Marine Pleistocene Deposits of the Taymyr Peninsula and their Age from ESR Dating

D. Bolshiyanov[1] and A. Molodkov[2]

(1) State Research Center - Arctic and Antarctic Research Institute, 38 Bering St., 199226 St. Petersburg, Russia

(2) Institute of Geology of the Academy of Sciences of Estonia, 7 Boulevard Estonia, Tallinn, Estonia

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Abstract - Electron spin resonance (ESR) dating and lithostratigraphic studies of marine deposits on the TaymyrTaimyr Peninsula suggest that a marine sedimentary environment dominated during isotope Stages 4, 5, 7, 8, 9 and 15. The marine basins were predominantly cold and influenced by freshwater.

Introduction

Marine Quaternary deposits are widespread on the Taymyr Peninsula but not well exposed due to active slope processes. It is thus important that studies of natural outcrops of Quaternary deposits are combined with information from bore-holes.

Based on the results of drilling carried out by the Central Arctic Geological Exploration Expedition (Norilsk) and the Polar Geological Exploration Expedition (Khatanga), a general understanding of the structure of the TaymyrTaimyr Pleistocene sediments has been gained. It has also been possible to retrieve samples for dating purposes from several of these bore-holes.

This paper summarizes preliminary results of studies of marine deposits on the Taymyr Peninsula. These studies were carried out during the four field seasons (1993-1996) of the joint Russian-German expedition „Taymyr-Severnaya Zemlya" and in previous expeditions to the western part of Taymyr (1986), to northern Taymyr (1988) and to the south-eastern part of the peninsula (1989-1990).

ESR dating methods

The electron spin resonance method (ESR) was used to date marine mollusc shells, found in investigated exposures and cores. This is an efficient tool for determining the age of exoskeleton remnants of malaco-fauna within a time interval of several hundred years to about 1 million years (Molodkov, 1989, 1992, 1993). The dating of subfossil mollusc shells with ESR is based on the ability of the mollusc shell material to accumulate the absorbed dose of natural radiation and preserve it over a long period of time (Ikeya and Ohmura, 1981). An estimate of the paleodose, accumulated during shell burial in embedding deposits, is performed by comparing the natural intensity of the shell signal in the ESR-spectrum (caused by paramagnetic carbonate centers) with the intensity of radioactive irradiation induced by a laboratory source. The radiation background consists of three components: (1) radiation from natural radionuclides scattered in the embedding deposits, with the main contribution to the exposure dose of shells made by ^{238}U, ^{232}Th, ^{40}K and the decay products of uranium and thorium (88%, on average, of the total dose); (2) radiation from the uranium and products of its decay incorporated in the crystalline matrix of the shell carbonate material (≅ 7%); and (3) cosmic radiation (≅ 5%). The radiation dose absorbed by the mollusc shell material is proportional to the concentration of

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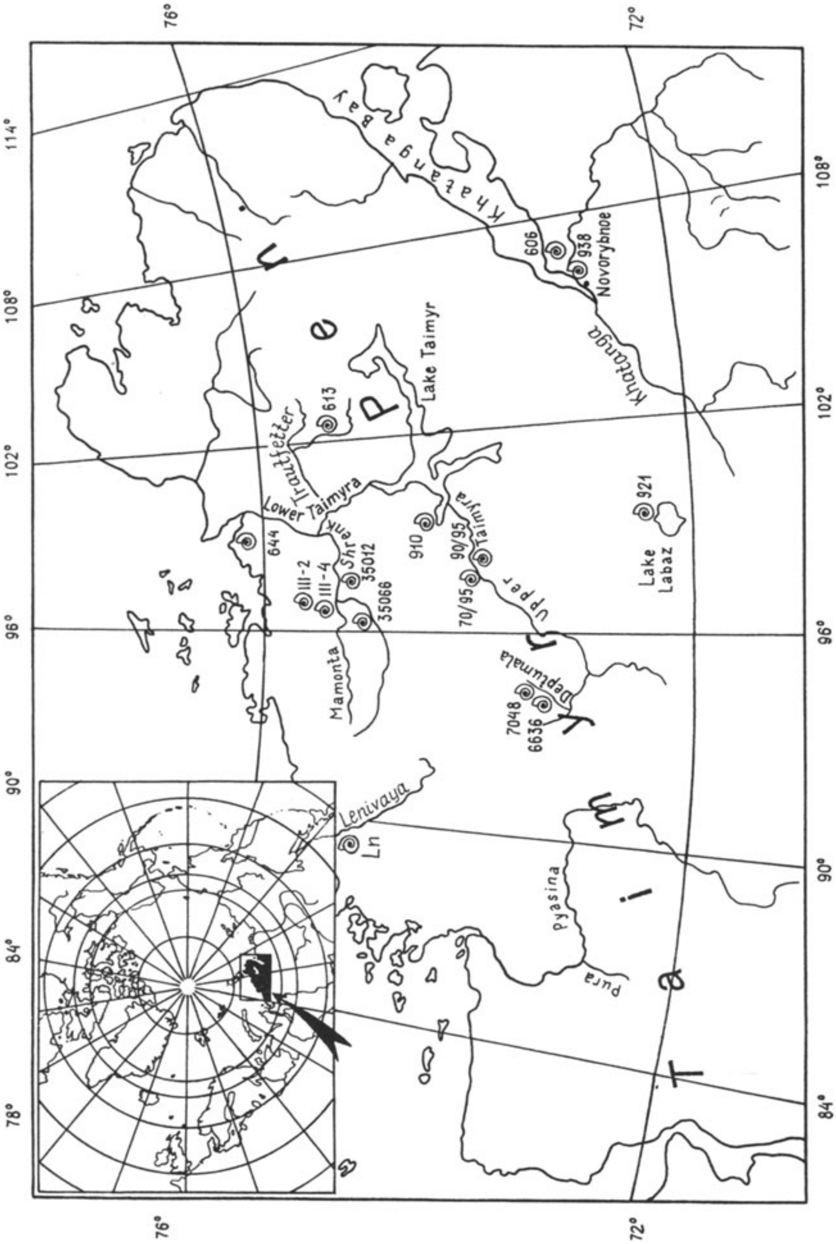

Figure 1: Overview map of the Taymyr Peninsula and investigated logs.

radioactive elements in the environment and in the shell itself, as well as to the time of exposure (shell age). Shell dating is performed by measuring the paleodose accumulated from the time of formation of the mollusc exoskeleton and the strength of natural radiation dose that affected the shell during its burial. To perform palaeodosimetric analysis of the shell material, the analytical line at 2.0012 (line-width $\Delta B_{pp} \cup 0.22$ mT, Molodkov, 1988, 1993) was separated. The dose-response curves with the use of this signal conformed most closely to the single exponential function.

The height of original absorption signal was used as an equivalent of the g=2.0012 centre concentration in the shell. Quantification of the 2.0012 centre concentration was obtained from the peak-to-peak amplitude of the relevant signal in derivative spectra of the shells by using an overmodulation (OM) detection method (Molodkov, 1988, 1993). The microwave power used for dosimetric reading was 2 mW with 100 kHz magnetic field modulation at 1 mT. The palaeodose for each sample was obtained by fitting with the reciprocal exponential function $-\ln(-I/I_{max})$, where I and I_{max} are the ESR signal intensity and the intensity of the level at saturation dose, respectively. The accumulated palaeodose, P_S, was estimated by extrapolation of the regression line to zero ESR intensity. The saturation value of ESR intensity, I_{max}, was found by iterative optimization.

The ages of the shell fossils from Taymyr were derived from the following equation (Molodkov, 1988, 1989):

$$T = \tau\left[-\ln\left(1 - \frac{P_s}{\tau \dot{D}_\Sigma(t)}\right)\right],$$

where τ is the mean lifetime of the 2.0012 centre in shell carbonate, P_s is the accumulated palaeodose since the mollusc exoskeleton formation, $\dot{D}_\Sigma(t)$ is the total radiation dose rate as a function of time, and T is the shell age.

The dose rate, $\dot{D}_\Sigma(t)$, is a sum of the doses due to different radiations

$$\dot{D}_\Sigma(t) = \dot{D}_c + W_\gamma \dot{D}_{ext\,\gamma} + W_\beta k_\beta \dot{D}_{ext\,\beta} + \dot{D}_{int\,\alpha,\beta}(t),$$

where $\dot{D}_c$ is the cosmic dose rate proportional to the sample,s latitude, altitude, and burial depth; $\dot{D}_{ext\gamma,\,\beta}$ is the external dose rate depending on radioactive element concentration in the sediment surrounding the shells; W_α and W_β are the correction factors for water (ice); k_β is the beta-attenuation correlation factor; $\dot{D}_{int\,\alpha\beta}(t)$ is the time-dependent component of the internal dose rate originating from the uranium incorporated in the shell substance.

In total, 22 samples were dated from 15 sections and bore-holes (Figure 1, Table 1). Some samples were dated two or three times as a control. The final ESR-age for samples with double or triple dating was determined as the mean arithmetic age.

Stratigraphy of Pleistocene deposits on Taymyr Peninsula

In our opinion, the Quaternary deposits of the Taymyr Peninsula can be roughly divided into two units: a lower unit up to 200 m thick, consisting predominantly of dark grey clayey-silty sediments with a large ice content, and an upper unit, 30-40 m thick and predominantly of a sand-pebbly composition. The lower unit forms part of the contemporary relief in the lowland valleys. This is especially clear in the western part of the peninsula where clayey silts are often eroded along the Pur, Pyasina and other rivers.

These exposures often show that the fine-grained sediments form rhythmic deposits of varved

Table 1: ESR results and radioactivity data for samples from Taymyr Peninsula

	Lab No.	Site/ Field No.	Locality	d (mm)	U_{in} (ppm)	U (ppm)	Th (ppm)	K (%)	D_c (mGy/a)	D_{int} (mGy/a)	D_{sed} (mGy/a)	D_S (mGy/a)	P_s (Gy)	ESR-age, T (ka)
1	126-109	644/8	Taimyr	0,50	0,60	1,18	2,40	1,25	50	325	1397	1772	140.0 ± 7.7	85.0 ± 15.0
2	127-109	606/1	Khatanga	0,50	0,60	1,06	5,95	1,74	20	380	2008	2408	270.0 ± 12.1	112.0 ± 20.0
3	128-109	613/5	Taimyr	1,60	0,60	0,80	1,34	0,76	140	354	597	1091	60.0 ± 1.8	70.0 - 37.0
4	138-051	6636/3	Taimyr	1,20	0,20	0,89	2,45	0,77	60	60	759	879	102.0 ± 4.6	116.0 ± 11.0
5	139-051	6636/3	Taimyr	1,60	0,85	0,89	2,45	0,77	60	227	685	972	105.0 ± 4.2	108.0 ± 8.0
6	140-051	6636/3	Taimyr	1,20	0,80	0,89	2,45	0,77	60	207	759	1026	115.0 ± 6.3	112.0 ± 18.0
7	141-051	6636/1	Taimyr	0,60	0,13	0,98	2,87	0,99	130	20	1124	1274	120.0 ± 6.0	94.0 ± 9.0
8	142-051	6636/1	Taimyr	0,70	0,68	0,98	2,87	0,99	130	162	1093	1385	126.0 ± 3.8	91.0 ± 8.0
9	143-051	606/13	Khatanga	0,30	0,23	1,46	6,90	1,91	60	64	2446	2570	360.0 ± 21.6	140.0 ± 11.0
10	145-051	7048	Taimyr	0,80	0,64	1,59	5,67	1,23	70	226	1507	1803	137.0 ± 5.5	76.0 ± 6.0
11	146-051	7048	Taimyr	0,40	0,67	1,59	5,67	1,23	70	158	1772	2000	160.0 ± 5.6	80.0 ± 6.0
12	211-065	910/1	Taimyr	1,45	0,60	1,61	6,17	1,22	110	177	1214	1500	165.7 ±9.9	111.0 ± 11.0
13	212-065	910/1	Taimyr	0,80	0,45	1,61	6,17	1,22	110	121	1433	1664	164.3 ± 9.8	99.5 ± 9.8
14	213-065	910/1	Taimyr	0,80	0,57	1,69	5,43	1,19	110	147	1381	1638	147.1 ± 8.1	90.3 ± 8.8
15	215-065	921/5	Taimyr	0,40	0,65	1,24	3,89	1,23	93	242	1459	1794	499.9 ± 11.0	283.0 ± 26.6
16	216-065	921/5	Taimyr	0,30	0,84	1,24	3,89	1,23	93	303	1536	1932	505.1 ± 12.6	265.0 ± 24.9
17	219-065	921/8	Taimyr	1,00	0,70	1,39	6,97	1,62	79	286	1579	1944	605.4 ± 12.1	316.5 ± 31.4
18	232-086	3501201	Taimyr	2,00	0,59	0,75	4,87	1,66	188	279	1086	1553	813.3 ± 14.8	535.5 ± 48.6
19	233-086	35066/03	Taimyr	0,80	0,44	1,32	4,86	1,34	132	126	1370	1628	187.8 ± 5.6	116.0 ± 11.1
20	234-086	35066/02	Taimyr	1,50	0,58	1,09	4,61	1,30	87	247	1061	1395	456.8 ± 9.0	332.0 ± 30.4
21	236-086	III-4/195	Taimyr	0,49	0,79	1,54	7,33	1,70	60	293	2025	2377	631.0 ± 7.2	268.4 ± 25.1
22	237-086	III-2/26	Taimyr	0,85	0,64	1,10	5,59	1,77	139	152	1605	1896	136.4 ± 10.4	72.2 ± 6.9
23	238-086	70/95	Taimyr	1,40	1,00	0,78	6,45	1,53	188	303	1254	1744	208.2 ± 2.4	120.0 ± 11.1
24	239-086	90/95	Taimyr	0,25	0,98	1,06	4,17	1,68	148	241	1936	2325	222.3 ± 4.1	96.0 ± 9.1
25	240-086	938/1	Khatanga	0,65	0,51	0,64	2,82	1,07	60	185	1012	1257	293.2 ± 16.7	235.5 ± 25.6
26	241-086	938/10	Khatanga	0,40	0,54	1,57	7,74	1,83	72	210	2238	2520	834.9 ± 46.0	336.0 ± 31.8
27	256-107	Lbz/ 1	Taimyr	0,51	0,55	0,81	4,78	1,45	148	214	1516	1878	592.1 ± 5.7	319.5 ± 30.3
28	257-107	Ln 1/2	Taimyr	0,89	0,22	1,58	4,60	1,39	103	56	1386	1545	132.5 ± 6.0	86.1 ± 8.5

Notes:
d is the shell thickness; U_{in} is the uranium content in shells; P_s is the palaeodose; U, Th, K are the uranium, thorium and potassium content in sediments; D_c is the cosmic dose rate; D_{int} is the time-averaged internal dose rate; D_{sed} is the sediment dose rate; D_S is the total dose rate. Uncertainties: determination of thickness, ± 40mm; U determination, ± 2-3%; Th determination, ± 3-4%; K determination, ± 1-2%; U determination in the shells, ± 1-3%; gamma irradiation, ± 3%.

clay. The lower unit is less frequently exposed in the lower reaches of the Upper Taymyra and Lower Taymyra rivers and in the valleys of the Khatanga, Shrenk and Trautfetter rivers. The clayey-silty sediments of the lower unit often include boulders and pebbles. However, the frequency of these coarse clasts does not exceed 5-10% by volume of the embedding sediments. The occurrence of coarse clasts has been taken as an argument for interpreting these sediments as being of glacial origin (Urvancev, 1931; Troitskii,1966; Kind and Leonov,1982, Zolnikov and Shevko, 1989). However, in all studied outcrops it was found that the sediments are clearly laminated. The lower unit sediment often contained a considerable amount of ice, in particular ice wedges and ice bodies of unknown origin up to 60 m in thickness.

The sediments are usually poor in fossils, sometimes totally barren. However, some fossils, though rarely observed, can be found in the upper part of the lower unit sediments, e.g. the marine mollusc *Portlandia arctica*, foraminifers of the genus *Hynesina* sp., freshwater and estuary species of diatoms (*Åunotia diodon, Eunotia pracrupta, Tabellaria fenestrata, Pinnularia sp, Cyclotella striata, Stephanodiscus astrea*), and marine species of diatoms (*Paralia sulcata)*. Most diatoms were redeposited from Cenozoic sediments. The palaeoenvironmental indications point towards cold and freshwater basins. The transition from more massive clayey silts to varved clays also indicates that brackish basins were replaced by freshwater basins. The pelecypod fauna of the lowermost part of the lower sedimentary unit is boreal in composition, indicating warmer sea conditions. The lower sedimentary unit consists of not only clay and silt but of more coarse deposits too. The roof of the lower unit lies at an altitude of 160 to -30 m a.m.s.l. and its relief is very contrasting (Figure 2).

The upper sedimentary unit is present mostly as erosional remnants of a marine deposit that once covered significant parts of the TaymyrTaimyr Peninsula. These deposits have often been considered glacial in origin due to their sharp morphology and sandy to gravely composition (Kind and Leonov, 1982). However, the internal structure of these deposits, although rarely exposed due to a lack of recent erosion and active slope processes, indicates a coastal deltaic facies of these sediments. Molluscs (*Hiatella arctica, Astarte borealis, Mya truncata)*, foraminifera (*Haynesina orbicularis, Retroelphidium ex gr. clavatum, Cribroelphidium granatum, Astrononion gallowayi, Bucella frigida, Cassidulina neoteretis*) and diatom (*Navicula placentula, N. radiosa, Stephanodiscus astrea, Tabellaria fenestrata, Pinullaria borealis, Cocconeis disculus, Amphora ovalis var lybica, Cyclotella kuetzingiana var. schumannnii, Caloneis bacillum)* assemblages, found in some sections belonging to this upper sedimentary unit, indicate a delta-marine, coastal-marine, cold and brackish sedimentary environment. The altitude of bedding of upper unit is from -45 to 175 m a.m.s.l. The most widespread level of marine terraces consisting of sand and pebbles of the upper unit sediments is at 100 m a.m.s.l. in the central part of Taymyr.

Discussion and conclusions

The deposits can be divided into a number of groups on the basis of their composition and their age, as determined by ESR dating:

1) sandy-gravely erosional remnants with a **scattered** distribution. Dating falls within a time frame of 70 to 100 ka BP.
2) Clayey silts of a deep-water facies of marine sediments of the same age - 86 ka BP.
3) Clayey silts aged between 116 and 140 ka BP.
4) Clayey silts aged between 235 and 268 ka
5) Sand of shallow-water marine facies aged 289 ka BP.
6) Sandy silts aged between 316 and 336 ka BP.
7) Sand and gravels aged 535 ka BP.

This is a first attempt to date marine Quaternary deposits of the Taymyr Peninsula. We did not have an opportunity to date all geomorphological levels. However, the bedding of studied sediments at very different altitudes suggests that their modern position is under the influence of

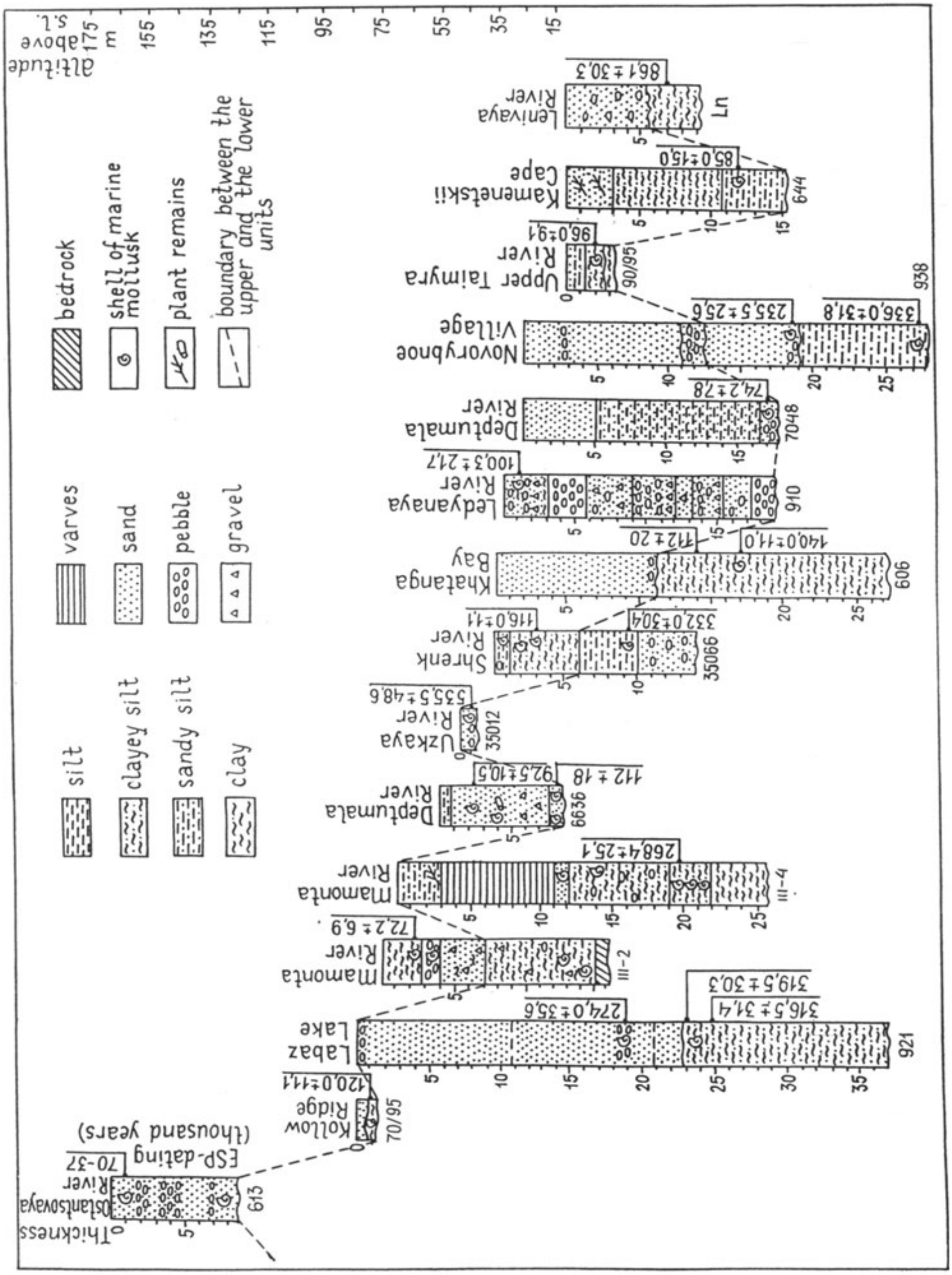

Figure 2: Sediment logs with ESR datings from the Taymyr Peninsula.

differential tectonic movements of the Taymyr Peninsula.

The ESR dates obtained thus suggest active marine sedimentation over the Taymyr Peninsula during isotope stages 4, 5, 7, 8, 9 and 15. These dates correlate well with the marine events of the Severnaya Zemlya archipelago during the same half million year time interval (Bolshiyanov and Makeev, 1995).

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