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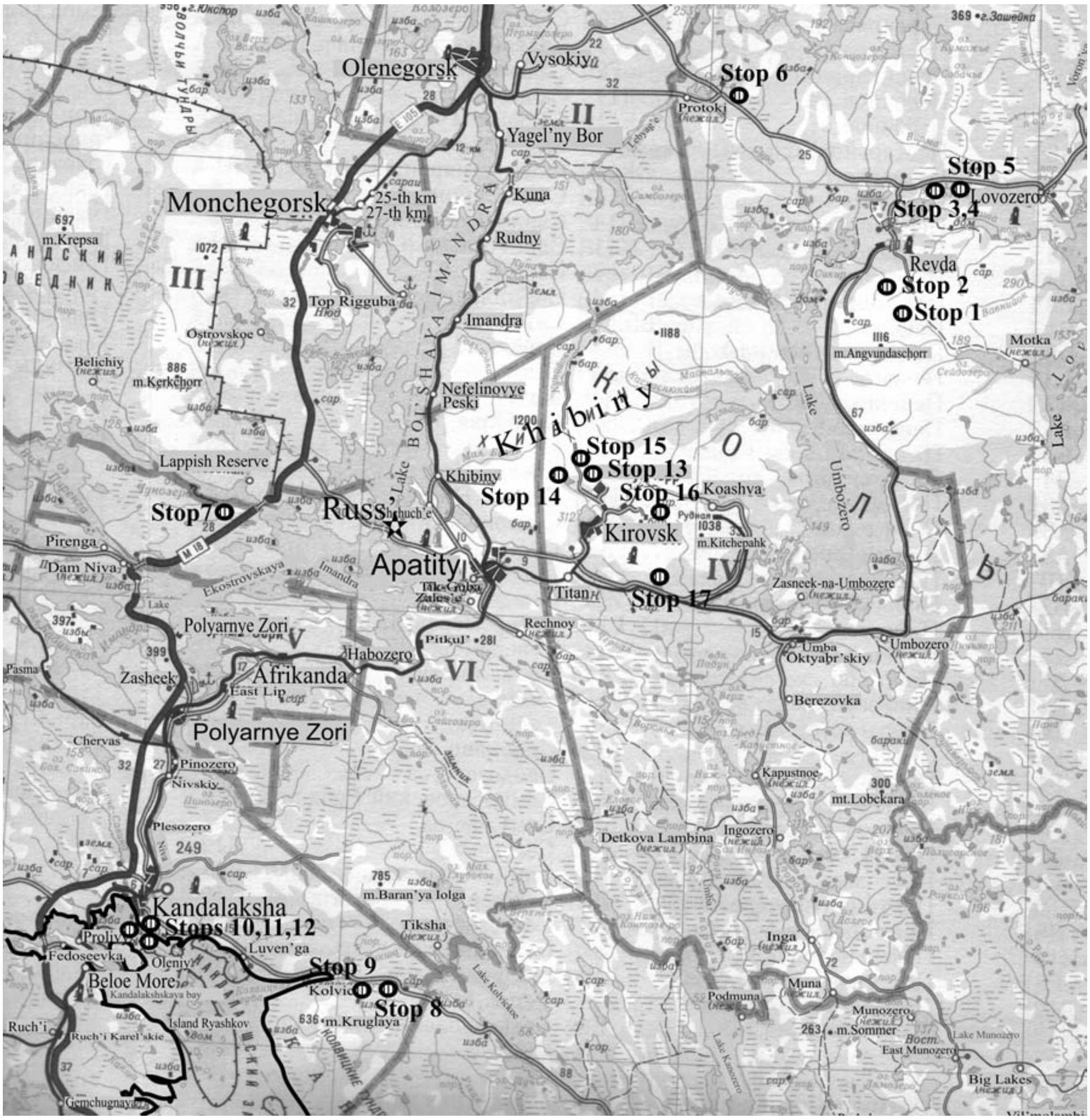

Fig. I. Map of field sites visited during the excursion.

Stop 1. Plateau-like summit of Alluaiv Mt. (1051 m a.s.l.)
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Quaternary Stratigraphic Records of Kola region

Korsakova O.

Geological chronicle of the formation of unconsolidated cover on the Kola region begins with the ***Moscowian (Saalian) glacial horizon***. It is overlaid by the ***Mikulinian (Eemian) Interglacial horizon*** and the ***Valdaian (Weichselian) glacial superhorizon.*** The latter one is subdivided into the ***Podporozh'e*** and ***Ostashcovian glacial*** and ***Leningrad interstadial horizons*** (Fig. II).

Moscowian (Saalian) glacial horizon (Q_{II}ms, MIS 6)

Moscowian tills and melt-water deposits (gIIms, fIIms, lgIIms, gmIIms) overlie the basement rocks and eluvium and are located in the deepest depressions of the pre-glaciation relief and river valleys. They are found by same researchers in various times (Armand et al., 1969; Yevzerov, Koshechkin, 1980; Semjonova, 1998; Korsakova et al., 2004; and another) on western and central parts of Kola region (on the northeastern slopes of the Pechenga Tundra, in the area of the Kovdor alkaline-ultrabasic massif and Umbozero Lake), on the South and Northeast Kola Peninsula within the Terskii Coast of White Sea (at the lower parts of the Kamenka, Strel'na, Chapoma, Ust-Pyalka, Ponoi rivers, and at the valley of the Iokanga river and at the head part of the Svyatoj Nos Bay). There is an opinion (Armand et al., 1969), that in these cases the formation of the Moscowian (Saalian) Glaciation' till came to the end in marine basin under the Dryas-like conditions (according to paleontological data).

Judging from petrographic composition of the detrital material from the till horizon of the Moscowian (Saalian) Glaciation, ice flows moved towards the north-east in the north-western part of the region, and towards the south-east in the area of Kovdor massif and southern coast of the Kola Peninsula (Geology ..., 1995).

Moskowian (Saalian) Glacial Horizon is overlaied by the Mikulinian (Eemian) or the Valdaian (Weichselian) Horizons in the all known sections.

Mikulinian (Eemian) Interglacial Horizon (Q_{III}mk, MIS 5e)

The Mikulinian (Eemian) Interglacial sediments are revealed in the peripheral parts of the Kola Peninsula and confined to the valleys of the rivers in the southern, eastern and north-eastern coast. In the central part of the region the sediments of the Mikulinian Interglacial were found only in one place.

The marine sediments of that time on the Kola region are known as the Ponoi beds (mIIIpn) in Russian scientific publications. This unit, which is composed of compact clays, loams, sandy loams, and fine-grained sands of the littoral and sublittoral zones, is exposed in the lower parts of the examined sections along the Varzuga, Strel'na, Chapoma, Ponoi, Kachkovka rivers, and at the head part of the Svyatoj Nos Bay. Paleoecological reconstructions (Lavrova, 1960, Grave et al., 1969, Gudina, Yevzerov, 1981) demonstrate that the sea basin, where these sediments accumulated, was characterized by a more favorable environment as compared with the modern one. The water salinity was close to the normal one, and its temperature was higher than in the present-day White Sea, which is typical of the first optimum of the Mikulinian (Eemian) Interglacial and correlated presently with oxygen isotope substage (OISS) 5e. All the data unambiguously indicate on the Mikulinian age of the Ponoi Beds, which were accumulated during the Boreal transgression. The upper sea limit reached near 150 m a.s.l. at the time of climatic optimum. The sea occupied a considerable area within the continent. The Barents Sea and the White Sea were connected by numerous straits. The Atlantic warm waters freely penetrated into the White Sea, where the boreal and boreal-lusitanian species of marine organisms started to extend.

The ESR/OSL-age of the Ponoi Beds ranges from approximately 120--130 to 100--105 ka (Korsakova et al., 2004). These geochronological data suggest the longer Mikulinian Interglacial that includes at least MIS 5e-d on Kola region.

The lacustrine and peat interglacial sediments are confined to the depressions of the basement relief in the stable tectonic areas of the central part of the Kola region. They were found on northern slopes of the Lovozero Tundras.

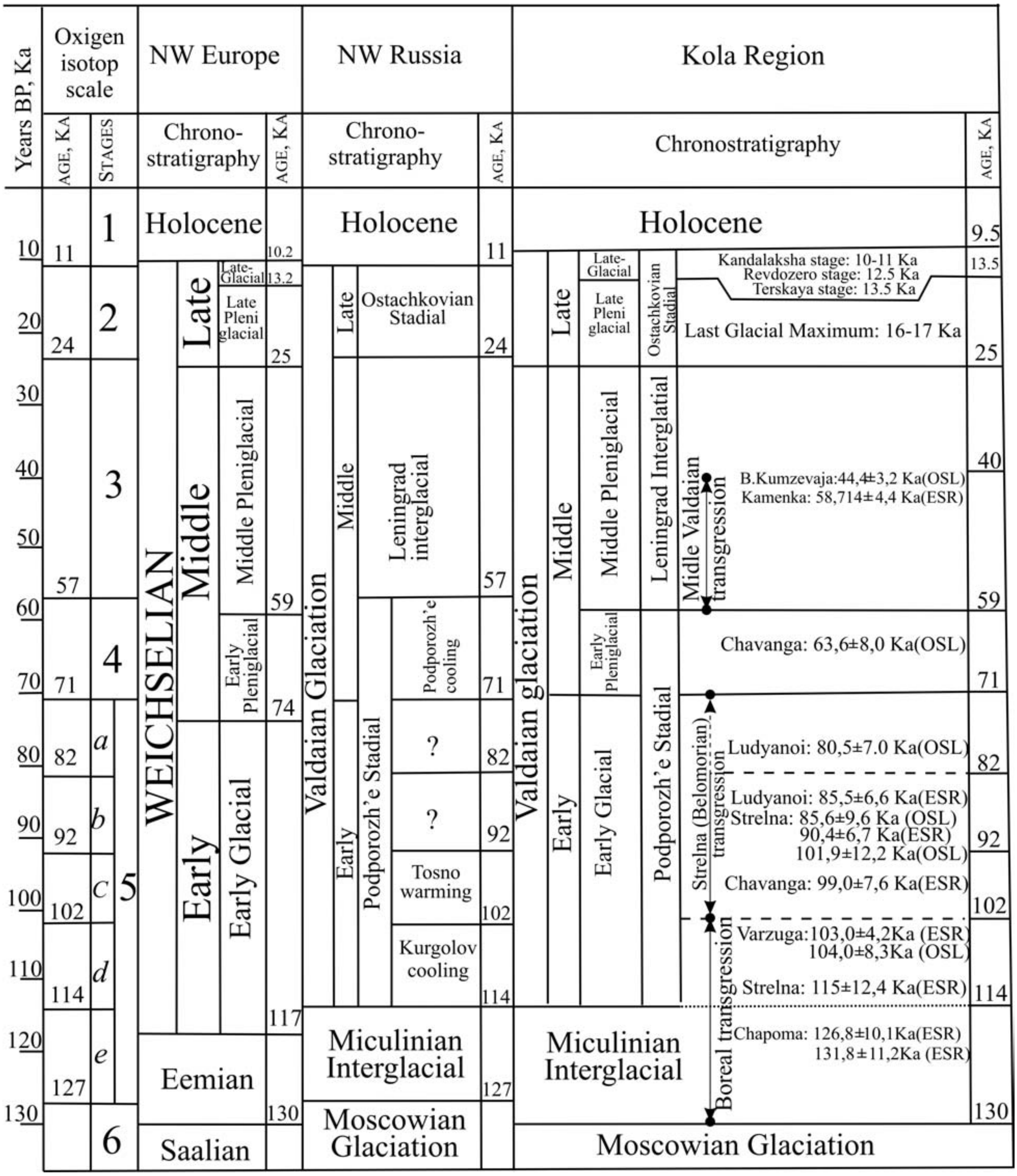


Fig. II. Comparison of chronostratigraphy in NW Russia and in NW Europe (after Tarnogradskii, Kapljanskaja, 1992; Additions to Russian Stpatigraphic Code, 2000) with chronostratigraphy in Kola region and their correlation with oxygen isotope scale.

Most of interglacial sections are confined to the areas of weak tectonic activity typical of the eastern Baltic Shield. The present-day absolute elevation of the roof varies from several meters up to 140 -150 m a.s.l. for the marine interglacial deposits, and reaches 210 m a.s.l. for the continental interglacial deposits.

Podporozh'e (Early-Middle Weichselian) Glacial Horizon (Q_{III}pd, MIS 5d – MIS 4)

The Podporozh'e horizon is credibly dated. Its position in the regional stratigraphy, the timing and the geological volume are still disputable (Semjonova, 1998, Yevzerov, Nikolaeva, 2000, Korsakova at el., 2004). At the present the Podporozh'e horizon has combined marine (mIIIst), glacial (gIIIpd), glaciomarine (gmIIIpd), glaciofluvial (fIIIpd), glaciolacustrine (lIIIpd) sediments of the Early-Middle Valdaian (Early-Middle Weichselian) age.

The marine deposits (in Russian scientific publications they are known as the Strel'na beds (mIIIst)) are mainly represented by the marine and subsaline sediments of the littoral and sublittoral zones of the thickness up to 30-35 m. Strel'na beds are composed from loams and sandy loams with mollusk shells, pebbles, boulders, and from fine- to medium-grained sands with lenses of coarse-grained varieties. The bedding conditions and structural--textural features of these marine sequences, ESR-age of subfossil mollusk shells, and OSL-age of host sediments (Korsakova at el., 2004) imply that they were formed during low-amplitude transgression, interrupted by short-term regressions and erosion during interstadial coolings, and followed the Boreal transgression. This transgression is named Belomorian after M.A. Lavrova (1960) and Strel'nitskaya after V.Ya. Yevzerov (Gudina, Yevzerov, 1981). The early Valdaian sea appeared no earlier than 100--80 ka ago in the southern Kola Peninsula. Paleontological remains enclosed in these sediments indicate on ecological conditions close to the modern one or colder (Grave at el., 1969, Lavrova, 1960). The lower part of the Strel'na Beds, composed of compact loam with abundant mollusk shells, is exposed under glacifluvioal sands near the water level of the Chavan'ga River at the altitude of 29 masl or lower. The Strel'na Beds (loams and sandy loams with mollusk shells, pebbles, boulders, and fine- to medium-grained sands with lenses of coarse-grained varieties) sandwiched between glacial sediments are observed at 42--52 masl near the Ludyanoi Creek mouth. Similar sediments are also recorded along the Varzuga and Chapoma river valleys, where they overlie the eroded surface of the Ponoi Beds.

Geocronological (ESR/OSL-ages) data and interglacial habit of the Strel'na Beds cause a discussion on the correlation of the Moscovian-Valdaian (Saalian-Weichselian) Interglacial to the whole MIS 5. The two transgressions (Boreal and Strel'nitskaya ore Belomorian) were successively developed in the continuously existing sea from 130 to 80-70 ka ago.

The deposits of the glacial paragenetic series of Podporozh'e horizon (till; glaciofluvial, glaciolacustrine, glaciomarine sand, clay, gravel, etc.) were revealed by prospecting of boreholes and shafts in the central (Grave et al., 1964), south-western (Biske, 1959), north-western (Nikonov, 1964), and western (Yevzerov, Koshechkin, 1980) parts of the Kola region. The till (gIIIpd) is characterized by highly consolidated material and represented by rubble sandy loam and rarely by loam in the Western Kola region. Glaciofluvial sediments as inequigranular sand and sandy loam are known in Kovdor area. The fixed thickness ranges from 1-2 to 22 m. The natural exposures of deposits that can be related to the Podporozh'e glacial horizon have been established on the Terskii Coast of the White Sea (Gudina, Yevzerov, 1981, Korsakova at el., 2004). It is the till (boulder loam, (gIIIpd)) in the Kamenka section, probably glaciomarine (gmIIIpd) boulder sandy loam and sand in Bol'shaya Kumzhevaya section, glaciofluvial (fIIIpd) and glaciolacustrine (lgIIIpd) sand and sandy loam in Chavan'ga section. The OSL-age of the latter ones is approximately 63 ka (Korsakova at. el., 2004).

For the present, the available data are not enough to reconstruct the limits of the distribution of the Early – Middle Valdaian (Weichselian) glacier in the entire area of the Kola region. There is an opinion (Yevzerov, Koshechkin, 1980) that the Early Weichselian ice sheet, advancing to the Kola region from the west, assimilated mountain glaciers in the western and central parts of the Kola region. The ice flow occurred in north-eastern and south- eastern from the ice divide zone. The ice divide zone was stretched in sublatitudinal direction from the Lotta river head to northern foothills Chibiny and Lovozero Mnts.

According to computer-based modeling data of Swedish and American researchers, the eastern part of the Kola Peninsula was free of ice of the Scandinavian center until approximately 70 ka ago (Näslund et al., 2003). The formation of the Podporozh'e glacial horizon in these areas was likely related to the development of the Kara glacier, rather than the Scandinavian glacier, in this area during the early Pleniglacial (OIS 4). This assumption is indirectly supported by finds of carbonate rock pebbles and boulders that are unknown in the Kola Peninsula but typical of the Paleozoic rocks in the northern Russian Platform (Zozulya et al.).

The Podporozh'e horizon overlies the marine and continental sediments of the Mikulinian (Eemian) Interglacial or the Moscowian (Saalian) till or basement crystalline rocks.

Leningrad (Middle Weichselian) Interstadial Horizon ($Q_{III}ln$, MIS 3)

The deposits of Leningrad Interstadial horizon are known in central part of Kola region from Imandra Lake to Panskiye Tundra, outcropped in more than ten localities (Lavrova, 1960, Grave et al., 1964, Armand et al, 1969 and another), in south-western Murmansk region (Armand, 1969), in Terskii Coast of White Sea (Gudina, Yevzerov, 1981, Korsakova et al., 2004). As a rule, these deposits are placed between two horizons of Valdaian (Weichselian) sediments of the glacial paragenetic series. They are represented by glaciolacustrine (lgIIIln) and melt-water (fIIIln) sediments (sandy loam, loam, inequigranular sand with pebble and boulder) of 2-20 m thickness in the central part of the Peninsula (Armand et al., 1969), and by marine (mIIIln), interstadial sediments (mainly by clay, loam, sandy loam with subfossil mollusk shells and other fossil remnants) of 1 m and less thickness in the area of Kandalaksha Gulf (Armand et al., 1969; Armand, 1969) and of 2-6 m thickness in the Terskii Coast (Korsakova et al., 2004). The latter ones were dated using the ESR- and OSL-methods, which made it possible to specify the geological--stratigraphic position of interstadial marine sedimentary units. The obtained geochronological dates (approximately 44 and 58 ka) point to its Middle Pleniglacial age (MIS 3).

There is an opinion (Yevzerov, Koshechkin, 1980), that Valdaian (Weichselian) glacial superhorizon combines sediments of two stages of the glaciation separated by interstadial deposits. The first stage of the Scandinavian sheet glaciation took place in the Early Valdaian (Weichselian) and corresponds to the MIS 5b, the second one – in the Early (partly), Middle and Late Valdaian (Weichselian) (MIS 2-4). The interstadial warming corresponds to Early Valdaian (Weichselian) (MIS 5a) and in the Kola region the Middle Valdaian (Weichselian) interstadial deposits (MIS 3) are not found out between horizons of the Scandinavian glaciation's tills, as it is in the northern Finland (Helmens et al., 2000).

Ostashkovian (Late Weichselian) Glacial Horizon ($Q_{III}os$, MIS 2)

The last glaciation's tills and melt-water sediments are the most common in the region. They are absent only in the Keivy Mnts. (eastern Kola Peninsula), and on the summits of mountains and uplands in the central and western parts of the region. In most cases they form top-section rocks and rarely overlain by latest lacustrine peat-bog, marine and deluvial deposits. Till is composed of the diamicton (rubbly silty sands, rubbly sandy loam and loam). The tills (gIIIos, gaIIIos, gkIIIos) of the Kola region are distinguished by the higher content of sandy fraction in all the facial varieties. The thickness ranges from the tens of centimetres to 30 m (Armand et al., 1969). The glaciofluvial (fIIIos), glaciolacustrine (lgIIIos) deposits are throughout confined to the tills of the last glacier. The glaciolacustrine deposits are represented by varved clay, loam, sandy loam and sand, and the glaciofluvial deposits are represented by inequigranular sand, gravel and rubbly pebble-bed.

Presently there are three view points on the evolution of the last glaciation and deglaciation in the region. According to the first view point the Kola region experienced the Scandinavian ice-sheet, composing of two flows and numerous lobes. During the late-glacial time the independed low active Ponoi glacier existed in the eastern Kola Peninsula (Lavrova, 1960; Strelkov, 1976; Yevzerov, 1990; and another).

The Late Valdaian (Weichselian) Scandinavian Glacier moved from the west conformably to the relief of the basement and was broke down into two ice flows - Barents and Belomorian. The mountain glaciers and an independent ice dome on the Keivy Mnts. formed in the western, central and eastern parts of the Kola in the course of continental ice expansion. The local glaciers were assimilated by the Scandinavian ice sheet and became active again during deglaciation of the area.

According to the overall gradient of the surface, the above-mentioned ice flows extended to the north-east and south-east. The Belomorian flow was split into Belomorian depression, complicated Khibina-Kolvitza and Umbozero lobes. The most active Belomorian lobe of the Belomorian flow occupied the sea basin and reached the White Sea Throat (Strelkov et al., 1976, Yevzerov, 1990). The front of the Khibina-Kolvitza lobe was placed in the lower streams of the Strel'na River. It was clamped between the Belomorian lobe and the Ponoj Glacier and was of a low activity. The Umbozero lobe was also of low activity because of the same reason (Yevzerov, 1990). The Barents flow dipped to the sea shelf (Samoylovich, Kostin, 1992), and as the Belomorian one came in contact with the Ponoj ice sheet.

According to the next view point the Barents Sea ice sheet invaded Kola Peninsula from north in the Late Valdaian (Grosswald, Hughes, 2002). The theory is not approved.

The third approach suggests the occurrence of only the Scandinavian ice sheet, invaded by the two flows. There was no Ponoj Ice Cap in late glacial time (Yevzerov, Nikolaeva, 2000, Hättestrand et al., 2003).

The evolution of the glacial flows and lobes resulted in the generation of the marginal forms. The multiple marginal forms have been distinguished. Four generation of the end moraines (terminal and recessional moraines) are distinguished in the Kola region (Yevzerov, Nikolaeva, 2000). At the last glacial maximum time (16-17 ka) the ice sheet covered the Kola Peninsula. The ice thickness amounted at 2500 m.

The degradation stages of the Scandinavian ice sheet have been correlated to the Late Glacial climatic cycles in the Kola region. Extensive peripheral covers were cut off from the active glacier and thick glaciofluvial deposits accumulated in the periglacial basins during the interstadial warmings. The glacier deformed the glaciofluvial deposits and built mainly push moraine ridges advancing during the interstadial coolings. Thus, each marginal belt was formed during the interstadial-stadial cycle of the glacier activity and were made up of two bands of marginal ridges: the inner band - a dump moraine (marginal esker), and the outer band - a push moraine (Yevzerov, Nikolaeva, 2000). The formation of three outer bands of marginal ridges corresponds to the three final stages (Oldest, Older and Younger Dryas) of the glacier activity on the Kola region: Terskaya (13,5 ka), Revdozerskaya (12,5 ka), Kandalakshskaya (10 - 11 ka). The total reduction of the glacier and its melting (i.e. the beginning of the deglaciation on the Kola region) is related to the glacier retreat from the marginal forms of Terskaya stage. Of note, the late glacial age of such forms is doubtful from the recent studies. This ice marginal system, the Keiva moraine complex, has been formed before the ice sheet reached the thickness and extent that it could overrun the whole Kola Peninsula, which probably was during a time near the Late Glacial Maximum. Hence, it appears that the Keiva moraine is a pre-LGM feature (Hättestrand, Clark; in press).

The termination of the deglaciation is related to the ice extinction in western part of the region, about 9500 BP. Around 9500 years BP glaciomarine sediments were replaced by marine deposits in the Pechenga River valley (Bakhmutov et al., 1994).

The Holocene (Q_{IV}, MIS 1)

The Holocene sediments are everywhere represented by the marine, lacustrine, alluvial, eluvial-deluvial, peaty and bog deposits, and by diatomite.

Lovozero area

Locality 1. Glacial landforms of N-W Lovozero Mountains

Korsakova O., Hättestrand C., Kolka V.

Lovozero massif is one of the two major nepheline syenite plutons situated in the central part of the Kola Peninsula and stand today as elevated plateau with steep precipitous slopes and flat summits. The summit surfaces (1000-1119 m a.s.l. on the western part and 600-974 m a.s.l. on the eastern one) are elevated almost a kilometer above the surrounding hilly plain because the active tectonic uplifting. They probably are the Mesozoic past-peneplain. The Lovozero massif occupies a territory of 25x25 km between two Lakes Umbozero and Lovozero with Lake Seydozero nestling in the central part. The western contact is only 5 km away of the Khibiny. Whole rock and mineral Rb-Sr isochrons gave ages of 370.4 ± 6.7 Ma for the main stage of igneous activity (Kramm and Kogarko, 1994).

The massif intruded the garnet-biotite gneisses of the Archean age. The zone of fenitized rocks extends for 50-200 m. Fenites are represented by eudialite-microcline and amphibole-oligoclase varieties. Numerous nepheline syenite veins and alkaline pegmatites penetrated the country rocks at the distance of more than 100 m from the contact.

The Lovozero intrusive complex has the form of a laccolith with a broad base. Due to subhorizontal position of layers in the differentiated complex, the geological map of Lovozero appears as a topographic plan of the area, and the key layers follow the contour lines of the map (Fig. 1.1). The alkaline rocks forming the Lovozero massif are represented mainly by plutonic and less abundant subvolcanic and volcanic magma products. The plutonic derivatives can be grouped in the following principal components: 1). Poikilitic feldspathoid syenites; 2). Lujavrite-foyaite-urtite layered complex; 3). Eudialite nepheline syenite complex (Arzamastsev, 2002).

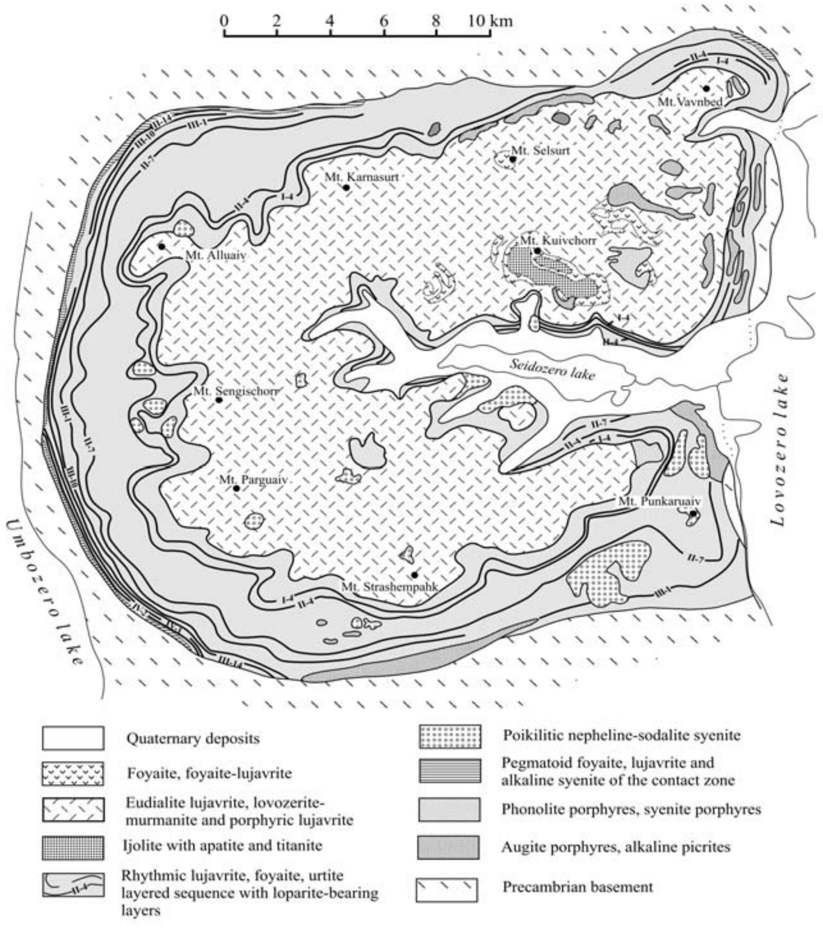


Fig. 1.1. Geological map of the Lovozero massif (after Arzamastsev, 2002).

Lovozero massif is rich in landforms resulted from the glacial activity and displaying both long-term glacial-erosion features and smaller scale landforms which in great detail record the process of the deglaciation of the area. Figure 1.2 shows main glacial-geomorphology features of Lovozero Mountains: glacial cirques, glacial lineated forms (drumlins, flutings), marginal moraines, end moraines, hummocky moraines, De Geer moraines, lateral meltwater channels, spillways, eskers, delta formations, ice-dammed lake shoreline, tors.

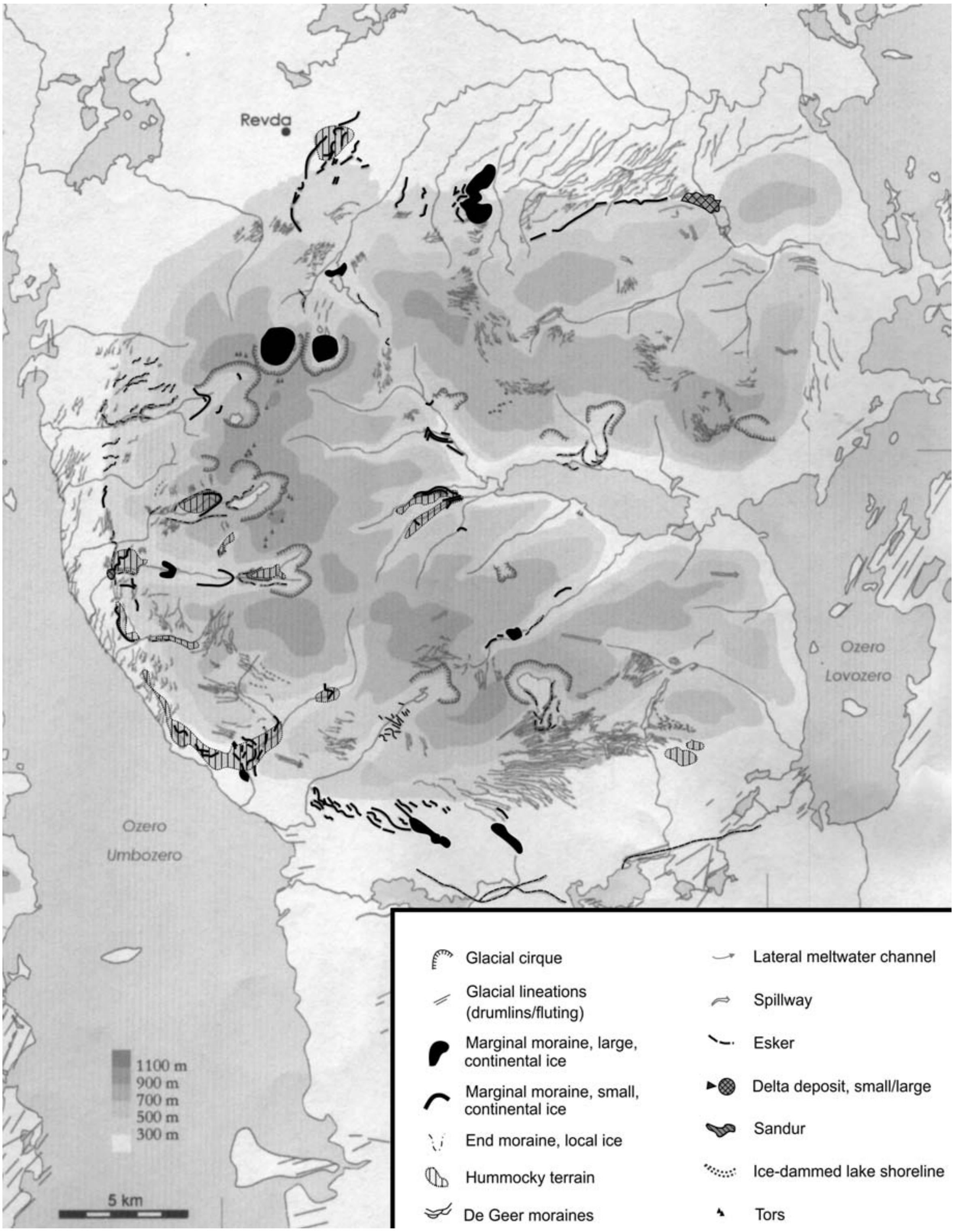


Fig. 1.2. Glacial Geomorphology of Lovozero Mountains.

Gemorphological data from aerial photo interpretation and fieldwork conducted by Class Hättestrand, Vasili Kolka, Olga Korsakova, Krister Jansson, Chris Clark, Nina Johansen, Arjen Stroeven, Derek Fabel in 2001, 2002 and 2004.

The main valleys are U-shaped with rivers and elongated lakes. The largest valleys are situated in the eastern (Chinglusuai, Chivruai, Seyd'iavriok Rivers with the tributaries and Seydozero Lake), northern (headstreams of Sergevan' River system) and western (Kitkuaiv, Tavajok, Sengisjok Rivers) parts of massif.

The main feature of the massif is that in late glacial when the glacier frontier was to the east of the massif, the most high summits were the nunataks. At time the frontier moved to the west of the massif, the mountain glaciers were formed in the most of large cirques.

Stop 1. Plateau-like summit of Alluaiv Mountain (1051 m a.s.l.)

Alluaiv plateau-like summit (N-W Lovozero Mountains) is accessible by car up to the top of 1000-1100 m a.s.l. Rocks of lujavrite-foyaite-urtite layered complex, eudialite nepheline and poikilitic feldspathoid syenites are exposed here.

The signature of weathering. The summit surfaces of Alluaiv Mountain and another points display extensive signs of prolonged weathering, such as felsenmeers and tors (Fig. 1.3).

a

b

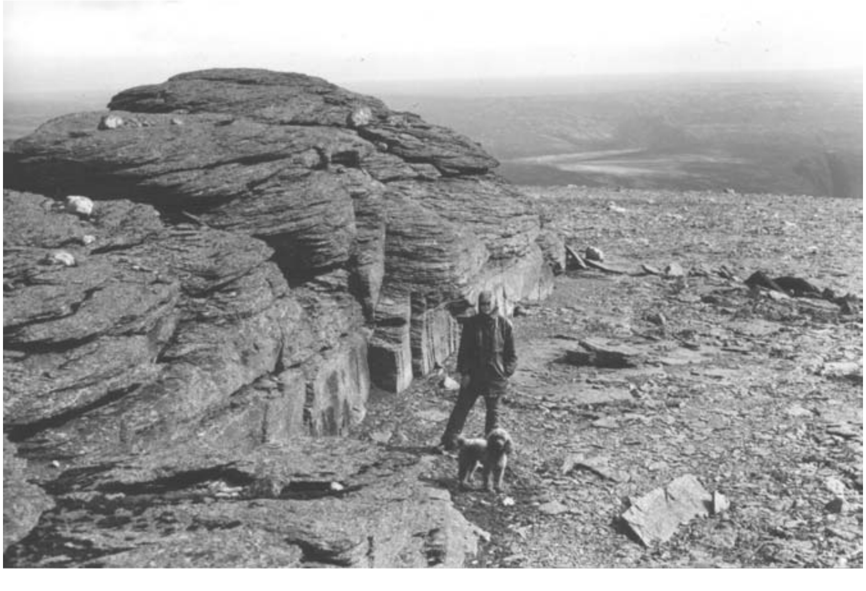


Fig. 1.3. Tor and felsenmeers on the top of Alluaiv Mt., N-W Lovozero Mountains (a) and on the top Strashempakhk Mountain, southern part of Lovozero Mountains (b).

The height of tors reaches 8-10 m. These landforms occupy the top position of almost all summits of Lovozero Mountains; especially on the more elevated western part. The surrounding tors have adjacent areas of spacious felsenmeers with different size blocs. The rare erratic boulders are usual for such weathering landforms (Fig. 1.3).

The top of Alluaiv Mountain is the tor surrounded by felsenmeers with single erratic boulders. Such landforms take a very long time to form, and they are easily eroded if subject to wet-based erosional ice flow. Hence, their presence indicates that these surfaces have escaped glacial erosion through multiple glacial cycles. However, shield erratics, which are commonly found all over these relict surfaces, indicate that the mountains were indeed completely overridden by Fennoscandian ice. However, the ice sheet over the mountain summits must have been cold-based; otherwise the tors and felsenmeers would have been eroded away. It is likely that the ice over the plateau was frozen to the bed and slow-moving, protecting it from erosion. Notice that much of the present-day ice cover is frozen to the bed too and erosion is minimal.

Glacial erosional landforms. The summit surfaces of Lovozero massif are dissected by numerous glacial cirques and glacial troughs (U-shaped valleys). Forms of this kind are 1st and 2nd

River on N-W Lovozero Mountains. (Fig. 1.4, 1.5).

Fig.1.4. U-shaped valley with Sergevan' River

Fig.1.5. 1st and 2nd Raslaka Cirques on North slope of Lovozero Mountains.

The floors of the cirques are situated between 600-700m a.s.l. and the headwalls rise above the cirques up to 1000-1100 m a.s.l. The cirques are opened into U-shaped valleys with rivers and elongated lakes. Most of the valleys in the peripheral parts of Lovozero Mountains show pure fluvial character.

No glaciers exist in the area with these large bedrock forms today, nor are there any signs of previous Holocene glaciation. If the Holocene is taken as the normal climatic conditions for interglacials, the conclusion would be that the cirques were formed during periods colder than today, but still not cold enough for ice sheet growth and overriding. Hence, these cirques and valleys are likely the accumulated effect of cirque and valley glacier activity during many Quaternary interstadials.

The ice-marginal features. End and lateral moraines, meltwater channels can be seen on N-W Lovozero Mountains, these forms and ice-contact deltas and ice dammed lake features – on another its parts. They are found on surrounding slopes and on valley sides inside the mountains. The 1st and 2nd Raslaka Cirques hold till (called "cirque infills") which seem to have been overridden by glacier ice and smeared out in the cirques (Fig. 1.5). The surfaces are hummocky and show no regular pattern, except occasionally faint flutings, for example in 1st Raslaka Cirque. These landforms are seen on the map as large marginal moraine (Fig. 1.2). On the intermediate and lower slopes surrounding Lovozero Mountain and in U-shaped valleys small marginal moraine can be also found. They look as a lateral moraines and arcuate end moraines.

The lateral meltwater channels are the signals carried environment information. These forms can be found on the lower slopes of N-W Lovozero Mountains (Fig 1.6). As usual, the forms have asymmetric cross section with steeper lower slope. The erratic boulders can be found on its bottom. The channels are formed during several days. In the following they can be used for surface washing out. The channels' deepness varies from a few tens of centimeters to several meters. They usually cross the slope surfaces across their dipping (Fig 1.6, b) and indicate on the predominant direction of the melt-waters washing out. Lateral meltwater channels encircle the summits. In northern mountains they cross the southern part of marginal ridge that marks the one of the main stages of the Kola region deglaciation (Fig. 1.7).

Notice that on the southern slopes of Lovozero Mountains (area of the Rayjavr Lake and Engporr Mountain) the one of the Europe largest meltwater channels' fields is revealed.

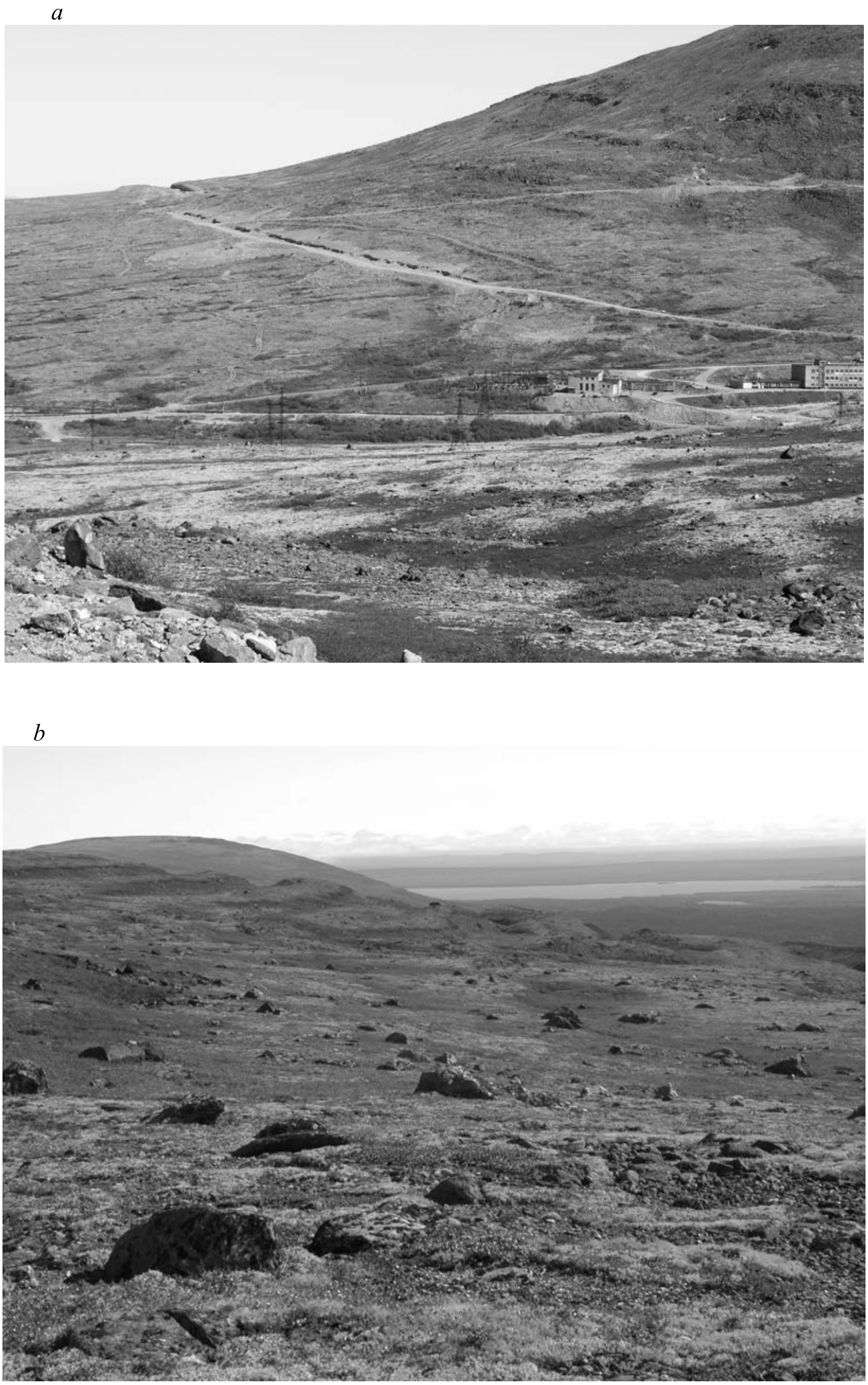


Fig. 1.6. Lateral meltwater channels on lower slopes of Northern (a) and Southern (b) Lovozero Mountains.

Fig. 1.7. Lateral meltwater channels crossing the southern part of dump moraine ridge on N-W Lovozero Mountains.

In some valleys in Lovozero Mountains, well developed end moraines indicate deposition from local cirque glaciation. In N-W Lovozero Mountains these arcuate end moraines are situated in U-shaped valleys. In some areas they overlap and cross-cut the marginal continental ice moraines extending into the valleys. Whether they are younger or older has not yet been unambiguously determined.

Interpretation

The general ice flow direction during the last deglaciation was from the west-northwest. This is reflected by ice marginal moraines and meltwater channels that show an average slope towards the east-southeast. In pre-Younger Dryas (YD) time, when the ice margin was still far to the east of Lovozero, the highest summits began to protrude through the ice surface as nunataks (Fig.1.8). Evidence of this is lateral meltwater channels that encircle some of the summits, especially on eastern Lovozero massif. East and above the inferred YD-position such extensive series of lateral meltwater channels are frequent, particularly on the southern and northern slopes of the mountain, whereas no moraine ridges are found, indicating that all meltwater was drained on the ice sheet surface and subglacial activity was minimal. Hence, it appears that the ice sheet was almost entirely cold-based before YD. As deglaciation progressed and the ice surface lowered, more and more of the mountains were exposed and basal conditions changed to predominantly warm-based. As a consequence of this, ice marginal moraines formed on the intermediate and lower slopes surrounding Lovozero Mountains.

At Younger Dryas time, most of Lovozero Mountains was ice free, although the ice sheet margin still onlapped the western side of the massif and ice lobes flowed up into the west-facing valleys and deposited arcuate end moraines and "cirque infills" - type of morainic formation with a hummocky surface found in the innermost part of Raslaka Cirques (Fig. 1.5). Their existence indicates that when formed, there must have been local ablation centers in these cirques, such that more and more material was brought into the cirques and deposited both in front of the ice margin and on the ice surface itself. Analogues to these conditions are presently found in Antarctic nunatak areas (Lintinen, Nenonen, 1997). When the ice melted, dead ice bodies buried in these moraine complexes melted, creating the hummocky morphology.

On the northern and southern margins of Lovozero Mountains, large end moraines testify to the position the ice margin at this time. However, according to the theory of the marginal belts formation (Yevzerov, Nikolaeva, 2000), these large end moraines have an Older Dryas age.

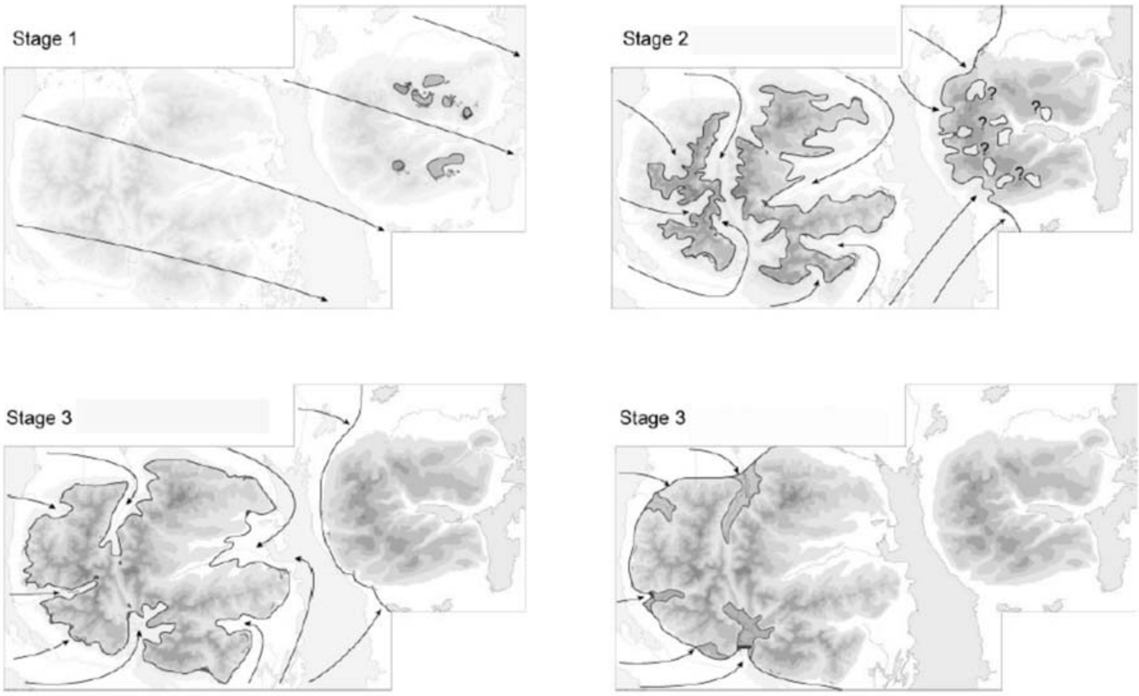


Fig.1.8. Ice marginal positions and ice flow direction (arrows) in Khibiny and Lovozero Mountains during cold stages of deglaciation.

As deglaciation progressed, the ice margin began to retreat out of the valleys and more and more valleys became ice free. The deglaciation of these mountain areas started a short time before the YD, and ended close to the end of this cold period of the last deglaciation.

Locality 2. Late Glacial ice-marginal formations in Lovozero area

Yevzerov V., Korsakova O., Kolka V.

Degradation of the Late Valdai ice sheet in the Kola region occurred in conditions of arctic climate with alternating phases of stadial falls of temperature and interstadial warming. External heat was not enough for the active ice margin to retreat (Yevzerov, 1996). In these environments, three belts of marginal ridges were formed in the region (Fig. 2.1).

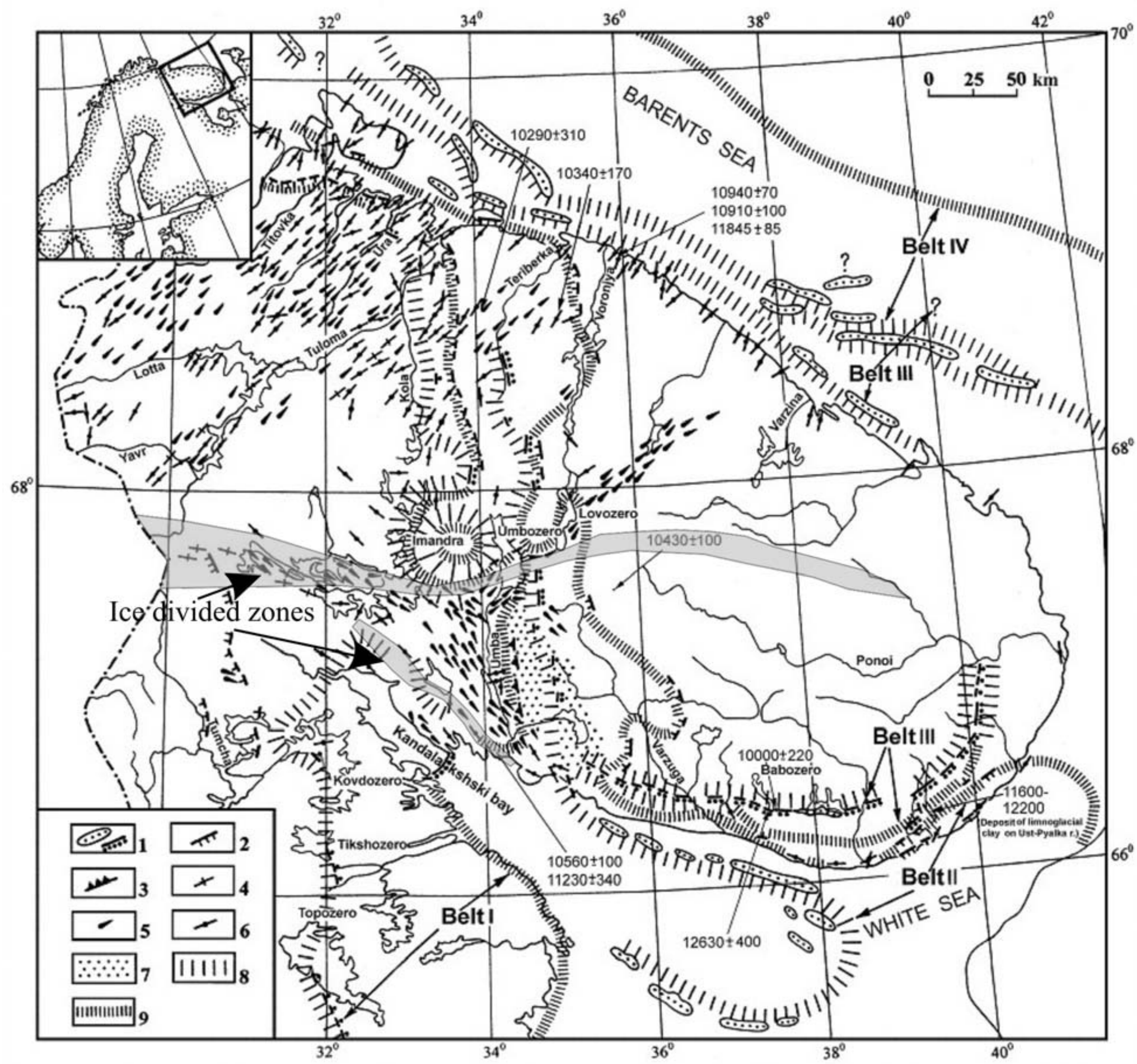


Fig 2.1. Kola recessive marginal belts: I – Kandalakshskii, II – Revdozerskii, III- Terskii. 1- marginal and interlobate dump moraine ridges; 2 - marginal push moraine ridges; 3 - marginal slopes; 4 - flutes; 5 - drumlins; 6 - ice striae; 7 - moraine complex; 8 - position of the ice front when dump moraine of marginal belts inner stripes were formed during interstadial warming; 9 - the same when push moraine ridges of marginal belts outer stripes were formed during stadial cooling. Closed contours showing the positions of ice front during different stages of deglaciation are in the central part of the Kola region around Khibiny (in the west) Lovozero (in the east) Mountains.

The degradation stages of the ice sheet in the Kola region have been correlated to climatic cycles - Oldest, Older and Younger Dryas, and to the previous interstadial warmings. Note, each marginal belt was formed during the interstadial-stadial cycle of the glacier activity and was made up of two bands of marginal ridges: the inner band - a dump moraine (marginal esker), and the outer band - a push moraine. The formation of three outer bands of marginal ridges corresponds to the three final stages (Oldest, Older and Younger Dryas) of the glacier activity on the Kola region: Terskaya (13,5 ka), Revdozerskaya (12,5 ka), Kandalakshskaya (10 - 11 ka). The inner band - a dump moraine was formed under interstadial conditions and the outer band - a push moraine was formed during followed stadial cooling. The all the belts of marginal ridges are named after stadial cooling - Terskii, Revdozerskii, Kandalakshskii. Most investigated of them are the recessive formations related to the Revdozerskaya stage of Scandinavian ice-sheet development. In one case (Ekman, Iljin, 1991) the marginal ridges to the north of Lovozero Mountains are related to the Younger Dryas (Salpausselka) stage, and to the south of Lovozero Mountains - to the Older Dryas (Neva stage). In next case (Yevzerov, 1996), the all the marginal ridges' complexes consist of two bands of the marginal formations and is correlated to the Older Dryas (Neva) stage.

Revdozerskii and Kandalakshskii marginal belts are crosscut by the road Olenegorsk - Lovozero (Fig. 2.2).

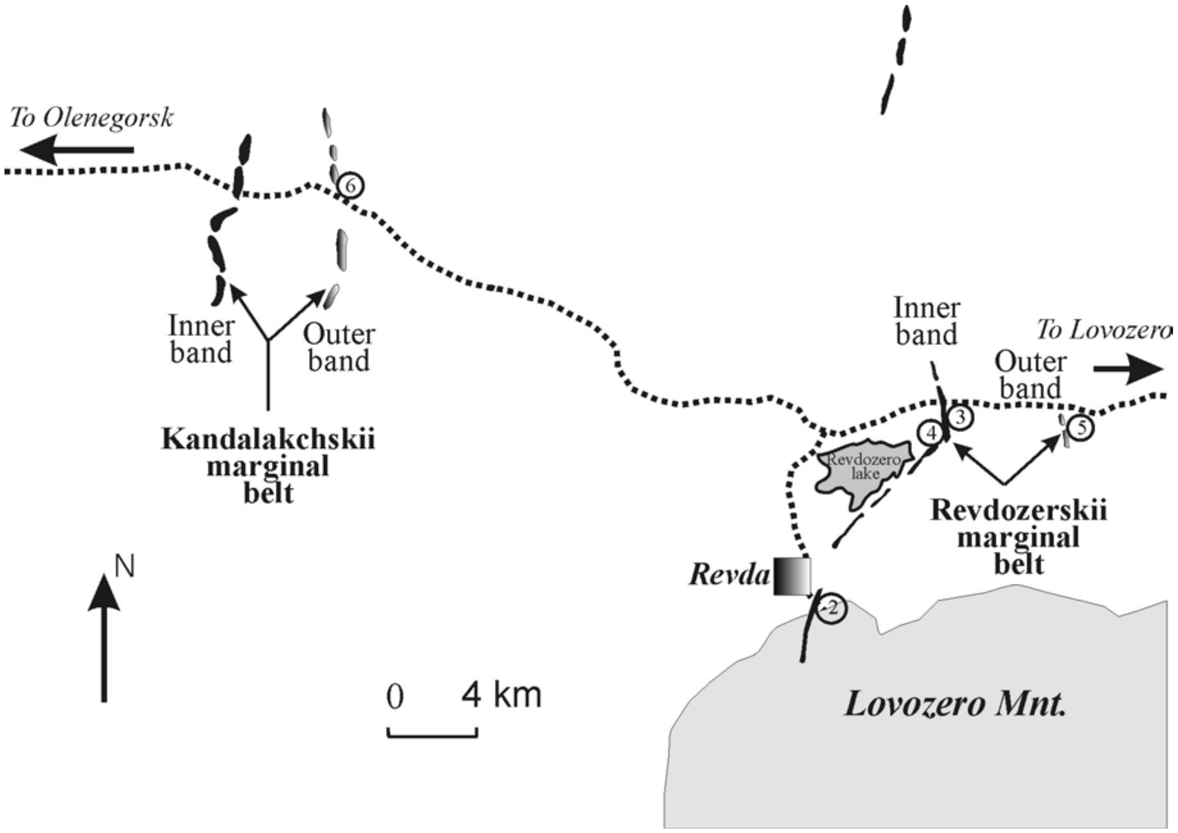


Fig. 2.2. Position of marginal moraine ridges in Lovozero area.
The stop numbers of Locality 2 are shown by figures in the circles.

Stop 2. Marginal ridge to the north of Lovozero Mountains

The marginal ridge is closed to the north foothills of the Lovozero Mnts. (Fig. 2.2). For 5 km it has sublongitudal strike and then turns to the north-east. The height if the ridge is up to 15 m, the width at foot reaches 30-40 m. The slopes are steep (up to 35^0). The south end of the ridge is cut by the lateral meltwater channels (Fig 2.3). The channels are well developed on the northern slopes of Lovozero massif. The ridge is composed of gravel-pebble-sandy sediments with large amount of boulders up to 1,5 m in diameter. The psephitic material is represented mainly by the local crystalline rocks (nepheline syenite), and by the erratics (gneiss-granite).

Fig.2.3. Marginal meltwater channel cutting the ridge near the foothill of the Lovozero Mnts.

This marginal esker marks the position of the glacier edge during the interstadial warming. It could be compared to the inner band of the Revdozerskii marginal belt. As the ridge is cut by the washout meltwater channels, tracing here and on the mountain slopes, the esker was formed previously than the glacier has moved to the east and climbed to the mountains along the river valleys. There is an opinion, that the ridge is the marginal form of the local (mountain) glacier, moving from the Raslak Cirques (Yevzerov, Strelkov, 1969).

Stop 3. Dump moraine ridge - the inner band of Revdozerskii marginal belt

The marginal moraine complex is situated north-east of the settlement of Revda, in the area of the north-eastern extremity of Lake Revdozero, south of the road Olensgorsk-Lovozero. The marginal complex has a complicated structure. It is represented by a locally developed dump moraine ridge extending from the north-west to the south-east in the form of five fragments, and a small glaciofluvial delta (Fig. 2.4). Stop 3 is located in the former open-pit, outcropping the fragment 2. Some fragments of the dump moraine ridge (fragments 3 and 5 on Fig. 2.4) are bordered with the push ridge to the west.

The fragments of the dump moraine ridge (Fig. 2.5) are up to 15-20 m high from the foot and up to 0,6 km long. Near the distal (eastern) side the terrace-like bench takes place, likely formed by the flowage of the debris from the glacier.

The dump ridge is built up of poorly sorted sand-gravel-pebble sediments with boulders. In the fresh outcrop of the ridge the layering structure was established (Fig. 2.6; Yevzerov, Kolka, 1993). Layers that contain abundant pebbles and boulders and dip to NE, E and SE, are interbedded with layers of coarse poorly sorted sand and pebble. Locally, in the section parts oriented across the ridge morphological axis, there are poorly developed folds.

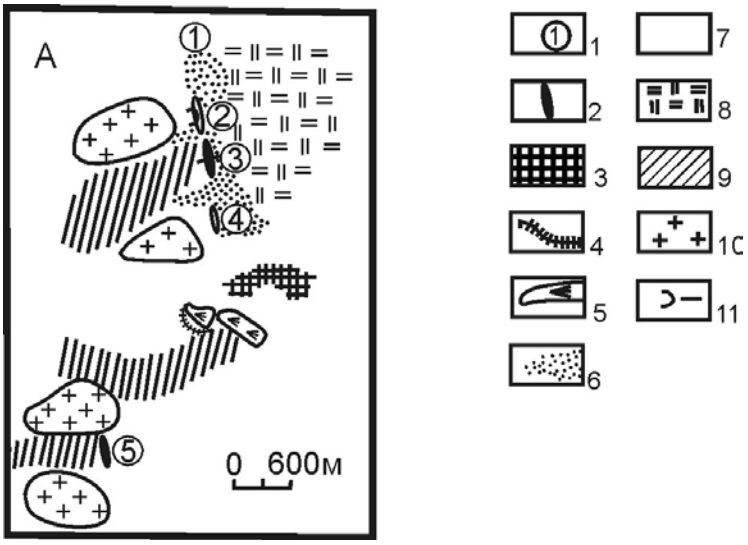


Fig. 2.4. Structure of the marginal complex in Lovozero area.
Legend: 1 - fragments of dump marginal ridge (1-5); 2 – dump moraine ridge bordered with the push ridge; 3 – hummocky moraines; 4 - esker; 5 - glaciofluvial delta; 6 - sandur; 7 - till plain, 8 – peat-bog glaciodepression; 9 – glaciodepression with cover moraine; 10 - crystalline rock outcrop; 11 - location of the studied sections.

Fig. 2.5. Fragment of the dump moraine ridge in Lovozero area, the view from the distal side.

The sediments are poorly sorted, and this feature indicates that the clastic material slipped down the ice slope and was insignificantly redeposited by water. The orientation of the pebbles' long axes along the ridge's morphological axis is observed; the longer axis dips in proximal direction (Fig. 2.7). These orientations of pebbles indicate that the sediments were pushed by the glacier.

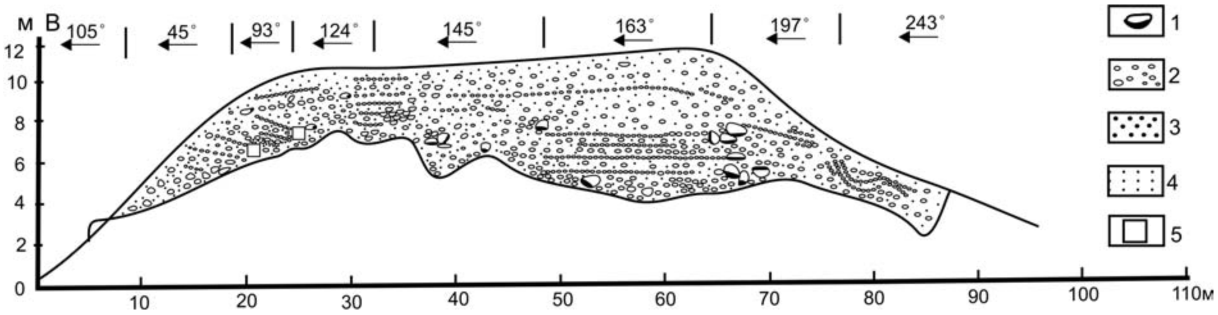


Fig. 2.6. Section of the dump moraine ridge (fragments 2 on Fig. 2.4) in Lovozero area. Legend: 1 - boulders; 2 - pebbles; 3 - gravel; 4 - sand; 5 - sites where orientations of pebbles were measured.

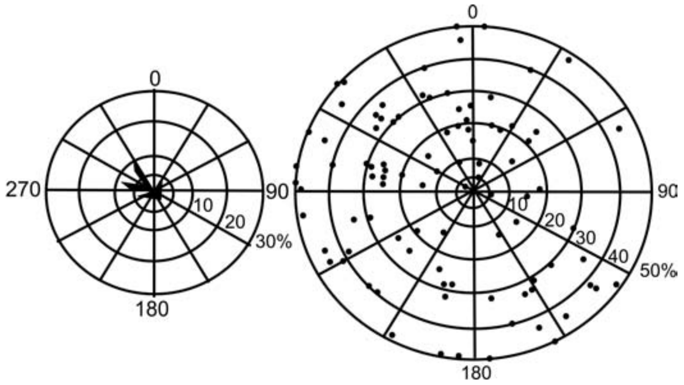


Fig. 2.7. Orientation diagrams for long axes of pebbles in the dump moraine ridge (fragments 2 on Fig. 2.4) in Lovozero area. Sites where the measurements were conducted are shown in Fig. 2.6.

Stop 4. Dump moraine ridge bordered with the push ridge - the inner band of Revdozerskii marginal belt

Dump moraine ridge bordered with the push ridge (fragment 3 on Fig. 2.4) is located in 300 meters to the south from the Stop 3. The inner structure of the ridge was studied in the fresh outcrops during the mining (Yevzerov, Kolka, 1993). The outcrop is oriented across the ridge strike (Fig. 2.4, fragment 3). It is built up of poorly sorted sand-gravel-pebble sediments with boulders. Indistinct layering and poorly expressed folds were revealed (Fig. 2.8).

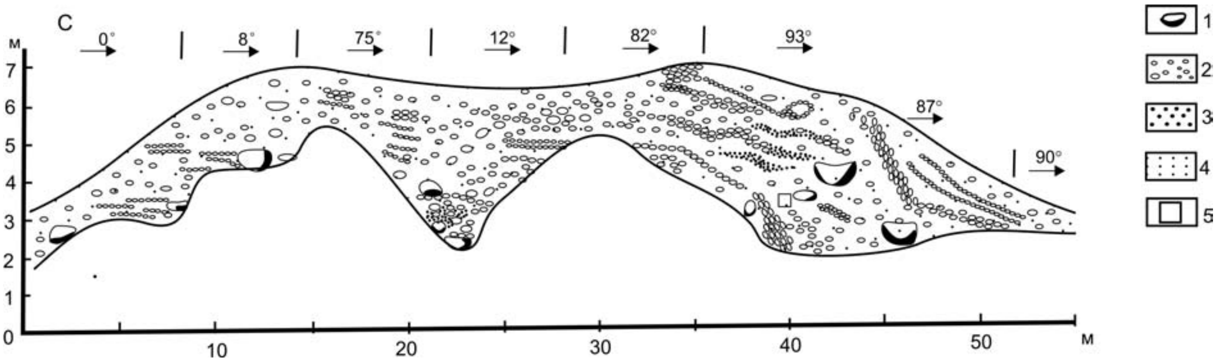


Fig. 2.8. Section of the dump moraine ridge (fragments 3 on Fig 2.4). Legend: 1 - boulders; 2 - pebbles; 3- gravel; 4- sand; 5 - site where orientations of pebbles were measured.

Orientation of the pebbles' long axes from this part of the dump moraine ridge (Fig. 2.9) confirms that the clastic material was removed from the glacier in the northeastern direction, across the ridge strike.

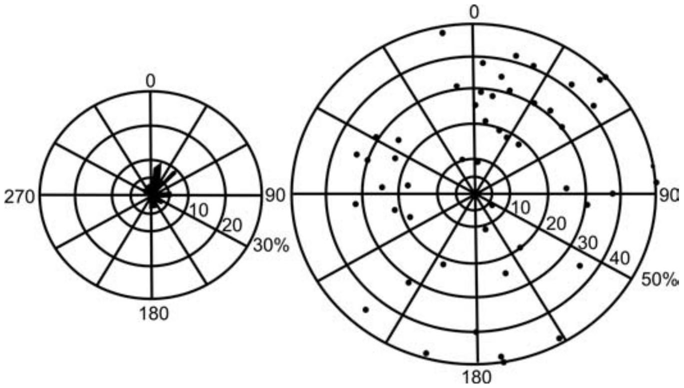


Fig. 2.9. Orientation diagrams for long axes of pebbles in the dump moraine ridge (fragments 3 on Fig. 2.4). Site where the measurements were conducted is shown in Fig. 2.8.

The smaller push moraine ridge as the leaned terrace is adjacent to the dump moraine ridge (fragment 3) from the west (Fig. 2.10). Its surface is hummocky.

Fig. 2.10. The push moraine ridge, adjacent as a terrace to the dump moraine ridge from the distal part.

The push moraine ridge has the complicated inner structure of the thrust sheet character (Fig. 2.11).

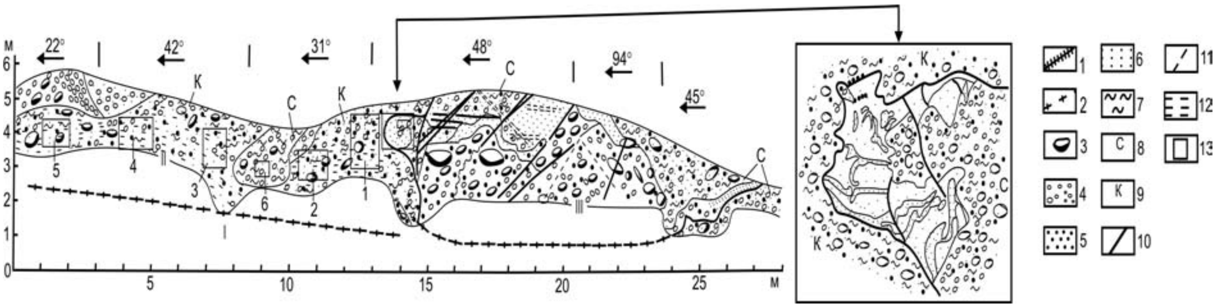


Fig. 2.11. Section of the push moraine ridge in Stop 4.
Legend: boundaries between thrust sheets (I – III): 1 - established; 2 - interred; 3 - boulders; 4 - pebbles; 5 - gravel; 6 - sand; 7 - clay; 8 - greenish-grey till; 9 - brown till; tectonic faults: 10 - established; 11 - inferred; 12 - foliation; 13 - sites where orientations of pebbles were measured.

Thrust sheet I is stand out in the section on Fig. 2.11 speculatively and its border is inferred by the underground waters discharges. The thrust sheet II (Fig. 2.11) is represented by brown foliated till. The structures of the layering-plastic flow in the basal till, being a flow cleavage, always dip in the opposite direction of the ice movement (Lukashov, 1980). Relics of the early paragenesis structural elements are found in the section: a foliated structure dipping to 180°-210° S at an angle of 10-20°. Late paragenesis elements were manifested in foliation bends resulting in the development of asymmetric folds (with a more gentle western limb); it is related to the deformation in high-density and high-viscosity rocks which were almost frozen. The orientation of early and later paragenesis structural elements is shown on diagram A, Fig. 2.12. The averages hinge-line is oriented across the ridge's morphological axis and plunges towards the south-east.

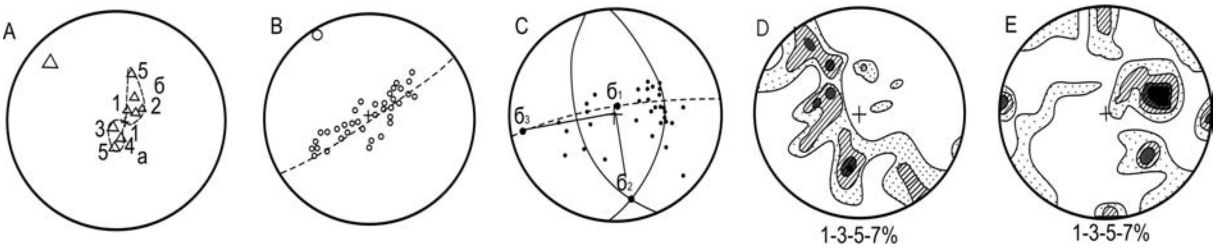


Fig. 2.12. Orientations of glaciotectonic structures and pebbles (section of the push moraine ridge, Stop 4).
Legend: <u>diagram A:</u> 1- maximum of foliation poles formed by shearing; 2 - averaged hinge line of folds formed by shearing; numbers on the diagram correspond to numbers of sites of measurements on the section (amount of measurements: in site 1 - 75, in sites 2-5 - 50), a - early paragenesis structural elements, (b) - later paragenesis elements; <u>diagram B</u>: 3 - poles of axial planes of folds that deform contacts and layering of the folds, 4 - poles of averaged hinge line of the folds; <u>diagram C:</u> 5 - poles of shear joints, 6 - their averaged planes, 7 - major normal stresses in the thrust sheet III; <u>diagrams D and E:</u>
measurements – 50).

The thrust sheet III (Fig. 2.11) is composed of glaciofluvial and glacial deposits. Its section illustrated both plicative and disjunctive dislocations. Tectonic faults cut the folds. The folds were found in the front of the thrust sheet III (Yevzerov, Kolka, 1993); they were of complicated shape (Fig. 2.11, in a box) which is possibly due to the influx of material. In the middle part of the thrust sheet III folds deform the layering and the geological contacts. Axial poles of fold planes are scattered along the great-circle path, which is common for cylindrical folds (Kazakov, 1980). On the diagram B (Fig. 2.12), all the poles are practically within one and the same plane to indicate that the plicative structures development took place in a single field of paleoglaciotectonic stresses.

Earlier the disjunctive dislocations were investigated. They were represented by various generations of shear joints (Fig. 2.11). The sequence of joint development was determined by observations in places where the joints are cross-cutting. Assuming the shear joints to have been developed in a single field of paleoglaciotectonic stresses, it was calculated the statistics of the measurements and obtained a common system of the joint orientations (Fig. 2.12, diagram C). Most of them dip towards the east-northeast at angles of about 50°. On the diagram the same scattered points are noted. It is accounted for the fact that in the till due to its anisotropy, the shearing could not be formed in straight lines, and in boulders the shear joints are developed mostly along weakened zones. The axis orientation for major normal stresses was reconstructed by the method of M.V. Gzovsky (1975).

The latest were the subhorisontal shear joints, along which a slight eastward displacement of upper blocks was observed (Fig. 2.11). After the development of shear joints dipping to the northeast, sand, loam and till were pushed along some of them. The till wedge was observed in the section (Fig. 2.11, part 6). Pebble long axes measured in the wedge's middle are scattered along the great-circle path (Fig. 2.12, diagram D). It is the feature indicative of flattening of the sediments (Lukashov et al., 1981). In the opposite side of the quarry, in front of the wedge, glaciofluvial material was protrusively intruded along a shear joint with a similar orientation

Stop 5. Push moraine ridge - outer band of marginal belt of Revdozerskii marginal belt

Recessive moraine ridge, corresponding to the outer band of Revdozerskii marginal belt, is located in 6 km to the east from the marginal esker (Stops 2 and 3), south of the road Olensgorsk-Lovozero (Fig. 2.2). The ridge stands out morphologically against adjacent gentle-hillocky plane, covered by the forest and locally swamped. It strikes from the north to the south up to 450 m. The relative height reaches 10-12 m, and the absolute levels are 205-209 m. As a rule, the western slope is longer and flat (Fig. 2.13**).** The interrupting terrace-like benches take place on the eastern slope. The numerous erratics of the gneiss-granites of up to 1.5 m in diameter are on surface of the ridge and especially on its eastern slope.

Fig. 2.13. Push moraine ridge - outer band of marginal belt of Revdozerskii marginal belt.

The ridge formation in this place was caused by the occurrence of the hard rock ledge in front of extending glacier. The ledge stands out presently as a hill of 240 m a.s.l. (Sergevan' Mountain).

Of note, the age of the push moraine ridge of Revdozerskaya stage was determined beyond the Locality 2. The paleomagnetic study of the limnoglacial clay from the periglacial lake in the south Kola Peninsula was performed (Fig. 2.1). It was established that the clay was deposited during Alleröd (Bakhmytov et al., 1993). It means that the push moraine ridges were formed during the Older Dryas reactivation of the glacier, becoming the dam for the periglacial lake.

Stop 6. Push moraine ridge - outer band of Kandalakshskii marginal belt

Fragment of the push moraine ridge of outer band of Kandalakshskii marginal belt is situated in 28 km from Stop 3, azimuth 300° (Fig 2.2). Its width is 20-25 m, and the height – 7-8 m. The ridge was mined to the north from the road Olenegorsk-Lovozero. It is composed of poorly sorted sand, containing 30-40 % of pebbles and boulders. Presently the section is covered by the talus.

Note that dump moraine ridge of Kandalakshskii marginal belt stands out also in the relief and is located in 5 km to the west from the Stop 6.

Discussion

first, the dump ridges formed to fix the glacier margin in a stationary position. The sediments are poorly sorted, and this feature indicates that the clastic material slipped down the ice slope and was insignificantly redeposited by water. G.A.Juozapavichus et al. (1981) and A.A.Jurgaitis (1984) drew an analogous conclusion when studying the formation of marginal glaciofluvial ridges in Belarus and in Baltic States. The ice slope was evidently steep and abrupt, since observations made by Ya.A.Lavrushin et al. (1986) at present-day glaciers show that favourable conditions for dump moraine can occur only at areas of steep or abrupt ice margin.

Apparently, the lower (I) and middle (II) thrust sheets of the push ridge, that bordered with dump ridge developed after formation of latter. Then, the glacier retreated at places. A thin layer of glaciofluvial sediments were deposited between the dump ridge and the glacier margin. When the glacier advanced again, the sediments were assimilated by ice to form the push ridge upper (III) thrust sheet. The material of thrust sheets was folded and then split in blocks by shear joints. The fluvioglacial sediments were protruding along some of the shear joints, and the till wedges intruded from the top.

The Older Dryas stadial cooling caused the reactivation of the glacier and the dump ridges of the Revdozerskii marginal belt were deformed in different rate.

The marginal forms of the different interstadial-stadial glacier cycles were formed by the same way.

Chuna - Kolvitsa - Kandalaksha area

Locality 3. Paleoseismic dislocations in the area of Imandra and Chunozero Lakes, central part of Kola region

Nikolaeva S.

Neogene-Quaternary activity is reflected in the seismicity of the Kola region. The existing knowledge about seismicity of the region corresponds to the short-term period of instrumental and macroseismic observations. The instrumental measurements began to be registered here since 1956 with start-up of the seismic station “Apatity”. For this period the territory of region was subjected to earthquakes with intensity 3-4, on the local parts - up to 5. Seismic activity zones are situated in the Kandalaksha Bay, on the Murmanskii Coast, especially in area of the Kola gulf, and in the Khibiny Mountains. The information about historical earthquakes is recorded in the archival documents, annals and newspaper publications. Such events are known on the Kola Peninsula since 17th century. The strongest historical earthquake has taken place in the Kandalaksha Bay in 1627 with intensity 8 in term of the MSK-64 scale (Deep structure …, 2004).

The traces of ancient strong earthquakes (paleoseismic dislocations) have been detected in the Kola region as a result of specific geological and geomorphological investigations. Paleoseismic dislocations are expressed in topography in the form of seismic ditches, scarps, gorges, fractures in crystalline rock and disturbance in Quaternary sediments bedding. The dislocations are accompanied by such phenomena as collapses, rock pillars, rockfalls, empty niches (blocks displaced away) and other seismic signatures, which are not found outside seismogenous structures, and are confined to activity fault zones. Dislocations are concentrated in specific localities - paleoseismic areas. The areas coincide with the position of particular Precambrian and neotectonic structures that are characterized by differential movements.

All of paleoseismic dislocations (PSD) were formed in late and post-glacial period. An earthquake in one locality near Murmansk was found to have taken place earlier than 8950±150 (TA-2293) years ago. This date is the time of the initial period of accumulation of organic sediments in the lake that formed during the earthquake, as a result of a slump which closed the creek valley (Geology…, 1995).

The magnitude of ancient earthquakes was calculated near 7.5. Naturally, these are approximate values because it is unknown how many earthquakes were responsible for the formation of the paleoseismic dislocations in each specific locality. However, these values are similar to the estimate of the magnitude of possible earthquakes (6.5), obtained by S.Mijamura (Miyamura, 1963) on the basis of instrumental data on the modern earthquakes of the Fennoscandian Shield, and also to the estimate of the magnitude of ancient earthquakes in Russian Karelia (6.1 to 7.5), obtained from the study of PSD by A. Lukashov (Lukashov, 1995). It is possible to assume, that in the late and post-glacial period the seismicity of territory much more surpassed the present-day one.

The scheme of ancient earthquake epicenters was made on the basis of geological data and aerial photograph interpretation (Fig. 3.1). Seismic dislocations are direct indications of residual tectonic deformations in the epicenter zones of ancient earthquakes. Residual deformations density distribution scale (numerals indicate the number of residual deformations over an area of 15x15 km): 1 – 1-3; 2 – 3-5; 3 – 5-7; 4 >7; the epicenters of 1542-2002 earthquakes, magnitude (M): 5 - ≥5.1; 6 - 4.1-5.0; 7 - 3.1-4.0; 8 - ≤3. The disposition of the edge of active ice is shown on the scheme 3.1 by dotted line (Younger Dryas) and continuous line (Older Dryas).

Largely, they are concentrated in the west and in the center of the Kola Peninsula. The epicenter of ancient earthquakes and the epicenters of most of historical and recent earthquakes coincide. This apparently testifies to the inherited nature of the historical and recent ones. The epicenters are concentrated in the area, which has been occupied by active ice during the Older and Younger Dryas (Yevzerov, Nikolaeva, 2003). Such distribution of dislocations is explained probably by fast deglaciation of the territory occupied by the Younger Dryas ice cover, and by the highest topographic gradient of the ice surface in some places of the area which was covered by active ice in the Older Dryas.

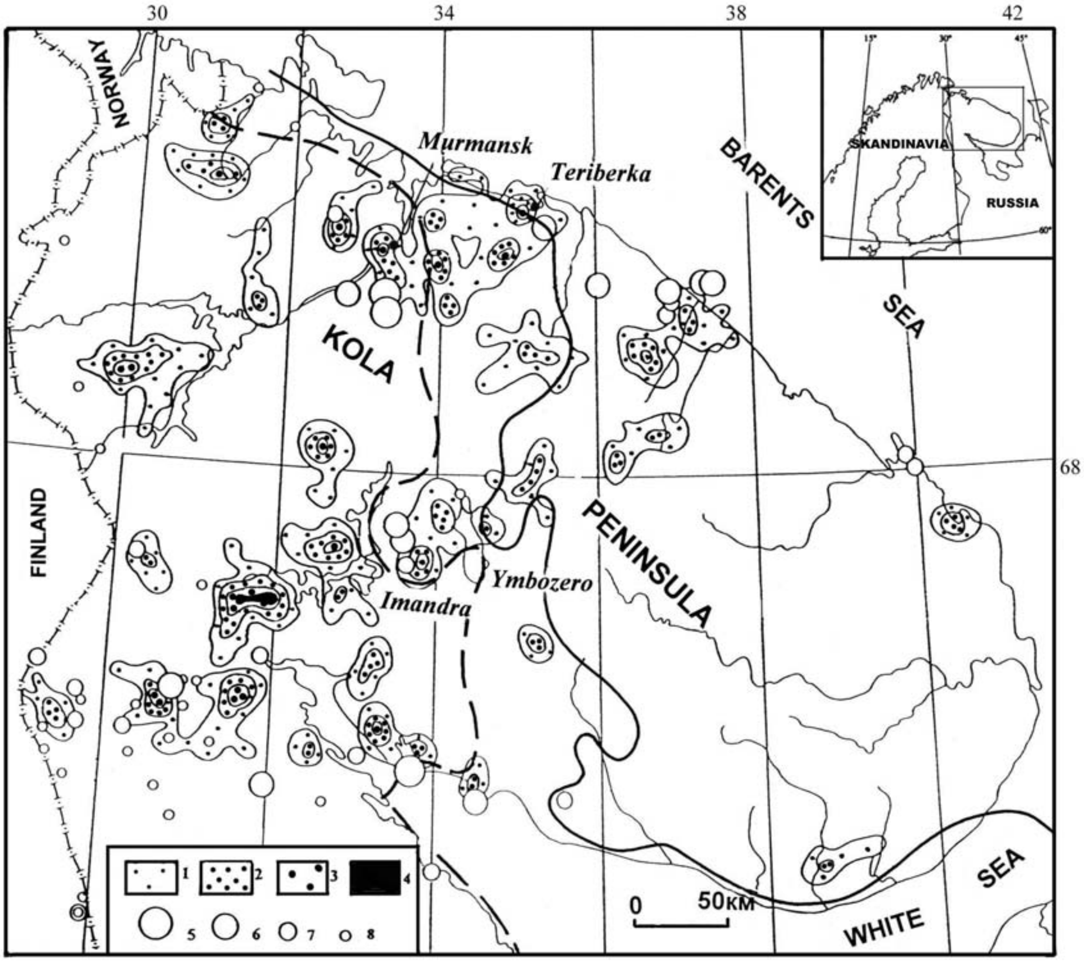


Fig.3.1. Scheme showing the density of residual deformations, the epicenters of present-day earthquakes and the disposition of the edge of active ice in the northeastern Baltic Shield.

Thus, it is possible to recognize that the northeast part of the Baltic shield is the area with rather high level tectonics of activity and seismic potential, than it was considered before. The wide development of newest dislocations and data on modern and ancient earthquakes testify the point.

Locality 3 is situated in southern part of the Kola Peninsula, approximately on continuation of the Kandalaksha Bay, in the area of Imandra and Chunozero Lakes (Fig. 3.2). The area is located in Belomorian domain with the Late Archean dome-fold and complex-fold structures reworked in Early Proterozoic. For the most part the area is composed of granite-gneiss, migmatite and gneiss containing amphibolite lenses, and also small bodies of the Early Proterozoic intrusion (Geology …, 1995). The structural elements of system strike in NW-SE (300°) and in sublatitudinal direction.

The territory is characterized by the dissected topography. Relative elevation of a relief reaches tens meters. The outcrops of crystalline rocks are numerous, however largely the surface is the low-thickness cover of colluvial, glacial, glaciofluvial sediments and bogs (Fig. 3.2). The direction of glacier movement predominantly coincides with direction of structural elements.

Interpretation of aerial photos has revealed on-land paleoseismogenic deformations in Kola Peninsula. They are expressed in the topography as a scarps, gorges, ditches and fractures.

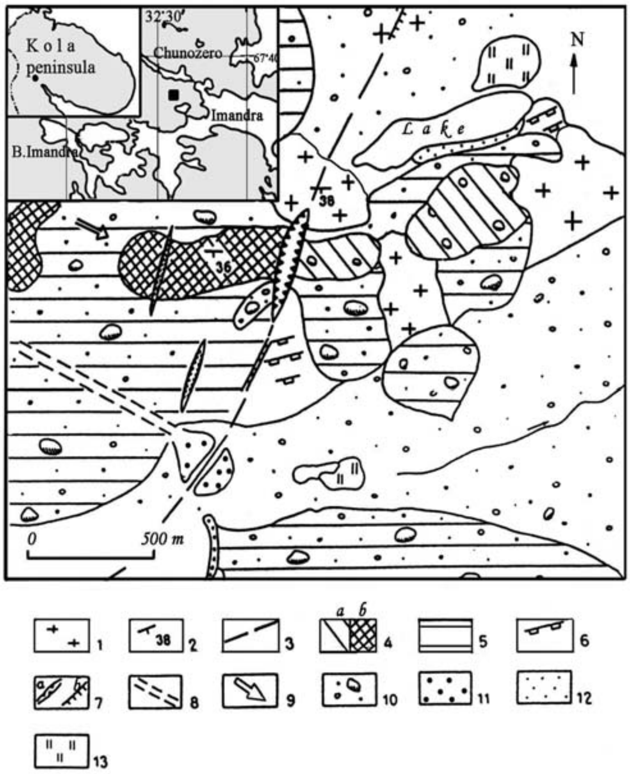


Fig. 3.2. Geological-geomorphological sketch map of Imandra and Chunozero Lakes area. 1- granite-gneiss; 2 - strike and dip of gneissousity; 3 - faults; 4 - hills: covered glacial sediments (a), without till cover (б); 5 - slopes; 6 – rock steps; 7 - gorges (a), scarps (б); 8 – meltwater channel; 9 - glacier movement direction; 10 - till; 11 - glaciofluvial deposits; 12 – lacustrine sediments; 13 – biogenic sediments.

Stop 7. Paleoseismic dislocation "Chuna"

"Chuna" dislocation (32º29`E; 67º 34`N) is located to the south of Chunozero Lake in zone of active fault. The tectonic active zone strikes in northeastern direction (5-25º) on distance of 5 km (Fig. 3.2). PSD is expressed in a relief as narrow gorge. The gorge disrupts the hill of absolute level 252.2 m a.s.l. (Fig. 3.2, 3.3-A).

Morphology "Chuna" dislocation. The gorge follows in NNE direction on distance of 0,4 km. The depth of gorge is 27 m, and width reaches 43 m in the central part, being narrowed at the ends. The bottom of gorge is filled fresh sharp-edged blocks of the different sizes up to 5 m. The gorge has no drainage. Edges of slopes are sharp. Numerous rockfalls, rock pillars, rock-slide, empty niches (blocks displaced away) belongs to the zone of an active fault (Fig. 3.3, B-E). It is normal fault. The maximum observed vertical displacement is 6 meters. The southeastern block is settled. Some more similar structures were revealed in this area.

Genesis of "Chuna" dislocation. The gorge extents at an angle of 45° to the last direction of the ice-flow and on the continuation crosscuts the glaciofluvial fan (Fig. 3.2). It is not concordant with trend of geological structures and relief. It seems unlikely, that deformations could be formed by glacial processes or intensive weathering of crystalline rock.

The dislocations are accompanied by such phenomena as rockfalls, pillars, empty niches (blocks displaced away) and other seismic signatures, which are not found outside seismogenous structures, and are confined to active fault zones. According to the classification developed by V.P.Solonenko (Solonenko, 1973) the following types of PSD are distinguished in Kola Peninsula: local seismotectonic (fault scarps, seismotectonic depressions and gorges, fracturing and brecciation, grabens); gravitational-seismotectonic (displacement-related rockfalls, rock slides, blocks displaced from ledges, niches); seismogravitational (rockfalls of crystalline rocks, slumps and debris flow slides and deformations of sedimentary layering in unconsolidated Quaternary sediments) (Fig. 3.3, B - E). Local paleoseismic dislocations form paragenetic groups characterized by seismotectonic, gravitational-seismotectonic, seismogravitational formations. They are concentrated within restricted areas and correlate with distinct geological structures and faults that show indications of Holocene movements.

It is essential to note, that the gorges of the similar forms of a relief were formed as a result of catastrophic earthquakes with intensity 9-10 numbers in areas of high seismicity (Hromovskih, 1965.). At the present time the modern and historical earthquakes are known. So, seismic events have taken place in 1912 and 1981 in area of Lake Imandra. It seems likely, that the gorge was formed by strong ancient earthquake, affecting both relief and the bedrock.

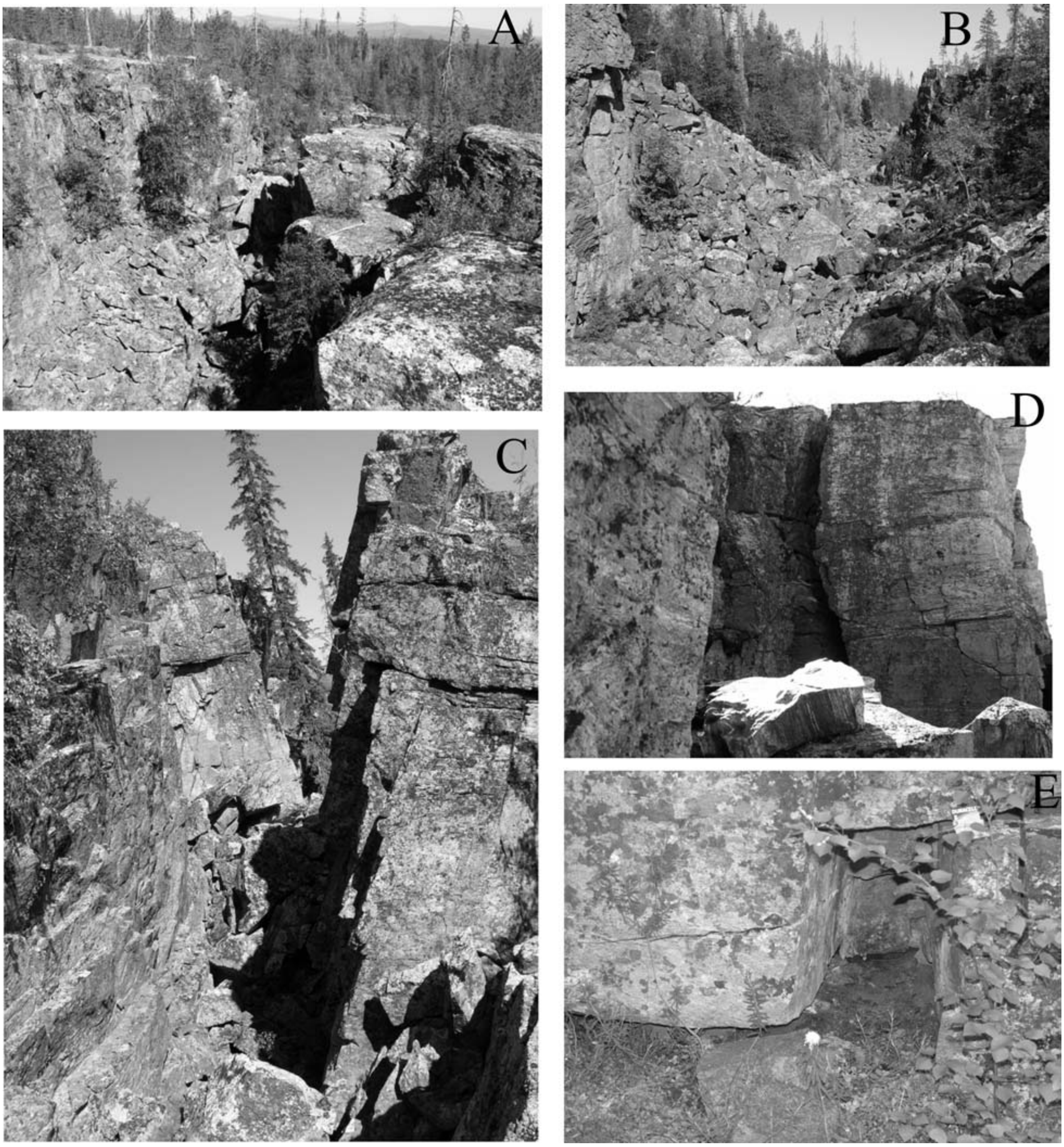


Fig. 3.3. View of seismic deformations of "Chuna" dislocation (photos by Vasili Kolka). Seismotectonic: fracture-gorge (A); seismogravitational: rockfalls of crystalline rocks (B), gravitational-seismotectonic: rock pillars (C, D), empty niches (blocks displaced away) (E).

The age of "Chuna" dislocation. Kola Peninsula belongs to the area affected by continental glaciation, following with deglaciation taking place at 13000-9000 years ago. Therefore, it is important to show that the dislocations were not caused by glacial processes or intensive physical weathering of crystalline rocks. Unconsolidated glaciogenic sediments are relatively thin, but also fill significant depressions in preglacial relief. Buttresses of crystalline rocks with relative heights of 5 and more meters were exposed by active glacial erosion. All earlier weathering products and older sediments, and fragments of rocks in gravitationally unstable sites were transported to lower hypsometric levels. Therefore, in areas where glacial formations occurred, positive topographical elements of the preglacial landscape have been exposed and consisted of crystalline rocks. As such areas have not subsequently been weathered, and were not covered by postglacial sediments, they have been more susceptible to gravitational rockfall and landslides.

The gorge must be formed after the last deglaciation of the region. The absence of till at the bottom of gorge and also the absence of traces of glaciofluvial processes on the walls of gorge testify to it. The fault crosscuts glaciofluvial deposits, indicating that at least the fragment of the fault is of Holocene age.

Discussion

The study of PSD, i.e., of geomorphic and geologic signs of deformation in rocks and relief caused by large past earthquakes, has recently become an actively developing trend of seismogeological research. Although Fennoscandia is not an area of high present-day seismicity, many PSD are at present known and partially studied within the area (Lukashev, 1995; Lagerback, 1990; Mörner, 1995 and others). At the present time there are little doubts that these disturbances were produced by ancient strong earthquakes which have hit on different areas of the Eastern Fennoscandia. Observed features as the morphology, dimensions and characteristic types of the PSD allow us to infer the intensities of earthquakes to be not less than 7 and possibly 8 or greater in the MSK-64 scale. Study of PSD and paleoearthquakes in Fennoscandia is of importance as very serious problem and should be a subject of special research.

Locality 4. Vilasselga marginal formations, SW Kola Peninsula

Kolka V., Korsakova O., Zakharchenko E.

Derivation of the Belomorian ice flow and its discrete lobes (Belomorian and Khibinsko-Kolvitskaya) in the western part of the region took place as the ice-sheet has degradated and the position of the ice divides and of the glacier frontier has been changed.

The dynamics of the Belomorian ice flow was complicated (especially during its degradation and breaking down to the lobes, different in activity), resulted in the complex of the marginal forms in the southern Kola region. These forms are known under the general name First/Marine Keiva (Lavrova, 1960). The separate parts of the Marine Keiva have its own local names. The westernmost part (from the Kolvitsa Bay to the Pilskaja Bay) is named Vilasselga, and it extents up to 65 km. It has the different interpretations as the marginal eskers (Lavrova, 1960), as the ice-divide glaciofluvial ridges (Ekman, Iljin, 1993).

Vilasselga ice marginal formation extents initially in sublatitudal direction along the depression between the Kandalaksha and Kolvitsa Mountains. There it is represented by the several ridges in the valleys of the Kolvitsa, Luven'ga and Tiksha Rivers. The Vilasselga turns to the south-east in the depression of the Kolvitskoye Lake and extents up to the Pilskaja Bay. The thickest ridge is located in the valley of Kolvitsa River. There it is abraded by the sea and partly overlaid by the marine sediments.

Stop 8. Glaciofluvial ridge in the valley of Kolvitsa River

The southern ridge of the Vilasselga has the subparallel extension along the Kandalaksha Bay coast, the Kolvitsa River and Kolvitsa Lake depression (Fig. 4.1).

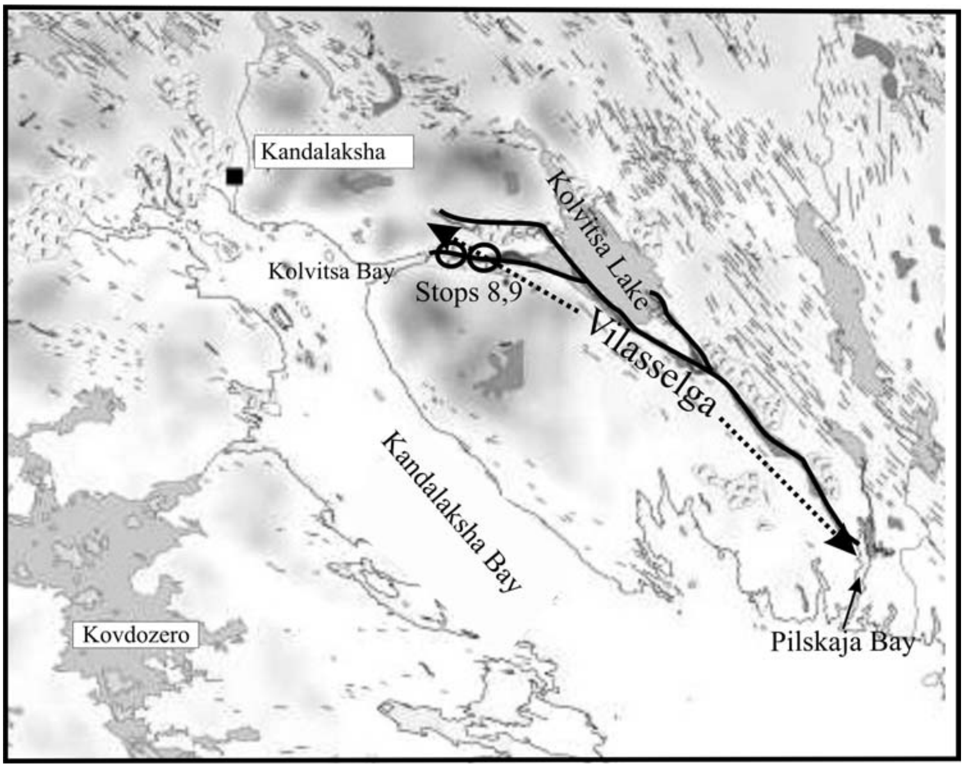


Fig. 4.1. Glacial geomorphological sketch map of Locality 4.

There it is represented by the bar of the 35 km extension and of 300 m width and of 30-40 m height. To the south-east from the Kolvitsa Lake it joints to the northern ridges of the Vilasselga.

The most part of the southern Vilasselga ridge is represented by the esker of the 70-80 m a.s.l. with steep (up to 30^0) slopes and wide crest (Fig. 4.2). The northern slope is steeper than the southern one. The boulder accumulations are usual in the ridge surface, especially in the southern slope and crest.

Fig. 4.2 Glaciofluvial ridge Vilasselga to the west of Kolvitsa Lake (southern view).

The gently inclined terraces are adjacent to the ridge both from the north and from the south. The southern slope is partly washed out.

Stop 9. Quarry opening the glaciofluvial ridge Vilasselga in the valley of Kolvitsa River

The sea abraded esker ridge Vilasselga and adjacent marine terrace are opened by the quarry in 2 km from the Kolvitsa settlement. The ridge is opened in the eastern part of the quarry and the overlying marine sediments are in southern and western parts.

The ridge is composed of boulder-pebble material with loam and sandy loam. The boulders and pebbles are rounded and well rounded. Sorting of the material is relatively bad, particularly because of the rapidly changing energy conditions. In the outcrop the vertical grain-size changes and badly developed stratification are seen (Fig. 4.3).

The southern wall is mostly closed by the land slides that suggests the occurrence of the clayey layers in the section of adjacent terrace. The subhorizontal beds of sand, sandy loam and gravel can be seen in outcrops. The sandy layers bear cross wave-like lamination.

The sandy horizon with the pebble and boulder interlayers is outcropped in the western part of the quarry (Fig. 4.4).

The layers bedding is inclined, dipping azimuth is 170-172^0, angle of dip - 5-8^0. The material is well washed out; the well rounded pebbles are observed. This outcrop opens the sediments of the marine terrace. The absolute level of its surface is 55-57 m.

Fig. 4.3. Structure of the northern flank of the esker ridge Vilasselga.

Fig. 4.4. Outcrop showing the rocks of the Vilasselga ridge washed out by the sea.

Discussion

Vilasselga was formed in subglacial environment as the glacier frontier retreated during Late Glacial time. Its geographic position corresponds to the interlobate zone, dividing the Belomorian and Khibiny-Kolvitsa lobes of the Belomorian ice flow of the Scandinavian ice-sheet.

The occurrences of marginal ridges in the Luvenga and Kolvitsa valleys and in the Kolvitsa Lake basin indicate that the ice moved along the valleys to the Kolvitsa depression. Of utmost importance for glacier advance towards the Kolvitsa depression was the accumulation of ice in the upper part of Kandalaksha Bay. Continental ice of Belomorian lobe advanced along the Kandalaksha Bay depression from north-west to east, south-east.

Khibiny-Kolvitsa lobe positioned to the north and advanced in the same direction. It was more active than the Belomorian one. The numerous drumlins and flutings, widely distributed on the plain to the north and north-east from the Kolvitsa Lake, support this point. The ice-divide zone between the two glacier lobes is marked by the remarkable on extension and impression Vilasselga ice-divide glaciofluvial ridge.

Beginning of the Vilasselga ice-divide glaciofluvial ridge formation is likely related to the last interstadial-stadial climatic cycle of the Late Glacial. The ridge ultimate formation has been finished in Post Glacial, when the glaciofluvial sediments were washed out and redeposited by the sea.

Locality 5. Late Glacial and Holocene evolution of Kandalaksha Bay recorded in bottom sediment lithostratigraphy of raised coastal lakes and shoreline features

Kolka V., Korsakova O.

Bottom sediment lithostratigraphy of raised coastal lakes and shoreline features in the White Sea depression reflect the sequence of the surface tectonic movements in the late- and post-glacial time. At present the several isobase schemes of the late-glacial and Holocene crustal rises are developed. In one of them the NE Baltic shield has undergone the glacio-isostatic doming with highest rise rate in the western part of region (Lavrova, 1960). The next scheme represents the block-like rise of the whole Kola Peninsula with almost uniform rates (Koshechkin, 1979). The different conclusions are made concerning of the position of the upper shoreline. The accuracy of these reconstruction is, in general, limited by the fact that shorelines can rarely be dated directly and existing radiocarbon dates are mostly from marine shells and archaeological material, which normally provide only minimum and maximum constraints, respectively, on former relative sea-level (RSL) change.

Recently the technique of the Norvegian scientists (Donner et al., 1977) was applied for the reconstruction of the RSL change of the Barents and White Seas. The investigation based on method of identifying and dating the marine-lacustrine transition (isolating contact) in sediment cores from raised lake basins. The lakes situated at various elevations between the marine limit and present sea level, were cored, and the result used to construct a RSL curve. Diatom analysis was used as an aid to identifying isolation contact and interpreting depositional environment.

Reconstruction of sea-level change has been made for White Sea coast using the relative sea-level curves (Kolka et al., 1998, 2000). The lithology and stratigraphy of raised coastal lake basins was studied in six areas (Fig. 5.1) in order to identify and date marine-lacustrine transitions (isolation contacts) and construct relative sea-level curves for the Late Weichselian and Holocene.

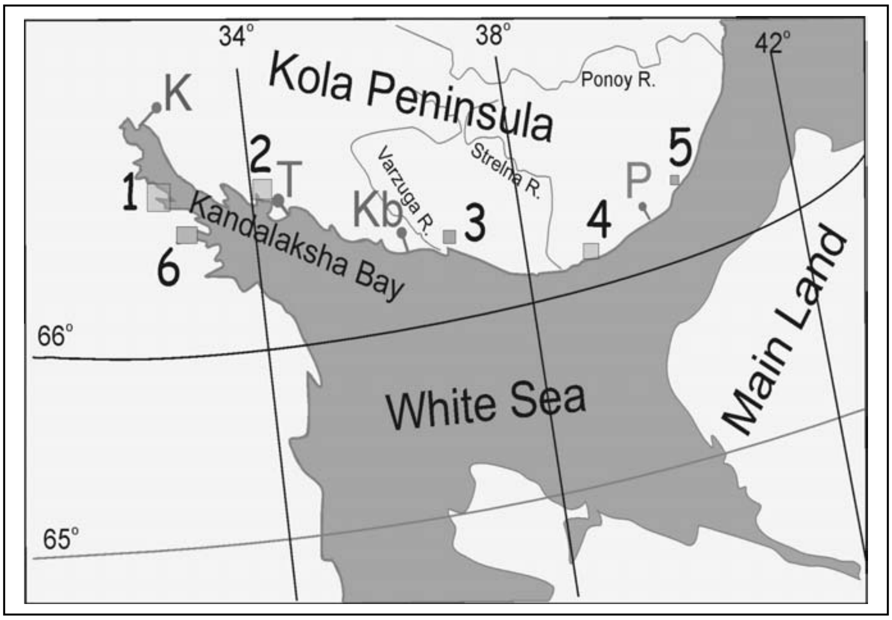


Fig. 5.1. Location map showing the study areas along The White Sea coast. Areas where raised coastal lake basins was studied: 1 – Lesozavod area; 2 – Umba area; 3 - Varzuga area; 4 - Chapoma area; 5 – Likhodeevka area. The line of morphological profiles: K – Kandalaksha; T – Tury Peninsula, Kb – Korabl' Cape; P – Pulon'ga River.

Various facies types and facies sequences controlled by relative sea-level change and also by climatic factors are recognized in the cores. Facies types are: (I) glacial lake (non-laminated clay), (II) mixed, lateglacial sea ingression, (silt and sand with plant detritus), (III) marine (mud silt, sand, shells/shell fragments), (IV) transitional (laminated or non laminated gyttja and silt), (V) lacustrine (gyttja, plant detritus). There were determined the diatom complexes corresponding to:

- the stage I, glacial lake (solitary freshwater species *Aulacoseira islandica, Pinularia isostauron* and fragments of marine ones);

- the stage II, lateglacial sea ingression (interbedded layers with predominance of mesogalobous *Coscinodiscus lacustris var.septentrionalis* and layers enriched by halophilous *Rhopalodia gibba var.vantricosa*);
- the stage III, marine (with predomination of polyhalobous and mesohalobous);
- the stage IV, transitional stage (mesohalobous and halophilous);
- the stage V, stage of contemporary freshwater lakes (with domination of indifferentes and halophodous).

The position and the age of the shoreline of transgressing sea correspond to the position and age of the sediments facies II, and of regressing sea to the sediments facies IV (Fig. 5.2).

Cores from different investigated areas show a complicated facies sequences comprising either all facies types or only a few facieses types. The factual evidence for the shorelines reconstruction in the Kandalaksha bay was obtained during the study of the lake basins in the Lesozavod and Umba areas (places 1 and 2 in Fig. 5.1).

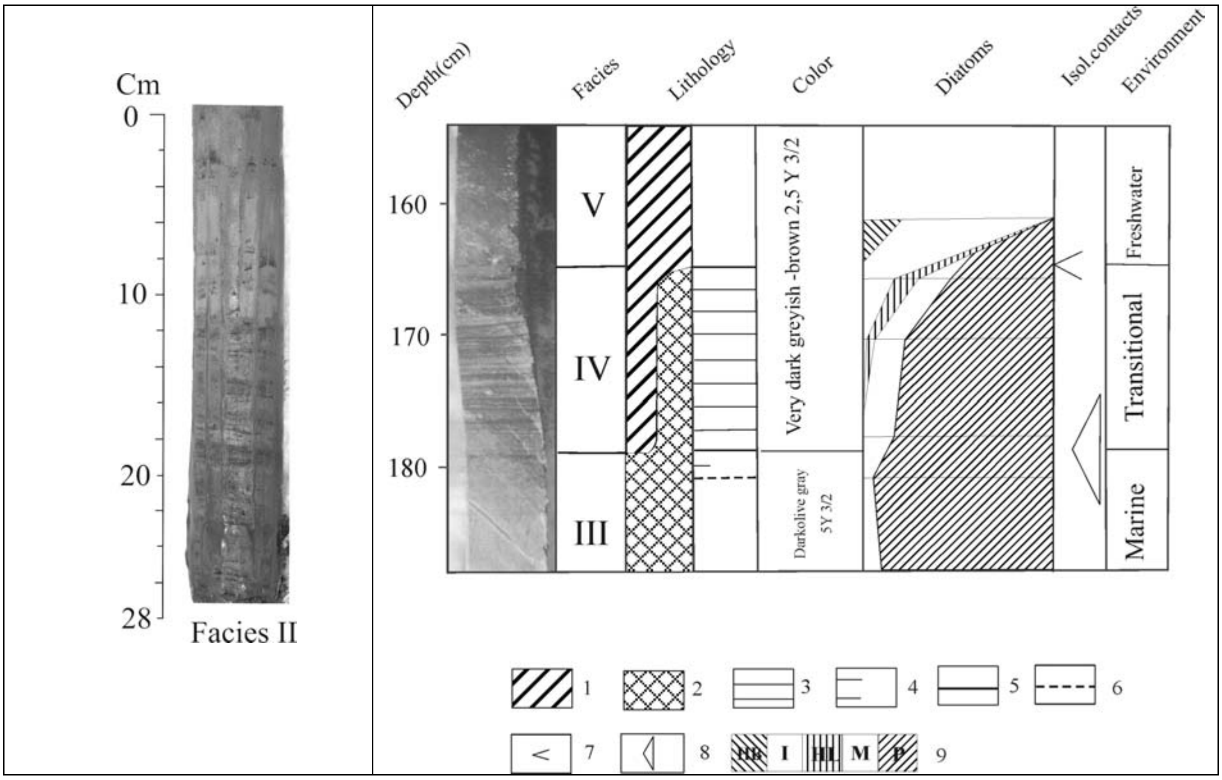


Fig. 5.2. Internal structure of facies II and stratigraphy of the transition between marine (facies III) and lacustrine (facies V) sediments.
1-gyttja; 2 – mud, sandy mud; 3 – lamination; 4 – weak lamination; 5 – sharp contact; 6 – gradational contact; 7 – marine-freshwater diatom transition; 8 – isolation contact; 9 –diatoms: HB-halophobous; I – indifferent; HL – halophilous; M – mesohalobous; P –polihalobous.

Lesozavod area (66°40’, 32°50’)

The marine-lacustrine transition (isolation contact) in sediment cores from ten raised coastal lake basins situated 3.2-104.0 m a.s.l. in the Lesozavod area, at the head of Kandalaksha Bay of White Sea, was identified and used to construct a relative sea level (RSL) curve for the Holocene (Fig. 5.3.). All the lakes show a comfortable, regressive I-II-III (marine-transitional-freshwater) facies succession in the uppermost part of the cores indicating a postglacial history of continuous emergence. The RSL curve shows rapid emergence between 10140±80 C^{14} yrs BP (lake at 104 m a.s.l.) and 9170±80 BP (lake at 59.9 m a.s.l), a relatively low rate of emergence between 9170±80 BP (lake at 59.9 m a.s.l) and ~5000 BP (lake at 30 m a.s.l.), and a moderate rate of emergence after 5000 BP. The low rate of emergence around 6000 BP probably correlates with the Tapes transgression.

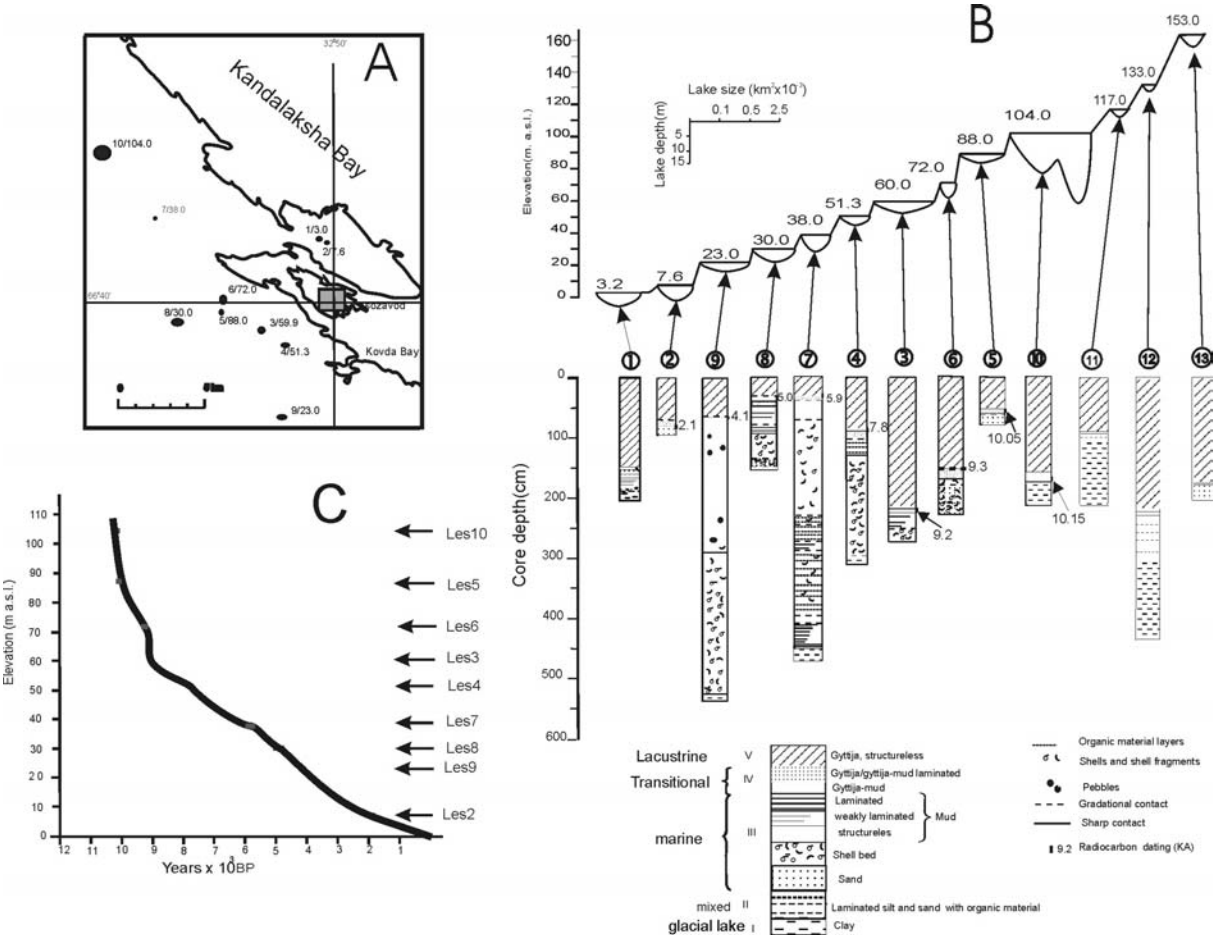


Fig. 5.3 Location map of the cored lake sites (A), overview of the investigated lake basins (B), relative sea-level (RSL) curve for the Lesozavod area (C).

Four lakes, situated between 23 and 51 m a.s.l. and one at 104 m a.s.l. contain postglacial lake sediment (facies IV; non-laminated clay) in the lowermost part of succession, overlain by marine sediment (facies III; silt, sand, shells and shell fragments). Shelly facies in the marine unit in the Lesozavod area include the following taxa: *Balanus sp., Echinoidea, Brachiopoda, Bivalvia (among them Tridonta borealis, Elliptica elliptica, Nicania montagui, Mya sp., Macoma calcarea, Mytilus edulis, Hiatella arctica* and *Chlamys islandicus*), and *Gastropoda* (among them *Puncturella sp., Oenopoda sp., Buccinum sp.*).

The data show that the upper shoreline in the head of Kandalaksha Bay is not below 104 m a.s.l. In addition the lithological study of the sediments of three lakes basins (situated 117 m a.s.l., 133 m a.s.l. and 153 m a.s.l) from the area was done, as there are the observations of the upper shoreline on the 145 m a.s.l. (Lavrova, 1960; Armand, Samsonova, 1969). Lithological sequence of bottom sediment from the lake at 117 m a.s.l. are similar to the sequence from the lake at 104 m a.s.l. in Lesozavod area and contain marine (weakly laminated mud) - transitional (laminated mud and gyttja) - freshwater (gyttja) facies succession (Kolka et al., 2000). The lithological sequences of the bottom sediment from the lakes at 133 and at 153 m a.s.l. contain postglacial lake sediment (non-laminated and weakly laminated clay), mixed sediment (laminated silt and sand with organic material) and lacustrine sediment (gyttja). These sequenses are similar to sequences retrieved from lakes situated above High Marine Line (HML) in inner part of Kola Peninsula (Yevzerov et al., 1998).

We can conclude that HML in head of Kandalakscha Bay is situated between 117 and 133 m a.s.l. The shoreline forms, observed here above 133 m a.s.l. most likely belong to the periglacial freshwater basin that existed in the White Sea depression during the Late Glacial. The abundance in the lower parts of sections of the periglacial lake sediments (facies I) indicates to the point.

Umba area (66°41', 34°28')

Umba area is located near the Younger Dryas marginal moraine. Nine lakes with different threshold altitudes (from 12 m a.s.l. to 72 m a.s.l.) were cored (Fig. 5.4.).

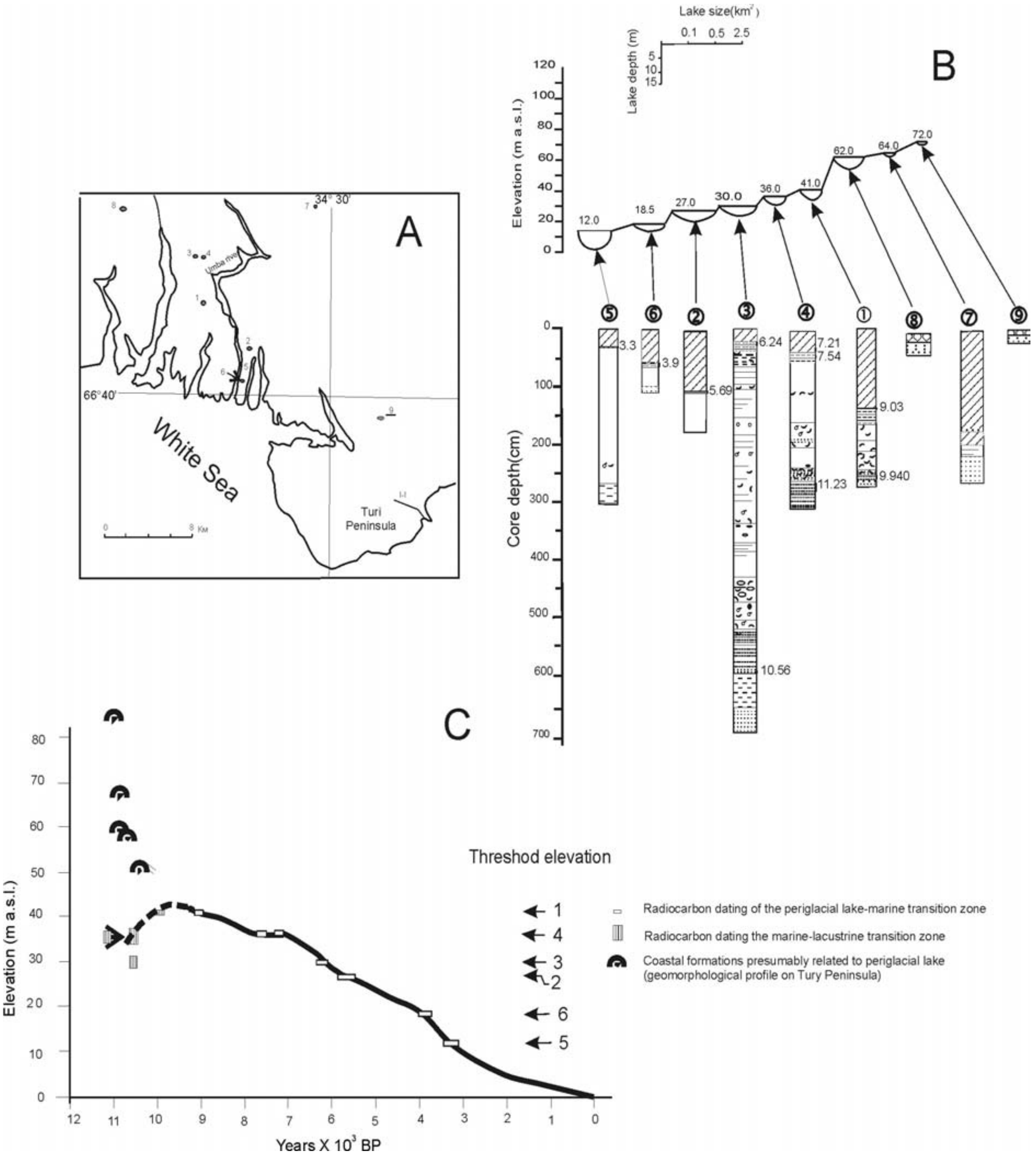


Fig. 5.4. Location map of the cored lake sites (A), overview of the investigated lake basins (B), relative sea-level (RSL) curve for the Umba area (C).

No marine sediment was found in lakes having a threshold altitude more than 50 m a.s.l. (lakes 7, 8, 9 on Fig. 5.4, A, B). Here, gyttia (facies V) lies directly upon glaciofluvial sediments (sand, coarse silt). This is explained by the fact that the lake basins situated presently above 50 m a.s.l. were packed by the dead ice during the Late Glacial.

The whole set of facies is established in the lakes situated between 30 and 40 m a.s.l. (lakes 1, 3, 4, Fig. 5.4, A). The sediments of the lowest-lying lakes (lakes 2, 5, 6, Fig. 5.4, A) are represented only by the regressive (from marine to freshwater) sequence. The transition sediments (from freshwater to marine) are dated in the sections 1, 3 and 4. Their ages are 9940, 11230 and 10560 yrs BP, respectively. Except, the transition sediments (from marine to freshwater) were dated in the lakes 1-6. The ages range from 3300 to 9000 yrs BP (Fig. 5.4, B). The data indicate that the late glacial marine transgression started ca. 11000 yrs BP and followed by the regression at 10000 yrs BP.

Analysis of the relative sea-level (RSL) curve for the Umba area shows that the regression rate was 1 cm/year. The insignificant transgression, correlated to Tapes transgression, occurred during the time span of 8000-7000 yrs BP (Fig. 5.4, C).

The altitude of raised coastal features (beach ridges and terraces) was measured at several localities. On the basis of this measurements the morphological profiles was constructed for four of these (Fig. 5.1): K - Kandalaksha (67°09’,32°25’) , T - Tury Peninsula (66°35’,34°42’), Kb – Korabl' Cape (66°17’,36°34’) (Fig. 5.5) and P - Pulon'ga River (66°18’,40°03’).

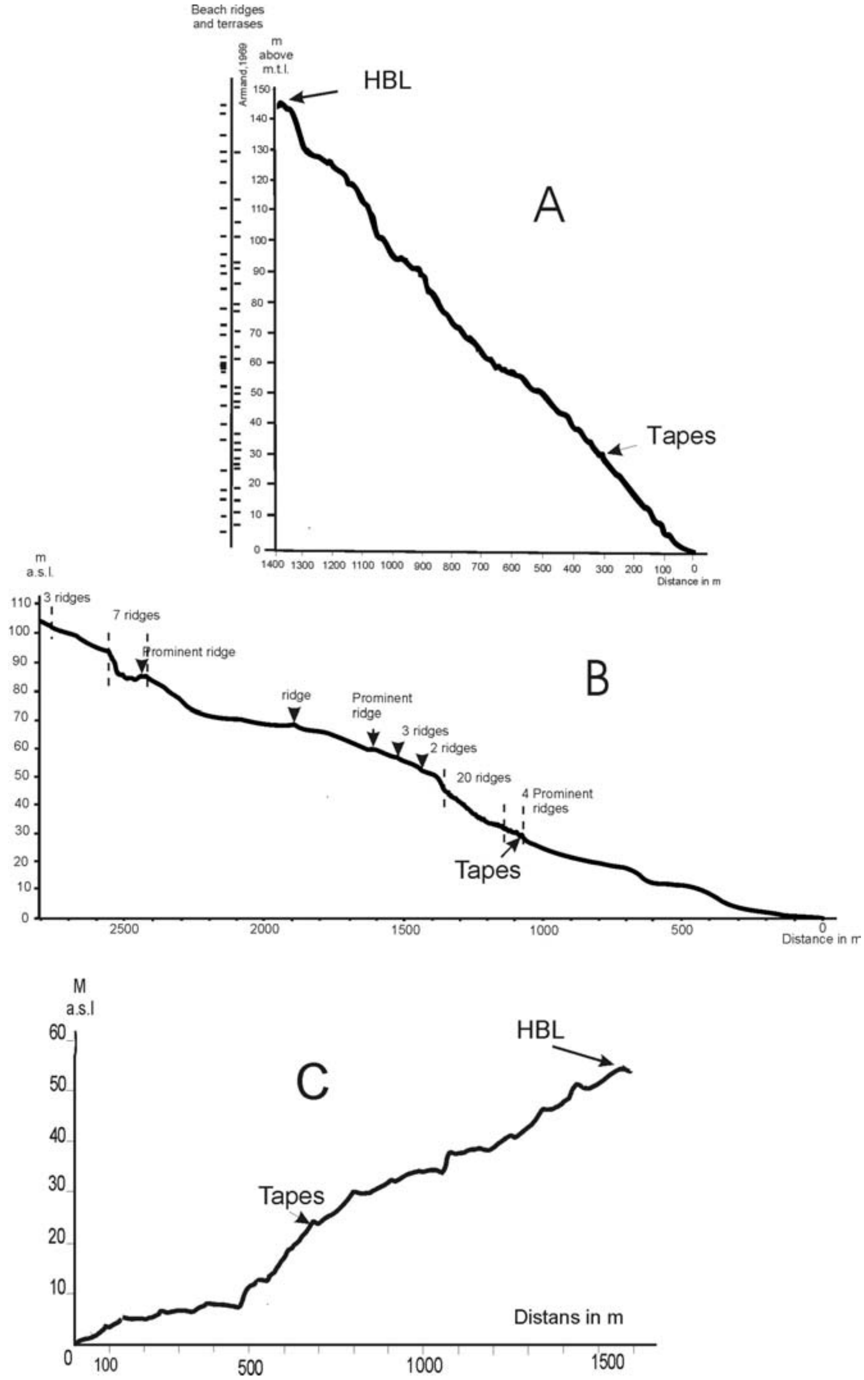


Fig. 5.5. Geomorphological cross-sections: A - Kandalaksha area (Krestovaja Mountain). For comparison, data on the altitudes of the beach features after Armand and Samsonova (1969) are shown on the left; B – Tury Peninsula; C – Korabl' Cape.

Morphological profiles allow two shore levels to be defined: High Basin Line (HBL) and (with variable definition) the Tapes transgression limit. The HBL represents the highest glacial lake during the Late Weichselian.

Its elevation ranges from 55 m Korabl Cape at to 145 m at Kandalaksha. The Tapes altitude was determined at Umba area (isolation contact dated to 6246 ± 140 BP, threshold - 30 m a.s.l.) and Lesozavod area (isolation contact - ca. 6000 BP, threshold - 38 m a.s.l.). The elevations correspond well with prominent beach ridges and terraces on the geomorphological profiles.

Bottom sediment lithostratigraphy of raised coastal lakes

A key area for understanding of White Sea evolution is the Umba - Tury Peninsula area (area 2, profile T on fig.1), where lithostratigraphic and geomorphological data can be compared. From the Tury Peninsula profile (Fig. 5.5, B) it is seen that the numerous regular beach ridges up to 50 m a.s.l. were formed by the regressing sea in Holocene. Four prominent 30 m a.s.l. ridges correspond to Tapes transgression. Intermittent beach ridges occurring above50 m a.s.l., up to 105 m a.s.l., probably formed in a glacial lake.

The same sequence of the periglacial lake and marine basin development in the White Sea depression is recorded in the bottom sediment lithostratigraphy of coastal lake 3 (Fig. 5.4, A) in Umba area (Fig. 5.6).

During the periglacial lake development stage (formation of irregular beach ridges in the upper part of profile, Fig. 5.5, B) the varve clays were deposited (sediments of the facies I, interval 13,82 – 13, 53 м). Salinization of the basin occurred ca. 11000 yrs BP and the regression of the sea began. This time the beach ridges were formed at 50 m a.s.l. (Fig. 5.5, B) and the sediment of transition zone (interbedding of mud and organic material) were deposited in the lake basin. The formation of the regular beach ridges below 50 m a.s.l. is related to the sea regression. This time the marine sediments were deposited and they are stripped in the drill-hole (Fig. 5.6). During the Tapes transgression the prominent beach ridges were formed at 30 m a.s.l. and the marine sedimentation in the lakes of the same altitude was interrupted and transition (from marine to freshwater) sediments began to deposit.

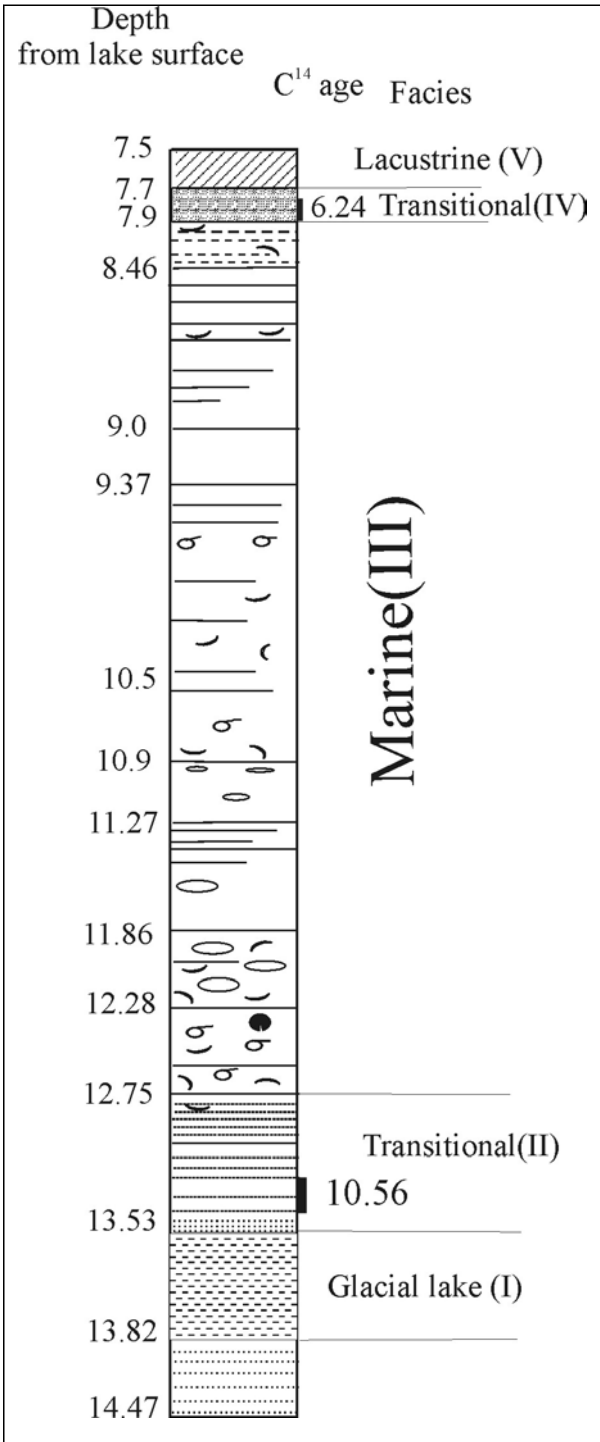
Archeological monuments as demonstration of the Holocene tectonics. The stone labyrinth

Eleven stone labyrinth are known from the Kola region. The native people call them “babylons”. The first description of the stone labyrinth was made by Academician K.M.Ber in 1844. He described the Ponoj labyrinths. The stone labyrinths represent sub-aerial structures, forming the oval or circle. The short axis of the labyrinth passes through the “entry” of the labyrinth. The labyrinths are built up from the rounded stones of 20-40 cm in diameter. The whale vertebra was found in on of the labyrinth near Varzina River. The labyrinths are of two types: simple and complex. The simple labyrinths are composed of the single stone line and formed the concentric spirals. The complex labyrinths are composed of two or three stone lines. The stone labyrinths are found also in the Northern Karelia, Arkhangelsk region, Norway, Denmark, Sweden, and most numerous labyrinth are found in Finland (more than fifty) (Gurina, 1982).

The all known Kola labyrinths are located in the sea coast, on terraces and beach ridges. They are separated from the present sea level by the several beach ridges, marking the sea regression. Even the low altitude of the labyrinths (4-7 m a.s.l.), the archeologists argue that the labyrinths were never flood by the sea. The absence of marine sediments and of surf traces in the labyrinths support the point.

There are several explanations for labyrinths’ construction. The most of investigators suggest religious character of the labyrinths. Another viewpoint is that the labyrinths are of fishery meaning. All of them are situated near the places rich in fish. It is suggested that the labyrinths are the drawings of the fishery tools or, probably, they mark the places rich in fish.

From the present-day position of the labyrinths, built in ancient time along the shoreline, it is possible to assess the intensity of rise of the areas of their locations.



7,5-7,69 - gyttja dark brown, weakly laminated.

7,69-7,86 - dark brown to black laminated muddy gyttja.

7,86-7,97 - brown laminated muddy gyttja.

7,97-8,15 - laminated mud interrupted by a 1 cm thick, organic-rich layer, in interval 8.07-8.08 – shell fragments.

8,15-8,46 - laminated mud with shell fragments.

8,46-9,0 - mud weakly laminated.

9,00-9,37 - massive mud.

9,37-10,9 - dark green weakly laminated mud with more light impurities and shell fragments.

10,9 -11,27 - dark green massive mud with muddy “concretions” more light colour.

11,27-11,86 - dark green weakly laminated mud with more light impurities and shell fragments.

11,86-12,28 - dark green massive mud with muddy “concretions” more light colour and rich shell fragments.

12,28-12,75 - dark green weakly laminated mud with more light impurities and shell fragments.

12,75-12,77 - brown layer of mud and organic material (organic material ~25%).

12,77-13,53 - interbedding of mud and organic material (ratio of mud and organic material ~55:45%).

13,53-13,82 - blue laminated clay (varve clay).

13,82-14,47 - sand laminated.

Fig. 5.6. Bottom-sediments litothostratigraphy of Umba area, lake3 with threshold 30 m a.s.l (Fig. 5.4, A).

Stop 10. Kandalaksha stone labyrinth

The Kandalaksha labyrinth is located on the Pitkul' Navolok Cape at 4 m a.s.l. It was found and firstly ascribed by S.N.Durylin in 1913. The Kandalaksha labyrinth is of complex type with encircled central part (Fig. 5.7). Its short axis is of 6 meters. The age of a labyrinth is defined by archeologists in the second millennium B.C.

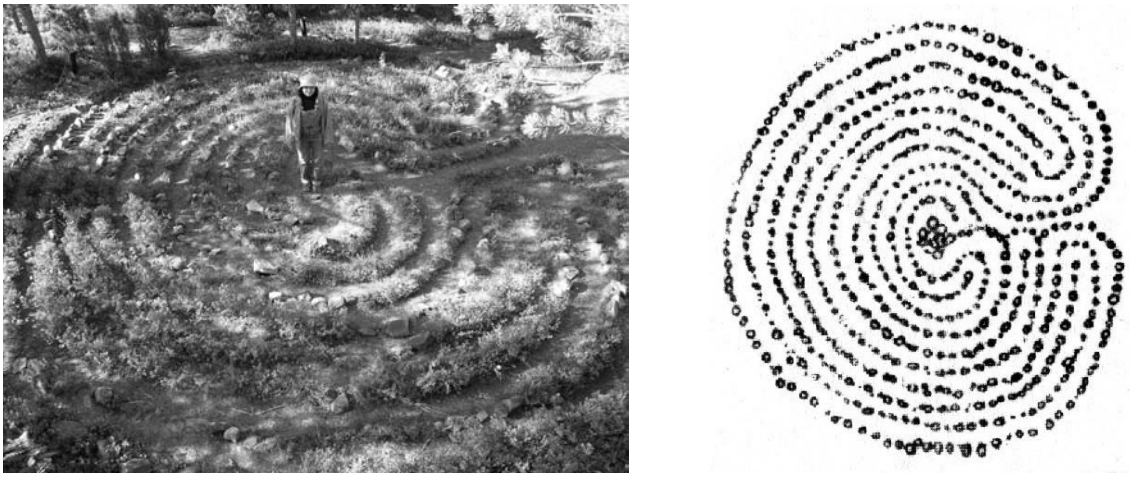


Fig. 5.7. Overview and scheme of Kandalaksha labyrinth.

From the position of the Kandalaksha labyrinth with respect to regressive sea it could be suggested that its age is significantly younger than 4000 yrs BP. According to the dating of the lake sediments of the Lesozavod area (lake 2, Fig. 5.3), the shoreline was at elevation 7,6 m a.s.l. at 2100 yrs BP. As the Kandalaksha labyrinth is at 4 m a.s.l. its age should be younger. Analyzing the RSL curve for the head of Kandalaksha Bay the age of the labyrinth is 1000-1200 yrs. It is during this time span the sea level was subsided on 4 meters.

Stop 11. Holocene coastal landforms on the slope of Krestovaja Mountain

Krestovaja Mountain (the absolute height 320,8 m) is situated on the head of Kandalaksha Bay. The coastal landforms here were revealed during the profiling of the south-eastern slope. They are observed up to height of 145 m a.s.l. (Fig. 5.5, A). In the lowest part of slope the wide beach ridges of 1,5 m high and of sandy composition are revealed. Up to the slope the beach features are expressed as the terraces. The width of terrace platform ranges from 7-10 to 30-70 meters. Up on the slope the platforms are narrower. Terrace cusps have the different steepness (from $8\text{-}10^0$ to $30\text{-}45^0$) and height (from 3-4 to 15 m). The edges and the back-lines of terraces are washed out; the edges are often dissected by the gorges. Terraces of the lower parts of slope are composed predominantly from the sand. Up on the slope the marine sediments contain more pebble material.

The large boulders (up to 1,5 m) are tend to place in cusps and back-lines of the older terraces (Fig. 5.8).The linear distribution of the boulders on the terrace surfaces is explained by shore ice removing. Thus the removed boulder can be seen on the present-day shoreline of the Kandalaksha Bay in the area of Krestovaja Mountain. (Fig. 5.9).

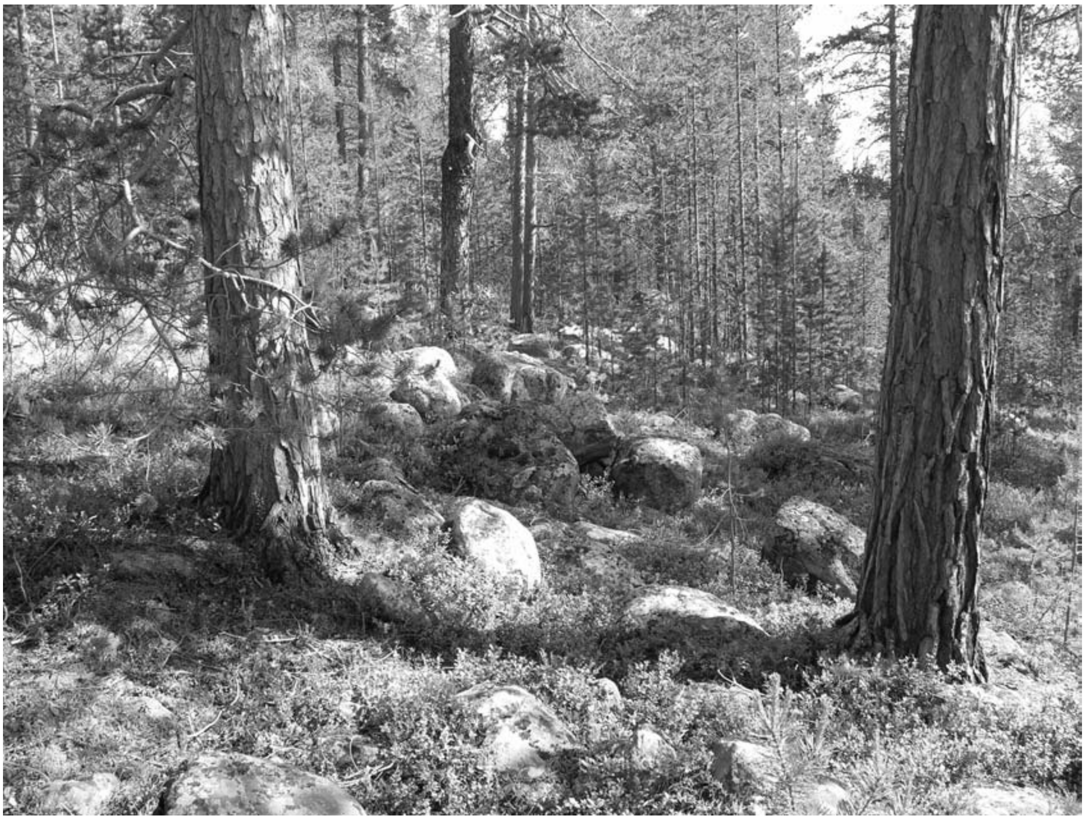


*Fig. 5.8. Glacial blocks on the marine terrace surface***.**

Fig. 5.9. Removed boulders on the present-day shoreline of the Kandalaksha Bay.

The coastal forms, composed of marine sediments, are traced up to absolute level of 120 m a.s.l. on the slope of Krestovaja Mountain. At this altitude the rounded pebble sediments with the layers of tight sand and gravel are outcropped (Fig. 5.10).

Fig. 5.10. Material of the marine beech form on Krestovaja slope at the elevation 120 m a.s.l.

Note that HML in head of Kandalaksha Bay is situated between 117 and 133 m a.s.l., which was established during the study of the lake sediments in Lesozavod area. The highest coastal forms in Krestovaja Mt. are related apparently to the freshwater periglacial basin of the Late Glacial time.

Stop 12. Glaciofluvial and glacial forms on the slope of Krestovaja Mountain

Glaciofluvial and glacial forms on the slope of Krestovaja Mountain are located on the absolute levels above 133 m (HML). The uppermost coastal forms are represented by the slightly appeared terraces, established by the instrumental profiling up from HML (Fig. 5.5, A). Their formation is related to the periglacial freshwater basin.

Above 145 m a.s.l. the slopes are covered by the glaciofluvial sandy-gravel-pebble with boulders sediments. The same sediments cover the saddle between Krestovaja Mountain and adjacent from the north-east Volosyanaja Mountain (abs. level 485,3 m). In some places the glaciofluvial sediments are covered by the till. The till forms the hummocky relief. The upper HBL glacial and glaciofluvial sediments are represented in the outcrop at 195 m a.s.l. (Fig. 5.11).

The glacial striation can be seen on the basement crystalline rocks (plagioamphibolite) on the pass between Krestovaja and Volosyanaja Mountains.

Fig. 5.11. Glacial and glaciofluvial deposits on Krestovaja Mountain slope at 195 m a.s.l.

Conclusion

The Belomorian glacial lobe of the Scandinavian ice-sheet filled the White Sea depression during the Late Weichselian. The glacier moved from the north-west to the south-east along the Kandalaksha Bay. In the Late Glacial time during glacier degradation the periglacial lakes were formed here. The mountain massifs of the Kandalaksha Tundra damped the lakes. As evidence of this stage are the upper basin levels on the slopes of Krestovaja Mountain.

The lithostratigraphic investigation and C^{14} dating of the sections and investigation of morphological profiles suggest that basins development in the Belomorian depression in a whole and in the Kandalaksha Bay particularly during the Late Weichselian and Holocene proceeded in a complicated way from the postglacial lake stage through the salting stage, stages of normal sea salinity to contemporary freshwater lakes on the coast.

The threshold of the postglacial lake was situated at the presently inundated mouth of the White Sea, during the Bølling (~12500 BP) to Younger Dryas (~11000 BP). One or several glacial lakes may have existed at that time, forming the Belomorian Ice Lake. This phase was followed by a marine incursion in Younger Dryas which, in turn, gave way to a regressive phase starting in the late Preboreal (~9000 BP). The regression was interrupted by the Tapes transgression around 6000 BP. The Tapes coastal forms of the Krestovaja Mt are located on the elevations around of 30-40 m a.s.l.

The uplift of the Kandalaksha coast is fixed historically. From the present-day position of the archeological monument “Kandalaksha stone labyrinth” the uplift for the last 1200-1000 years comprised 4 m.

Khibiny area

Locality 6. Late Glacial landforms on Southern Khibiny Mountains and Prikhibinskaja plane

Korsakova O., Hättestrand C., Kolka V.

Khibiny Mountains are situated in the central part of the Kola Peninsula, 66°33' - 67°55'N, 33°13' - 37°16'E. Topographically, it is a dome-shaped mountain massif with the highest point 1200 m a.s.l. (the highest point on the Kola Peninsula). The massif covers an area of 35x38 km (1330 km^2). The main orographic feature of the Khibiny Mountains is their table form shape. The largest river valley, Tul'jok River, is situated in eastern Khibiny. The most valleys represent the troughs, and the widest ones (for example Tul'jok, Belaja Rivers) have the box-like shape due to the flat floor. Large through valleys with Kunijok and Kukisjok Rivers and elongated lakes cross Khibiny from north to south. Deep canyons, U-shaped and wide river valleys cut through the massif. Some of the mountains are cupped with extensive plateaus, and encircled with cirques and steep slopes. The deepness of the large cirques reaches of 400m. As large landforms in the Khibiny massif the some plateau-like summits and cutting valleys are formed by long-time interaction of endogenic and exogenic processes. Cutting valleys reach the 800 m amplitudes. The smaller landforms are of glacial and meltwater origin.

Khibiny Mountains is the world's biggest alkaline pluton. Massif is located in the contact of Archaean gneisses and Early Proterozoic Imandra-Varzuga palaeoriftogenic volcanic-sedimentary complexes which form Lapland-Kola-Belomorian collisional structure. The Khibiny massif is a concentrically zoned multiphase intrusion composed of agpaitic nepheline syenites and to a lesser amount, of ultrabasic alkaline rocks (Fig. 6.1). From the oldest to the youngest the components are as follows: remnants of the alkaline volcanic complex; peridotites, pyroxenites, melilite-bearing rocks; nepheline syenites of the peripheral zone ("khibinites"); melteigite-ijolite-urtite layered complex; K-nepheline syenites ("rischorrites"), juvites, urtites and related apatite-nepheline rocks; nepheline syenites of the central part of the massif (foyaites) and pulaskites; dykes of essexite, alkaline picrite, nephelinite, phonolite, trachyte; carbonatites; pegmatites and hydrothermal veins (Arzamastsev, 2002). Rb-Sr isochron dating give the age of the Khibiny nepheline syenites of 367.5 ± 5.5 Ma, foidolites and carbonatites give the age of 366.6 ± 19.8 Ma (Kramm and Kogarko, 1994).

As in the case with Lovozero Mountains, the Khibiny Mountains are also extraordinarily rich in glacial erosional features and landforms which record the course of deglaciation of the central area of Kola region (Fig. 6.2).

Most evidence of glacial activity is observed in central part of the massif. The highest plateaus are surrounded by *glacial cirques* and steep slopes. Some of the plateaus have *tor-formations*. The summit surfaces are covered by *felsenmeers* of nepheline syenite, and few erratics are found on the plateaus comparing to the Lovozero Mountains. On the weathered bedrock no glacial striae is seen. Large areas of *drumlins* are present on south of the Khibiny Mountains. These have size values of 300 m – 10 km in length, and 100–1000 m in width, and elongation ratios between 3 and 10. The orientation of the drumlins suggests two main directions of ice movement – towards east-north-east and south-east (Yevzerov, 1993, and others).

Extensive suites of ice-marginal features, such as end and lateral moraines, meltwater channels, ice-contact deltas and ice dammed lakes features are found on surrounding slopes and on valley sides inside the Khibiny Mountains.

Marginal moraine ridges often appear in valleys as *large end moraines*, for example in through valley with Kunijok and Kukisjok Rivers. In rare cases they are represented by arcuate end moraines, for example north-east part of massif (Fig. 6.2). Marginal moraine ridges commonly include both till and glaciofluvial material.

Of interest, the town of Kirovsk is built on the Khibiny largest marginal moraine ridge. Geological and geophysical data of V.I.Kotelnikov and D.P.Tsymplyakov (1937) show, that the ridge consists of two, or maybe three moraine layers, that are separated by sediments of varied granulometric composition. The uppermost part of the ridge section was studied in detail by A.D.Armand (1964).

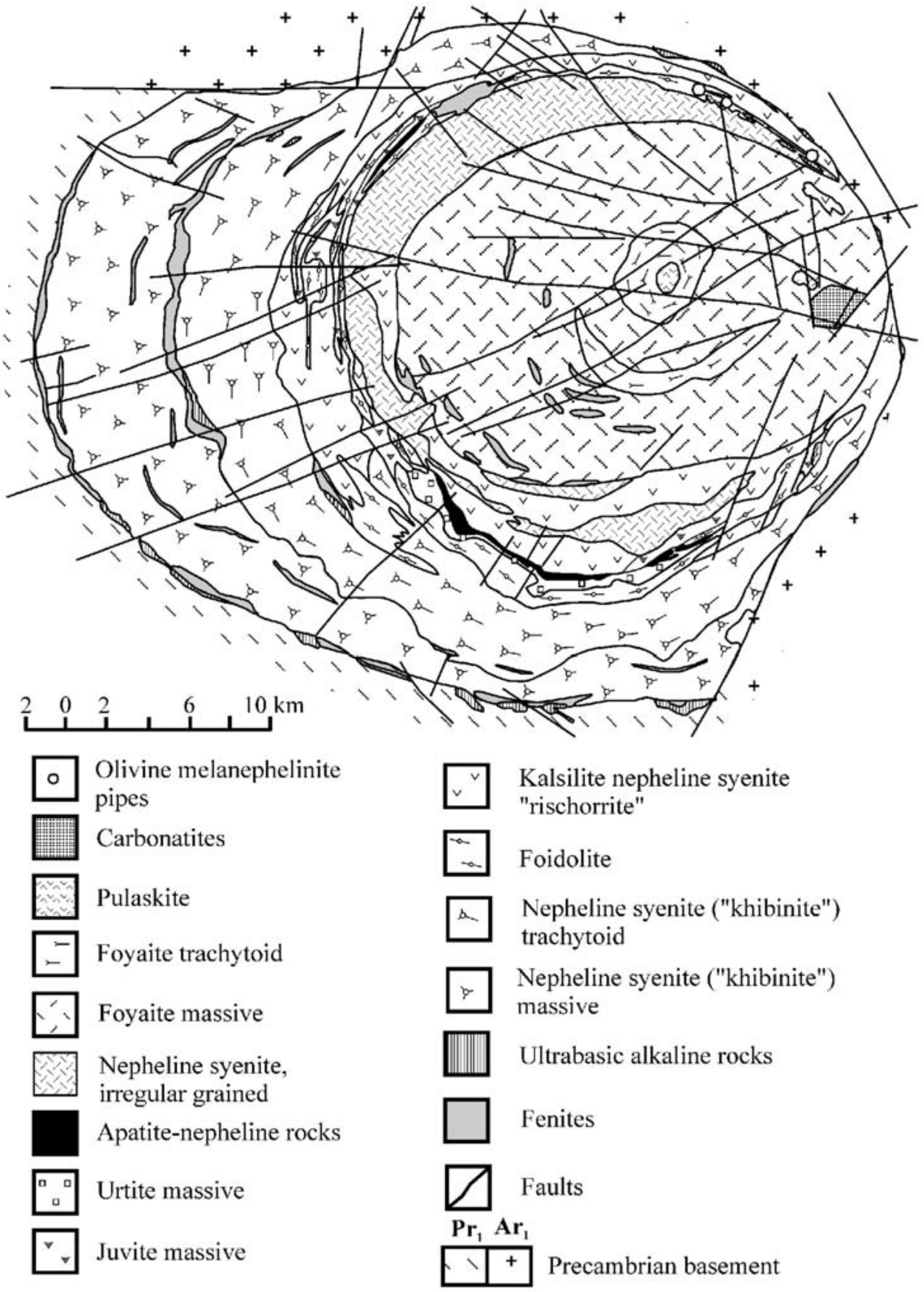


Fig. 6.1. Geological map of the Khibiny massif (after A. Arzamastsev, 2002).

The upper layer of the till almost completely covers the ridge and locally is overlain by glaciofluvial, glaciolacustrine and lacustrine sediments. In the south-western part of the ridge, the till is underlain by over 11 m-thick sequence of glaciolacustrine sediments. Varves are represented by line-grained grey sand and blue silt. There are 950 varves with thickness from 0,3 to 3 cm. To the north, near the Bol'shoy Vud'javr Lake, the till is underlain by gravelly-pebbly diagonally bedded glaciofluvial sediments with boulders. The beds dip at angles of 24-31° to the N, NE and NW. The sediments underlying the till are commonly deformed by the glacier. The glacier was rather sheet-like than local, that is confirmed by the high content (89 – 95%) of the erratics in the till. The low content (12%) of the local rock boulders is also observed in underlying glaciofluvial sediments. In the Kirovsk area, the ice sheet advanced from the south.

The buried till also contains a great number of erratics (after N.L. Kheruvimova, who carried out geomorphological studies in the Bol'shoy Vud'javr valley in 1938). It was also formed by a glacier sheet. It is established, that in the Bol'shoy Vud'javr valley the thickness of the loose layer reaches of 155 m.

Widespread marginal landforms are *lateral moraines*. They are present over the whole massif, especially in the south-western part, on 300-700 m a.s.l., in the valley with Tul'jok River (eastern

Khibiny) – to 800 m a.s.l. These moraine ridges are a few meters high, 5 – 20 m wide and 20 – 300 m length.

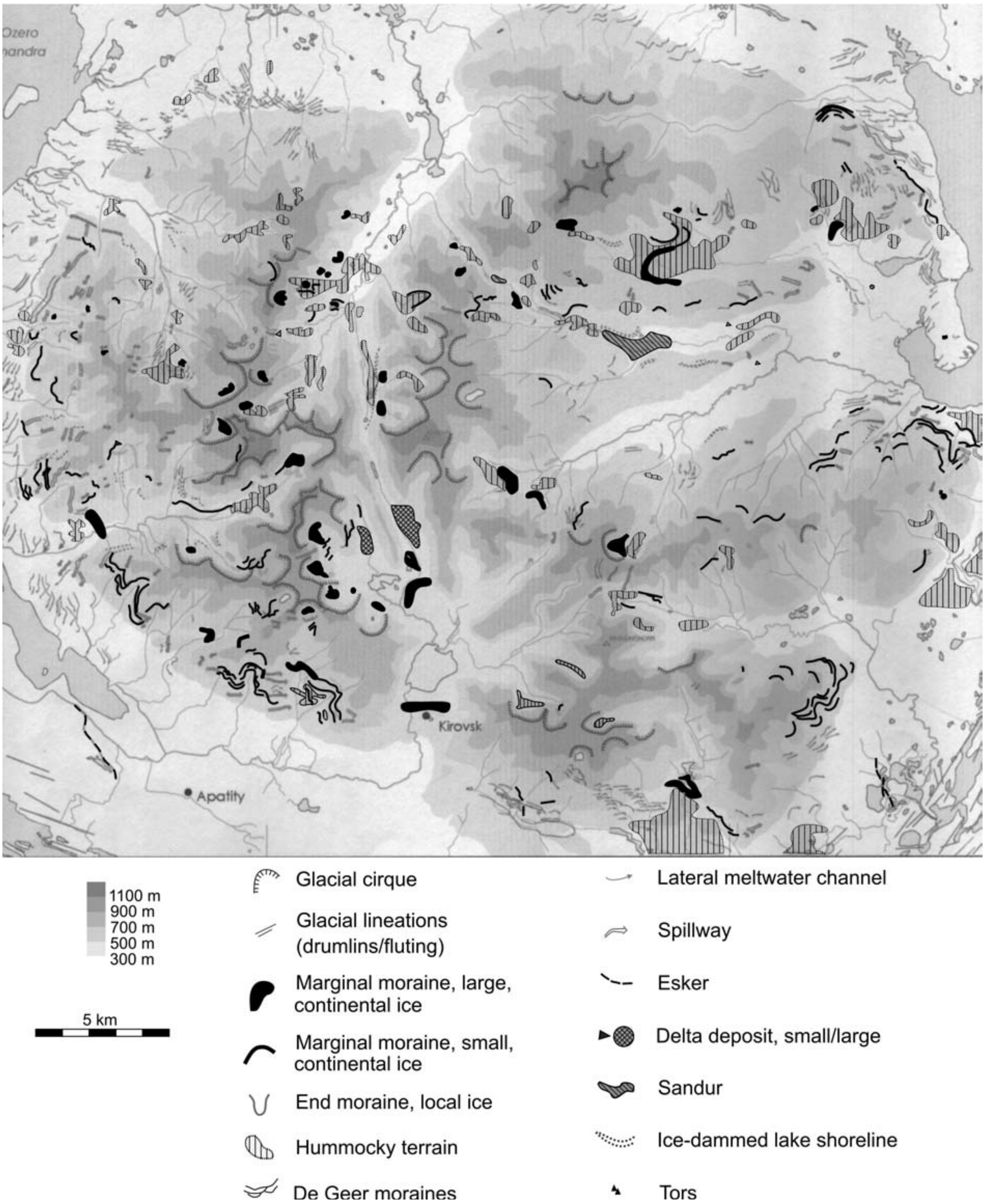


Fig. 6.2. Glacial Geomorphology of Khibiny Mountains.
Gemorphological data from aerial photo interpretation and fieldwork conducted by Class Hättestrand, Vasili Kolka, Olga Korsakova, Krister Jansson, Chris Clark, Nina Johansen, Arjen Stroeven, Derek Fabel in 2001, 2002 and 2004.

<u>Lateral meltwater channels</u> can be seen in the peripheral parts of Khibiny Mountains. They are dry channels running on slopes at an oblique angle to contours. The direction of the channels hence follows the lateral margin of the former glacier or ice sheet that guided the water course along the slope. They almost invariably occur in series, with 2–20 and more parallel channels on a slope.

Spillways are commonly dry channels that normally run perpendicular to contours, on slopes or across cols. They indicate discharge of meltwater during drainage of ice dammed lakes or the meltwater drainage during deglaciation of glaciers and ice sheets.

Spillway channel and *fossil shorelines* on mountainsides reveal evidence for and ice-dammed lakes (Fig. 6.2). They appear on such mountainsides where the perquisites are favorable due to topography with the possibilities for an ice tongue to dam meltwater. The traces are very distinct. There is often the situation, the shorelines continue around the mountainside and where the shoreline disappears a lateral moraine emerges.

Ice dammed lakes features are large *glaciofluvial deltas* in through valley with Kunijok and Kukisjok Rivers and in southern foothills Khibiny Mountains (Lovchorr area), *aqueoglacial plain* in valley with Malyi Vud'javr Lake.

A *sandur* with meltwater channels running in a different direction than present channels covers the floor of largest fluvial valley with Tul'jok River in eastern part of Khibiny Mountains (Fig. 6.2). Fossil *small deltas* are present here. A few *eskers* are situated in the south-eastern Khibiny piedmont.

Landforms similar to *De Geer moraines* are found in several valleys and cirques, for example in Tachtarvumchor area. They look as discrete ridges ranging from short and straight to long and undulating. The width of the ridges is about 15 m, the distance between them - 50-300 m, their height – a few meters. The ridges sometimes continue in a lateral moraine along the mountainside.

Hummocky moraine areas can be seen in the eastern part of massif and in the through valley with Kukisjok, Kunijok Rivers and elongated lakes; smaller areas are present over the Khibiny. The areas with hummocky moraine are found below 700 m a.s.l. Their size is 500x200 – 5000x3000 m (Fig. 6.2).

Stop 13. Top of marginal moraine ridge in Malyi Vud'javr valley

The floor of the Malyi Vud'javr valley represents the aqueoglacial plain. The south-eastern slope of the valley is formed by the thick marginal moraine ridge (large end moraine), the Stop 15 is on it surface (Fig. 6.3). The relative height of the ridge reaches of 80 m, the width of the basement is 400-500 m. Erratics are universally on it surface. The large end moraine marks the position of the glacier lobe, invaded into inner part of Khibiny from the south along Belaya River valley and Bol’shoi Vud’javr Lake.

Fig. 6.3. Overall view to the Malyi Vud'javr valley.

The cirques of Tachtarvuwchorr can be seen in western part of Malyi Vud'javr valley. The cirques floor is hummocky with irregular ridges and channels (Fig. 6.4). It means that there must have been local ablation centers in these cirques when more and more material was brought into the cirques and deposited both in front of the ice margin and on the ice surface itself. The hummocky morphology was created by the dead ice bodies buried in these moraine complexes. Note that analogues to these conditions are presently found in Antarctic nunatak areas (Lintinen, Nenonen, 1997).

In the west of the Malyi Vud'javr valley approaching to the Tachtarvumchorr cirques the gently sloping terraces are placed on the heights of 400-600 m a.s.l., they indicate on regression of the periglacial lake and occasionally bear the De Geer moraines (Fig. 6.5, 6.6). To the north-east of Malyi Vud'javr valley the glaciofluvial delta is located, which at present is undergone to industrial exploitation (Fig. 6.7). From the dipping of the cross bedding in the deltaic sediments it is evident that the material discharge was from the north, i.e. during the melting of the glacial lobe, invaded to the inner Khibiny along Kunijok River valley. To the south of delta the smaller marginal ridge can be seen (Fig. 6.7). The ridge is partly washed out.

Fig.6.4. Cirques of Tachtarvumchor Mountain.

Fig. 6.5. Periglacial lake shorelines on western slope of Tachtarporr Mountain.

Fig 6.6. De Geer like ridges in Tachtarvumchorr cirque.

Fig. 6.7. Glaciofluvial delta and marginal moraine ridge in Kukisjok through valley.

Stop 14. The aqueoglacial plain in valley with Malyi Vud'javr Lake

The floor of the Malyi Vud'avr valley represents an aqueoglacial plain, composed of pebble and gravel-pebble sediments with coarse-grained sand (Fig. 6.8). The lacustrine sediments began to deposit here at time, when the valley was still occupied by the blocks of the dead ice. The smaller erosion-accumulative terraces on the slopes of relief occupy the more high hypsometric place (up to 480 m a.s.l.), than the surface of the marginal moraine ridges in Malyi Vud'avr valley (Fig. 6.5). It means that the basin here was dammed by the glacier, invaded along the through valleys of the Kunijok and Kukisjok Rivers.

It is likely the periglacial basin was formed initially along the mountain slopes between the depressing ice edge and slope surface. As the ice melted, the glaciolacustrine sediments were deposited in the floor of the valley. As the ice melted completely, the sediments of the periglacial lake covered the floor of the valley, forming the glaciolacustrine plain. The blocks of the dead ice preserved for the longest time in the floor depressions, presently occupied by lakes.

Fig. 6.8. Outcrop showing the sediments of the aqueoglacial plain in Malyi Vud'javr valley.

Sedimentation in the lake troughs begins in the early Holocene that is confirmed by the paleonthological study of the bottom sediments of Kupal'noe Lake and by the C^{14} dating.

The results of the investigation are summarized on Fig. 6.9. According to the diatom analyses (performed by Dmitry Denisov*)* seven zones were marked in sequence. They correspond to a Holocene climatic periods.

Zone I reflected the beginning of Holocene (Preboreal period). Diatom flora was represented by cryophilic benthic taxa, including *Pinnularia divergentissima*, *Tetracyclus rupestris*, *Cymbella norvegica*, and temperature-indifferent cosmopolite taxa *Gomphonema acuminatum*, *Fragillaria construens* developed. At this stage of the lake development the total abundance of C was low (28,5 mill. spec./g of dry weight), whereas the specific variety of H' was high (4,1 bit·spec^{-1}).

Zone II corresponds to the beginning of Boreal period. The increase of average annual temperature caused the reduction of cryophilic and rising of thermophilic (*Epithemia sorex*) and indifferent (*Nitzschia palea*) diatom taxa. C amount to 85 mill. spec./g of dry weight. The highest H' was registered for this zone was (4,3 bit·spec^{-1}).

Zone III correlates with the middle of Boreal period, that occurred with further increasing of C (97,7 mill. spec./g of dry weight) and stormy development of indifferent diatoms (N - 37,1%).

Planktonic taxa (*Cyclotella radiosa, Cyclotella antique*) were revealed. This fact shows that Kupal'noe Lake became deeper. Further average annual temperature growth took place at this period. Lowering of specific variety was observed in this zone (H' - 3,9 bit·spec^{-1}). The relative abundance of eutrophic-lakes tolerance species (*Gomphonema acuminatum*) was reduced. Among the thermophile taxa (*Cymbella angustat)* predominated. It is likely the ice buried in the floor of the lake troughs has completely melted in that time.

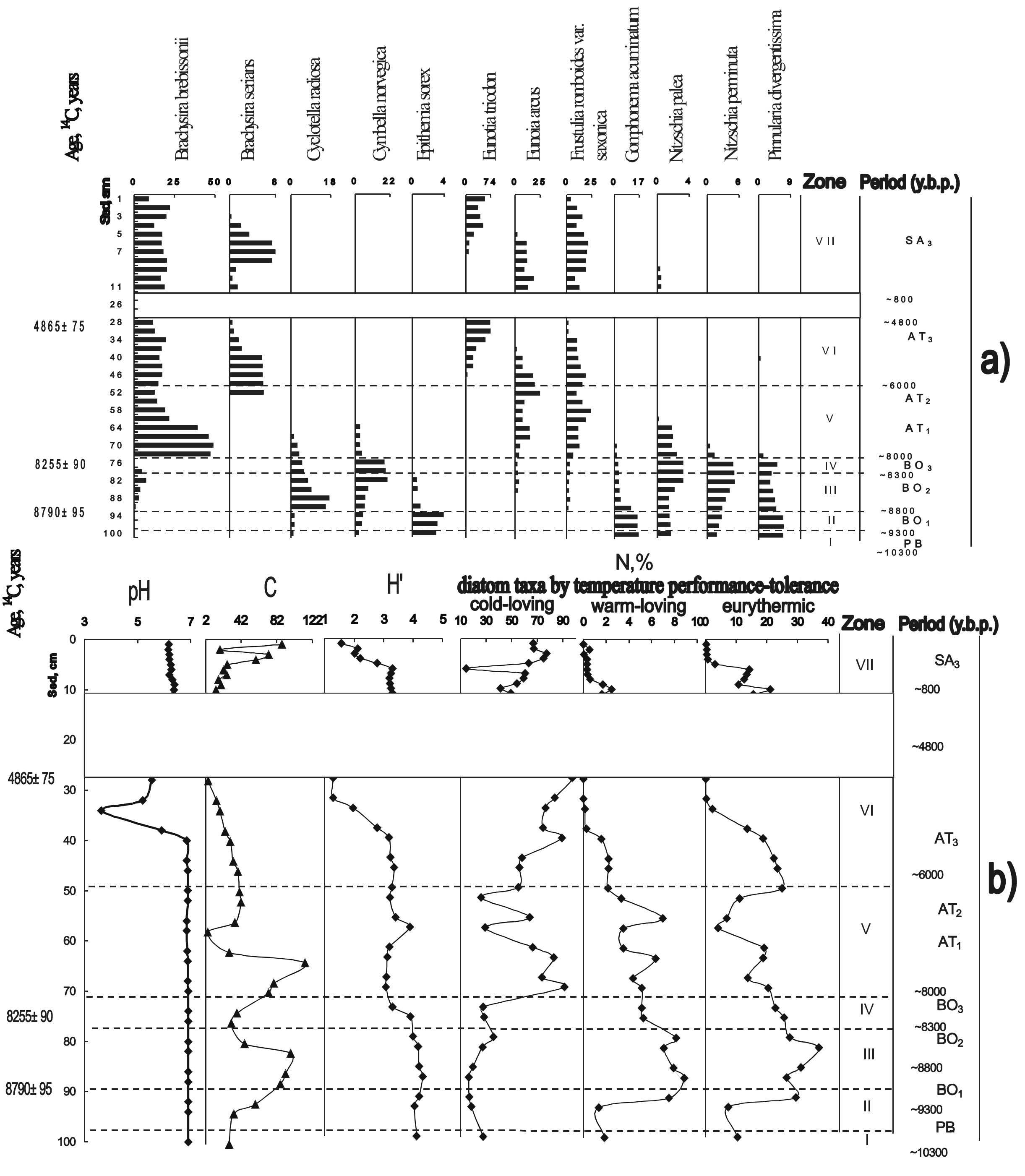


Fig. 6.9. Stratigraphic profiles of the diatom paleocomplexes in the Kupal'noe Lake sediments sequence: a) - relative abundance of the main diatom species (%); b) – theoretic pH values (pH), total abundance (C, mill. spec./g of dry weight), Shannon specific variety index (H', bit·spec^{-1}) and relative abundance (N, %) of a whole cryophilic, thermophile and eurythermal diatom taxa. Holocene periods: PB – Preboreal, BO – Boreal, AT – Atlantic, SA – Subatlantic (after Denisov, 2003)

Zone IV corresponds to the end of Boreal period that was marked with a short-term fall of temperature in the north-eastern part of Russia. Abrupt decrease of C (less than 30 mill. spec./g of dry weight) and thermophilic taxa (to 5.1%) took place. Specific variety also reduced (H' - 3,3 bit·spec^{-1}). *Cymbella norvegica* (cryophilic) and *Nitzschia palea* (indifferent) became dominant under End-Boreal climatic conditions.

Zone V and zone VI (Holocene climatic optimum) correspond to the Atlantic period, when the average annual temperature became higher again. Diatom complexes reflects the increasing of total taxa abundance (C - 113 mill. spec./g of dry weight) and the reducing of specific variety (H' - 3,0 bit·spec^{-1}). Abrupt growing of relative abundance of cryophilic taxa (91,3 %) was observed at this stage. Lake-ecosystem changes were essential. At this stage the temperature was not the main factor for the whole series of diatoms taxa, pH became a limitative factor of the development of the lake ecosystem. The middle part of the Atlantic period was characterized by relatively cool and dry climatic conditions, that well correlates to the decreasing of C (less than 4,1 mill. spec./g of dry weight), and increasing of H' (to 3,8 bit·spec^{-1}). At the end of this Atlantic period H' reduced to 1,3 bit·spec^{-1}, C – to 4,7 mill. spec./g of dry weight. The dominant specie was *Eunotia triodon*.

Zone VII corresponds to last centuries of the lake history (Subatlantic period). The natural pH in this period amounted to 6,38 and then it decreased to 6,1 which corresponds to acidiferous falling on the watershed of the lake. Climatic situation was characterized by increasing of cryophilic diatom taxa. Diatom flora was poor at this stage, and further decrease of H' was observed. Heavy metal started to accumulate in the sediments from the 6-7 cm layer.

Stop 15. Ice-marginal delta in Kukisjok through valley

Large delta deposits occupy the floor of Kukisjok through valley above the valley of the Malyi Vud'javr Lake (Fig. 6.2, 6.7). They are represented presumably by the sandy-gravel material, bearing the pebbles and boulders. At present the deposits are mined and the landform preserved only in its rear part. Their surface is hummocky. The hills are elongated. The relative height of relief is up to 15 m (Fig. 6.10).

Fig. 6.10. Surface of delta, absolute height about 550.

The cross bedding is marked in the sandy-gravel sediments of the distal part of delta. The dipping of layers (110^0) indicates on the drainage from the north in this part of the valley (Fig. 6.11). The delta formation is related to the melting of the ice lobe, invaded into inner Khibiny along the through valley with Kunijok and Kukisjok Rivers from the north.

It is likely, the formation of the marginal ridge, located beneath the delta, is also related to the earlier activity of the same lobe. However, we should note that the paleogeographic interpretation of the ridge is disputable. There is an opinion that it was built by the cirque glacier during its interaction with ice-sheet (Armand, 1964).

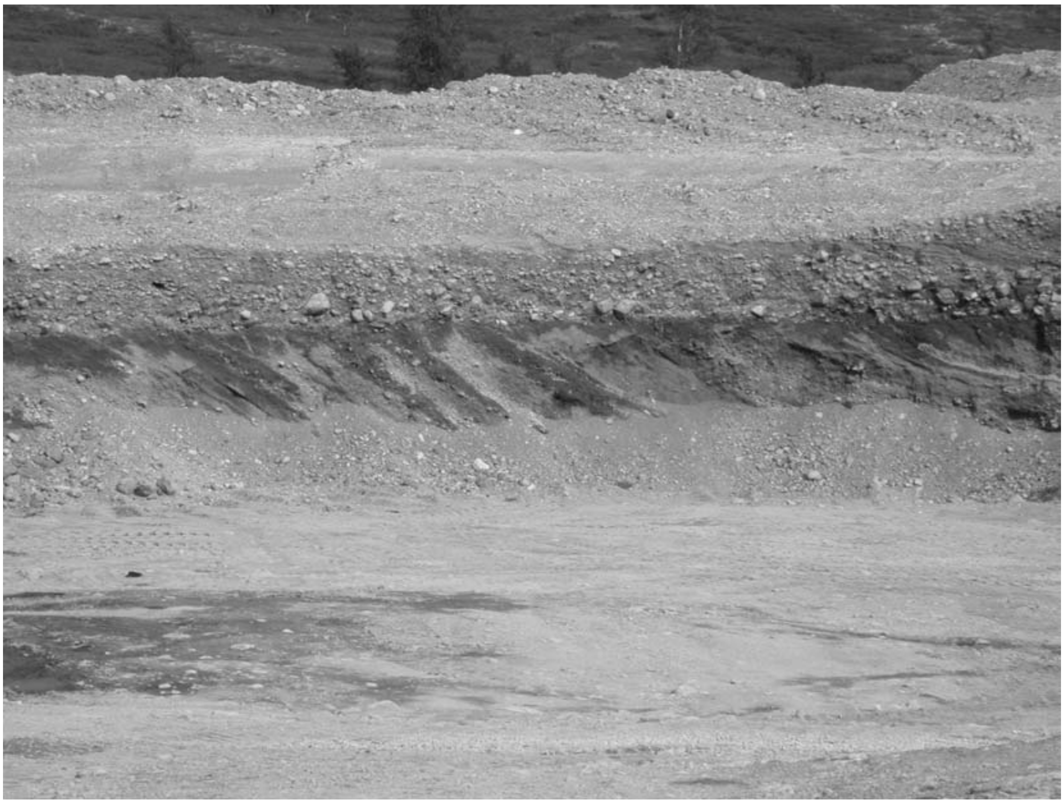


Fig. 6.11. Cross bedding in deltaic sediments.

Stop 16. Rasvumchorr Plateau, Central Mine of "APATIT Co"

"APATIT Co" is one of the largest in Russia mining-processing enterprises and at the same time is the main supplier of phosphorus raw material (apatite $Ca_5(PO_4)_3F$) for the production of mineral fertilizers. The enterprise was founded in 1929-1930. The ore excavation is carried out in three underground mines (Kirovsky, Yukspor, Rasvumchorr) and two quarries (Central and Eastern). On the whole, 60 % of ore is excavated in open pits and 40 % in underground mines. The underground mines have prospected reserves for more than 30 years, quarries - Central and Niorkpahk - for 10-15 years. The total registered reserves of apatite-nepheline ores of the Khibiny group of deposits are estimated as almost 4 bln.t., which corresponds to 600 mln.t. of P_2O_5, i.e. the enterprise is provided with prospected reserves for another 50-55 years. The processing of ore is carried out by two dressing plants. Now "APATIT Co" produces 10 mln tons of apatite concentrate per year.

The Central open-pit mine of "APATIT Co" is located on the height of 1100 m a.s.l. The depth of quarry is 625 m, the lower mining horizons are located at 475 m a.s.l. The length of the quarry is 3 km from east to west, and the width is about 2 km. It is most highland quarry in the Murmansk region. The construction of the mine started in 1961. The first quarry excavator was started to assemble on the 1st February of 1961, and the stripping of the deposit was started on the 7th of August. The first ore has been excavated in June of 1964.

The Central mine is intriguing by their excavation technology and ore transportation. The stripping of the ore body and the disposal is carried out with maximum use of gravitational forces.

This allowed to obtain the less expensive ore in this mine with best indices of the labor productivity. After the explosion the apatite-nepheline ore is carried out to the ore chutes by the dump-trucks of 75-120 t capacity. The ore chutes present six vertical shafts on the different absolute levels. The ore is dump down using the ore chutes and loaded to railway carriers on the levels of 200 m a.s.l. and transported to the dressing plant. The scoop of excavator holds 10 m^3 of ore. The monthly output of ore in the Central mine is 500-600 thousands m^3. The minimum P_2O_5 content in ore comprises 4% and reaches up to 16%.

Fig. 6.12. Overview of the Central open-pit mine of "APATIT Co".

Glaciofluvial formations in Prikhibinskaya plain

The Prikhibinskaya plain, as the most part of the Kola Peninsula, represents the peneplain. Its surface was disrupted during the neotectonic stage. The uplift of the Khibiny massif was accompanied with the formation of the elevated foothill in the south of Khibiny and of Imandra and Umbozero lakes' depressions.

The most part of the Prikhibinskaya plain is covered by moraine and glaciofluvial sediments of the last Valdaian glacier. These units are related to two different in time stages: the stage of the ice movement and the stage of melting of the stable ice. From the distribution of the key-rock clasts in sediments it was established that the centre of the last ice-sheet was situated to the west of central mountain massifs. In this case the local glaciers reached the foothills only at time preceding the Last Glacial Maximum, and not after (Armand, 1964).

The differently directed subglacial landforms, parallel to ice-flow are revealed. The orientation of the drumlins and flutings suggests two predominant directions of ice movement in South Prikhibinskaya plain: east-north-eastward and south-eastward (Fig. 6.13.). These landforms have size values of 100 m – 10 km in length, and 100–1000 m in width, and elongation ratios between 3 and 10.

The most of exogenous landforms within the Prikhibinskaya plain were formed at the late glacial time during glacier melting. The summits of the highest hills and ranges were exposed firstly.

They were washed out by the meltwater streams, forming the spillways. The kame terraces were formed on the slopes of the hills and ranges. Hummocky moraines, eskers, kames were formed as ice melted.

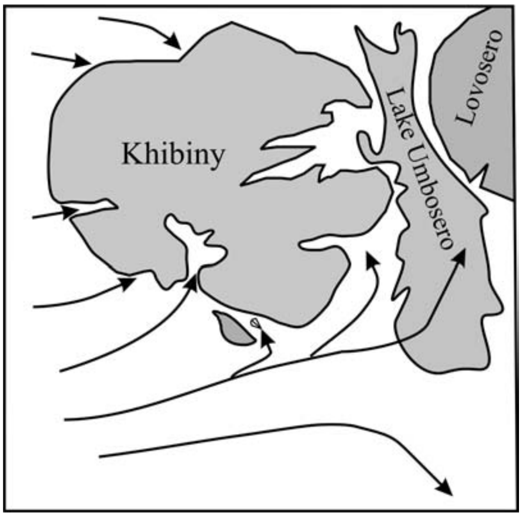


Fig. 6.13. Directions of ice movement in Khibiny Mountains area.

Stop 17. Quarry opening sediments of glaciofluvial delta in southern piedmont of Khibiny Mountains

The glaciofluvial delta is located in the depression between the Khibiny Mountains in the north and the bedrock outcrops in the south. During the glacier degradation stage the drainage of meltwaters happened along the depression. Presently the Aikuaivenchjok River flows along the glaciofluvial valley. From the vertical electric sounding data the valley is over-deepened up to 25-30 m (Armand, 1964). There are abundant drumlins in the west, south and east.

The delta is composed of the gravel-pebble with sand and boulders sediments (Fig. 6.14 фото 41). The inclined bedding of dipping azimuth 320 ° is marked in sandy layers (Fig. 6.15). The gravel-pebble layers are inclined in the same direction. The till overlaid the deltaic deposits (Fig. 6.16). In the distal part of delta the glaciotectonic deformations in the form of faults can be seen (Fig. 6.17). From the earlier studies the availability of different glaciotectonic dislocations was established in deltaic sediments (Yevzerov, Kolka, 1993). Specifically, they are sandy diapers and thrusts (Fig. 6.18).

Fig. 6.14. Section of glaciofluvial delta in southern piedmont of Khibiny Mountains.

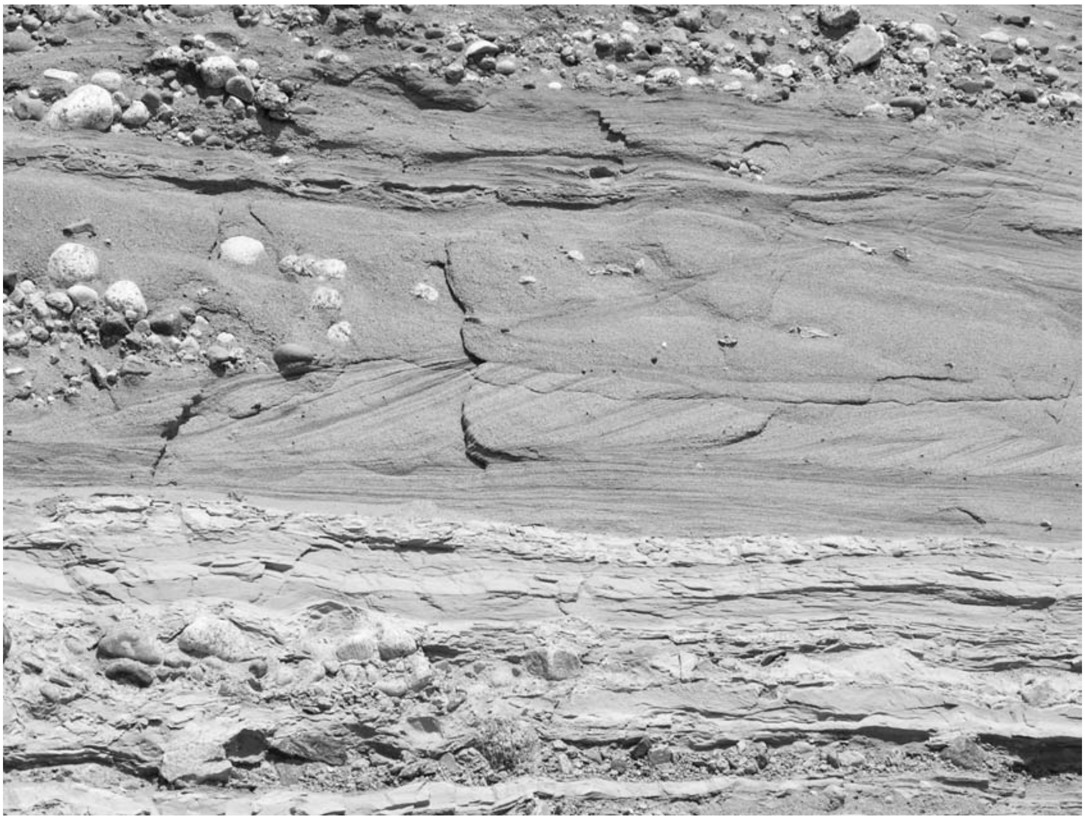


Fig. 6.15. Inclined bedding in sandy layers (glaciofluvial delta in southern piedmont of Khibiny Mountains).

Fig. 6.16 Section of glaciofluvial delta with the till overlying the deltaic deposits in southern piedmont of Khibiny Mountains.

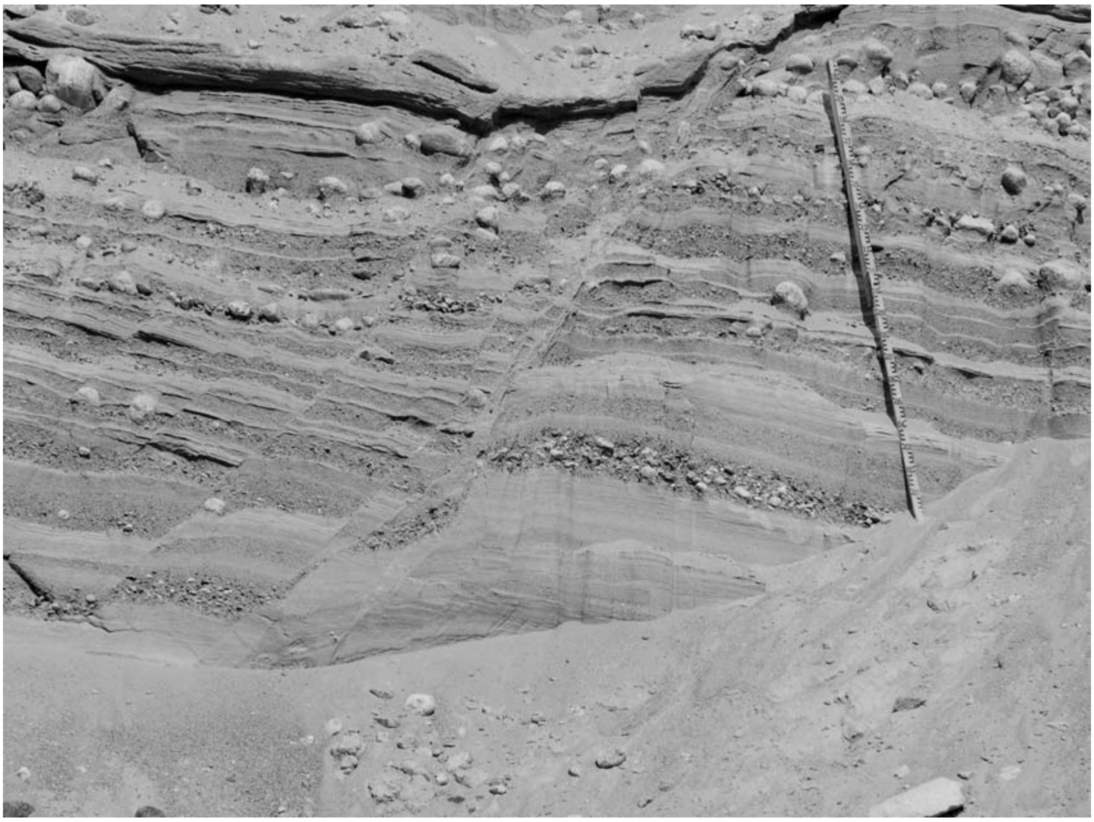


Fig. 6.17. Distal part of glaciofluvial delta in southern piedmont of Khibiny Mountains with the glaciotectonic deformations in the form of faults.

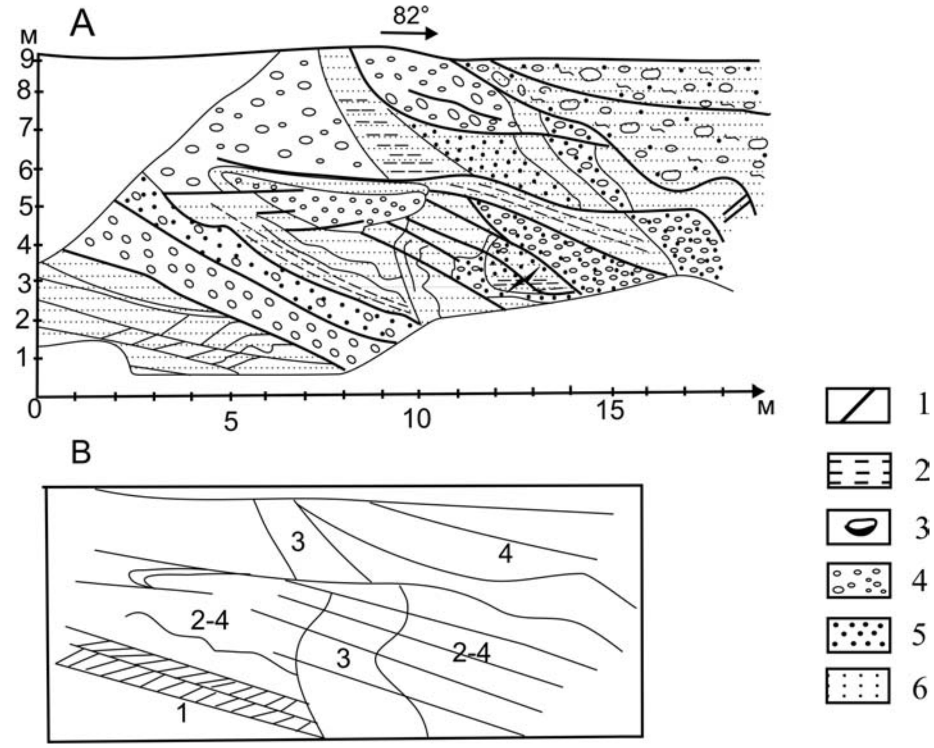


Fig. 6.18. Longitudinal section of the middle part of the giaciofluvial delta in southern piedmont of Khibiny Mountains with sandy diapers and thrusts (A) and succession of the glaciofluvial delta developments (B)(after Yevzerov, Kolka, 1993).
Legend: 1 – tectonic faults; 2 - foliation; 3 - boulders; 4 - pebbles; 5 - gravel; 6 - sand.

Thrusts and the sandy diaper were observed in the section of the middle part of the delta (Fig. 6.18). Sandy diaper was destroyed by the thrusting and foliated in the upper part. Spatial relationships of the structural units are illustrated in the stereogram on Fig.6.19, which presents data on the position of poles of bedding, ruptures, complementary fractures, foliation (shearing?) and folds.

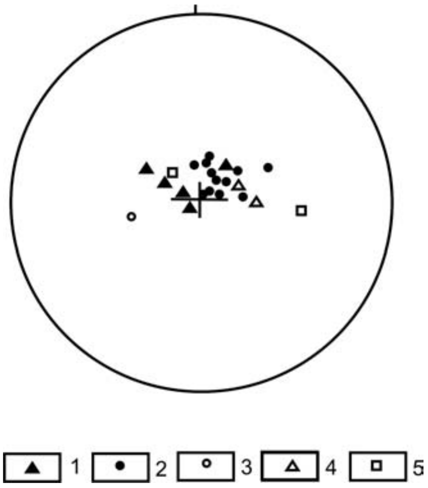


Fig. 6.19. Spatial relationships of structural elements in the middle part of the giaciofluvial delta in southern piedmont of Khibiny Mountains. Wulff net, projection on the upper semisphere (after Yevzerov, Kolka, 1993).
Legend: 1 - bedding poles; 2 - – rupture poles; 3 - fracture poles; 4 - poles of foliation; 5 - poles of fold limbs.

The dipping of the bedding in the deltaic sediments (310-320°) suggests that the flows of glacial meltwater were moved to north-west direction. Reactivation of the glacier caused the deformation of the sediments. Glaciotectonic dislocations of the glaciofluvial deposits provide evidence for minor ice movements directed to the north and north-west and related to local topography of crystalline rocks.

Discussion

The summit surfaces of Khibiny massif, like ones of Lovozero, are dissected by numerous glacial cirques. These landforms were formed before Late Glacial maximum during periods still not cold enough for ice sheet growth and overriding, during many Quaternary interstadials. Erratics on the surfaces of the highest Khibiny plateaus indicate that the massif was covered by the last glacier.

Extensive suites of ice-marginal features, such as end and lateral moraines, meltwater channels, ice-contact deltas and ice dammed lake features are found on surrounding slopes and on valley sides inside the mountains. These ice marginal landforms allow a reconstruction of the glaciation history of the region to be made.

All over Khibiny Mountains, both in valleys within the massif, as well as on the outside slopes, large numbers of lateral moraines show the course of deglaciation. The sheer number of moraines, indicating repeated halts, and/or re-advances during the ice marginal retreat suggests that these moraines represent the Younger Dryas cold period. At some point in time, it appears that the ice completely engulfed Khibiny, and ice lobes flowed up into valleys all around the massif, in some cases even turning 180^{o} and reaching far into the east-facing cirques. Witnesses of these stages are a particular type of morainic formation - "cirque infills". In Khibiny Mountains these cirque infills are very distributed deposits with a hummocky surface found in the innermost part of the almost cirques, and they are sometimes demarked by a steep ice-contact slope on the valley side. Their existence indicates that there were local ablation centers in these cirques. The hummocky morphology was created by the melting of dead ice bodies buried in these moraine complexes. Cirque infills were formed during the stage, when the Khibiny massif manifested as nunataks and the glacier frontier was to the east. The stage is probably Older Dryas (Fig. 1.8).

As deglaciation progressed, the ice margin began to retreat out of the valleys. The Malyi Vud'javr valley accommodated the dead ice for a long time. The periglacial basins were formed near the slopes of the dead ice. The uppermost basin levels in the mountainsides are related to these periglacial basins. Probably, in Allerede and in the beginning of the Younger Dryas the frontier of degraded glacier reached the Khibiny foothills. In terms of the areal deglaciation the periglacial basins were formed in the Bol'shoyi. Vud'javr valley and in the Prikhibinskaja plane and the glaciofluvial, glaciolacustrine and deltaic (Kirovsk marginal ridge, Koashva delta) sediments were deposited.

The last, probably Younger Dryas, cooling caused reactivation of the glacier lobes, newly invading along the valleys to the inner Khibiny. During this period the deltaic sediments in the Prikhibinskaja plane and the glaciofluvial sediments of the Kirovsk ridge were deformed and overlaid by the till.

Recessive stages of the glacier development are fixed by the position of the marginal moraine ridges in the main river valleys of Khibiny Mountains (Fig. 1.8). In the south Khibiny Mountains these landforms are the large end moraines in Malyi Vud'javr valley and in Lovchorr plateau, and the Kirovsk ridge.

As more and more valleys became ice free, the normal water drainage in these valleys was dammed by the receding ice tongues. Hence, ice dammed lakes were formed. The water level of these glacial lakes was controlled by the lowest pass point leading over to neighboring valleys.

Glaciolacustrine sedimentation occurred firstly in the basins along the slopes, and then on glacier surface. As the dead ice melted, the supply of material occurred by the meltwaters and by the washing out and accumulation of the glacial deposits.

The specific feature of the Khibiny is that in late- and post-glacial there was no of the local glaciation as was in the Lovozero massif. The reasons of the phenomenon have not yet established.

Museum of Geology and Mineralogy, Geological Institute KSC RAS

The Museum of Geology and Mineralogy was founded in 1930-ies attached to the Khibiny Mining Station of the USSR Academy of Sciences, which was later reorganized into the Kola Science Centre RAS.

The Museum and associated archives store over 9000 samples of the minerals, ores and rocks of the Kola Peninsula, and exhibit the following:

- a systematic collection of minerals;
- a collection of ores and other types of mineral resources;
- a collection of rocks, and
- a collection of new minerals, discovered on the Kola Peninsula.

Fig. 1. Systematic collection of minerals in the Museum of Geology and Mineralogy, Geological Institute KSC RAS.

The collections appear to be a most complete range of the Kola Peninsula minerals, including rare and new minerals, which are unique in habit, colour, size and assemblages that make the collections valuable and excite curiosity of the visitors.

The systematic collection of minerals has over 1200 samples exhibited in the showcases grouped in native elements, sulphides, halogenides, carbonates, sulphates, oxides and hydroxides, phosphates, and silicates. The collection of the Khibina and Lovozero minerals impresses with its appearance and diversity, especially because the most minerals are rare mineralogical specimens.

The Kola Peninsula is a mining area extremely rich in apatite, copper, nickel and cobalt, iron, rare metals, and micas, as well as in high-alumina ceramic and abrasive materials, and facing and decorative stones. Over 800 samples of different ores and minerals from these deposits are exhibited in the Museum.

The petrographic collection of igneous, metamorphic and sedimentary rocks from different massifs of the Kola Peninsula has over 900 samples.

Over 130 new minerals of 210 first found on the Kola Peninsula, including 56 minerals discovered by the researchers of the Geological Institute, are to be admired in the exposition hall of the museum.

Polar-Alpine Botanical Garden and Institute

The oldest on the Kola Peninsula Institute of the Russian Academy of Sciences, Polar-Alpine Botanical Garden-Institute (PABGI) was founded in 1931 as a project of well-known botanist, Professor N. A. Avrorin, as research and educational institution. First years after it formation the Garden was an independent research institution. Since 1936 the Garden was a subdivision of the Kola Research Station of Soviet Academy of Sciences (later - the Kola Branch of Soviet Academy of Sciences, currently - the Kola Science Centre). In 1967 the Botanical Garden was given the status of research institution. In 1981 PABGI was awarded the order of "Honour Symbol" for its contribution in biological science development, plant protection in the North and because of its 50th anniversary.

PABGI is the northernmost in Russia (latitude 67° 38' North) and one of the three Botanical Gardens in the world located above the Arctic Circle. The total area of the Garden is 1670 hectares, including 1250 hectares of natural reservation. Most of the Garden is located on slopes of Takhtarvumchorr and Voudjavrchorr mountains. From the foot (312 m above sea-level) to flat tops (about 1068 m over sea level) valley tundra, sparse boreal spruce and birch taiga, subalpine crook-stem forest, alpine tundra and mountain arctic desert change each other. The northernmost in the world Arboretum of the Garden is located near the town of Apatity in 25 km from the basic territory. The Arboretum was created in the period 1985-1999, and it is one of the most interesting landscape compositions of the PABGI.

Fig. 2. PABGI building at the foot of Vudjarvchorr Mountain

The Polar-Alpine Botanical Garden-Institute conducts researches of local vegetation and soils, mechanisms of plant adaptations in the North, and working out the basic principles of plant protection and utilization. On the basis of plant introduction new technologies for landscape architecture and plant protection from pests and deceases are developing.

The reserve area of the Garden includes northern, north-eastern and, partly, southern and south-eastern slopes of Voudjavrchorr Mountain as well as north-eastern slope of Takhtarvumchorr mountain. Here, despite of the altitude range not exceeding 700 m, different types of vegetation successively change each other as follows: forest, birch crook-stem forest, mountain tundra, and rocky mountain desert. The forest occupies the mountain foot and the lower slope part. It is presented by mixed spruce-birch forests (bushes, more seldom grasses). The birch crook-stem zone is located 400 m a.s.l. It is characterized by decreasing role of spruce in the tree layer and prevalence of Betula tortuosa Ledeb. and Betula callosa Lindq. The most common are birch crook-stem with dwarf-shrub layer. At the height of 430 - 460 m birch crook-stem woods are replaced with mountain tundra. These are shrub tundra dominated by Betula nana L. Shrub-lichen, moss-lichen and other types of tundra are located higher. Penetration of mountain tundra downwards, along mountain circa directly into the forest zone is of great interest. The plots of overgrown rocky screes look very pictorial.

The unique collections of PABGI are both national and international pride. The collections include open-ground nurseries of introduced herbs, trees and bushes as well as aboriginal plants. The collection of tropical and subtropical plants is placed in two greenhouses. At present the PABGI collections consist of over 8,000 samples referred to more than 3,000 species. For the 70 years of introduction practice about 30,000 samples of 6,500 plants were tested in the Garden. The collection of introduced herbs, trees and bushes is unique by both number of plants acclimated above the Arctic Circle, and by their systematic and geographical diversity. The Herbarium of the Garden including over 200,000 samples is of great interest for botanists.

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