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Foraminiferal complexes and palaeooceanographic reconstructions of the Middle and Late Pleistocene interglacial basins in the North of Siberia

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Abstract: Foraminiferal complexes (Ob, Kazantsevo, Karginsk) from the Middle and Late Pleistocene deposits of North Siberia are described. Distinctive species for the Ob (Holsteinian) foraminiferal complex are *Milionella pyriformis, M. grandis grandis, Retroelphidium obesum* and *R. subclavatum*. In the Kazantsevo (Eemian) foraminiferal complex, *Retroelphidium atlanticum, R. boreale, R. propinquum* and *Haynesina magna* dominate, whilst *Cibicides rotundatus* and *Trifarina fluens* are characteristic of the Karginsk (middle Weichselian) complex. Palaeooceanographic maps of the Middle and Late Pleistocene palaeobasins are compiled for the maximum extent of sea transgressions and the palaeobasin coastlines are reconstructed. Hydrological parameters (depth, salinity and temperatures of the bottom waters) are provided only for the Kazantsevo and Karginsk palaeobasins.

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INTRODUCTION

Numerous data from the exploration of abyssal deposits of the Central Arctic, the Norwegian and Greenland seas have appeared over the last twenty years. Continuous sequences and a low rate of deposition permit the observation of vertical successions of the palaeoenvironments. In marine deposits of Baffin Island, Greenland, Spitzbergen and the Arctic coast of Eurasia, the rate of sedimentation is fairly high, allowing establishment of palaeogeographical reconstructions for certain time intervals.

Most of the material collected over recent years has enabled reconstructions of palaeobasins during the last sea transgression phases in Northern Siberia, i.e. the Ob (Holsteinian) and Kazantsevo (Eemian) interglacials and Karginsk (middle Weichselian) interstadial (Fig. 1).

MIDDLE PLEISTOCENE

Ob (Holsteinian) foraminiferal complex and Ob palaeobasin

The foraminiferal complex with a high quantity of specimens and species diversity (up to 4000 specimens and about 30 species in a standard sample) is distinctive of Middle Pleistocene sediments. *Retroelphidium subclavatum* (GUDINA), *R. obesum* (GUDINA), *Haynesina orbicularis* (BRADY), *Islandiella islandica* (NORVANG), *I. inflata* (GUDINA) and *Cassidulina reniformis* (NORVANG) are dominant in the complex. Accessory species are: *Tappanella arctica* GUDINA et SAIDOVA, *Alabaminoides mitis* (GUDINA), *Toddinella lenticularis* (GUDINA), *Quinqueloculina borea* GUDINA, *Milionella grandis grandis* (GUDINA), *M. pyriformis* (SCHLUMBERGER), *M. subrotunda* (MONTAGU), *Pateoris circularis* (BORNEMMAN), *Pyrgo williamsoni* (SILVESTRI), *Dentalina baggi* GALLOWAY et WISSLER, *D. pauperata* d' ORBIGNY, *Fissurina orbignyana* SEQUENZA, *F. sacculus* (FORNASINI), *Bucella hannai arctica* VOLOSHINOVA, and specific species include: *Milionella pyriformis* (SCHLUMBERGER), *M. grandis grandis* (GUDINA), *Retroelphidium obesum* (GUDINA) and *R. subclavatum* (GUDINA 1976). Generally, all taxa are typical of an interglacial foraminiferal complex at 100–150 metres depth, with high salinity and low-positive temperatures of the bottom layer waters of Arctic seas (Fig. 2). This interglacial complex was formed following extension of the Boreal-Arctic foraminifers to the shelf seas of the Eurasian sector. Penetration of comparatively warm North-Atlantic waters in the oceanic basins of Northern Europe and Siberia is requisite for such a species expansion. The influence of the Pacific waters is neither observed in Siberia, nor in Northern Europe. The boundary between the Boreal Atlantic and Arctic regions passes east of the Yenisey River meridian (GUDINA 1976).

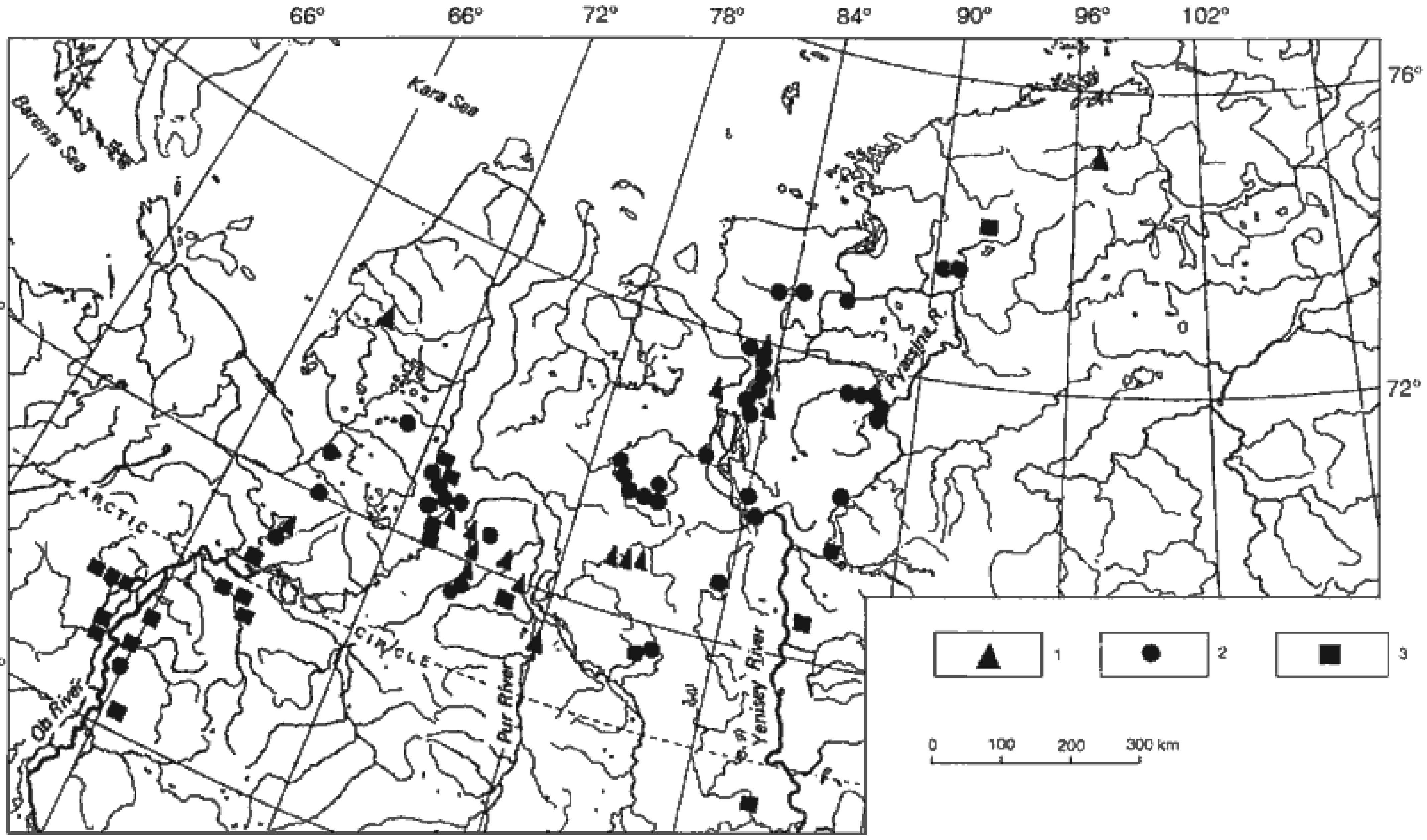

Fig. 1. Location of investigated sections of Quaternary deposits.
1 – Karginsk (OIS 3) sections; 2 – Kazantsevo (OIS 5) sections; 3 – Ob (OIS 7) sections.

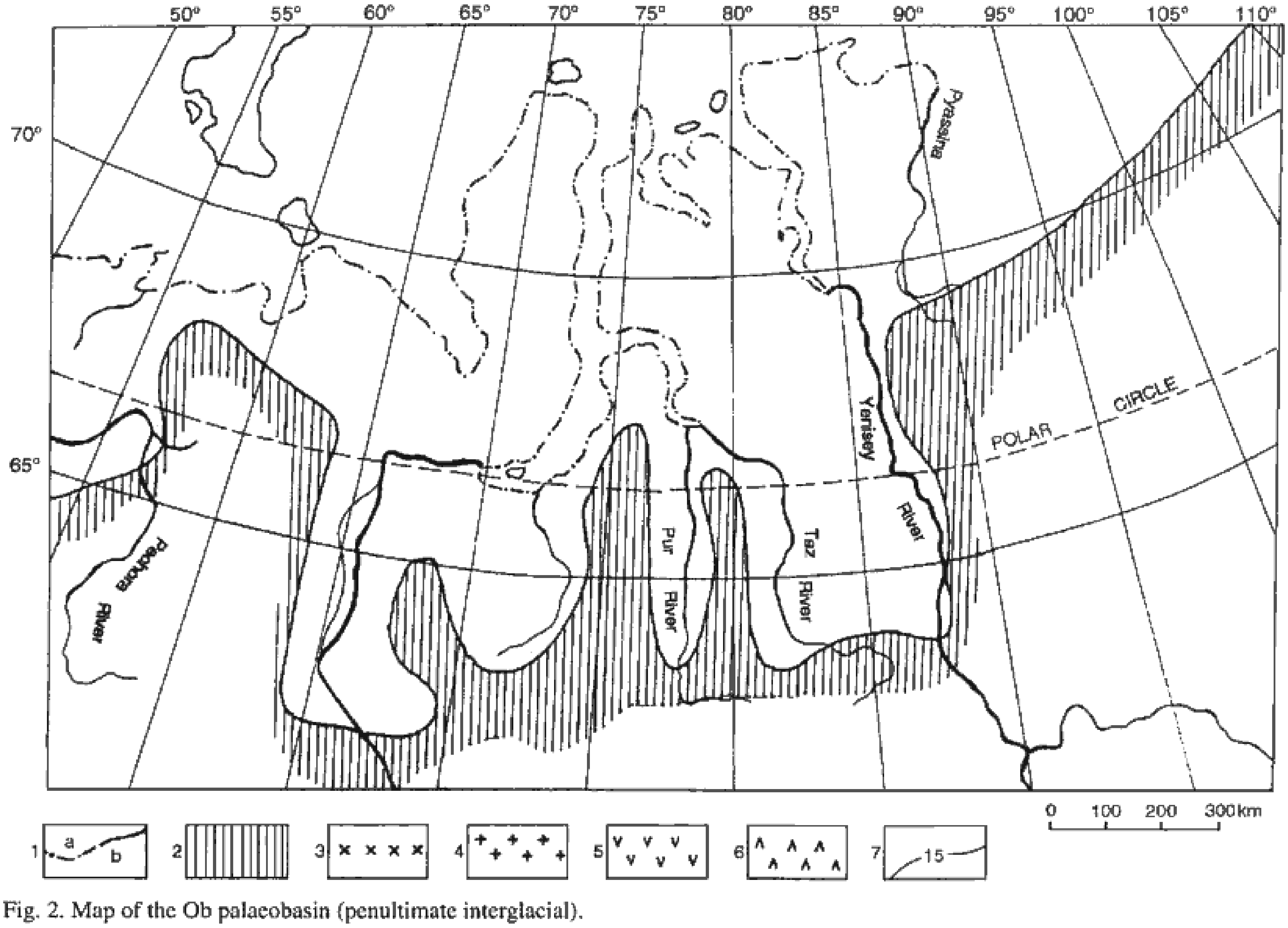

Fig. 2. Map of the Ob palaeobasin (penultimate interglacial).
1a – modern shoreline, 1b – palaeobasin shoreline; 2 – land area; 3 – nearly normal marine salinity; 4 – reduced salinity; 5 – low salinity; 6 – the lowest salinity value; 7 – isobathes.

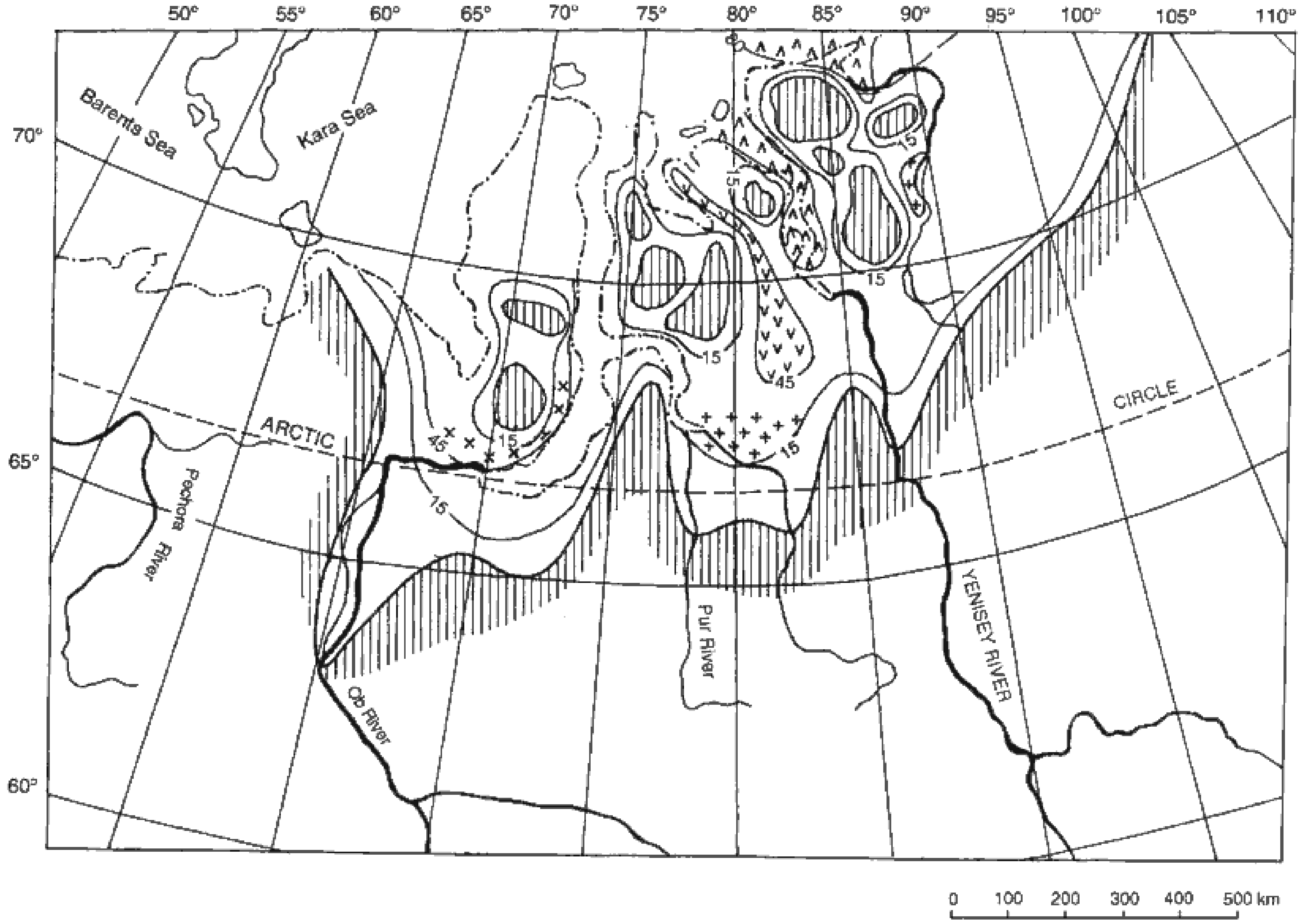

Fig. 3. Map of the Kazantsevo palaeobasin (last interglacial). For explanation see Fig. 2.

LATE PLEISTOCENE

Reconstruction of the two Late Pleistocene transgression basins-Kazantsevo (Fig. 3) and Karginsk (Fig. 4) can be done in more detail because of a larger number of studied sections.

Kazantsevo (Eemian) foraminiferal complex

This complex consists of 75 species and subspecies of foraminifers. Its quantity usually ranges from several tens to hundreds of (sub)species, and may have up 4000–5000 specimens per a standard 100 gramm sample. Warm-water (boreal and arcto-boreal) forms comprise up to 56 % of all species. Cold-water (boreal-arctic and arctic) taxa are much less frequent and comprise only 27 % of all foraminifers. The Kazantsevo complex overall can be characterized as dominantly boreal. *Retroelphidium atlanticum* (GUDINA), *R. boreale* (NUZHDINA), *R. propinquum* (GUDINA), *Cassandra helenae* FEYLING-HANSSEN et BUZAS, *Cassidulinna reniformis* (NORVANG), *Haynesina magna* LEVTCHUK, *H. orbicularis* (BRADY), *H. astertuberculata* (VOORTHUYSEN), *Cribroelphidium granatum* (GUDINA), *Bucella depressa* ANDERSEN and *B. troitzkyi* GUDINA are dominant. They are followed by *Retroelphidium propinquum* (GUDINA), *R. boreale* (NUZHDINA), *R. williamsoni* (HAYNES), *Hyanesia magna* LEVTCHUK and *Quinqueloculina oviformis* GUDINA. The remaining, sporadically-distributed species amount to only 1–2 %. Nevertheless, despite their small quantity, they contribute significantly to the complex diversity. They include species of the *Polymorphinidae*, *Glandulinidae* and *Nodosariidae* families, different millioides, discorbides, certain buliminides and some others. The total composition and structure of the Kazantsevo complex indicate formation of sediments in the sublitoral area of the basin with low-positive temperatures of the bottom waters approaching zero (LEVTCHUK 1984).

In terms of taxonomic diversity, the Kazantsevo complex is similar to the older Ob complex. However, significant differences in the foraminiferal assemblages exist between the two complexes.

In the Kazantsevo marine sediments of Siberia, a series of *Retroelphidium* is apparent: *R. boreale, R. hyalinum, R. propinquum, R. williamsoni* and also *Elphidiella arctica, Discorbis deplanatus, Quinqueloculina agglutinana, Q. oviformis, Q. deplanata* and *Pyrulina cylindroides*. On the other hand, *Retroelphidium subclavatum* and *R. obesum* are absent in the Kazantsevo beds, but are characteristic of the pre-Kazantsevo Middle

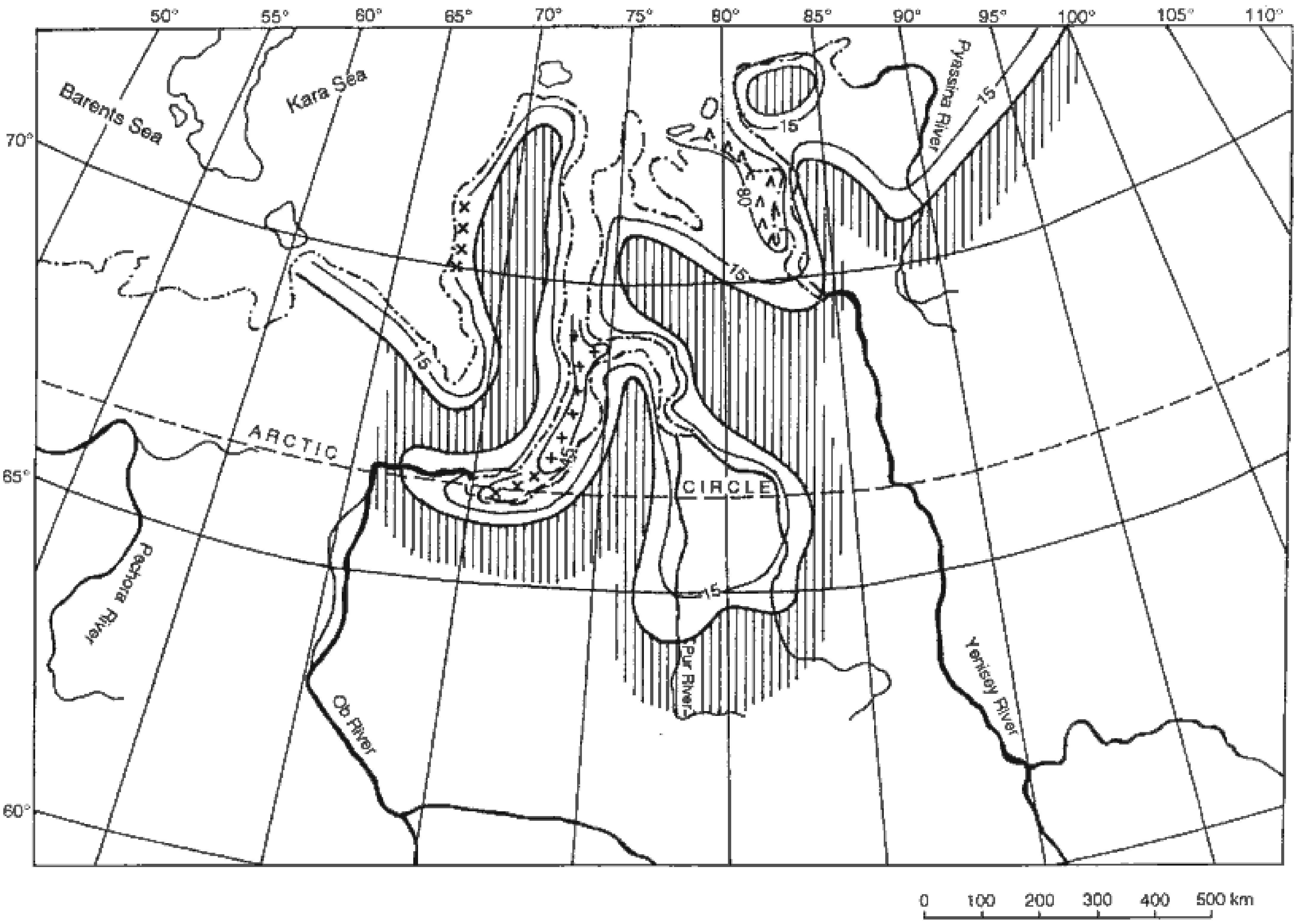

Fig. 4. Map of the Karginsk (mid-last glacial interstadial) palaeobasin. For explanation see Fig. 2.

Pleistocene sediments. In last interglacial sections in West and Central Siberia, they are replaced by *R. boreale, R. hyalinum* and *R. propinquum.* The specimens of particular species of the Kazantsevo complex are larger than equivalent species in the pre-Kazantsevo beds. Another distinctive feature of the Kazantsevo complex is the presence of a greater number of warm--water elements than in the Middle Pleistocene Ob complex. Boreal forms are also more numerous in the Kazantsevo complex.

The absence of *R. boreale* and *R. propinquum* is the most distinctive feature of the Kazantsevo complex compared to the Karginsk complex. *Cibicides rotundatus* and *Trifarina fluens*, which are only in an accessory group of the Kazantsevo complex, become distinctive components of the Karginsk interstadial complex. A warm-water association occurred for a relatively short period of time - the Malokhetsk interstadial (LEVTCHUK 1984).

The Karginsk (middle Weichselian) foraminiferal complex

This complex generally consists of 85 species and subspecies. Thermophilous forms are dominant in the number of species and prevail also in the quantity of specimens forming about 55 % of the complex. *Retroelphidium atlanticum* (GUDINA), *R. hyalinum* (BRODIEWICZ), *R.* ex gr. *boreale* (NUZHDINA), *Cibicides rotundatus* STSHEDRINA, *Cassidulina reniformis* (NORVANG), *Islandella helenae* FEYLING-HANSSEN et BUZAS, *I. inflata* (GUDINA), *Astrononion gallowayi* LOEBLICH et TAPPAN, *Cribroelphidium granatum* (GUDINA) and *C. subarcticum* (CUSHMAN) dominate. Accessory group consists of oolins, lagens, fissurines and discorbises. Peculiar species are *Cibicides rotundatus* STSHEDRINA, *Trifarina fluens* TODD, *Discorbis punctuatus, Guttulina lactea* (WALKER et JACOB), *Globulina inaequalis* REUSS, *Sigmomorphina undulosa* TERQUEM, *Fissurina danica* (MADSEN) and *Retroelphidium* ex gr. *boreale* (NUZHDINA). The accessory group consists of oolins, lagens, fissurines and discorbises.

PALAEOBASIN RECONSTRUCTION METHODS

Palaeooceanographic maps of the interglacial palaeobasins have been compiled on the basis of distinguished types of foraminiferal associations for the maximum evolution stage of these transgressions. Hydrological parameters (depth and salinity) have been obtained following the palaeoecological analyses of the foraminiferal complexes (GUDINA 1976, GUSSKOV 1986, GUSSKOV - LEVTCHUK 1988). Comparative palaeoecological analyses were made of fossil and modern foraminiferal complexes. It is known that different foraminiferal taxons have more or less the same adaptation degree, but they reach the maximum distribution only in comparatively short intervals of most favourable conditions (SAIDOVA 1961). Taking into account the relative abundance of certain taxa and their correlation, optimal conditions for each taxon and for the entire association can be established (GUDINA 1976). Similar data on modern foraminifers are well represented in literature (GUDINA 1964, SAIDOVA 1961, TROITSKAIA 1970, 1973, FURSENKO et al. 1979, FURSENKO - FURSENKO 1970, 1973). This allows rather exact estimates of hydrological parameters of ancient marine basins.

Three different facies, characterizing certain depths within the upper sublitoral zone, were distinguished during the analyses of the Kazantsevo and Karginsk foraminiferal complexes (LEVTCHUK 1984, GUSSKOV 1986). The richest foraminiferan distribution characterizes depths of 60–100 m, with 50 % of the abyssal species comprising dominant taxa and about 40 % accessory taxa. In the 30–60 m depth zone, the proportions of the abyssal species are reduced in both dominant (25 % of total composition) and accessory (25 % of total sum) groups. The most shallow litoral facies content are only characterized by abyssal species of the accessory group (25 % of total composition). These are common for a depth of 0–30 m.

The correlation between the euryhaline and stenohaline groups has been used to define the salinity degree of the palaeobasin basal waters. The most typical representatives of the euryhaline forms are elphidiides and nonionides, whereas cassidulinides and islandiellides are typical of the stenohaline forms. The salinity was close to modern arctic seas, i.e. 34–35 % is the datum mark. All the other salinity definitions, made upon the change of the percentage of euryhaline and stenohaline forms, are distinct from the datum mark. The following salinity gradation has been reconstructed for the Kazantsevo and Karginsk palaeobasins:

1 – nearly normal marine with the following percentage of stenohaline and euryhaline forms: 65 % elphidiides and nonionides, 35 % cassidulinides and islandiellides. All stenohaline forms compound the dominant group.
2 – reduced salinity – the stenohaline forms' component is reduced to 20 %, but almost all of them, with few exceptions, compound the dominant group.
3 – low salinity-cassidulinides and islandiellides with percentage reduced to 12 %, while half of them contributes to the composition of the accessory group.
4 – the minimum salinity value-stenohaline forms are absent or present in small quantities (up to 7 %) in the accessory group.

The palaeobasin coastline was reconstructed from bathymetric data and the data on distribution of marine molluscs (Antropogene 1982, TROITSKIY 1979).

Reconstructions of the Kazantsevo (Fig. 3) and Karginsk (Fig. 4) palaeobasins are summarised below.

The Kazantsevo palaeobasin

Maximum depths of 60–100 m in this basin were established in the northern part at the Pyassinskaia Depression. The salinity of marine waters was about normal. Depths of 30–60 m were estimated for the Chugunovsk Yary, the Yenisey Gulf, the central part of the Gydan Peninsula. In these parts of the basin with similar depths, the salinity was different, depending on the contact of the region with the sea. Access of sea was greater in the area of the Yenisey Gulf (the salinity was about the same as the normal marine). A reduced salinity was marked in the central part of the Gydan Peninsula, a low salinity in the region of the Chugunovsk Yary. The littoral shallow waters with a depth of 0–30 m were in the Yamal Peninsula and in the southern part of Gydan. The salinity of the local marine water was defined by the proximity of this region to the sea. The lowest salinity occurred in the southern and western part of the Yamal Peninsula. The palaeobasin areas with low salinity were detected in the southern part of Gydan Peninsula.

There are no values of temperature of the bottom waters of the Kazantsevo palaeobasin, as the change of the quantity of thermophilous taxons are negligible, and because of this it is impossible to establish temperature series similar to those of gradational salinity. A reduction of the particular species and the biotic variety from the west to the east is apparent; this is a distinctive feature of benthonic foraminifers from the Pleistocene palaeobasins of Northern Eurasia (GUDINA 1976, LEVTCHUK 1984).

Comparing the structures of the Kazantsevo foraminiferal complex and contemporal foraminiferal assemblages, it is possible to draw the conclusion that the bottom water temperatures of the Kazantsevo palaeobasin were higher than those of the present Kara and Laptev seas. The common temperature background for abyssal waters of the Kazantsevo palaeobasin is defined as low-positive, whereas the abyssal temperatures of the Kara and Laptev seas are mainly negative (ZENKEVITCH 1963, Encyclopedia of Oceanography 1974). The high thermal capacity of the Kazantsevo basin can be explained by a more effective warming. The presence of rather great quantities of boreal species (46 % of total amount) and one lousitan species (*Retroelphidium williamsoni*) indicate another important factor affecting the water temperature rise in the Kazantsevo basin, namely the intensification of the Atlantic water flow. The main part of the Atlantic water enters the Kara sea through the Jugorski Shar, Karskiye Vorota, and deep trenches between the Franz-Josef Land and North Land. Boreal forms, especially the the lousitan species, which migrate from the west to east following the warm Nordcap Stream, evidently penetrated into the the Kara sea through the southern streams, as the Atlantic waters coming from the north are already significantly cooled down and their features are similar to the Arctic water masses (Encyclopedia of Oceanography 1974). The same migration way of the boreal moluscan fauna was described by Troitskyi (1979). Thus, it may be supposed that positive temperatures of the bottom waters of the Kazantsevo basin were not as much because of the seasonal climatic warming, but mainly because of a constant inflow of the warm Atlantic stream and also because of the total absence of the ice-cover in the basin during the climatic optimum of the transgression.

The Karginsk palaeobasin

This palaeobasin was marked by 60–100 m depths in the Gulf of Yenisey with water salinities nearly normal. Areas of 30–60 m depth were localized in the southeastern part of the Yamal Peninsula, with reduced salinity. The least depths (0–30 m) with the lowest salinity were established in the northwest and in the south of the Yamal Peninsula.

DISCUSSION

It is known that the development of the northern Eurasian Quaternary basins is mainly controlled by the hydrological regime between the Atlantic and Arctic Oceans. The model of the hydroexchange reconstructed by Kellog (1976, 1977, 1980) has been confirmed by later explorations of the North Atlantic (Barash 1988, Barash et al. 1989, Duplessy et al. 1980, Duplessy - Shackleton 1985). Later studies have been devoted principally to two different circulation models – firstly, the circulation model for interglacials and secondly, the same model for glacials. The essence of the difference between these models is in the mechanism forming the arctic hydromass, the main component of the North Atlantic abyssal waters. The warm branch of the Gulf Stream (Norway Stream) penetrated into the Norway-Greenland basin during interglacials. Atlantic water submerges while cooling, and forms the oxygen-enriched Arctic abyssal mass, which in turn reverts to the North Atlantic. The interglacial circulation model conforms completely to the modern hydroexchange mechanism between the Atlantic and Arctic oceans. The abyssal Arctic and essentially Atlantic waters were formed not because of the subsidence of the oxygen-enriched surface waters, but because of the poorly saturated abyssal waters of the North Atlantic in the Norway-Greenland basin (Barash 1988).

Therefore, the water circulation scheme between Atlantic and Arctic oceans was opposite to the interglacial surface waters that were directed from the Norway-Greenland basin to the Northern Atlantic, and the bottom waters in the opposite direction. The existence of such different exchange mechanism controls not only the formation of the constantly different abyssal hydromasses (different salinity, temperatures, oxygen saturation etc.), but also it defines the degree of penetration of the arctic hydromasses into the arctic region. Penetration of the surface Atlantic waters into the Arctic ocean, including the shelf seas, was much greater during interglacials than at other times (Kellog 1976, 1977, 1980). These two factors, i.e. the type of the abyssal hydromass and the penetration degree of the Atlantic hydromasses into the Arctic, control the Atlantic fauna migration (Gudina 1976, Gudina - Evzerov 1973). It is especially distinct from analysing the zoogeographical dispersity of foraminiferal complexes in Pleistocene of the Eurasian sector of the Arctic. The total number of taxa and the systematical variety of coeval foraminiferal complexes decrease from west to east; the single specimen quantities of most species decrease as well. The warm-water species diminish in the same direction. New taxa (species, generas) first appear in the west, and later in the east. Monotype and polytype foraminiferan generas are constantly present, but the total quantity of both are greater in the western region. Taking into account that the North Atlantic stream dominantly affects the Arctic marine complexes during the Quaternary, as Pacific migrants do not pass further than the Chukchi Sea (Gladenkov 1978), the above factors not only promote the migration of the Atlantic fauna, but have a principal control on the formation of arctic fauna complexes in general.

Thus, the development of Quaternary marine transgression and the distribution of Atlantic fauna, particularly foraminifers throughout the Arctic, can be almost completely explained by interglacial circulation. The Karginsk (middle Weichselian) transgression slightly differs from this scheme. According to the published data, age analogies of the Karginsk deposits are known only in the northeastern part of the North Sea (Knudsen 1989, Sejrup et al. 1987) and in the southwestern part of the Norwegian Sea (Jansen et al. 1983). Miller et al. (1989) mentioned the absence of the wide glacial activity during this time without discussing the problem of distribution of marine deposits due to the lack of appropriate information. Barash (1989) suggests in his work on the Quaternary palaeoecology of the Atlantic ocean that, in the interstadial interval (about 30 ka ago) in the Biskai Gulf, "the bottom circulation was similar to that of glacial", i.e. the oxygen-enriched bottom waters did not penetrate into this region. However, the results on foraminifera distribution in the Karginsk deposits in the north of Siberia, completed by the authors (GUSSKOV 1986, GUSSKOV - LEVTCHUK 1988, 1995, LEVTCHUK 1984), testify against this. The Karginsk foraminiferal complex was rather rich and taxonomically diverse. It consists of 85 species and subspecies. The zoogeographical variety of the warm-water association is also interesting: 22 species are arcto-boreal, 14 species are boreal, 2 species are boreal-lousitan, and 3 species are lousitan. The lousitan species, *Trifarina angulosa*, is sometimes found in abundant quantities (LEVTCHUK 1984). Thus, according to its systematical composition, the Karginsk complex can be compared with the interglacial complexes, particularly with the Kazantsevo complex in some respects (GUSSKOV - LEVTCHUK 1995, LEVTCHUK 1984), although it differs because it was not warm-water during the entire time. Different-aged foraminiferal associations reflect climatic alterations during the transgression development. Different ages of these associations are confirmed by absolute dating methods with more than 100 radiocarbon dates (KIND 1974, sine 1982).

Cold-water foraminiferal associations characterized the initial stage of the transgression (the early Karginsk association) in which elphidiides, nonionides and cassidulinides prevail. Warm water forms are single. The taxonomical composition is mostly diverse in the Malokhetsk association, corresponding to the phase of maximum transgression (42–35 ka BP). The particular association contains multiple warm-water groups, including not only boreal and arcto-boreal forms typical of these regions, but also boreo-lousitan and lousitan forms whose areas are situated in the modern Arctic seas west of the Kola Peninsula in the Gulf Stream influence zone (DIGAS 1970). Foraminifers are not found in the Konoschelsk stadial deposits (ca. 32 ka old).

The youngest part of the Karginsk complex is contemporaneous with the Lipovsko-Novosiolovsk interstadial (30.7–24 ka BP). The species quantity decreases and cold water taxa dominate despite the significant quantity of warm-water forms.

Thus, according to available evidence, it becomes clear that the Atlantic-derived foraminifers form the basis of the Karginsk foraminiferan complex. As the migration of the Atlantic forms into the Arctic shelf of Eurasia is associated with the warm Northcap Stream (GUSSKOV - LEVTCHUK 1995), it is possible to assume that the Atlantic waters were present in the given region and that there was interglacial circulation between Atlantic and Arctic Oceans at certain stages of the Karginsk non-glacial interval, particularly the Malokhetsk and Lipovsko-Novosiolovsk interstadials.

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