

ESR/OSL ages of long-debated sub till fossil-bearing marine deposits from the southern Kola Peninsula: stratigraphic implications

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BOREAS



Molodkov, A. & Yevzerov, V. 2004 (May): ESR/OSL ages of long-debated sub till fossil-bearing marine deposits from the southern Kola Peninsula: stratigraphic implications. *Boreas*, Vol. 33, pp. 123–131. Oslo. ISSN 0300-9483.

The occurrence of sandy clay deposited in a warm marine environment just below the till of the last glaciation has created controversy about its age and stratigraphic position in the sedimentary basin of the Kola Peninsula. Data on marine microfauna, diatoms, malacofauna and pollen composition indicate that during the period when the sandy clay was deposited the climate was similar or even warmer than at present. According to ^{14}C dates, sedimentation of the sandy clay occurred around 40 ka BP. Based on these data, some researchers have attributed these marine deposits to the third Late Pleistocene Belomorian (*sensu* Lavrova 1960) interglacial transgression. At the same time there are geological indications suggesting re-deposition of these sub till sediments. To solve this problem we have reinvestigated the sub till interglacial marine deposits from the Varzuga section ($\sim 66.4^\circ \text{N}$ and 36.6°E). Four different marine shell species and enclosing sandy clay sediments taken from the sub till marine unit of the section were dated by the electron spin resonance (ESR) and optically-stimulated luminescence (OSL) methods at about 103 and 104 ka, respectively. The results indicate that the sub till marine deposits belong to the first Late Pleistocene Boreal transgression that, according to our previous studies of the marginal areas of the Eurasian North, has occurred in the time interval from approximately 145 to 70 ka BP.

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There is ongoing debate concerning the stratigraphic subdivision of the Late Pleistocene deposits on the Kola Peninsula. Some researchers (e.g. Yakovlev 1956; Apukhtin 1957) assert that the deposits of at least three marine interglacial transgressions – Boreal/Eemian/2nd neointerglacial, Mologo-Sheksnin/Onega/3rd neointerglacial and Onego-ozerskian/4th neointerglacial – are sandwiched between the tills of the Dnieper/Saalian and Late Valdai/Weichselian glaciations. Others have distinguished only two transgressions – Boreal/Ponj (Eemian in West Europe) and Belomorian. According to palaeoclimatic data (e.g. Armand & Lebedeva 1966) and malacofauna composition (Lavrova 1960), both these transgressions were accompanied by a considerable warming of interglacial rank. This has allowed some researchers to correlate Belomorian with deposits of the second independent interglacial transgression (Lavrova 1948, 1960; Legkova 1967) or with the final phase of Boreal/Eemian transgression (Lavrova 1961). Later, the deposits of the Belomorian transgression were considered again as Late Valdai (Nikonov 1966) or as the marine bed of the third Late Pleistocene independent interglacial transgression (Yevzerov & Gudina 1971).

In the early 1990s, on the basis of all the geological data available, Yevzerov (1993) concluded that, at many sites, the Boreal transgressive deposits are overlain by deposits of the second independent but relatively colder transgression named Strel'ninian. Therefore, it turned out again that the 'warm' deposits of Belomorian transgression should belong, in this case, to the third

transgression that has occurred here, presumably in Middle or Late Valdai time.

Traces of the first two transgressions – Boreal and Strel'ninian – are distinctly recorded in a number of type sections on the coast of the Kola Peninsula. The deposits of the third, much-discussed, Belomorian interglacial transgression are revealed in the type section T-16 located on the right bank of the Varzuga River on the southern coast of the Kola Peninsula (Fig. 1). These deposits, represented by a greenish-grey or dark-grey fossil-rich sandy clay, about 6 m thick, are situated between the underlying sandy bed attributed to the second relatively cold Strel'ninian marine transgression, and the overlying unit of sandy diamict interpreted by most as till of the last glaciation. The standpoint concerning the attribution of these deposits to the Middle Valdai/Weichselian (Belomorian?) interglacial transgression was corroborated by two (LU-141A and LU-141B) radiocarbon dates around 40 ka (Yevzerov *et al.* 1976). Besides, a 'warm' marine bed of the same stratigraphical position has also been found on the left bank of the Varzuga River, below Sobachy stream, that can also be taken as indirect evidence of the occurrence of deposits of the third interglacial in the southern part of the Kola Peninsula.

However, after closer examination of this section, Yevzerov (1993) came to the conclusion that these sub till sediments could not be attributed to an independent transgression and in contrast to the lower marine bed (lower Strel'ninian clay) that occurs *in situ* above the underlying Boreal/Ponj transgressive deposits, the

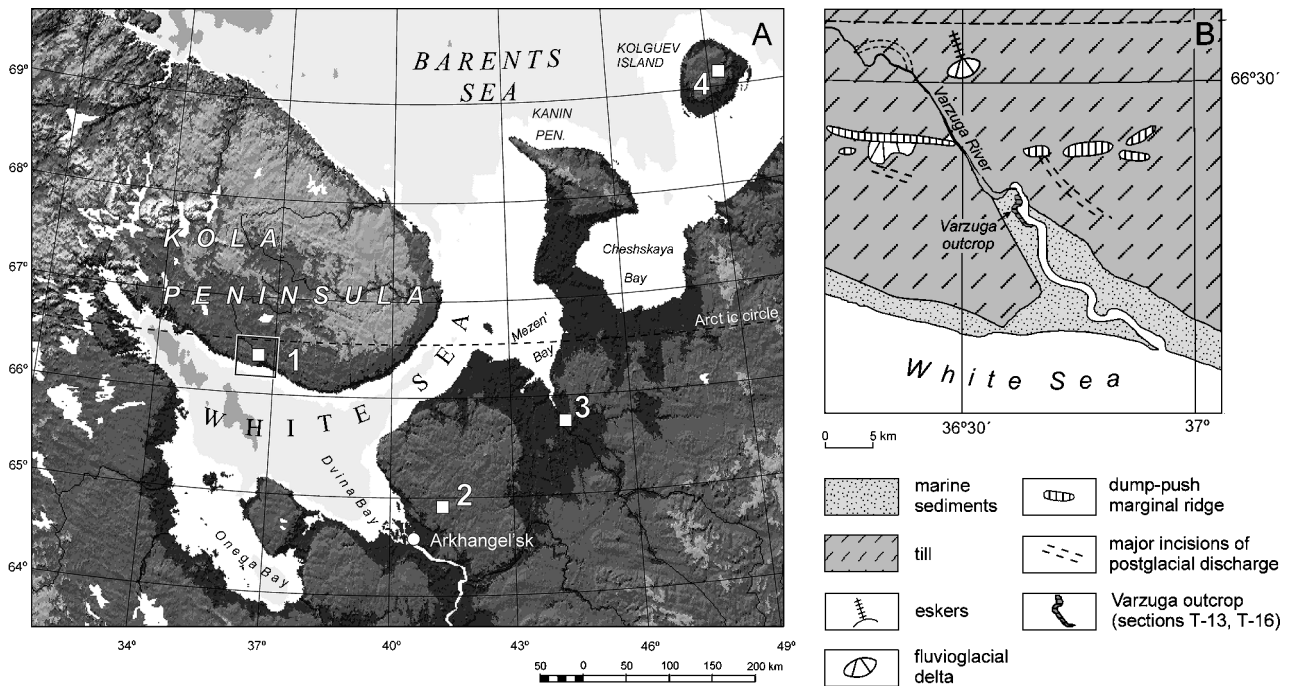


Fig. 1. A. Location map of the sites discussed in this study: 1 – Varzuga; 2 – Lod'ma; 3 – Zaton; 4 – Loc. 30. B. Sediments and landforms in the area of the lower reaches of the Varzuga River (square around 1 in A).

higher fossil-bearing sediments are likely re-deposited. An additional indication of possible re-deposition of the upper fossil-bearing sediments is their erosional contact with underlying deposits of Strel'nian transgression and the occurrence of a fragmented till remnant along the contact.

One reliable way to solve this long-debated stratigraphic problem in the sedimentary basin of the Kola Peninsula, to reconstruct the temporal position of this marine interglacial event and to elucidate the true stratigraphical position of the corresponding deposits, is to carry out a cross-checked chronological study of the questionable sediments. The establishment of such independent chronostratigraphic control is crucial for the proper understanding of Late Quaternary history of the region and associated climatic changes in the Eurasian North. In order to provide decisive evidence for the debatable transgressive event in the western part of the White Sea coast, new investigations were undertaken in 2001 and 2002 on the disputed fossil-bearing deposits of the sub-till marine unit in the type section T-16 (~37 m a.s.l.) of the Varzuga outcrop. The results and possible implications for the reconstruction of the Late Pleistocene environmental changes in the study area are reported in the present paper.

Regional setting

Interglacial deposits, both continental and marine, have

been found in many localities of the Kola region. Marine sediments occur mostly in peripheral areas of the eastern and southern parts of the Kola Peninsula. In the northeastern part of the Kola Peninsula the shorelines of the basin formed at the time of maximum transgression are found raised by neotectonic uplift to 150 m a.s.l. Some sections have been studied in particular detail by geological and palaeontological methods. Because of the proximity to the main Fennoscandian ice centres and isostatic response of the lithosphere and mantle to ice loading, the first Late Pleistocene transgression, in the North known as the Boreal, started and reached its maximum still under the relatively severe climatic conditions of the late Dnieper/Saale Glaciation. The climatic and hydrobiologic conditions became more favourable in the course of the regression. The former reflects the interplay of eustatic sea-level and glacio-isostatic rebound effects. The sediments of Boreal transgression occur mostly in the eastern and southern peripheral areas of the Kola Peninsula and also in the eastern part of the White Sea coast. A few sites have also been found in the central part of the Peninsula; this indicates that during the transgression the sea occupied a vast area within the continent. As a result, Fennoscandia was evidently cut off from the mainland during the high sea-level stand of the last interglacial (e.g. Grichuk 1982; Molodkov & Raukas 1998).

The Baltic/Eemian and White Sea basins were probably connected through the system of shallow

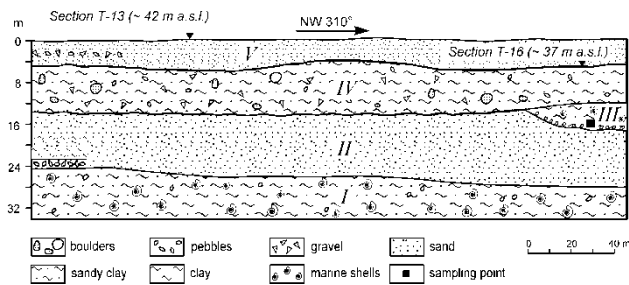


Fig. 2. Sketch of the Varzuga section with location of the sampling point: I – Ponj Bed; II – Strel'na Bed; III – lens of sandy clay; IV – till of the last glaciation; V – postglacial deposits.

sounds in the Ladoga–Onega depression (Lavrova 1948). The Barents Sea and the White Sea were also connected by numerous straits. Warm waters of the Atlantic with boreal and boreal–lusitanian species of marine fauna penetrated into the White Sea from the North (Lavrova & Troitsky 1960).

Study site

The structure of the Quaternary cover in the study area is shown in Fig. 1. The most complete records of Late Pleistocene sediments are represented by two type sections (T-13 and T-16) of the Varzuga outcrop (Fig. 2) located on the south coast of the Kola Peninsula at about 66.4°N and 36.6°E on the right bank of the Varzuga River where in the c. 700-m-long area upstream of the Kletnoy rapids several exposures over 30 m high occur.

The lower visible part of the sections is represented by 6 to 9.5-m-thick shell-rich deposits of black to light grey sandy clays and clays (I). The erosion surface of the unit is overlain by about 12-m-thick dark olive sandy bed (II). In section T-13 there follows a 1.5-m-thick sandy pebble unit which passes up into sandy clay and finally into pure sand. In the T-16 section the sandy bed (II) is overlain by an up to 6-m-thick lens of greenish-grey and dark-grey sandy clay (III). Erosional contact is observed between lens of sandy clay (III) and underlying sandy bed (II). Sandy clay (III) is overlain by a till (IV) composed of cherry-brown sandy clay with pebble, gravel and boulders. The top of the section is represented by the bed (V) composed of yellowish grey sand with some intercalations of pebble and gravel.

The exposures were studied by a number of researchers (M. A. Lavrova, A. D. Armand, R. M. Lebedeva, A. A. Nikonov, N. I. Apukhtin, V. Ya. Yevzerov, V. I. Gudina and others). Almost all of them supposed that sediments of at least two marine transgressions separated by erosion and situated beneath the unit of sandy diamicton, interpreted by most researchers as till of the last glaciation, can be confidently distinguished in these sections. Most of the investigators consider the lower

marine sequence as Boreal/Ponj in age. Accumulation of the next thick layer of marine deposits is considered to have taken place during the Boreal/Ponj transgression by some (e.g. Armand & Lebedeva 1966; Grave *et al.* 1969), and the independent Middle Valdai Strel'nian transgression by the others (Yevzerov 1993). Both sequences are exposed in sections T-13, T-16 and many others in the south and southeast margin of the Kola Peninsula.

The deposits of the third and the most debatable Belomorian interglacial transgression are revealed in the type section T-16, where they form a lens of fossil-bearing sandy clay (Fig. 2). The lens is traced over some 25 m. Small pebbles and shell fragments are fairly evenly dispersed throughout the sandy clay. The basal part of the lens consists of up to 60% of pebbles, boulders and scattered rocks with abundant remains of marine shells, which show no sign of reworking.

Boreal or mainly boreal species account for 39% of the total fauna found in a pebble layer at the bottom of the lens, 39% are arcto-boreal and 22% are arctic and mainly arctic. The arctic forms *Astarte borealis* and *A. crenata* var. *crebricostata* dominate the assemblage. The composition of the fauna suggests a littoral or upper sublittoral origin for these deposits, under hydrobiologic conditions somewhat more favourable than those of the White Sea at the present time.

At the base of the lens, Gudina & Yevzerov (1973) found a large number of foraminifera representing 44 species. This assemblage, like those from other typical Boreal transgressive deposits (e.g. Ponj and Svyatoj Nos sections; Gudina & Yevzerov 1973), is dominated by a cibicidid-trifarid-cassidulinid association and comprises many lusitanian, boreal–lusitanian and boreal forms, e.g. *Globulina inaequalis*, *Guttulina lactea*, *Sigmomorphina undulosa*, *Hyalinea balthica*, *Elphidium excavatum*, *Trifarina angulosa*, *Lagena semilineata*, *L. sulcata*, *Elphidium boreale*, etc. Representatives of the most abundant form, *Cibicides rotundatus*, were distinguished by their poor state of preservation; many of them were abraded and their walls distorted. At the top of the lens the number of foraminifera was much reduced. Only isolated examples of 3 species were found there, all in a poor state of preservation. Higher up in the section, the foraminifera disappeared completely.

Poretsky (Lavrova 1960) has identified 29 species of marine and brackish water diatoms and 22 freshwater species from the lower part of this deposit. Colder water forms dominate the assemblage. As a result of his study of diatom flora, Poretsky concluded that the sandy clay was deposited in a shallow sea.

Blagoveshchensky (Lavrova 1960) found numerous pollen grains derived from woody plants in the sandy clay component of the deposit. Spores (33–64%) usually dominate over pollen of woody (31–50%) and herbaceous (1–17%) plants. In the total pollen of woody taxa (except the lower part of the spectrum) birch

dominates, making up most (48–65%) of the flora. Also found among that group are pine (13–37%), alder (1–10%), dwarf birch (3–13%), willow (1–9%) and spruce (1–6%). The pollen spectrum considered reflects the phase of birch forest-tundra and sparse birch-pine forest with an admixture of alder in the lower part of the sandy clay. At present, birch-pine and pine forests dominate in the lower reaches of the Varzuga River. Therefore, in the period when the deposition of sandy clay started, the climate must have been similar or even warmer than that at present, and somewhat drier in the beginning.

In the early 1970s, Arslanov determined the age of mollusc shells collected from the sandy clay using the radiocarbon method. His results showed ages of 40930 (LU-141A) and 37040 (LU-141B) years (Yevzerov *et al.* 1976), which corroborated the idea of some (e.g. Lavrova 1948, 1960; Apukhtin 1957) that these deposits most likely represented transgressive deposits of the Middle Valdai interglacial.

Samples

In order to provide new chronological data on the controversial transgressive record in the western part of the White Sea coast, three sediment samples were collected from the disputed fossil-bearing subtidal marine deposits at the type section T-16 (~37 m a.s.l.) located on the south coast of the Kola Peninsula at about 66.4°N and 36.6°E on the right bank of the Varzuga River (Fig. 1). These deposits (see sampling point in Fig. 2) are situated above the second sandy bed immediately under the sandy diamicton. The underlying sandy bed is attributed to the second Late Pleistocene transgression (Yevzerov 1993). Samples were taken in 2000 at a depth of 16 m about 30 cm from the bottom of the lens for dating with two independent radiation exposure dating methods – electron spin resonance (ESR) and optically stimulated luminescence (OSL).

The ESR method has been applied to the four different bivalve mollusc species (TLN-309-042 to TLN-312-042) taken directly from the section. Two samples of the surrounding sediment were taken for gamma-spectrometry to provide data on natural background radiation. From the same level inside the lens, one more sediment sample (TLN-1405-031) was taken for OSL dating using feldspar grains.

Age determination

Radiation exposure dating methods are based on measurement of the amount of radiation-induced charges trapped in a mineral (e.g. quartz, feldspar, biogenic carbonate) and created by the natural radiation resulting from radioactivity in the mineral itself and from the environment (enclosing matrix and cosmic). A

mineral sample will therefore have trapped charges the amount of which relates directly to the total radiation dose (palaeodose, P_s) the mineral has received during its burial. Deposits are dated by measuring the palaeodose, P_s , needed to produce the observed ESR/OSL signal, and the environmental dose rate, D_Σ , affecting the mineral-palaeodosimeter during burial.

The ESR dating technique and the analytical procedure which we used have been detailed elsewhere (e.g. Molodkov *et al.* 1998).

The principle of age determination using the luminescence techniques can be found in various publications (e.g. Aitken 1998; Wintle 1997; Wallinga 2002). Briefly, feldspar grains in the size range 100–150 μm were extracted from the sediment under subdued filtered light in the laboratory by a procedure including wet sieving, heavy liquid flotation (collecting 2.54–2.58 g cm^{-3} fraction), and treatment by 20% to 40% HCl acid to remove carbonates. The alpha-activated surface layer was removed by etching in 10% HF for 15 min. The OSL measurements were made with a computer-controlled Ingrid-Type SLM-1 reader using 860 nm stimulation. The IR stimulated luminescence decay curves were measured in the 410 nm wavelength range. For artificial irradiation a precisely calibrated ^{60}Co radiotherapy unit delivering $6.5 \times 10^{-2} \text{ Gy s}^{-1}$ was used. After irradiation, all aliquots were stored at room temperature for at least one month before measurement to allow fading of possible short-lived laboratory-induced OSL signals in the emission band at about 410 nm, and to test samples for anomalous fading. This test and our numerous stratigraphically and radiocarbon-controlled studies of Holocene deposits (see, e.g., Bitinas *et al.* 2002) showed no evidence of anomalous fading at least for the samples from the Baltic–White Sea area (Scandinavian source region).

Precise reconstruction of palaeodose P_s was performed by extrapolating the regression lines to zero ESR/OSL intensities. The multiple-aliquot additive-dose procedure was applied to both the luminescence analysis of monomineral feldspar grain fraction (100–150 μm) of the sediments and the resonance analysis of 70–400 μm fraction of mollusc shell material. The data points used for ESR regression are the means of six measurements of $g = 2.0012$ ESR signal (Molodkov 1988, 1993) for each aliquot. In the case of OSL, additive dose-dependent curves were constructed using 6 ‘natural’ discs and 7 sets of artificially dosed discs (6 discs in each set). The average palaeodose was determined by taking the weighted mean of the palaeodoses obtained for each set of discs.

Correlation coefficients (r) obtained by the fitting of the eight luminescence data points are very high – ranging from 0.99953 to 0.99999. The values obtained from the ESR data points range from 0.99940 to 0.99996. The curve fitting results indicate the reliability of the determination of the key parameter of the

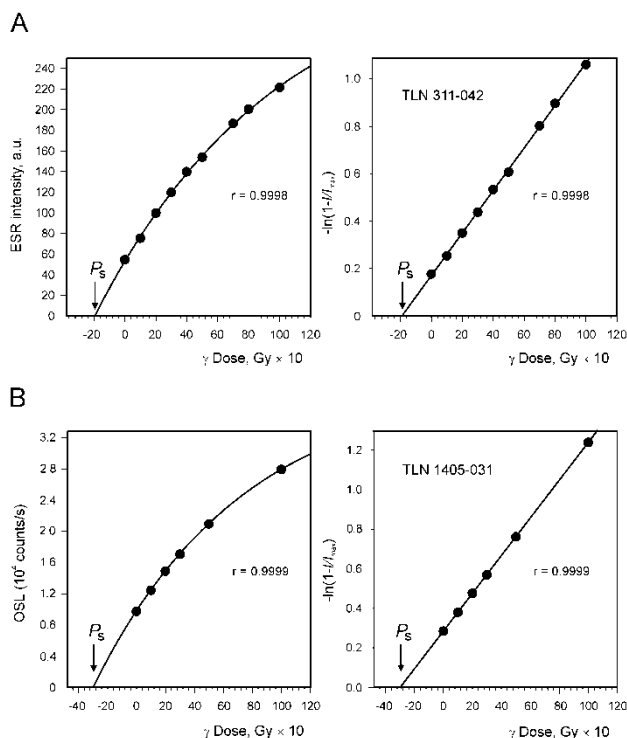


Fig. 3. Dose-response curves of some ESR (TLN 311-042; A) and OSL (TLN 1405-031; B) samples from Varzuga section and evaluation of the accumulated palaeodose, P_s , by the non-linear (left) and the logarithmic (right) fitting of the data points. Each point in ESR dose-response curves (A) shows the mean of 6 read-out values. An example of a real OSL signal growth with dose is shown in (B); I is the ESR/OSL intensity; I_{max} is the ESR/OSL intensity at saturation dose; r is the correlation coefficient.

radiation exposure dating methods – the stored palaeodose, P_s (Fig. 3).

The *in situ* water content was 17.2%, and this was taken as a reasonable estimate of the mean water content throughout the period of sample burial. Estimates of the cosmic dose (Yokoyama *et al.* 1982) were based on half of the present depth of burial in order to take into account the increase in thickness of the deposits during the controlled time interval. The dose rate and ESR/OSL ages of the samples were calculated using software authored by A. Molodkov. Dose-rate conversion factors by Adamiec & Aitken (1998) were used in both cases.

Results and discussion

Analytical data and the results of ESR/OSL dating are listed in Table 1, which summarizes the experimental results for OSL analysis of the deposits under discussion. Using these, the OSL age for sample TLN-1405-031 was determined in 2001 as 104.0 ± 8.3 ka.

Table 1. ESR/OSL results and radioactivity data for mollusc shells and sediment samples from the Varzuga section

No.	Lab. no.	Dating method	d (mm)	U_{in} (ppm)	U (ppm)	Th (ppm)	K (%)	D_c (μ Gy/a)	D_{int} (μ Gy/a)	D_{sed} (μ Gy/a)	D_{Σ} (μ Gy/a)	P_s (Gy)	ESR/OSL-age (ka)
1	TLN 309-042	ESR	1.7	0.82 \pm 0.08	1.50 \pm 0.06	8.73 \pm 0.44	2.22 \pm 0.04	50.2 \pm 5.0	250.2 \pm 25.0	1359.1 \pm 68.0	1659.5 \pm 83.0	183.9 \pm 10.5	112.5 \pm 8.0
2	TLN 310-042	ESR	0.8	0.21 \pm 0.01	1.50 \pm 0.06	8.73 \pm 0.44	2.22 \pm 0.04	50.2 \pm 5.0	192.1 \pm 19.2	1692.0 \pm 84.6	1934.4 \pm 96.7	196.8 \pm 16.6	103.0 \pm 11.0
3	TLN 311-042	ESR	0.7	1.00 \pm 0.08	1.50 \pm 0.06	8.73 \pm 0.44	2.22 \pm 0.04	50.2 \pm 5.0	256.8 \pm 25.7	1735.7 \pm 86.8	2042.7 \pm 102.1	191.2 \pm 11.0	94.0 \pm 6.5
4	TLN 312-042	ESR	1.6	0.73 \pm 0.07	1.50 \pm 0.06	8.73 \pm 0.44	2.22 \pm 0.04	50.2 \pm 5.0	216.7 \pm 21.7	1397.8 \pm 69.9	1662.7 \pm 83.1	183.4 \pm 15.4	110.0 \pm 10.3
5	TLN 1405-031	OSL	-	-	1.50 \pm 0.06	8.73 \pm 0.44	2.22 \pm 0.04	50.2 \pm 5.0	63.0 \pm 6.3	2651.4 \pm 132.6	2863.9 \pm 143.2	297.7 \pm 18.0	103.0 \pm 4.2
													104.0 \pm 8.3

Notes:

d is the shell thickness; U_{in} is the uranium content in shells; U, Th, K are the uranium, thorium and potassium content in sediments; D_c is the cosmic dose rate; D_{int} is the internal dose rate; D_{sed} is the sediment dose rate; D_{Σ} is the total dose rate; P_s is the palaeodose.

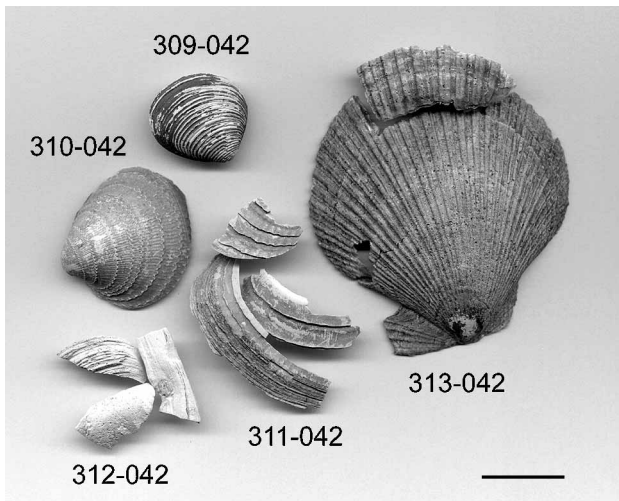


Fig. 4. Marine shells from the lense of fossil-bearing sandy clay at the Varzuga site, type section T-16. The scale bar is 20 mm long.

The age of the deposits was also independently determined by ESR dating of mollusc shells collected from the deposits immediately adjacent to the sampling point from which the sample for OSL dating was taken. The ESR analysis was performed on broken and whole well-preserved aragonite shells (TLN 309-042 – TLN 312-042) belonging to four different marine mollusc species (Fig. 4). The fifth shell composed of calcite (TLN 313-042) was not dated in this work owing to the presence of very intense Mn^{2+} lines that strongly interfere with the analytical radiation-induced signal ($g = 2.0012$; Molodkov 1988, 1993) used for numerical dating.

The weighted mean of four ESR age determinations on different shells (see Table 1) is 103.0 ± 4.2 ka, which is in close agreement with the age obtained by OSL on feldspar extracted directly from the surrounding deposits.

Thus, the above results and close geological examination of the section (Yevzerov 1993) clearly indicate that the lens of Varzuga sandy clay is most likely re-deposited. The numerical ages obtained allow one to link the time of the formation of the sandy clay with the Last (Mikulinian/Eemian) Interglacial *s.l.* that, according to the materials of ESR chronostratigraphic studies over the marginal areas of the Eurasian North (e.g. Bolshiyarov & Molodkov 1999; Molodkov & Raukas 1998; Molodkov & Bolikhovskaya 2002; Bolikhovskaya & Molodkov 2002), can be compared with the time interval from approximately 145 to 70 ka. Our dating results are indirectly corroborated also by the results of other studies (Molodkov & Raukas 1988, 1998; Makeev *et al.* 2000) according to which deposits of the same age were revealed in the eastern part of the White Sea coast in the outcrop at Zaton site and on

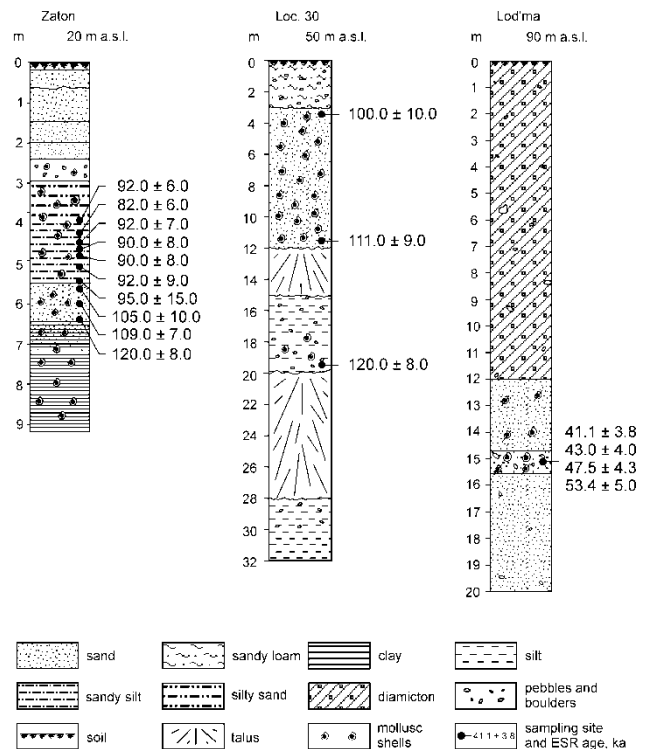


Fig. 5. Stratigraphy of the profiles studied in the eastern part of the the White Sea coast with the ESR dating results obtained on mollusc shells (modified from Molodkov & Raukas 1998).

Kolguev Island located in the southeastern part of the Barents Sea (Fig. 1).

The Zaton profile is located on the left bank of the Mezen River about 1.5 km upstream from the Zaton settlement. The base of the profile is composed of marine clays with abundant mollusc fauna (Fig. 5). Upwards the clays become gradually richer in sand and turn into sandy silt followed by silty sand. Boreal mollusc fauna (*Littorina littorea* L., *Mytilus edulis* L., *Macoma calcarea* Chemn., *M. baltica* L., *Maetra elliptica* Brown., *Neptunea despecta* L., *Astarte borealis* Chemn., etc.) dominates. Lusitanian–boreal species, such as *Cardium edule* L. var. *rusticum* and *C. fasciatum* Mont., are also represented (Devyatova 1982).

In this profile, we partly dated an almost continuous marine succession at a depth of 3.8 to 6.4 m (Molodkov 1988; Molodkov & Raukas 1988, 1998). The shells of five different mollusc species taken from silty-sandy deposits gave series of dates from 120 to 82 ka. The sub till sediments from the Varzuga section can confidently be correlated with the lower part of marine deposits dated at the Zaton section.

The exposed part of underlying marine clays, which most likely accumulated in deep water conditions during the maximum of the interglacial marine trans-

gression (pollen zone M_{4a} after Grichuk 1961 or 'e', after Jessen & Milthers 1928), is unambiguously older than 120 ka. Marine conditions lasted here until the end of the pollen zone M_7 ('h') (Devyatova 1982). This time period is probably represented in the section by the shell-bearing silty sand overlying the sandy silts dated by ESR to c. 92–82 ka BP.

On Kolguev Island, correlative deposits of the Boreal transgression were revealed in the 32 m profile exposed in the central area of the Island, the Peschanka River valley (4 in Fig. 1) at about 50 m a.s.l. The middle and the visible lower parts of the section comprise horizontally laminated silts with an inclusion of large detrital material and mollusc shells. The upper portion of the section is composed of horizontally laminated sands with pebble, gravel and boulders (D. Bolshiyarov and V. Makeev, pers. comm. 2000). The most abundant are the shell species: *Chlamys islandicus* Mull., *Arctica islandica* L., *Astarte sulcata* Da-Costa with a smaller number of *Neptunea despecta* L., *Serripes groenlandicus* Brug., *Cryptonatica clausa* Brod. et Sow., *Spisula elliptica* Brown, *Lunatia pallida* Brod. et Sow. (Makeyev *et al.* 2000). Mollusc shells were collected

for ESR dating from the three successive stratigraphic levels (Fig. 5). A shell sample from the lower level was taken at a depth of 19.5 m and was dated to 120.0 ± 8.0 ka BP. Shells from the overlying 9-m-thick sand layer were taken at depths of 11.5 and 3.5 m, and gave stratigraphically consistent ages of 111.0 ± 9.0 and 100.0 ± 10.0 ka, respectively (Makeyev *et al.* 2000; Molodkov & Raukas 1998). It is obvious that the sub till marine sandy clay filling the lens in the Varzuga section was most likely deposited at the same time as the upper sandy layer of this profile.

The examples presented indicate that the deposits studied in the Varzuga section most probably belong to the long Boreal transgression, which occupied the vast coastal area of Eurasian North probably over the whole oxygen isotope stage 5 (Molodkov & Raukas 1998; Molodkov & Bolikhovskaya 2002). Deposits of the marine transgression are recorded more than 1000 km inside the present coastline from the Kola Peninsula in the west to the Taymyr Peninsula in the east (Lavrova 1961). The marine episode represented by the sub till sediments in the Varzuga section can most likely be correlated with isotope substage 5c.

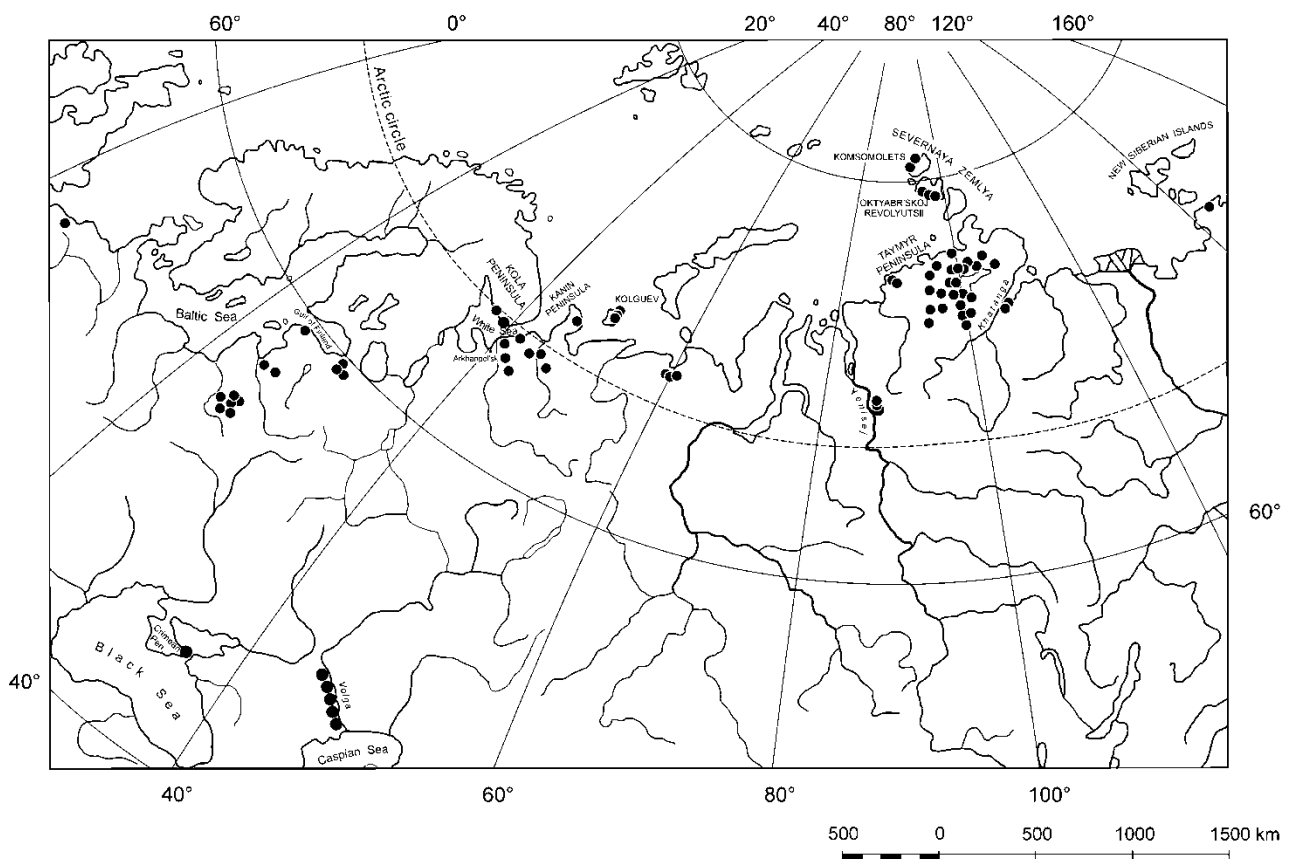


Fig. 6. Map showing the localities of collected shell samples (circles) ESR-dated from 145 to 70 ka (modified from Molodkov & Bolikhovskaya 2002).

A series of ESR datings averaging about 46 ka (see Fig. 5) was also obtained in one of our previous studies in the eastern part of the White Sea coast at the Lod'ma site (see Fig. 1) (Molodkov & Raukas 1998). These datings support the opinion of a number of researchers that one more Late Pleistocene transgression, which could take place in the Middle Valdai (Middle Weichselian), occurred in this region. But unlike the very warm Middle Valdai interglacial transgression distinguished by many on the Kola Peninsula, this marine event has not yet yielded any interglacial indications.

In order to correlate the data from the Varzuga section with those obtained on the vast area of Northern Eurasia we now consider the distribution of ESR ages on more than 140 mollusc shell samples collected from about 60 sites along the continental margin of the Eurasian North in the Black Sea and Caspian Sea basins (Molodkov & Bolikhovskaya 2002) (Fig. 6). According to the time-dependent frequency distribution of all the ESR dates obtained for the last interglacial (Fig. 7), the whole Boreal transgression can be divided into several separate transgressive and regressive phases. High-frequency intervals (peaks I to V) can be correlated with the periods of a relatively mild climate and submergence of the coastal parts of the land. The low-frequency intervals (troughs 'a' to 'e'), in turn, may be correlated with coolings and phases of sea regression (Fig. 7) (Bolikhovskaya & Molodkov 2002). From our data it follows that the time of the Varzuga sub-till sandy

clay sedimentation can most likely be correlated with the third transgressive phase of the Boreal Sea and relatively warm climatic condition between about 113 to 102 ka.

It is noteworthy that deterioration of the hydrobiological conditions in the course of sandy clay accumulation is clearly reflected by the gradual upward decrease in the number of foraminifera (Gudina & Yevzerov 1973). The same tendency of the hemispherical climate change is recorded by ESR data in the marginal areas of the European North: the third relatively warm climate phase ended and was replaced by the cooler conditions about 102 ka ago (Fig. 7).

Conclusions

The results of this study have led to the following conclusions:

- ESR/OSL age determinations on the long-debated sub-till fossil-bearing lens of shallow-water marine deposits from the Varzuga section demonstrate that it is a re-deposited material.
- The use of two independent dating methods applied to two different minerals – feldspar and biogenic carbonate – taken from the questionable deposits unambiguously indicate that the deposits studied belong to the first Late Pleistocene Boreal transgression and were formed, most likely, about 103.5 ka ago during the third relatively warm climatic period (between 113 and 102 ka) recorded by ESR on warm-climate-related deposits of Northern Eurasia.
- The datings obtained, along with other independent environmental indications, may be regarded as evidence supporting a relatively high post-substage 5e sea-level stand.
- Most likely, the marine deposits studied belonged to a marker horizon that according to the data obtained from the adjacent marine environments can be confidently referred to the most significant Quaternary transgression, in the Eurasian North known as the Boreal, which was simultaneous or longer than the Eemian transgression in western Europe.
- Microfauna composition together with *in situ* malacofauna and pollen encountered in the lower part of the studied deposits indicate a climate similar or warmer than at present, and subsequent deterioration of the hydrobiological conditions.
- Despite the dating results obtained on the Varzuga section, the existence of a relatively cold-water Middle Valdai transgression at approximately 46 ka cannot be excluded.
- It is noteworthy that our data from the present and previous studies do not yet supply any reliable evidence to support a glacier advance within the oxygen isotope stage 5 on the Kola Peninsula and in the eastern part of the White Sea coast.

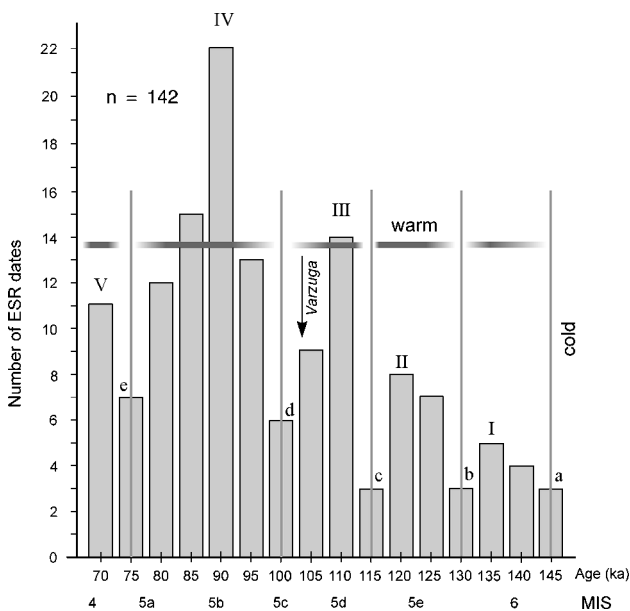


Fig. 7. Frequency distribution of ESR ages between 145 and 70 ka obtained on marine ($n = 135$) and lacustrine ($n = 7$) interglacial deposits (Molodkov, determinations 1985–2002) and phases of relatively warm (I–V) and cool (a–e) climate (modified from Bolikhovskaya & Molodkov 2002).

Acknowledgements. – We extend our sincere thanks to Olga Korsakova and Vasily Kolka for help during collection of the samples at Varzuga, to Tatyana Balakhnichova and Marina Osipova for their contribution to the laboratory work reported here, to Helle Kukku for improving the English text, and also to the anonymous referees for valuable suggestions and constructive comments on an earlier draft of this paper. This research was supported by the grants nos 3625 and 5440 from the Estonian Science Foundation.

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