed medium-grained sand with largely displaced asymmetric wavy stratification (current ripples). Outcrops: *a–c*, at Point 1, Stratum 5, *d*, around Point 2 (analogous to Stratum 4 in Fig. 6*a*).

genesis, presented in Layer 1 of Stratum 5, whose description is given below. The age of the fine-grained sediment sample taken from the middle part of the section in the southern side of the quarry is 14.0 ± 4.5 ka (dated using the radiothermoluminescent method, the analysis performed by O.A. Kulikov (Ananiev, 1998a). The transition from coarse-grained fluvioglacial to glacial-lacustrine sediments is abrupt in all the outcrops.

Unlike the strata above, Stratum 5 lays horizontally in a plane parallel to the bedrock slope and form an inclined stratification in perpendicular section that is determined by the unevenness of the sedimentation surface itself, i.e., stratification in this case is a result of mainly downward sedimentation from suspended sand-aleurite material that is typical for a lake. The presence of current ripples and weak wave ripples points at sediments accumulation in peripheral (shallow-water) zone of the lake basin.

During the study, three outcrops of stratum 5 were prepared and documented. In the first outcrop section of medium-grained sands with alternating weakly-cut (parallel) oblique-wave bedding (current ripples) and parallel symmetrical wavy lamination (wave ripples), a well-seen wavy slate of dark gray silt could be observed (Fig. 5*a*). Its wave length is 6–11 cm, and its ripple index (wave length to height ratio)—4–6 cm. This interlayer marks the undulating bottom of one of the oblique-wave formations and is deformed in a way some of the ripple tops are sharpened and inclined to evidence the redistribution of sand-aleurite material after sedimentation. The lamination character points at mostly washed-in sedimentation. The incidence direction of the oblique layers and the positioning of the steep (anterior) slope of the asymmetrical wave ripples indicate the water flowed mainly from the east to the west relative to the bedrock slope.

In the second outcrop (Fig. 5*b*) located in 4 m from the first one, a layer of coarse-grained sand (large-scale criss-cross (cutting) synclinal stratification in which lenses' thickness may reach 10–15 cm, and width—up to 70 cm) with in-layer accumulations of dark-colored minerals cover medium-grained sands with largely deformed oblique-wave stratification. The sediments here have all the signs the material has been mixed and squeezed upward with multiple manifestations of a thin dark aleurite break and formation of plumes. The overlying layer can be referred to large-scale ripple structures, which is confirmed by the symmetrical composition of the synclinal formations and by the layers formed in parallel to the formation bottom, unlike current ripples characterized by asymmetrical formation sutures and nonconformable bedding of oblique layers relative to formation boundaries.

The third outcrop (Fig. 5*c*) located in 5 m eastward from the second is a group of medium-grained sand formations of asymmetrical parallel stratification with dark gray aleurite interlayers. Its wavy layers are inclined to the west at the angle of 15° for they have got deposited on an inclined bottom. The largely displaced current ripple in the upper part of the outcrop conveys the impression of curvilinear oblique stratification. The directed displacements of the asymmetrical current ripples spreading from the bottom to the top of the section correspond to the prevailing eastward motion of the medium in the direction of the bedrock slope. However, if one looks from the top, both the length and height of the ripples reduce. For instance, the characteristic wave length of the belt in the bottom of the stripping is 25–35 cm (ripple index 7–8), while at the top it is 15–20 and 5–6 cm, respectively. The low ripple indices are more characteristic for wave than current ripples and are likely due to the oblique section the wavy stratification has been observed in.

Point 2 (terrace edge). This is the lowest site in the northwestern part of the quarry (Fig. 1, Point 2) that is limited on three sides by a bench of 3.0–3.5 m in height and opens the margin area of the fluvioglacial terrace. In the west, the site is adhered by a fluvioglacial terrace curtain of 5 m in height, transforming into a slop of the v-shaped valley of the creek flowing from the Snezhnyi glacial cirque. The bench slopes contain well prepared fluvioglacial residues overlaying lacustrine formations.

The eastern and northern part of the bench embrace an obliquely stratified formation analogous to Stratum 4 opened in a washout in Point 1. The changed direction of the outcrop wall has gradually reduced the layer incidence angle to zero in the northern wall, so the stratification here goes either straight horizontal or parallel-synclinal. The maximum (true) incidence angle comprises 10°–12° SSW. The formation is composed of parallel, straight-lined and relatively thin (2–10 cm) sand-and-gravel layers extended along the strike. The layers are mostly homogeneous.

In the western wall of the quarry is a large-scale obliquely stratified formation that extends 150 m. Its true incidence angle is 15°–20° south in a section perpendicular to the strike. The material here is rougher than that of the first obliquely stratified formation with the prevalence of the pebble beds (thicker than 0.5 m) that have been replaced by thick (up to 1.5–2.0 m) boulder-pebble sediments with sand-gravel interlayers southwards.

The lacustrine sediments in Point 2 could only be studied in the bottom part of the northern bench, where they were partly covered by a talus. For their documentation, the surface was stripped in a number of places. Slack water sediments (Fig. 6, signs 3–7) form a large lens limited in its lateral directions by oblique fluvioglacial formations (Fig. 6, signs 1, 2). The scale of the material has increased from the bottom up while the sediments had been filling the basin. The top reaches its highest point in the center of the northern wall (Fig. 6*a*) where silty thinly bedded sediments overlay typical varve clays. This is the place where facial transitions between lacustrine and fluvioglacial sediments are most fully presented for they contain interim, seemingly, nearshore facies with small current ripples.

The abovementioned transitional sand-aleurite formation (Fig. 6*a*) is a rhythmic interbedding of medium-grained sands and silts with the properly-structured current ripples that have formed by the flow-transported sand sediments along both the steep (oblique stratification) and smooth slopes. The thing interrelating the wavy stratification with current ripples is the significant asymmetry of stratification and ripple index exceeding the characteristic values for wave ripples (5–10). The layers composition is clearly two-part and varve (aleurite in sand) with the direct sorting indicating normal flow velocity pulsation (abrupt increase and slow reduction). It is characterized by asymmetric weakly and strongly displaced waves with rounded tops. In the ripples (Fig. 5*d*) the layers are thicker in the steep (anterior) slope and their material is bigger than of that of the smooth slope. The layers form the series (3–15 bands) displaced relative to one another, forming the synclinal gaps filled with sand material. In the lenses sometimes one can distinguish obliquely stratified textures with accumulations of dark-colored mineral grains. The sand-aleurite bands are 5–18 mm thick, their wave length—10–22 cm, amplitude—1–3 cm, ripple index—8–15.

As a rule, from the bottom up, the asymmetric ripples displace southward as well as the anterior (steep) slopes of the waves that also look southward. It brings us to the conclusion that a flow of higher intensity (no seasoned obliquely stratified series) in the shallow part of the lake basin had preserved its southward direction for a relatively long time. Most likely, it happened due to that melted glacial waters coming from the north that had formed the big obliquely stratified formation comprising the upper part of the terrace's section.

In the outcrop (Fig. 6*a*) placed below the nearshore facies, we observed a gradual transition into tight varve loams with typical textures to envelope large detrital rocks (dropstones). The outcrop bottom part contains boulders and the textures changing from abutment to enveloping. It also has abrupt, dome-like layer bends in the places where the inclusions near the stripping plane. The adhering layers go to the substrate edge, wedging near its top (asymptotic contact). The enveloping layers go over the dropstones, getting thinner above their tops and widen in the gaps between the boulders. The observed textures occurred due to gradual leveling of the irregularities on the rocky bottom of a periglacial lake by sediments. At the height of 20–30 cm above the dropstones, the layers stop bending completely and the stratification becomes parallel. The bends are 2–3 mm thick and each 6–14th bend is much lighter than the others. In general, in their composition prevail dark (winter) layers, indicating the sediments accumulated in a relatively deep (distal) part of the lake.

In the other two outcrops (Fig. 6*b*, *c*), the lacustrine residues have been significantly washed out and their erosion contact is overplayed by obliquely stratified fluvioglacial material. The outcrops demonstrate different examples of

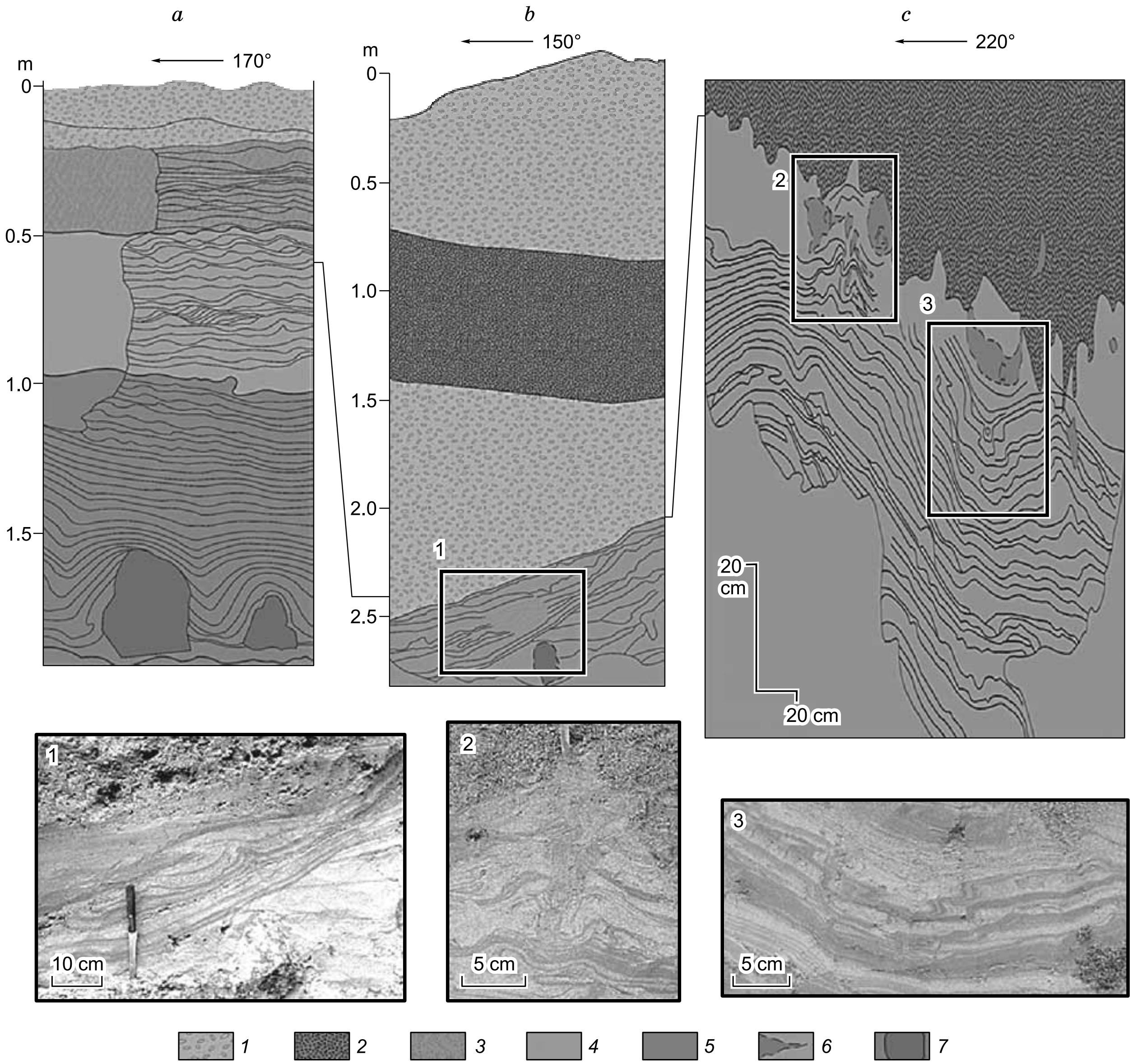

Fig. 6. Deformation structures in the glacial-lacustrine sediments opened in the western edge (Point 2) of the sand-gravel quarry at the bottom of the Southern Kukisvumchorr mountain. *1*, *2*, layers of fluvioglacial genesis: *1*, homogeneous gravely sands, *2*, homogeneous coarse-grained sands; *3–5*, layers of glacial-lacustrine genesis: *3*, medium-grained sands with oblique wavy structure; *4*, rhythmic cross-bedding of silt and fine-grained sands with parallel and displaced (to the south) current ripple; *5*, varve loams with enveloping and abutment structures; *6*, inclusions of dense, homogeneous silts; *7*, dropstones. Photos of outcrop fragments with stratification deformations: 1, inclined anticlinal microfold; 2, subvertical v-shaped structure; 3, disharmonic plication with small flexures.

disturbances of both horizontal and inclined stratifications. For instance, in the top of the glacial-lacustrine sediment layer (Fig. 6*b*) is a singular peaky anticlinal fold inclined in the direction of the layer inclination that is limited by a dark thickened layer (5 cm), whose boundary is twisted in the direction of the fold's inclination. From the bottom the folding is limited by an interlayer of coarse-grained sand.

In the other outcrop (Fig. 6*c*) are abrupt layer twists, whose changing thickness to the degree of bend cross-clumping indicates intense postsedimentary redistribution of the deposits. For instance, in the right part of the stripping (fragment 3), the gray silts become curved and form flexures in which the layers inclination becomes vertical and even reverse. The top of the layer also contains a subvertical v-shaped structure of 15 cm in length and 5 cm in width (fragment 2). The material here wedges into the enveloping sediments top down breaking the layers and making them curve downward. The layers push the material aside forming twin synclinal sand-layer widenings as compensation.

Quaternary complex in the Vuonnemiok River valley. In the southeastern part of the Khibiny is the Koashva quarry that penetrates a finite moraine closing the Vuonnemiok

River valley. The ridge formation period is determined to be the Allerød–Younger Dryas (Evzerov and Nikolaeva, 2000). The outcropped late Quaternary complex (Nikolaeva, 2014) is 65–70 m thick and composed of (top to bottom) a late Valdai glacial moraine; a fluvioglacial sand-gravel-pebble bed; glacial-lacustrine varve sediments; and an unsorted bounder-block moraine of mountain glaciation. According to drilling data (Chuvardinskii, 1985) the varve sediments layer extends continuously along the Vuonnemiok River valley and deepens at the incidence angle of 2°–3° relative to its depression line. Its thickness varies from 2 to 12 m, gradually reducing at the upstream and edges of the valley.

Inside the subhorizontal layer (5–7 m thick) of the glacial-lacustrine deposits in the south-western wall of the quarry we found two disturbed horizons propagating within strictly limited stratigraphic boundaries. Morphologically, they are different from the local deformations in sand-silt sediments described above and have been considered in detail in (Gorbatov and Kolesnikov, 2016).

The upper horizon of 0.5 m thick is expressed only in its outmost southeastern part of the bed and manifests itself as a sequence of narrow, overturned and twisted synformal and wide antiformal folds with prevailing northeastern vergence.

The lower horizon traced as far as 300 m is 0.6–1.0 m thick and underlaid by a sand-gravel-pebble moraine. The folds of northeastern vergence prevail here as well. Among the relatively simple folds of isoclinal, fan-shaped and box-like forms we spotted a complex fusiform fold with a mushroom-like core (Fig. 7). The varve sediments contain singular inclusions of large coarse waste and coarse-grained sand. With no cut-off, the folds are overlaid by an unstructured homogenous horizon with large detrital silty inclusions that sometimes includes the fragments of deformed varve loams. The horizon has an even top overlaid by thin-layered varve loams.

In the central part of the northwestern wall of the quarry where the varve deposits adhere the crystalline pluton, a folded deformation of 20 m in length and 1.8–2.5 m thick was found. The deformation structure is composed of light and dark gray silt and consists of a few beds that form overlaying, overturned and plunging folds with the amplitude of up to 2 m. The axial planes of folds are inclined from the

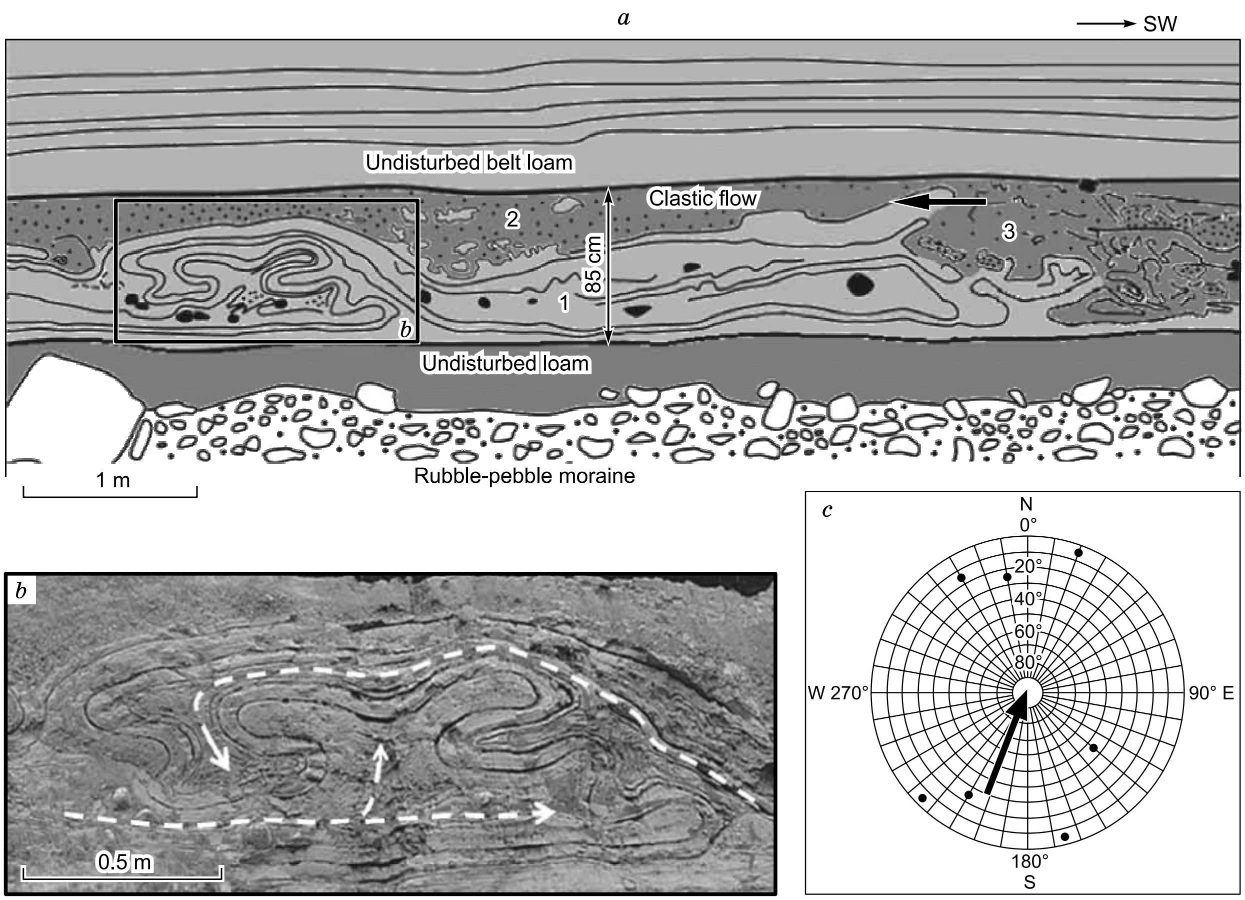

Fig. 7. Fragment of a folded horizon in the bottom of the varve-clay layer stripped in the southeastern wall of the Koashva carrier. *a*, outcrop schematic showing a deformed horizon including: 1, plicated loams with pebbles; 2, unstratified silts with the fragments of Stratum 1; 3, macro-fragmented and mixed stratified silts; *b*, photo of a complex diving fold with mushroom-like core and a schematic reflecting the way the material moves; *c*, circular diagram depicting the azimuths and incidence angles of axial planes based on the measurements from the southeastern wall of the quarry (Nikolaeva, 2009), and the reconstructed movement direction of the detrital flow that formed them.

rocky wall north-northeast. The gaps between the folds are filled with dark gray homogeneous aleurite with large detrital inclusions. The placative structures attenuate with the distance from the rocky pluton.

SEDIMENTATION EVENT SEQUENCES IN FORMATION OF THE DESCRIBED SEDIMENTS AND THEIR RELATION TO DEFORMATION EVENTS

Kukisvum finite moraine. The investigated section of the proximal (inner, turned to the glacier) slope of the Kukisvum finite moraine demonstrates a transition of a partially rewashed and strongly sanded moraine (Strata 1, 2) through fluvioglacial deposits (Strata 3–6) with subordinate layers and lenses of glacial-lacustrine sediments (Strata 4–7). The section composition brings us to the conclusion that before moraine formation due to glacier advancement from the south in the early Valdai, fluvioglacial flows had acted in the glacier's front bringing from its body some detrital material and forming small lakes accumulating stratified sediments as the lenses enveloped by fluvioglacial deposits. Such stratification of the fluvioglacial material demonstrates that it had been formed by a number of currents that often migrated and changed their direction.

Here, we have to discuss a number of characteristic features of the fluvioglacial sediment section in the Kukisvum moraine ridge:

1. The transitions between different structures and granulometric differences do not contain an expected sequence that is typical, for instance, for alluvial facies.

2. The material is about to undergo reverse sorting throughout the whole bed—all parts of the section (from the bottom up) get rougher including fine-grained sand-aleurite sediments and coarse-layered, large detrital moraine-like formations.

3. The sediments have a number of facial types of subaqueous sediments such as (a) coarse-layered sequences with lens-like and chaotic stratification (facies of powerful subglacial (?) flows; (b) small sand lenses of oblique stratification (facies of the small currents and creeks that often change their direction); (c) fine-grained sands with low-angle wavy stratification (facies of a planar flow or the shallow part of the lake); (d) varve loams (distal, deeper lacustrine facies)

All the deformation structures determined in the moraine section (repeated tongues, microfolds and ovoids are related to the top of Stratum 7 in the common section (Fig. 2, Stratum 3) that is composed of rhythmically interlaying sands and silts (low-angle wavy and displaced stratification) overlaid by gravel-pebble sediments.

Fluvioglacial terrace at the bottom of the Southern Kukisvumchorr mountain. Observing the inner composition of the fluvioglacial terrace in the two points located near the back suture of the terrace (Fig. 1*A*, Point 1) and edge (Point 2) has enabled us to separate at least four consequential sedimentation events that occurred in the Late Pleistocene (1–3) and Holocene (4) periods while forming the current shape of the relief:

1. Accumulation of the varve silt enveloping dropstones in the distal part of a small periglacial lake basin. The varve stratification and presence of dropstones confirms its glacial feeding.

2. Accumulation of sand-aleurite sediments with current-ripple marks in the shallow part of the lake in presence of periodic melted water inflows from the north, which is confirmed by ripple mark direction.

3. Short-term discharge of glacial water down the Kukisiok river valley formed a large obliquely stratified sequence (Fig. 3) that nonconformably overlays glacial-lacustrine sediments.

4. The fluvioglacial deposits in the vicinity of the back suture of the terrace are overlaid by a blanket of colluvial accumulations.

The sufficient thickness and oblique stratification unidirectionality of the upper boulder and gravel-sand bed in the sand-gravel quarry indicate two characteristic properties of sedimentation during Sedimentation Event 3, which is the high velocity of current and its unidirectionality. The detrital material was trained along a wide front, and that allows us to consider the sediments the upper part of the terrace is composed of as the facies of a powerful streamflow in its discharge area (such as a periglacial lake inflow) that acted for a relatively short time, cause this flow formed only a single obliquely stratified sequence but of rather sufficient thickness (more than 8 m).

All the bed incidence azimuths in all the outcrops are concentrated in the southern bearings, which is the evidence the water flow went from the north to the south (down the Kukisiok river valley) since sedimentation occurred on the anterior slope of a levee that has a significant extension, width and straightness. What is interesting here is the smooth slope of the layers of the obliquely stratified sequence that varies within 10°–20°, which makes the considered sediments closer to marine facies (10°–25°) rather than to alluvial ones (20°–30°) (Botvinkina, 1962).

A possible source a powerful flow could have been a catastrophic discharge of the waters (spillway) of the lake located in the ice-dam through valley of the Kuniiok River that went through the Kukisvumchorr pass (the direction of the discharge is indicated with the arrow in Fig. 1). The fluvioglacial terraces in the Poachiok River valley were also formed due to similar spillways (Anan'ev, 1998a,c).

The bottom bed of lacustrine genesis (Stratum 5) in Point 1 contains sand with regular wavy stratification produced by current ripple. Its low ripple index (4–6) is characteristic for subaquatic sedimentation, and its symmetry and absence of displacement indicate the presence of weak but directional currents that are typical for nearshore parts of shallow lakes.

The stratification of the fine-grained sediments in Point 2 reflects seasonal changes between water current (summer) and stagnant (winter) sedimentation types with rhythmically—alternating depositions of sand and aleurite materials. Displacement of wavy layers (Fig. 6*a*) occurred due to ripples moving down the flow (from the north to the south) because sand deposited mainly on their anterior and steeper slop. As the flow velocity reduced, the ripples stopped their motion and were covered by the fine-grained material falling from suspension. The increased velocity, in the other hand, made the sand layers increase abruptly while the ripples displaced forming the oblique-wavy stratification. Increasing flow velocity may also result in destruction of the sand layers in a lenses chain. What is noteworthy is the rhythmicity of the bed and the unidirectionality of the ripples (throughout the whole outcrop) that point at long-term preservation of flow direction in presence of seasonal flow velocity pulsation.

Layer by layer study of the fluvioglacial terrace section has allowed us to establish that the disturbances such as singular anticlinal folds, current ripple deformations, shale twists, plications, etc., belong to the bed of rhythmically interlaying sand-silt sediments accumulated in the shallow part of a small periglacial lake (Sedimentation Event 2). All the disturbances are irregular and neither form extended along the strike horizons nor repeat themselves in sections, rather most of them are related to the partly washed-out of lacustrine sedimentary layer top overlaid by an obliquely stratified fluvioglacial sequence. Thus, the singular v-shaped intrusion (Fig. 6*c*, fragment 2) belongs to the upper boundary of the sand-aleurite bed, while the current ripple deformations—to inner part of the lacustrine sedimentary sequence.

Koashva quarry. Studying the Quaternary sediments opened by the Koashva quarry has allowed us to separate at least four Late Pleistocene sedimentary events:

1. Sedimentation of the eroded bedrock of the main moraine by mostly the detrital nepheline syenites of the Khibiny pluton during the mountain valley glacial phase of the early Valdai.

2. Sedimentation of varve loams and silts in the periglacial lake locked in upper part of the Vuonnemiok valley being dammed by the edge of retreating late Valdai glacier during the Allerød(?) warming (12.7–13.4 ka). The sedimentation was accompanied by the deformation events manifested in the extended horizons of plicative deformations.

3. Sedimentation of the obliquely stratified sequences of sand-grave-pebble sediments related to a facies of the fluvioglacial delta accumulated at the edge of the late Valdai glacier. Prevalence of western and south-western incidence azimuths (Nikolaeva, 2009) evidence that the glacial water moved up along the Vuonnemiok river valley.

4. Sedimentation of the main moraine of the late Valdai glacier by mainly allochthonous detrital, acid, base and metamorphic rocks. The moraine formed the body of the finite levee during glacier advancement in the phase of late Dryas cooling (11.7–12.7 ka).

CONCLUSION. GENESIS OF DEFORMATION STRUCTURES AND THEIR COMPARISON AGAINST SEISMOGENIC DISTURBANCES

The found deformation structures got developed in glacial-lacustrine sediments of different lithological types: from varve clays and silts with horizontal and low-angle wavy stratification to medium-grained sands with oblique-wave bedding. Their association with subaquatic sediments confirms they occurred in soft, water-saturated sediments during their accumulation or right after this process was complete, but before the sediments lost their capability for plastic deformations. Since the found significant contortions could not have been preserved at the bottom of the basin it is apparent that the sediments had deformed after they were overlaid by new layers.

The formation of various nontectonic deformation structures in the weakly lithified subequal sediments may have been related to the dynamic sedimentation conditions (traction effect; pore pressure changes in the sediments moved by bottom currents and waves; fast sedimentation); underwater landslides (sediment liquefaction on inclined surfaces); convective, glaciogenic and cryogenic processes; and seismic effects.

Despite the development of interlayer plicative deformations in the sediments that are genetically related to moraines (at least those in the moraine section and the Koashva quarry), the glaciodynamic factor of their formation can be excluded for two reasons. First, the glaciotectonic dislocations should cover the whole bed of stratified glacial-lacustrine deposits and contain areas of intensive contortion; chaotic or fold-overthrust vergent structures, and possibly, collapse dislocations and large load marks (Gruszka et al., 2016) in case a moraine is formed over a weakly consolidated or partly-melted substrate with buried ice lenses. No structures of this kind have been observed in the strippings studied. Second, moraine material onlapping a consolidated and relatively competent fluvioglacial or limnoglacial substrate seems to often occur without any sufficient deformation of the latter but rather by encroachment of a thrust or a detachment along a subhorizontal surface (Piotrowski et al., 2001).

Since the deformations observed formed almost right after accumulation of yet soft, water-saturated sediments in a lake, their genesis can be explained by the inner factors related only to aleurite and fine-grained sand sedimentation conditions in shallow water of lakes. Deformation of such sediments is usually caused by their increased ability to liquefaction and other thixotropic effects even in presence of the very small static and dynamic loads that occur during sedimentation (heterogeneous static pressure, current and wave effects) or right after it (frost penetration). It is noteworthy that the most intensive convolutions are associated with the fine—and small-grained sands and silts easily losing their adhesion in water-saturated conditions even at the lowest external loads such as seismic quakes or an area with inverted density gradient (Tsuchida and Hayashi, 1971). It also should be pointed out that no expressed convolution structures present in the sediments, either in those saturated with clay particles (varve loams) or in large detrital sediments such as coarse-grained and gravel sands.

In our opinion, the most apparent reason for the formation of the small-size convolution structures (anticlinal direct microfolds and ovoids) in the moraine sections and fluvioglacial terrace must have been the convective instability of subhorizontal water-saturated sediments (Figs. 2, 5*a*) under the conditions of inverted densities; and a combination of the convective mechanism with an underwater landslide along inclined slope (Fig. 6, photo 1).

Thus, the periodic narrow anticline structures of rising intrusion subdivided by wide synform folds (Fig. 2, right photo) at the first glance are similar to central depressions. Such deformations occur due to convectional instability (Stage II) (Artyushkov, 1963a,b) in a two-layered medium with inverted density (for instance sands over silts) when the viscosity of the upper layer is less than that of the bottom one (Artyushkov, 1963a,b). Ovoids and drop-like fragments (pseudonodules) in this case can be considered as a finite result of the instability developing in layered sand (Stage III). Analogous interpretation for contrasting viscosities in a two-layered model with inverted densities has been given for the dome-like structures of descending intrusion (load marks) divided by the diapir-like anticlinal folds forming in presence of seismic fluidization (Alfaro et al., 1997, see Fig. 6).

Now let us illustrate the general feasibility of the two conditions set by E.V. Artyushkov (1963a,b) that are sufficient for developing of convective instability in soils. These are (a) inverted sediments density and (b) low resistance to soil shear that is sufficient for autodevelopment of small primary perturbations at the uneven interlayer boundary, for instance in presence of low-angle wavy bedding. The first condition is apparently fulfilled due to sequencing of the sand and aleurite layers with contrast density in the studied sections. Making sure that the second condition is fulfilled is far less trivial task, however the shear resistance in presence complete water-saturation can be very small and yet sufficient for convection development. In this case it should be taken into account that growing sediment consolidation due to the pressure of overlaying layers increases shear resistance significantly, so the convection structures are likely to be formed right after accumulation of their host sediments.

The small layer raptures of thrust kinematics in the moraine section seem to have been a result of fragile deformation of a consolidated sediment and formed later than the plicated deformations associated with them. A possible reason for their formation could have been the lateral pressure of a glacier during formation of the levee forming the upper part of the section.

The complex contortion structures with fracturing and partial mixing of separated layers (Fig. 5*b*) that do not have a clear boundary between deformed and nondeformed sections are most close in their texture to the roiling structures as they described by L.N. Botvinkina in her classification (1962). Such structures are typical for shallow-water sedimentation conditions and are related to affecting fluid, water-saturated sediments by the eddy motions of water that neither wash them out nor produce any suspension and only deform the sediments.

Association of complex sediment transitions with the roiling structures is confirmed their development in sands with oblique-wave stratification that points at the presence of bottom flows in shallow lake waters that may result in roiling of accumulated sediments, and since the layer contours remain washed out, the sediments must have presented their semifluidized condition.

Some of the deformation structures can hardly be divided from the textural features of their host sediments. For example, the low amplitude waves (Fig. 5*a*) in the bottom part of the sand-gravel quarry must have been a result of the secondary deformation (due to convective instability) of parallel current ripples that in places transformed into oblique-wave stratification. Since the diapir-like layer bends could not have been preserved at the bottom of the basin, the sediments got warped after being overlaid by other sediments. Analogous sediment structures related to wavy stratification deformation are capable of forming relatively extended horizons, which can be the basis of their incorrect classification as seismites.

It cannot be excluded that the transition of sediments into the fluidized state so necessary for development of convolution structures while forming a fluvioglacial terrace could have been related to the frost penetration and top melting cycles during changing the sedimentation regimes at the time boundary between Sedimentation Events 2 and 3. This does not contradict to spreading the deformations in Late Pleistocene sediments. This assumption is also supported by the deformations in section of fluvioglacial terrace (Point 2) that are associated with the lacustrine sediments top, as well as the v-shaped body found among them that looks like a small ground vein—a pseudomorph formed in an ice wedge (Fig. 6*b*) in paragenesis with disharmonic flexural folds.

The deformation structures considered above should be distinguished from the enveloping textures (Fig. 6*a*) that are not related with postsedimentary deposit distribution and are a result of sedimentation of an uneven surface and large detrital inclusions such as dropstones.

The small deformation structures (tongues, ovoids, layer twists, etc.) studied in the two sections do not satisfy the main criteria earmarked in (Sims, 1975; Hempton and Dewey, 1983; Obermeier, 1996; Wheeler, 2002; Van Vliet-Lanoë et al., 2004; Deev et al., 2013; Korzhenkov et al., 2014) for the seismogenic convolutions that occur due to well-known string earthquakes despite that these deformations have developed in a medium susceptive to earthquakes. In particular, these structures do not extend along the strike, do not repeat themselves in sections, they are asynchronous, have no lateral convolution, paragenesis with clastic dikes and other manifestation of fluidization and hydronic fracturing. Moreover, the available data do allow us neither to verify the suddenness of their formation nor to prove synchronous distribution of the deformation structures in a closed area, where deformation intensity increase closer to their its center, which is typical for seismites.

The collected data have enabled us to suggest the following criteria for classification of the deformations found in glacial-lacustrine sediments as the sedimentational structures related to local physical and mechanical sedimentation conditions and to describe their differences from seismogenic convolution:

1. Development of deformation structures in sand-aleurite sediments susceptible to thixotropy while consolidation.

2. These is a close link between the morphology of deformation structures and the sedimentation conditions of host sediments and their structural features (granulometric composition and stratification type).

3. The sections do not contain extended lateral deformation horizons that periodically repeat themselves among undeformed sediments, which do not allow one to correspond separated convolutions with the effects of periodical fast external processes such as earthquakes.

4. Absence of clear stratigraphic relation between the convolutions to indicate their synchronous formation despite their relatively wide spreading in the sections.

5. Development of convolution structures in sequences with inclined stratification that does not allow excluding their formation due to a gravity flow or to a landslide.

6. Absence of systematic data to describe the convolution elements' morphology or their orientation in space.

Now let us consider the genesis of folds in the glacial-lacustrine sediments opened in the Koashva quarry. These deformations are significantly different in their morphology and occurrence from the small deformation structures we have considered above, while a number of their features (shape systematicity, presence of seasoned horizons) make them similar to seismogenic deformations, yet at the same time there are serious reasons not to consider these structures as seismites.

According to S.B. Nikolaeva (2014), formation of folds in the varve clays of the Koashva quarry is related to underwater landslide of the sediments accumulated on the inclined parts of the lake basin that could have occurred due to disbalance of their critical equilibrium point due to the dynamic effects of seismic quakes. The sequencing of disturbed and undisturbed layers may be related to alternating periods of seismic activization and seismic quiescence.

In our opinion (Gorbatov and Kolesnikov, 2016), the high repeatability of systematically oriented folds in the plicated horizon and their ubiquitous overlaying by homogeneous sand-aleurite sediments (Fig. 7) allows us to assume that their formation could have occurred under the condition of consolidated sediments traction caused by the friction of dense detrital flow. For instance, measurements of the azimuth and axial-plane incidence angle of a few folds in the southeastern wall of the quarry (Fig. 7*c*) have demonstrated a presence of almost sublatitudinal mechanical effect affecting their formation (marked with the arrow), which does not contradict the hypothesis of the dense detrital flow coming from the southern edge of the valley. Analysis of the structure of the twisted fold shown in Fig. 7 has justified our conclusion that this hypothetical detrital flow that had sedimented the homogeneous material and twisted the underlaying layers counterclockwise flew from SW to NE, i.e., from the slopes of Kitchepakhk mountain adjacent to the Koashva quarry to the center of the Vuonnemiok river valley (this direction is marked with an arrow in Fig. 1*B*).

It should be underlined that the deformed horizons have no signs of vibrational liquefaction such as abrupt fluctuation of outburst, intrusion and liquefaction thicknesses (Obermeier, 1996) that should have occurred in presence of powerful seismic quakes. Enveloping of the most extended part of some of the folds by subhorizontal layers clearly demonstrate that while contortion, plastic layer sediments were dense enough and did not disperse under their own weight. In presence of seismic fluidization this microrelief could not have sustained. The most probable reason for formation of the plicated horizon might have been a mud stream going down the slopes of an adjacent mountain pluton or from the upper part of a valley after a glacier burst. This discharge may have formed a dense detrital flow that had deformed the consolidated varve loams.

The performed investigation into the sedimentation conditions and deformation mechanisms of soft sediments of the Khibiny pluton has not allowed us to confirm the seismic genesis of the deformation structures as new one as those described in earlier publications. The section of varve silts in the Koashva quarry has demonstrated that even the most seasoned horizons of intensive contortion that are extended for hundreds of meters along the strike and separated by undeformed sediment layers, despite of their similarity to seismogenic convolutions (systematic folds similar in shape and orientation, their instantaneous formation, etc.), may not be related to seismic effects.

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