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Environmental Evolution in the Laptev Sea Region During Late Pleistocene and Holocene

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THEME 12: Gashydrates and Permafrost: Onshore and Offshore

Summary: The Laptev Sea Shelf (LSS) is marked by a virtually continuous distribution of offshore relic ice-bonded permafrost (IBP). Main features of IBP formation and evolution have been created under the influence of LSS exposure and submerge by sea water, accumulation of ice complex, its thermal erosion, thermokarst lake and alas formation during the Late Pleistocene-Holocene glacioeustatic cycle. Natural events versus time on the LSS and its influence on permafrost evolution in the form of a paleo-scenario adapted for mathematical simulation of offshore permafrost are described in this paper.

INTRODUCTION

The Laptev Sea Shelf is characterized by virtually continuous distribution of offshore ice bonded permafrost (IBP) (ROMANOVSKII et al. 1998). Investigations of offshore permafrost are very complicate, time and funds consuming. A mathematical simulation of offshore permafrost is required to receive better results. A proper paleogeographical scenario adapted for simulation is essential to solve the problem of mathematical model creation.

The aim of this paper is the paleo-reconstruction of natural events and conditions for the last glacioeustatic cycle (from about 120 Kyr B.P. to the present time). Paleo-reconstruction presented in the form of a paleo-scenario adapted for mathematical modeling of IBP evolution and its recent state.

INITIAL POSITIONS FOR PALEO-RECONSTRUCTING OF THE LAPTEV SEA SHELF ENVIRONMENT EVOLUTION

To develop a paleogeographic scenario of the formation and evolution of the Laptev Sea Shelf (LSS) permafrost, we used available data on the Quaternary geology and results of geocryological studies of this region (Geocryology of the USSR, Vol. 3, and 4, 1989; Geocryological Map of the USSR, 1996). Materials on the geocryological structure and occurrence of submarine permafrost obtained in the course of realization of the Russian-German project (ROMANOVSKII et al. 1998) and the published data also were used.

The paleogeographic scenario is based on the concepts of permafrost formation on the LSS during its exposure in the process of sea regression and its degradation after submerge by sea water in the course of the transgression. The major causes of regressions and transgressions on the LSS were glacioeustatic oscillations of the global sea level. In the Late Cenozoic, there was no glaciation on coastal plains and shelves of Arctic seas east of the Taimyr peninsula (SHER 1992, SHER 1997a,b). Therefore, in this region there was no glacioisostatic movement of the earth crust. This circumstance makes it possible to use the curves on glacioeustatic sea level variations in the Late Pleistocene and Holocene (CHAPPEL et al. 1996, FAIRBANKS 1989) derived in recent years for reconstructing changes in the Laptev sea-land boundary with time.

Analysis of the entire body of published data made it possible to select the curves of sea level variation which correlate best with major natural events (both global and of the East-Asian sector of the Arctic) in the Late Pleistocene and Holocene. Taking into account the synchronous character of glacioeustatic changes in the sea level, we used these curves to segregate the ranges of depths with similar time intervals of exposure-flooding of the LSS and, consequently, similar temperature oscillations on its surface. A reconstruction based on modern permafrost conditions (Fig. 1) is presented in Table 1. and in schematic maps (Fig. 2) and related profiles (Fig. 3).

As emphasized above, the key factors in the formation of offshore permafrost of shelf seas in the East-Asian sector of the Arctic are the beginning and respectively the duration of perennial freezing of deposits on the shelf. Numerous investigators assume here the occurrence of the Kargan transgression, when the permafrost formed on the previously exposed shelf degraded totally (ZHIGAREV 1997, DANILOV & ZHIGAREV 1977). However, the most recent data indicate that during the Kargan Interstadial the ice sheets decreased by less than 30 % of their volume, whereas global sea level did not rise above the modern isobaths of -35; -70 m. (Fig. 4). To such data are referred the results of oxygen isotope analysis of bottom sediments (e.g. CHAPPELL et al. 1996, TARAKANOV et al. 1992, KOTLYAKOV & LORIUS 1992). Thus, in the Kargan Interstadial the sea level varied within the

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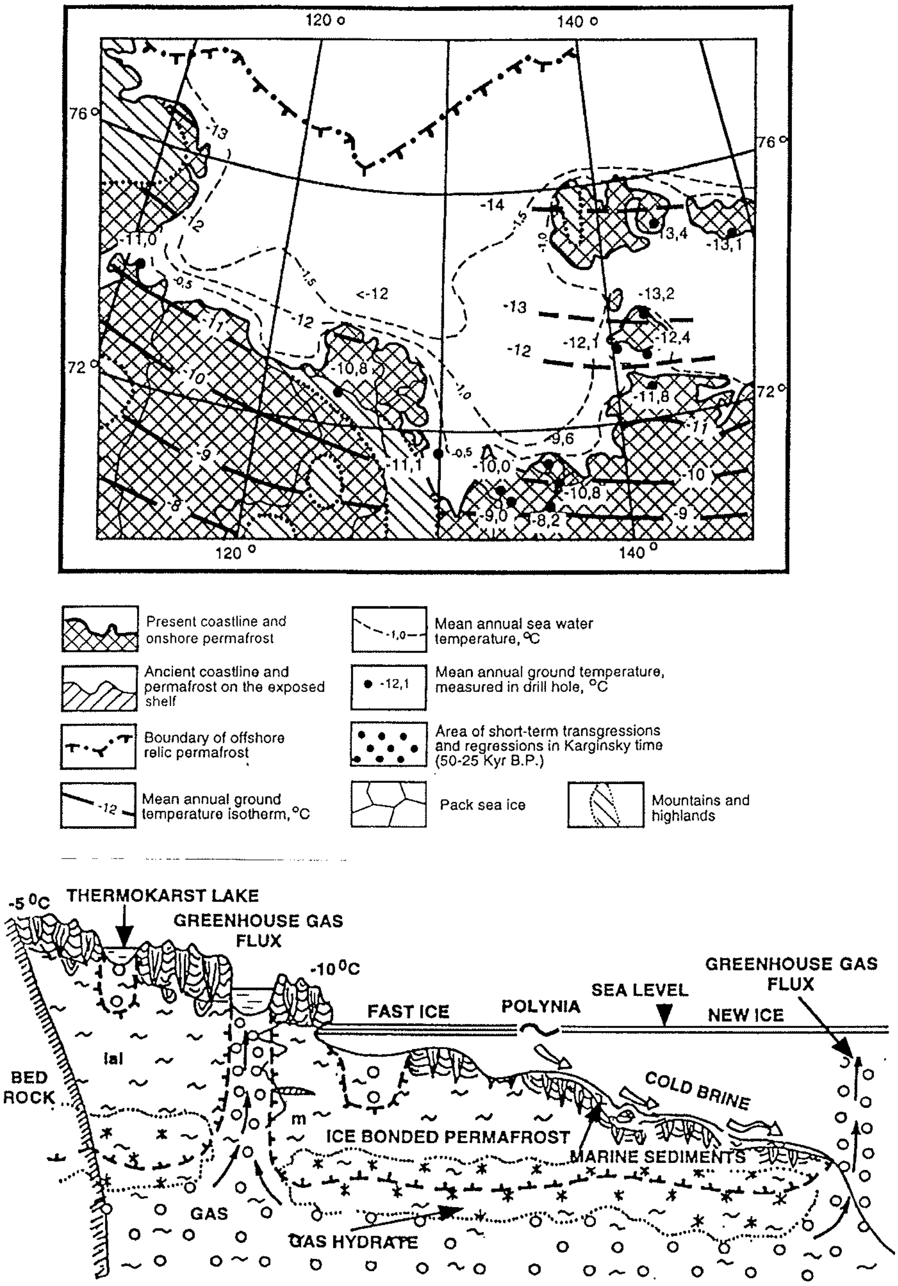

Fig. 1: Recent permafrost conditions in the Laptev Sea region (LSR): Map of permafrost distribution, temperature zonation, and schematic profile of onshore and offshore permafrost.

Zone between modern isobaths (m)	Permafrost evolution initiation Kyr. B.P.	completion Kyr. B.P.	duration Kyr.	Environmental events and ice-bonded permafrost evolution
0 to 20	115 to 110	75 to recent	>100	Shelf exposure; permafrost aggradation
20 to 60	110	87	23	Sea level fluctuation; permafrost aggradation and degradation
20 to 45	87	9.5	77.5	Shelf exposure; permafrost aggradation
45 to 65	77	44	33	Sea level fluctuation; permafrost aggradation and degradation
45 to 65	44	10.5	33.5	Shelf exposure; permafrost aggradation
65 to 100	44	24	20	Sea level fluctuation; permafrost aggradation and degradation
65 to 100	24	13	11	Shelf exposure; permafrost aggradation
100 to 120	24 to 19	18 to 13	11 – 1	Shelf exposure; permafrost aggradation

Tab. 1: Formation of ice-bonded permafrost on the Laptev Sea Shelf (LSS); events versus time.

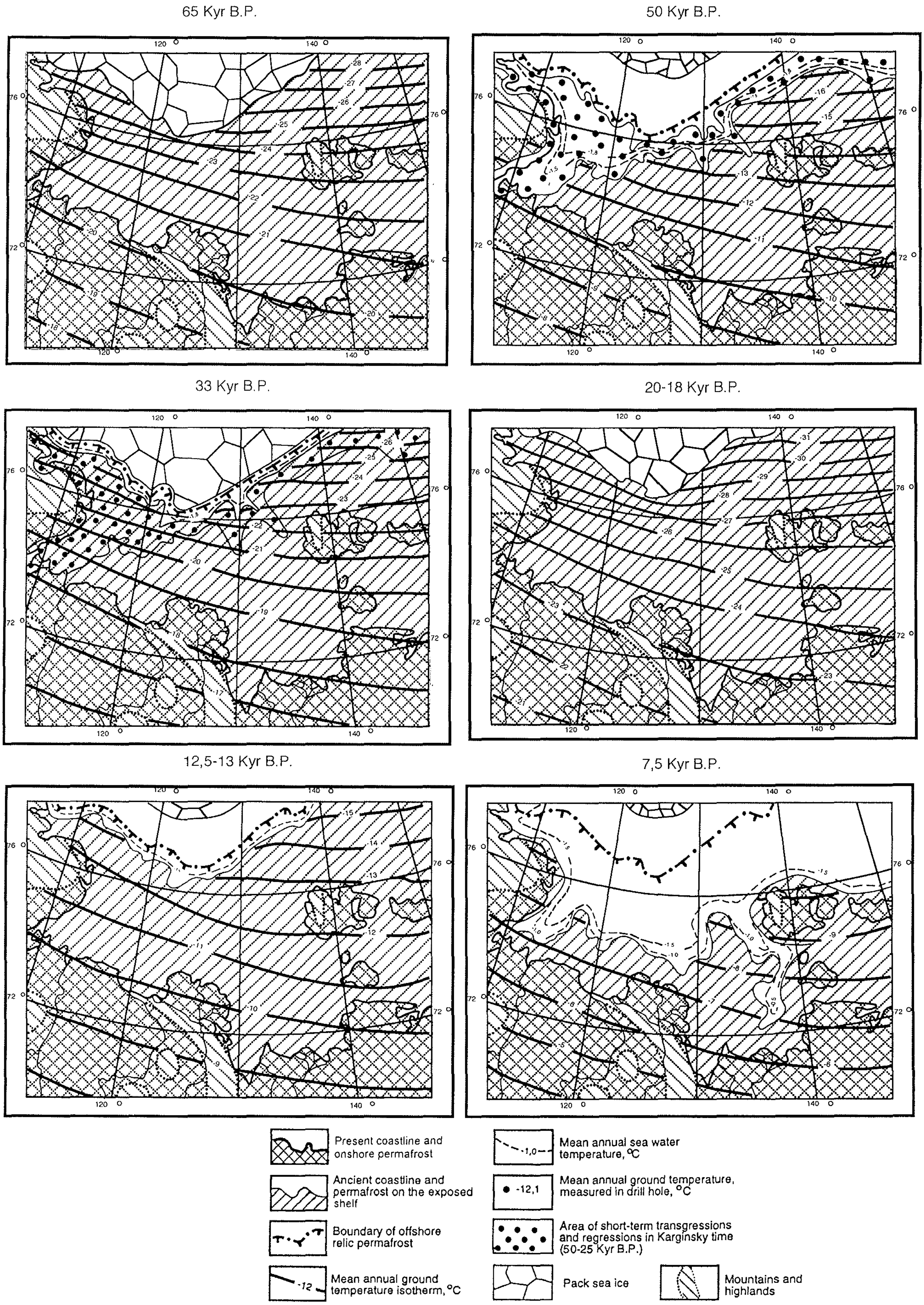

Fig. 2: Schematic maps of permafrost distribution and temperature zonation in LSR during the Pleistocene-Holocene glacio-eustatic cycle.

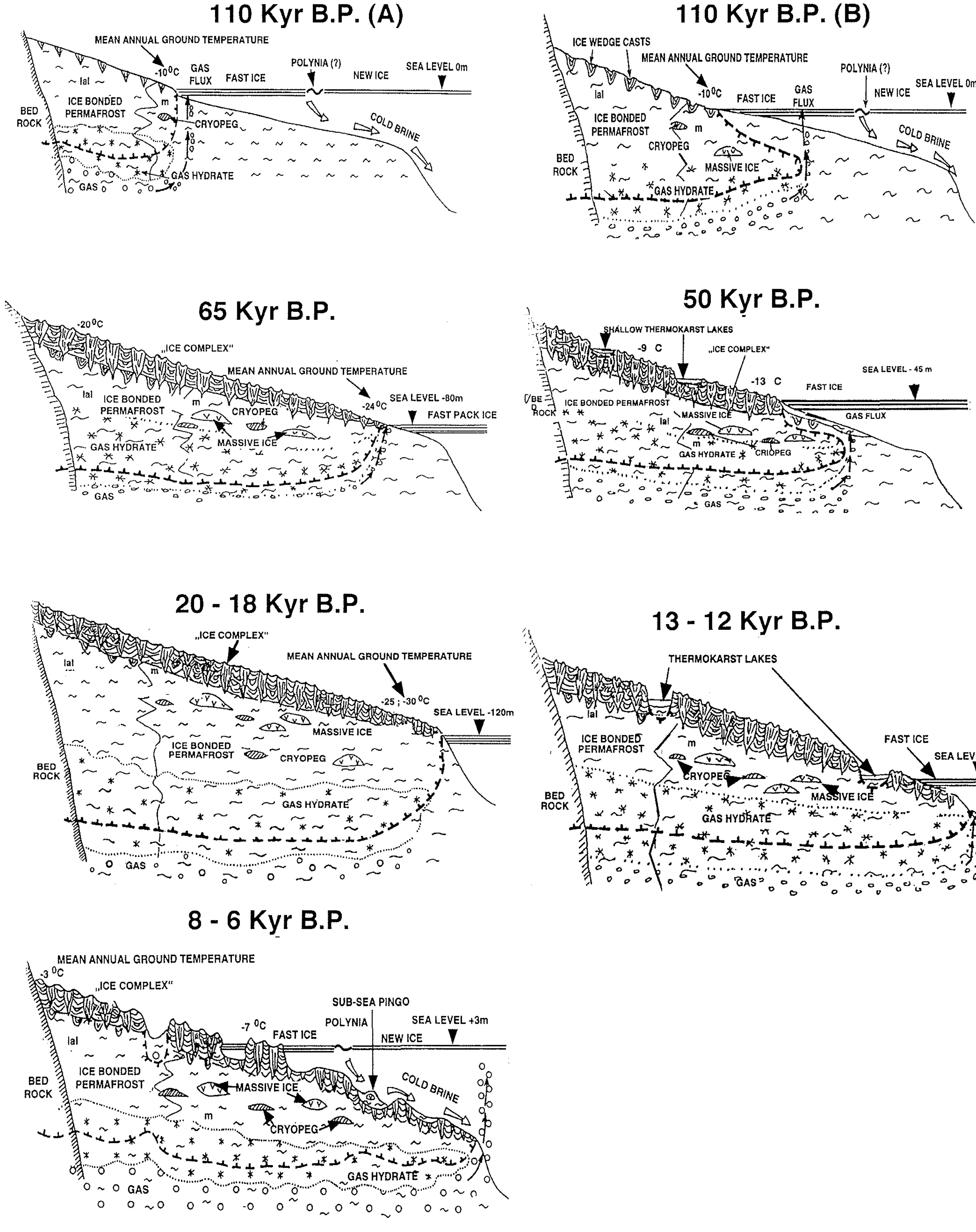

Fig. 3: Schematic profiles of both onshore and offshore permafrost conditions during the Late Pleistocene-Holocene glacio-eustatic cycle.

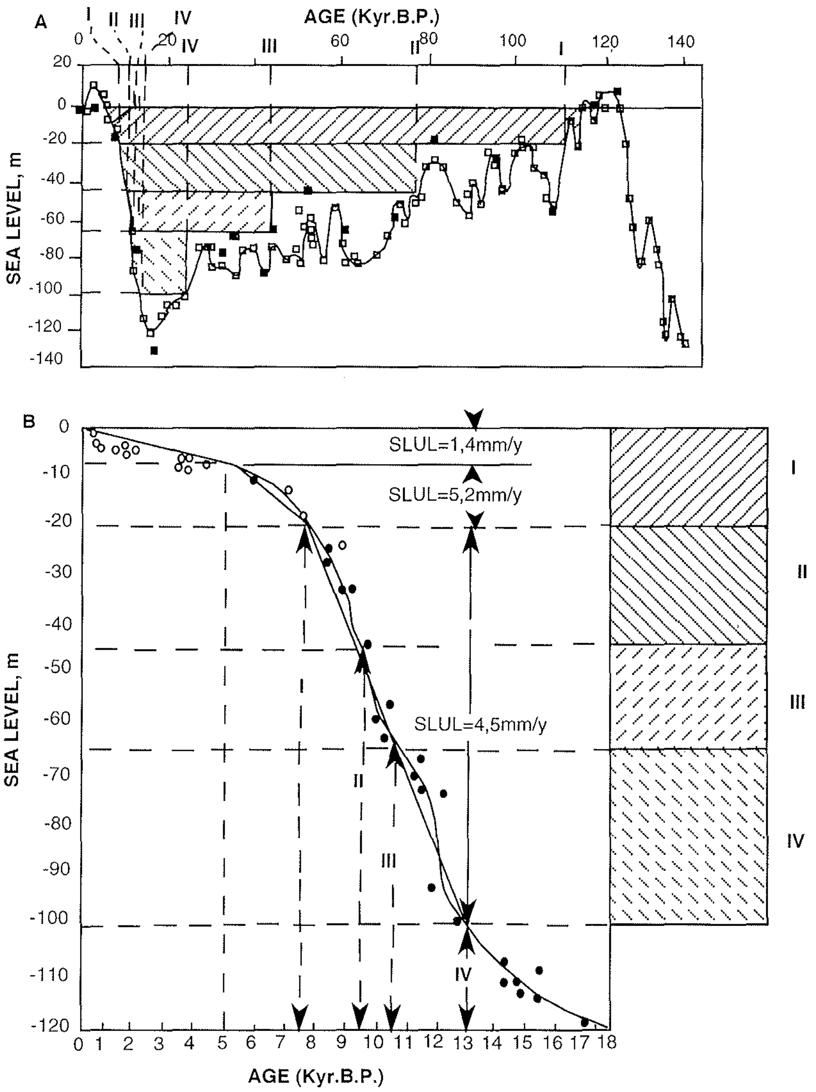

Fig. 4: Glacio-eustatic variation of sea level versus time; A after CHAPPEL et al. (1996), and B after FAIRBANKS (1989). Curves of glacio-eustatic variation of sea level adopted for paleogeographical scenario and map of upper boundary condition compilation for modelling of offshore permafrost thickness of the Laptev Sea Shelf; SLUL rate of sea level uplift (mm/y).

indicated range of heights, i.e. it was substantially lower than the modern level. No traces of the Kargan transgression were found in the East-Asian sector of the Arctic (NEIZVESTNOV 1981). The formation of "ice complex" on Novosibirsk Islands and coastal lowlands of East Yakutia characterize this period.

The authors of the proposed paleoscenario made the following assumptions:
(1) the coincidence of the sea boundaries in the Kazantsevoan Interglacial with the modern ones and
(2) the absence of ice-bonded permafrost under the sea at the end of Kazantsevoan transgression (Fig. 3 (A)).

Let us make reservation that the absence of Kazantsevoan marine deposits on the modern coast and the exposure of Middle and/or Early Quaternary sediments with polygonal ice wedges in the base of a number of coastal cross sections are indicative of the possible existence of "pre-Kazantsevo" permafrost at the shelf sites with depths of 30-40 m. (Fig. 3(A–B)), (ROMANOVSKII 1958, ARKHANGELOV et al. 1996). The permafrost could exist on the surface as well as in the form of a relict layer, which was unable to thaw totally during the last interglacial.

Oscillations of the mean annual ground temperature (t_{ma}) for the Laptev Sea Region on the whole were assumed to be synchronous with the planetary climatic changes imprinted in the ice core from the Vostok station (Antarctic) (BARNOLA et al. 1987, KOTLYAKOV & LORIUS 1992). These changes of t_{ma} were defined more accurately with regard to time and absolute values for North-East Asia using the results of paleogeographic and paleopermafrost studies of BAULIN et al. (1981), KAPLINA (1981), ROMANOVSKII (1977, 1993), ZUBAKOV & BORZEMKOVA (1983), and others.

Respective curves were plotted to reflect changes in the mean annual ground temperatures with time giving due account for the existence of permafrost temperature latitudinal zonation and the differences of sea water temperatures at different stages of the last regression-transgression cycle. Therefore, the above-mentioned curves were plotted according to the following scheme: temperature of sea floor sediments (t_{sf}) before regression equal to that of sea water - abrupt decrease of temperature to the latitudinal-zonal value at the moment of regression (Δt_r) - variation of t_{ma} of the exposed shelf in accordance with climatic changes in the North-East Arctic - abrupt rise of temperature at the moment of flooding by the transgressing sea (Δt_t) - t_{sf} after transgression (Fig. 5).

The time interval under reconstruction embraces only the Late Pleistocene-Holocene regressive-transgressive cycle. This cycle may be subdivided into periods of sea regression and transgression. These periods have different durations depending on water depths in particular shelf regions.

MAIN SUBSTAGES OF THE LSS DEVELOPMENT IN THE PERIOD OF SEA REGRESSION

The period of sea regression was a time interval of permafrost aggradation on the exposed shelf. The shelf exposure was irregular. At certain substages it was replaced by short-term periods of sea advance (Fig. 2). Hence, the aggradation of permafrost was for a certain time replaced by its degradation from the surface due to short-term sea level fluctuations. Recurrent oscillations of climate and temperature of deposits occurred under constantly severe conditions. The strongest cooling and greatest lowering of sea level was characteristic of the Sartanian Glaciaton (cryochron). The sea level lowering was from 120 to 140 m (CHAPPEL et al. 1996, FAIRBANKS 1989, SELIVANOV 1996) (Fig. 4). The gradual character of the shelf exposure was expressed in the successive reduction of the period of freezing from the inner parts of the exposed shelf to its periphery (Table 1). In this case the substages of short-term sea retreat-advance cycles (e.g. the substage from 110-80 Kyr B.P. or the depth range of -20 -45 m) are excluded from the time of permafrost expansion to the north. This approach to the problem makes discrete the permafrost formation scenario, when adapting it for mathematical modeling.

During sea regression the shelf became the site of freezing of sea water-saturated sediments and rocks. Their freeze/thaw temperature ($t_{f,t}$) was about -2 °C. Permafrost aggradation was accompanied by the formation of lenses of cryopegs (high con-

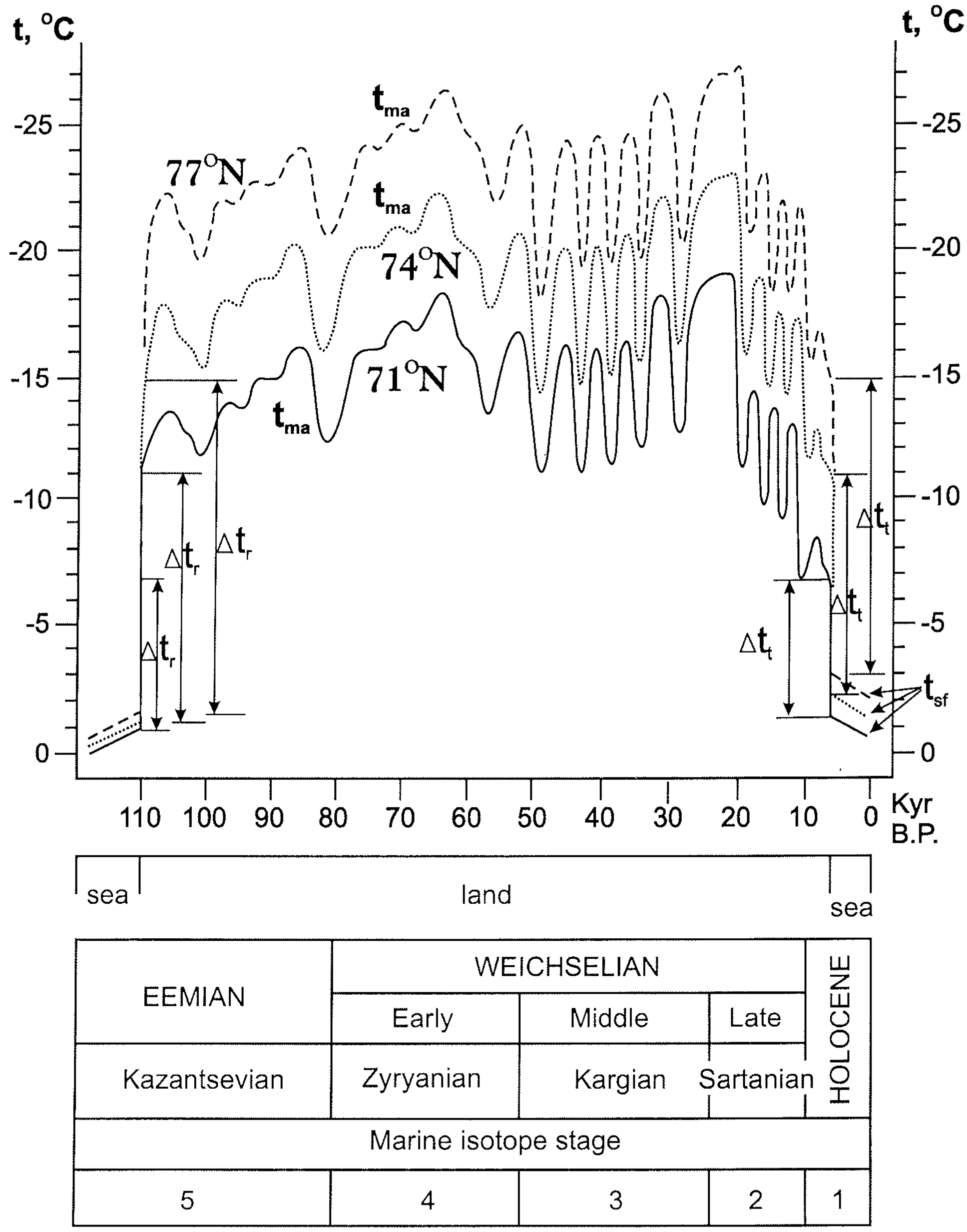

Fig. 5: Variation of the sea floor temperature (t_{sf})and mean annual ground temperature (t_{ma}) during the Late Pleistocene-Holocene glacio-eustatic cycle. Curves of temperature variation plotted for different latitudes taking into consideration permafrost temperature zonality of the Laptev Sea Region; Δt_r and Δt_t describe jump of temperature due to regression and transgression of the sea

centrated saline water with negative temperature), the appearance and subsequent expansion of a gas hydrate stability zone (GHSZ) (Fig. 3, 65- (20-18) Kyr B.P.). The lowest mean annual temperatures of air and deposits existed in the Sartanian cryochron (Fig. 3, 20-18 Kyr B.P.). According to numerous investigators (V.T. Balobaev, I.I. Borzenkova, T.N. Kaplina, A.A. Velichko, and others), t_{ma} were 8-15 °C below those measured today. The Zyriankan glaciation-cryochron was characterized by the temperatures 1-2 °C warmer that those in the Sartan cryochron (Arkhangelov et al. 1996, Barnola et al. 1987). We have assumed that the lowering of t_{ma} was -10 °C in the last Sartanian cryochron and -8 °C in the Zyriankan cryochron.

The Kargan Interstadial is remarkable for the occurrence of several thermo- and cryochrons (Lozhkin 1977, Kaplina & Giterman 1983, and others). Kaplina (1981) does not rule out the possibility of local thermokarst appearance and formation of lake taliks at 68 °N and further to the south (Fig. 3, 50 Kyr. B.P.). At the same time, the "ice complex" was formed over the entire territory of present coastal lowlands and Novosibirsk Islands. Thus, it may be assumed that the temperature regime on the LSS during the Kargan Interstadial differed very little from that of Zyriankan cryochron, as indicated by the expansion of the "ice complex".

The proposed scenario assumes similar of temperature zonation the modern and Late Pleistocene permafrost (Fig. 5). Under contemporary conditions the warming role of the snow cover decreases from south to north. This factor dominates in the formation of temperature regime of deposits on the Yana-Indigirka lowland and Novosibirsk Islands. This factor is also responsible for the latitudinal temperature decrease from -5 to -7 °C in the snow-covered open woodland in the south to -15 °C on the blown off, snowless rocks of the Yedoma on the Malyi Lyakhovsky and Kotel'nyi islands (Geocryology of the USSR. West Siberia and Far East, 1988) (Fig. 1). The permafrost temperature zonation in the Late Pleistocene were differed little from that today.

The exposure of the shelf induced formation of syncryogenic surface deposits saturated with syngenetic ice wedges and segregated ground ice ("ice complex"). The accumulation of such thickness deposits during cryochrons is much faster than during thermochrons due to their higher ground ice content (Romanovskii 1977, 1993) (Fig. 3 (B)). Considerable differences in the "ice complex" thickness (from a few metres to 50-60 m and possibly more) show that its accumulation was irregular. The largest thickness of the "ice complex" is supposed to be near the modern coast where the shelf was exposed for the longest time as well as in negative tectonic structures subjected to most recent subsidence. The latter sentence is confirmed by the fact that in the area of Lena delta rift (Drachev et al. 1995) the "ice complex" extend below sea level (Grigoriev 1993), whereas on the shores of Dimitri Laptev strait it lays everywhere on the layer of aleurites with low ice content up to 18 m thick. This territory is referred to tectonic uplift. It is not precluded that the higher thickness of the "ice complex" is rather significant in relation to the distribution of post-rift depressions within the Laptev Sea shelf limits (Drachev et al. 1995). The mean calculated rate of vertical movements during the Cenozoic is not over: 0.5-2 mm/year. However, in numerous rifts a higher rate, reaching several millimeters per year and more, was revealed for the Late Pleistocene and Holocene (Nikonov 1977). Therefore, in the parts of rift grabens where the duration of the shelf exposure was not long, amounting to 50-100 Kyr, there is every reason to suppose the possibility of accumulation of many tens of meters of syncryogenic ice-rich deposits. Thus, the saline deposits of the shelf were covered by non-saline sediments at $t_{f,t}$ of 0 °C.

THE MAIN SUBSTAGES OF THE POSTGLACIAL SEA TRANSGRESSION

The sea transgression started approximately 18 Kyr B.P. Submergence of the Laptev Sea shelf lied to the degradation in the evolution of shelf permafrost. Time of transgression may be divided into two substage: the first substage, from 18-16 Kyr to 8-7 Kyr B.P. and the second, from 8-7 Kyr B.P. to the present time (Fig.2).

The most important feature of the first transgression substage its high speed, especially starting from 13 Kyr B.P. when sea level raise reached 15 mm/year. The advance of the shoreline inside the shelf occurred at different shelf sites with a mean speed of 40-80 m/year. This led to the flooding of the "ice complex". The poor development of sea thermoerosion was considerably favored by low temperatures and extensive sea ice cover. The value of t_{sf} (-2 °C) on the whole reduced its impact on IBP. The transition rate of frozen deposits into cryotic ones was low because of small rates of salt's diffusion through silty products of the erosion of terrestrial syncryogenic deposits. The major supply of terrestrial sediments to the sea was brought about by their runoff with river waters and roiling of thawed subaerial deposits on the sea floor.

Transgression proceeded against the background of recurrent climate oscillations with a trend towards warming that was reflected on the paleotemperature curves (Fig.5). During the themochrons at the end of Pleistocene-beginning of Holocene, lake thermokarst developed on the shelf and coastal lowlands in the north-east of Eurasia (Kaplina & Lozhkin 1979) (Fig. 3, 13-12 Kyr B.P.). The authors date it back to the Bølling (12.8-12.3 Kyr B.P.) and Alleroed (11.8-11.0 Kyr B.P.) interstadials and apparently preboreal thermochrons (about 10-9.5 Kyr B.P.), because alases already existed as a relief form in the boreal optimum. A large number of closed lake taliks were flooded on the shelf by the advancing sea. By covering thawed deposits saturated with fresh water, the sea waters at negative temperatures induced their freezing with the formation of subsea pingos (Are 1988, Romanovskii et al. 1998) (Fig.3). At the same time, the progressive development of lake thermokarst continued on lowlands. Nowadays, these lakes may be emission sites of gases accumulated in Late Cenozoic (Zimov et al. 1997).

The second transgression substage covers the period from 8-7

Kyr. B.P. to the resent time. It is characterized by humidization of the climate of East Siberia (SHER 1997) and a slow rise of the sea level. The latter circumstance determined the development of thermoerosion of sea shores which proceeded with the mean speed of 4-6 m/year. As a result of thermoerosion, which could reach locally several tens of metres per year, many islands formed by the "ice complex" disappeared during the recent times. During the last 7-8 millennia the LSS expanded by 30-50 km under the impact of this process.

The most important consequence of thermoerosion is the cut-off of the ice-richest upper part of the sections of Quaternary deposits. As a result of this, the degradation of IBP proceeded faster because the sea water affects often saline deposits which have $t_{f,t}$ below 0 °C and low ice content.

In the Early and Middle Holocene (8-6 Kyr B.P.) lake therrnokarst developed widely on coastal lowlands (Fig. 3). Thermokarst lakes and depression - alases- become the accumulation sites of sediments formed from the thawed and degraded deposits of the "ice complex". This phenomenon substantially reduced the bulk of particulate river runoff.

Freshening of the sea water by the river related to warming and humidization of climate raised the t_{sf} in the littoral zone, often to its positive values. This process has played an important role in the increase of IBP thawing and in the formation of closed submarine taliks (Fig.1 and 3, 8-6 Kyr B.P.) in the zone between the shoreline and the isobaths of -10, -15 m.

The open submarine and lake taliks, formed as a result of the "ice complex" thawing under subaerial conditions, possibly disintegrated locally the GHSZ. These lakes are now the sites of greenhouse gas emission (ZIMOV et al. 1997). At the same substage, open taliks were formed on the shelf along active faults with high values of geothermal heat flow, their formation being also dependent on seismic events.

A characteristic feature of the second transgression substage is the formation of river deltas and "delta permafrost": dynamic, with high variations of temperature and thickness of frozen deposits and with the presence of epicryogenetic, syn- and paragenetic facies of river, lacustrine, coastal-marine and delta sediments (GRIGORIEV 1966, GRIGORIEV 1993, KATASONOV 1972).

An important part in the permafrost preservation on the LSS is played by Siberian Polynya (flaw lead) the southern boundary of which coincides with the northern edge of fast ice. Its position in the eastern part of Laptev Sea corresponds to water depth of 20-40 m (DMITRENKO et al. 1995). Formation of low-temperature and heavy brines in winter is associated with the existence of this Polynya (DETHLEFF 1994, CHURUN & TIMOKHOV 1995). Sinking to the sea floor and along the shelf slope, such brines cool, since the time of polynya formation, the bottom sediment, thus preserving IBP from thawing (Fig.1).

Before completing the discussion of the developmental shelf history, it should be noted that part of the described measurements of parameters of natural environments is reflected in the curves of upper boundary conditions for mathematical modeling (Fig. 5). Other data are used below for compiling a map of distribution and thickness of the Laptev Sea shelf permafrost.

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References

Are F.E. (1988): Thermal abrasion of sea coasts (Parts I and II).- Polar Geography & Geology 12: 1-157.

Arkhangelov A.A., Mikhalev, D.V. & Nikolaev V.I. (1996): Reconstruction of the formation conditions of permafrost and paleoclimate in North Eurasia.- In: The Development of Permafrost Regions and Periglacial Zone of North Eurasia under Conditions of Ancient Man Dispersal. Moscow, 85-109 (in Russian).

Barnola J.M., Raynond D., Korotkevich Y.S., Lorius C. (1987): Vostok ice core provides 160000 years record of atmospheric CO_2.- Nature 329: 408-414.

Basisty V.A. & Buiskich A.A. (1955): The role of neotectonics in the cryolithozone evolution.- In: ICAM-94 Proceedings, Permafrost and Engineering Geology: 327-331.

Baulin V.V., Danilova N.S., & Sukhodol'skaya L.A. (1981): History of perennially frozen grounds evolution and techniques for their investigation.- In: The History of Eurasia Permafrost Evolution. Moscow, Nauka, 24-60 (in Russian).

Chappell J., Omura A., McCulloch M., Bandolfi J., Ota Y. & Pillans B. (1996): Reconciliation of Late Quaternary sea levels derived from coral terraces at Huon Peninsula with deep-sea oxygen isotope records.- Earth Planet. Sci. Letters 141: 227-236.

Churun V.N. & Timokhov L.A. (1995): Cold bottom water in the southern Laptev Sea.- Rep. Polar Res. 176: 107-113.

Danilov I.D. & Zhigarev L.A. (1977): Cryogenic deposits of Arctic shelf.- In: Frozen Grounds and Snow Cover. Moscow, Nauka, 5-62 (in Russian).

Dethleff D. (1994): Dynamics of the Laptev Sea flaw lead.-Rep. Polar Res. 144: 49-54.

Dmitrenko I.A. and the TRANSDRIFT II Shipboard Scientific Party (1995): The Distribution of River Run-off in Laptev Sea: The Environmental Effect.- In: H. KASSENS et al. (Eds.), Russian-German Cooperation, Laptev Sea System.- Rep. Polar Res. 176: 114-121.

Drachev S.S., Savostin L.A. & Bruni I.E. (1995): Structural pattern and tectonic history of the Laptev Sea shelf.-Rep. Polar Res. 176: 348-366.

Ershov E.D. (ed.) (1996): Geocryologival Map of the USSR. Scale 1: 2 500 000 - Moscow.

Fairbanks R.G. (1989): A 17 000-year glacial-eustatic sea level: influences of glacial melting rates on Younger Drias event and deep ocean circulation.- Nature 342: 637-642.

Fartyshev A.I. (1993): Distinctive Features of the Laptev Sea Offshore Permafrost.- Novosibirsk: Nauka, 136 pp. (in Russian).

Geocryology of the USSR East Siberia and Far East. (1989): Moscow: Nedra 176-184 (in Russian).

General Geocryology (1978): Izd. MGU: 464 pp. (in Russian).

Grigoriev N.F. (1966): Perennially Frozen Deposits of the Littoral Zone of Yakutia.- Moscow: Nauka, 180 pp. (in Russian).

Grigoriev M.N. (1993): Cryomorphogenesis of the estuary zone of Lena River.- Yakutsk: Permafrost Institute, 174 pp. (in Russian).

Kaplina T.N. (1981): History of North Yakutia permafrost.- In: The Eurasian Permafrost History. Moscow: Nauka: 153-181 (in Russian).

Kaplina T.N. & Giterman R.E. (1983): Base cross section of deposits of second half of late pleistocene on the Kolyma lowland – Molotkovsky Kamen.- In: Izv. AN USSR. Geology 6: 79-3 (in Russian)

Kaplina T.N. &Lozhkin A.V. (1979): Age of alasses deposits of Yakutian coastal lowlands (radiocarbon dating).- Izv RAN. Geology 2: 69-76 (in Russian)

Katasonov E.M. (1972): Types of permafrost and problem of cryolithology.- In: Geocryological and hydrogeological investigation in Syberia: 5-16 (in Russian)

Kotlyakov V.M. & Lorius C. (1992): Global climate change during the last glacial-interglacial cycle.- Izv. RAN. Geography 1: 5-22 (in Russian)

Kunitsky V.V. (1989): Cryolithology of the lower reaches of Lena River.- Yakutsk Permafrost Institute: 162 pp. (in Russian).

Lozhkin A.V. (1977): Radiocarbon data of upper pleistocene deposits on Novosibirskie Islands and age of "Edoma" serie on North-East of USSR.- In: Reports of AN USSR. 235, 2: 435-437 (in Russian).

Neizvestnov Ya.V. (1981): Cryohydrogeological conditions in the Arctic shelf zone of the USSR.- In: The Cryolithozone of the Arctic Shelf. Yakutsk, 18-27 (in Russian).

Nikonov A.A. (1977): The Holocene and contemporary movements of the Earth Crust.- Moscow, Nauka: 240 pp. (in Russian).

Romanovskii N.N. (1958): Paleogeographycal condition of quternary deposits formation on the B.Lyahovsky island.- In: Voprosy geographii polyrnyh stran: 68-81 (in Russian)

Romanovskii N.N. (1977) Formation of polygonal structures.- Novosibirsk. Nauka, 215 pp. (in Russian)

Romanovskii N.N. (1993): Fundamentals of the lithosphere cryogenesis.- Moscow, Izd. MGU: 335 pp. (in Russian).

Romanovskii, N.N., Gavrilov, A.V., Kholodov, A.L., Hubberten, H.W. & Kassens, H. (1997): Reconstruction of paleo-geographical condition of Laptev Sea Shelf during the Late Pleistocene- Holocene glacioeustatic regression- transgression cycle.- Cryosphere of Earth 2: 42-49. (in Russian)

Romanovskii N.N., Gavrilov A.V., Pustovoit G.P., Kcholodov A.L., Kassens H., Hubberten H.W., Niessen F. (1997): Distribution of offshore permafrost on the Laptev Sea Shelf.- Cryosphere of Earth 3: 9-18. (in Russian)

Romanovskii, N.N, A.V.Gavrilov, A.L. Kholodov, G. P. Pustovoit, H.W. Hubberten, F. Niessen, H. Kassens. (1998): Map of predicted offshore permafrost distribution on The Laptev Sea Shelf. PERMAFROST.- In: Proceedings Fifth International Conference on Permafrost. Yellowknife, Canada, 967-972

Selivanov A.O. (1996): Changing of World Ocean level during Pleistocene-Holocene and sea shores development.- Moscow, 268 pp. (in Russian)

Sher A.V. (1992): Biota and climate in Arctic North-East Siberia during Pleistocene/Holocene transgression.- In: Proceedings of the 22nd Arctic Workshop. Boulder, 125-127.

Sher A.V. (1997a): Environmental reconstructing at the Pleistocene / Holocene boundary in the East Siberian Arctic and its role in mammalian extinction and establishment of modern ecosystems (Communication 1).- Cryosphere of Earth 1: 21-29. (in Russian)

Sher A.V. (1997b): Environmental reconstructing at the Pleistocene / Holocene boundary in the East Siberian Arctic and its role in mammalian extinction and establishment of modern ecosystems (Communication 2).- Cryosphere of Earth 2: 3-12. (in Russian)

Tarakanov Yu. A., Klige R.K. & Selivanov A.O. (1992): Investigation of the ancient geoid on the base of data about sea terrases height.- Water supply 4: 24-29. (in Russian)

Telepnev E.V. (1981): Subaqual frozen zone in the coastal part of Bolshoy Lyakhovsky island.- In: The Cryolithozone of Arctic Shelf. Yakutsk Permafrost Institute: 44-52 (in Russian).

Zhigarev L.A. (1997): The Oceanic Cryolithozone.- Moscow: Izd. MGU, 312pp. (in Russian).

Zimov, S.V., Voropaev V.V., Semiletov I.P. , Davidov S.P., Prosiannikov S.F., Chapin F.S., Chapin, M.S., Trumbore S., & Tyler (1997): North Siberian lakes: a methane source fueled by Pleistocene carbon.- Science 277: 800-801

Zubakov V.A. & Borzenkova I.I. (1983): Paleoclimates of the Late Cenozoic.- Leningrad, Gidrometeoizdat, 215 pp. (in Russian).