THE QUATERNARY DEPOSITS OF THE BARENTS SEA AND VALDAI GLACIATION OF THE EURASIAN ARCTIC SHELF

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ABSTRACT

High-resolution seismic reflection data acquired in the Barents Sea during 1984-1990 and engineering drilling data allowed us to determine the genesis of Quaternary shelf deposits. Seismic, geologic, and geomorphologic data indicate that glaciers did not cover all of the Barents Sea during the Late Valday (Würme) glacial epoch. Our model of Eurasian Arctic shelf glaciation shows that during the Valday (Wisconsin) glaciation, glaciers in the western sector flowed about 100 km onto the shelf as extensions of several ice bodies located on adjacent land, islands, and shoals. In the eastern sector, however, the situation was different because there are practically no traces of sheet glaciation. The paucity of glacial deposits argues against the pan-Arctic model of the Valday glaciation in the Northern hemisphere.

INTRODUCTION

One of the most important questions about Late Pleistocene paleogeography is the dimension of the last Arctic glaciation (Dunaev et al., 1989). The answer to this question has both theoretical and practical meaning in projecting economic activity on the Arctic shelf including prospecting, geological engineering, bio-production, and navigation.

Four main concepts of glacial environment and extent of ice within the Arctic basin and shelf during late Pleistocene time are: (1) seasonal ice predominated, (2) old pack ice predominated, (3) a thick (to 3.5-km) glacier sheet on the shelf expanded landward, and (4) major ice spreading centers were located on land and partly on the shelf. The latter two hypotheses are the most popular in the scientific community. In Russian literature, Grossvald (1983, 1988, 1991) proposes that the Recent Kara Sea shelf was the main ice source for the pan-Arctic glacier sheet in the Late Quaternary. From that source, he proposes that ice flowed not only to northern Siberia, but after merging with the North American ice sheet, extended over Novaya Zemlya and Pai Hoi to Northern Europe. Ice carrying detrital material from the Kara Sea thus formed, in particular, Kolguev Island. According to this model, a floating glacier of about 1 km thick existed in the central Arctic.

Our data support the idea of a limited expansion of glacier ice on land and on the adjacent shelf based on high-resolution seismic reflection data and geological seafloor samples (Dunaev et al., 1989; Henrich et al., 1989; Pavlidis et al., 1990). Many Russian institutes, such as the P.P. Shirshov Institute of Oceanology of the Russian Academy of Sciences, "Sevmorgeologia," VSEGEI, "Soyuzmorinzhgeologia," MMBI RAN, and others, have collected a great amount of data on the bottom geomorphology and Quaternary geology of the Russian Arctic seas. The most valuable information was obtained by a multibeam echo-sounder, a high-resolution seismic-profiler, a "Parasound" system narrow-beam seismic reflection profiler, and geological engineering drilling (Fig. 1) (Pavlidis et al., 1990).

MORAINES AND GLACIOMARINE SEDIMENTS

The area of glacier sheet expansion is most clearly delineated by the position of the corresponding end moraine assemblages. Moraines reliably indicate the glacial environment and serve as a good marker of glacier boundaries by their accumulative forms. The characteristics of marine moraines were determined using a number of geomorphological, seismo-acoustic, and geological criteria. In seismic profiles, moraines are expressed as reflections that are incoherent, of variable amplitude, and chaotic, with diffractions that reflect the great inhomogeneity of moraine materials (Fig.2). Moraine bodies have a characteristic morphology. They unconformably overlie stratified sediments and are characterized by local variations in thickness. Geologic samples usually consist of dense (2.0-2.4 g/cm^3) loam with inclusions of coarse clastic debris.

However, recognition of these morphostructures is by no means simple. Similar positive bathymetric features, formed by different heterogenous processes,

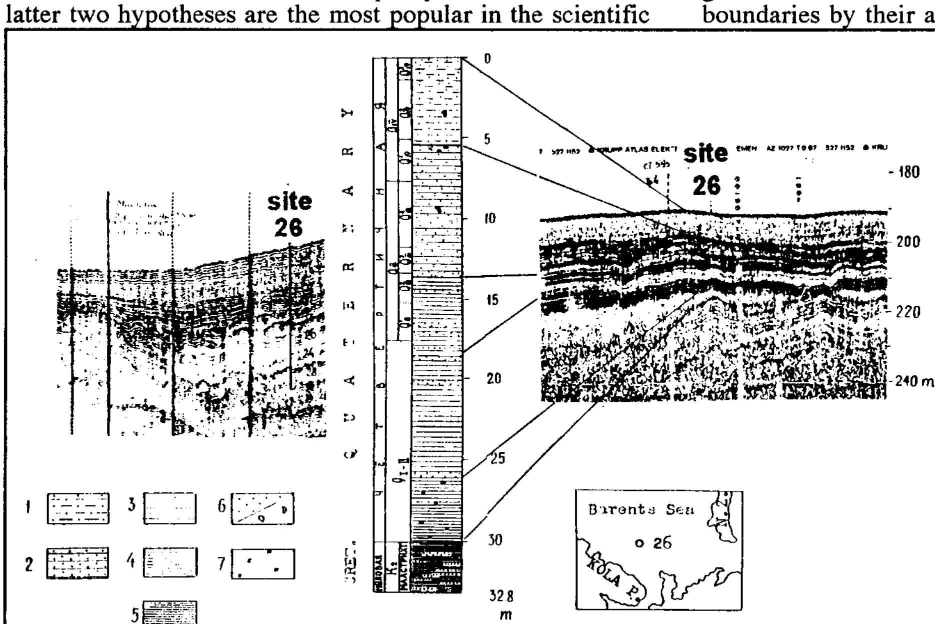

Fig. 1. High-resolution seismic reflection sections (left: multi-electrode sparker system, right: 3 kHz PARASOUND profiler) of glaciomarine sediments at the foot of Kanin Bank, Barents Sea, and lithology of the drill site 26 (center): 1-clayey-sandy silt; 2-sandy-silty clay, plastic; 3-silty clay, tightly plastic; 4-silty clay, compact; 5-argillaceous clay; 6 - sand/fossil shells; 7 - gravel debris.

such as permafrost, neotectonic, and sliding, have been identified as being related to moraines (Dunaev, 1987). Therefore, it is possible that some moraines may be misidentified.

Glaciomarine deposits are usually of low density (less than 1.9 g/cm^3) and are characterized by less contrasting thickness changes compared to moraines and by well-stratified intervals in otherwise generally acoustically transparent records (Fig.3). Morphologically, this type of deposit is less rugged and, like moraines, may create or accentuate positive forms (Fig.3c). The dimensions and features of glaciomarine deposits are determined by their position with respect to the discharge area of the glacial material, by their mechanical composition, and by the local dynamics of hydrology and climate.

End moraines of the last glaciation are distinct and easily mapped on the Barents shelf along the western slope of the Admiralteiskiy Rise (Fig.4). An almost continuous chain of end moraines extends west of Novaya Zemlya for more than 500 km. The end-moraine complex delineates the maximum expansion of the Scandinavian glacier sheet onto the Barents shelf. Tongues from this sheet sloped down the Kola Peninsula into the sea to a depth of about 150-170 m and extended for several tens of kilometers farther as shelf ice tongues that did not exceed 170-200 m in thickness (Dunaev et al., 1989). Apparent glaciofluvial deposits lie on the eroded top of horizontal layered late Pleistocene-Holocene marine sediments in front of the moraine ridge (Fig.5).

Two main moraine types were detected on the Barents shelf; they are termed "dark gray" and "red-brown" according to their lithological composition. "Dark gray" moraines are identified over almost all of the Barents Sea and are usually composed of clay-loam deposits with a various admixture of coarse detrital material. "Red-brown" moraines are detected only north of Novaya Zemlya from Russkaya Gavan' Bay to Cape Zhelanie at depths of 175 m and a distance of 100 km offshore. Its red-brown, sometimes yellowish-brown, color is probably due to oxidized iron from Permian sandstone. According to its granulometric composition, the red-brown moraine is related to typically clayey deposits and contains a comparatively small amount of coarse detrital material.

Pre-Holocene clayey deposits (d=1.8-1.9 g/cm^3) occur in water deeper than 150 m and generally below 240 m. The distribution of these deposits, their composition, pattern of bedding, and absence or extreme scarcity of Arctic microfauna allow us to conclude that they are subaqueous in origin but formed in a subglacial environment. These deposits are abundant in the Medvezhinskiy Trough area of the Central Barents Sea, where Scandinavian scientists (e.g., Elverhøi, 1984) believe the environment was similar to the present shelf under the ice of the Weddell Sea in Antarctica.

In the Central Barents Sea basin, two major types of pre-Holocene deposits were studied. The first consists of extremely fine-grained sediments (predominantly micron size). The second type is more coarse-grained with considerable admixture of mainly silt-size particles. Deposits of the first type are composed of dense dark-gray clay that is 95-99 percent pelite, of which 60-67 percent of the particles are less than 1 micron in size. They usually underlie 2-2.5 m of Holocene ooze. The extremely fine sediment size in these deposits is probably a result of settling of suspended particles in a subglacial low-energy hydrodynamic environment similar to that presently observed in most polar seas of the eastern Arctic (Aksenov et al., 1987). Glaciomarine deposits in some basins north of Novaya Zemlya are found at sub-seafloor depths of 390 m and consist of dense dark-gray clay approximately of

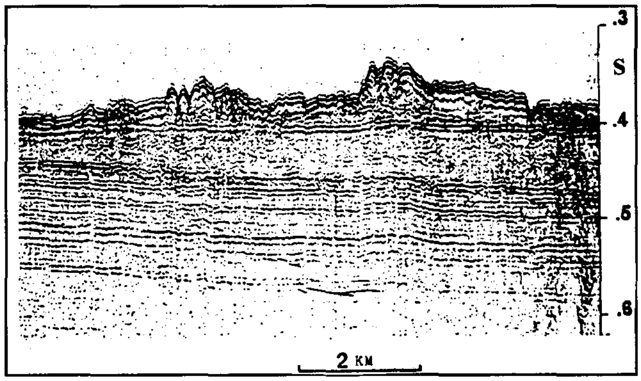

Fig.2. The typical moraine on the single-channel seismic (airgun 0.31) reflection record, South Barents Basin.

the same granulometric composition. These deposits underlie a 1.5 m-thick layer of silt ooze composed of 97-percent pelite particles with a 52-percent micron size fraction.

The second type of the pre-Holocene deposit is characterized by an abundance of coarse angular detritus that exhibit an increase in the sand-silt size fractions resulting in a double- or triple-peak in the grain-size distribution curve.

Thick marine deposits have been observed in South Novaya Zemlya Trough (Fig.6). We believe they accumulated during the Pleistocene without considerable hiatuses. High-resolution seismic reflection profiles from Novaya Zemlya bays prove that traces of glacial deposition and erosion exist only north of the archipelago (Nordenschield, Russkaya Gavan' bays, etc.) and do not support the proposed junction of the Novaya Zemlya and Northern Urals glacial sheets. South of the archipelago, but still within the northern island (e.g., Mashigin Bay), the simply stratified sediments are almost acoustically transparent without large intraformational hiatuses or inclusions typical of glacial complexes (Figs.7 and 8).

SEA-LEVEL CHANGE

The amplitude of synchronous marine regressions should be considered for a better understanding of the paleogeographic situation. During the last glaciation, the sea level in the Barents Sea basin, as well as of the World Ocean, was recorded at a depth about 90-100 m below present sea level. This is supported by the reconstruction of ancient coastlines from bottom-feature topography and the structure of young sediments. In the region of the western slope of the Gusinaya Bank, a transgressive sedimentary series was encountered in wells at a depth of 60 m near the edge of a sea terrace, indicating that the area was an island during the last glacial maximum. Forty centimeters of Holocene marine ooze overlie the rear slope of the 2-m-high sandy coastal swell, which in turn overlaps lagoon ooze of the Flandrian transgression.

The subsided marine terrace is located on the north-western slope of the Gusinaya Bank at a water depth of 98 m. A typical lagoon ooze facies was excavated near the edge of the bank, below the sand layer, at a depth of 30 cm. It may have formed under the protection of the outer bar, the remains of which were preserved as a gentle 2-m swell at the outer edge of the terrace. A similar terrace on the northern slope of South Novaya Zemlya Trough in the Pechora Sea has traces of its edge and rear suture in 100 m and 90 m water depths, respectively. Olive lagoon ooze with pronounced fine laminae (possible seasonal varves) lies beneath an 88-cm-thick layer of homogeneous Holocene marine ooze.

Bathymetric data from the southern Barents shelf show that bottom morphology becomes considerably more rugged below 90 m, except in large basins like the South Barents Sea Basin with preexisting plains. The variable bottom topography of the shelf was formed under a similar geological environment; its less rugged character at shallower depths may be due to the smoothing effect of erosional and depositional processes of the latest post-glacial transgression. The effect of regional tectonic subsidence, which may be about 0.05 mm/yr for platforms of the Northern Eurasia shelf, is essentially compensated by sedimentation. The minimum subsea depth of occurrence for glaciomarine deposits approaches -125 m, indicating that sealevel was lower than 100 m. To provide the environment necessary for the accumulation of these facies, sea depth would have to have been sufficient to allow the floating of large ice blocks that supply the detrital material.

Regression intensity has been verified by the results of our research in different areas of the Barents and Kara sea shelves. On the western sea slope of Novaya Zemlya, terrace plains are observed at depths of -20, -46, -60, -80, and -90 m. At similar depths, terrace plains were observed on the marine extension of Yamal Peninsula structures (-20, -30, -40, and -60 m) and within the marine structure of the Western Kara Rise (-25, -32, -46, and -90 m). It should be noted that the higher the position of the terrace (e.g., the younger it is), the narrower it is. This phenomenon may be evidence for shorter periods of marine transgression that slowed down or stabilized as they developed. Local tectonic patterns and variable wave-energy regimes seem to explain small deviations from the level of -100 m in the minimum depth of ancient coastlines of the Valday glaciation maximum. The level of -60 m occurs most widely and evidently reflects the start of the slowing down of the Flandrian transgression. This level seems to be a geomorphological expression of the boundary between the glacial and the following interglacial epoch. These data, and data published in the literature, allowed us to construct a schematic regional model (Fig.9) that illustrates sea-level changes during the Anthropogene.

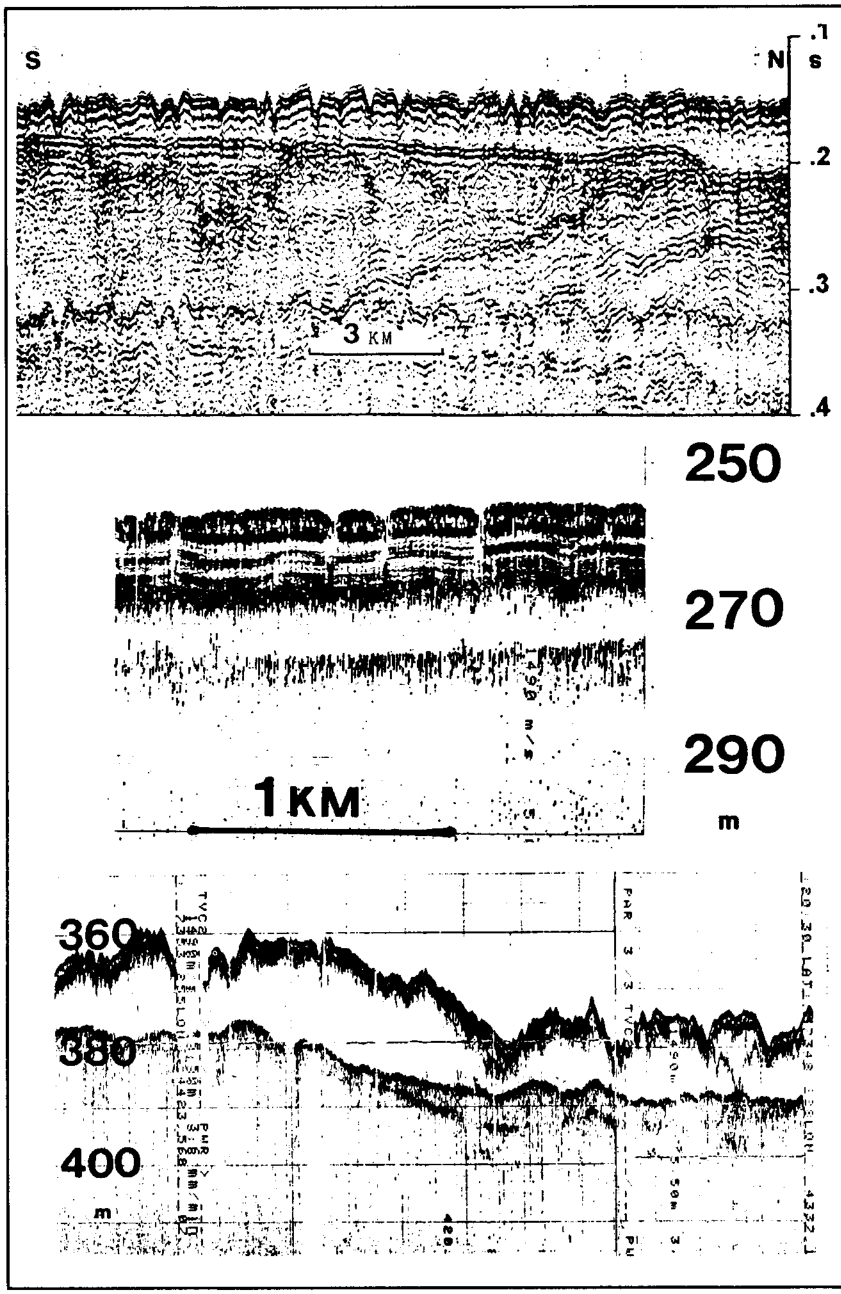

Fig.3. Glaciomarine sediments: a) seismic reflection (airgun) record on Murmansk Rise; b) PARASOUND (4 kHz) record in the Nordkap Trough; c) PARASOUND (3 kHz) record in the South Barents Basin.

PALEOGEOGRAPHY

Analysis of data from the Barents and Kara shelves and adjacent areas indicate that during Valday time, the glaciation of the western Arctic sector started from several ice spreading centers located on adjacent land, islands, and parts of the present shallow shelf. The problem of determining the dimensions of ice masses and the distance they extended from the corresponding domes and shields requires additional investigation. However, we can say that the lateral expansion of ice flows onto the shelf did not exceed 100 km, even from the largest ice-spreading-centers, and was probably only about several tens of kilometers.

This conclusion is most clearly illustrated by interpreted seismic reflection profiles from the region of the greatest glaciation, the Scandinavian region (Figs.5 and 10). The profiles show that glacial and glaciomarine deposits are distributed in distinct areas. The bases of end moraines that extend the farthest from the coast (80-90 km) rest at depths of 220 and 240 m, and their thickness locally exceeds 100 m. Well-preserved morphology, sediment-density data, and the presence of only a thin (tens of centimeters), or nonexistent discrete Holo cene cover, allow us to date the moraine to Valday time (Wisconsin).

Some shelf depressions, remote to glacial centers, contain loose, comparatively thin deposits (less than 100 m) that are absent from the surrounding slopes. The origin of these depressions and the deposits they contain may be explained not only within the concept of shelf ice shields, but also from a paleogeographic and paleotectonic standpoint as well. It is possible that icebergs frozen in mobile pack ice dropped their sediment load in the deeper water forming these deposits in the depressions and not on the slopes or the shelf.

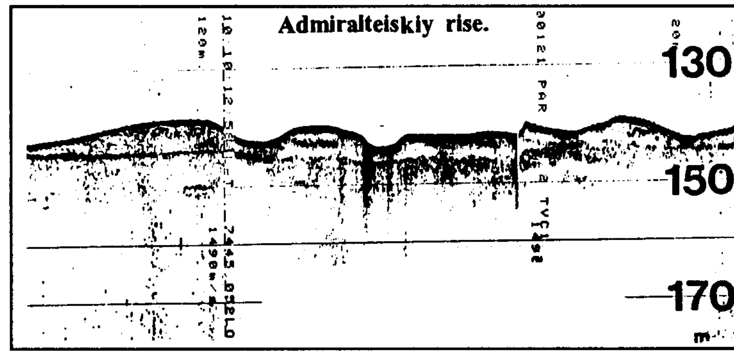

Fig.4. Frontal moraines along the western slope of the Admiralteiskiy Rise (PARASOUND record, 3 kHz).

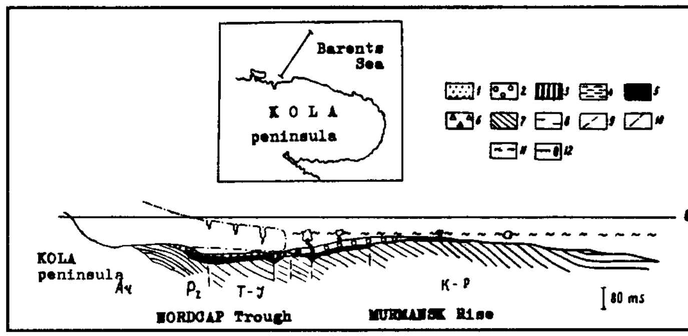

Fig.5. Paleogeographic interpretation of seismic reflection profile from Kola Bay to South Barents Basin: 1-moraines (Q); 2-glacio-marine deposits; 3-subaqual facies (Q-Q); 4-river facies (N); 5-older subaqual facies; 6-older weathered rocks; 7-Meso-Cenozoic sediment rocks; 8-granitoids; 9-faults; 10-proposed contours of Valday glacier sheet; 11-sea level in Valday time (Q); 12-present sea level.

The spreading center for the Novaya Zemlya glacier sheet was located on the northern island, from where it flowed onto the Litke Plateau, Ludlove Rise, and Admiralteiskiy Rise (where a secondary ice-spreading center may have existed). The Novaya Zemlya glacier sheet flowed toward the Kara Sea mainly as shelf ice over the deep Eastern Novaya Zemlya Trough leaving traces, such as moraines, at its edges. No other traces of glaciation have been detected over the shelf of the western Kara Sea.

Seismic reflection profiling by the authors in the St. Anna and East Novaya Zemlya troughs shows that their bathymetry and structure resulted from tectonics and under-ice sedimentation (Dunaev et al., 1989). This conclusion disputes the idea that the Kara glacier plugged a giant east-west pit in the East Novaya Zemlya Trough and flowed into the ocean along the St. Anna trough, forming a glacier sheet in the Eastern Siberian and Laptev seas that was larger than the Greenland sheet (Grossvald, 1988). Support offered for this hypothesis is the existence of the arch-like swells south of the Novosibirskie Islands, which have been claimed to be shoved moraine (Grossvald, 1988), without any data on their inner structure.

However, these morphostructures' definite repeating pattern (e.g., every 10 km near Bunge Island), their confinement to certain depths that correspond to respective stages of quasi-stable sea levels, composition of their deposits, their individual dimensions and shape, and the precise position of each feature in the general pattern of structures, is evidence for their sea wave genesis or, possibly, the marine reworking of ancient glacial sediments deposited by local glaciers from the islands.

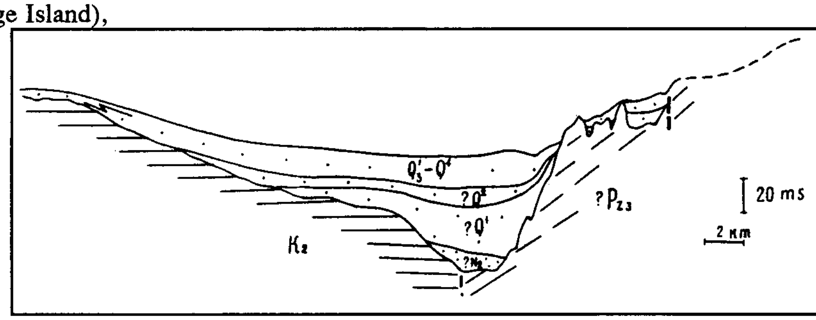

Fig.6. Seismogeological section of South Novaya Zemlya Trough.

Analysis of lithological and morphofaunistic data and radiocarbon dating in the Laptev Sea by Holmes and Creager (1974) indicate that at the end of the last glaciation, a great part of the Laptev Sea was alluvial plain composed of deposits derived from land by the Lena, Yana, Anabara, Khatangi, and other rivers.

Finally, we shall consider the situation that existed at the end of the last glaciation in the eastern parts of the Eurasian Arctic Shelf. Here, in contrast to the western parts, no traces of shelf ice have been detected, except near the mouths of fjords in southeastern Chukotka. A distinct continental climate with predominately arid conditions, especially in winter, was favorable for the formation of permafrost ground layers and ground ice but formed no conditions for the generation of large terrestrial glaciers. The absence of these glaciers is supported by the research of Makeev et al. (1989), Tomirdiaro (1987), and others.

In the Chukotka Peninsula proper, our data and investigations by Ivanov (1986) indicate the glaciation of Chukotka during the considered epoch was of the mounta-in-valley type and the glacier tongues did not go beyond the limits of fjords.

The paleo-coastline along the margin of the Bering Sea shelf is located at a depth of approximately -100 m based upon drilling, geomorphology, and micropaleontology data, as well as from absolute geochronology (Hopkins, 1967, 1973). During the Sartan Glaciation, most of the Bering Shelf was an alluvial plain with abundant river valleys. The Bering gulf region was a denudated area. To the north, in the Chukchi Sea, Holocene marine ooze is underlain mainly by cryogenic deposits including lacustrine, alluvial, and loess that is composed predominantly of silt. Loess and cryogenic deposits also underlie Holocene deposits of the Eastern Siberia Sea

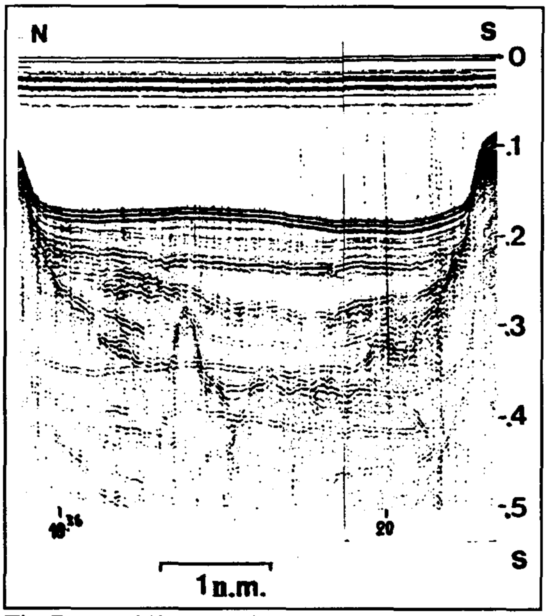

Fig.7. Meridional seismic reflection (airgun, 0.31) section of Mashigin Bay, Novaya Zemlya.

and are analogous to the Edomnoy facies of the coastal plain of Northern Yakutia.

While discussing the scale of the last glaciation in the Arctic, we cannot avoid the description of the Arctic Basin itself during the cold period of the Late Pleistocene. Rejecting the proposed occurrence of ice dome in the Arctic Basin, our data support the hypothesis that thick pack ice not only covered the entire basin but existed in the "corridor" of the Northern Atlantic far southward, almost reaching 60° N. lat. According to Kellogge (1980), accumulation of terrigenous clayey "mute" sediments in the Norwegian Sea occurred during the last glacial maximum under the cover of old pack ice.

Based upon our data and paleogeographic reconstructions for deep basins of the Barents Sea and Medvezhinskiy Trough by Matishov (1984) and Pawell (1984), clayey sediments accumulated subglacially in the area that Grossvald (1988) maintains contained the main path of ice and erosion from the glacier dome in the Kara Sea over the Novaya Zemlya and the Barents shelf.

Special conditions existed during the cold period of the late Pleistocene at the edge of the subareally exposed shelf within the Eastern Arctic seas. Under regressive conditions, thick shore ice formed along the coast of the frozen ocean and bordered the marginal part of the Arctic loess-cryogenic plain. No evidence exists for a paleocoastline in the Chukchi and Eastern Siberia seas below -50 m. Therefore, late Pleistocene glaciers in the Arctic Basin were not continuous along the entire shelf, especially in the western part (Fig.10).

The above observations, especially comparison of sea-terrace levels with nonglacial regions, make it possible,to critically reconsider the existing concept of thick glacial masses and their isostatic effect during the late Pleistocene-Holocene in the Arctic. Moreover, the response of the crust to such loading has not yet been sufficiently determined (Levkov, 1980; Morner, 1981; Verbitsky et al., 1986). The thickness of the proposed glacier shield should be reestimated. The wordwide Quaternary sea-level low stand seemed to occur simultaneously with volume changes of the oceanic basins due to regional tectonic processes. The formation of the Arctic Ocean Basin has been going on since the Paleogene and

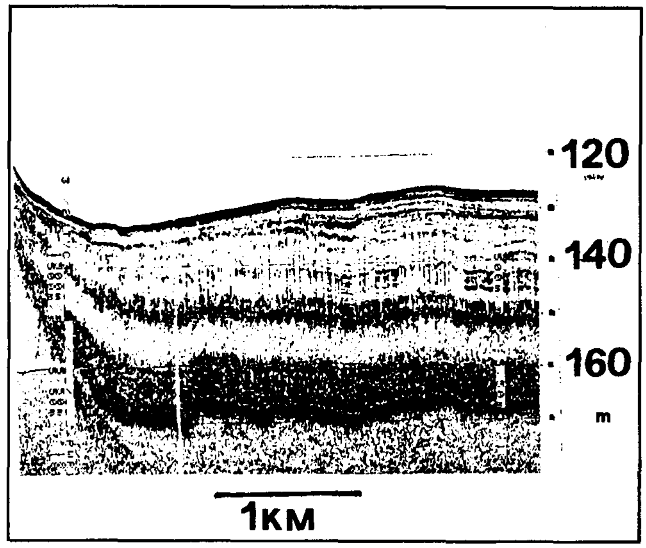

Fig.8. Fine structure of glaciomarine sediments in Mashigin Bay (PARASOUND record, 3 kHz, latitudinal profile).

has affected the isostatic conditions of the adjacent shelf and shore resulting in differential uplift, especially along basin marginal zones.

WHY NOT PAN-ARCTIC GLACIATION?

Avoiding the examination of the facts from the standpoint of the pan-Arctic glaciation concept, we shall just note that this concept does not agree with:

- the actual data on ecology of high endemic fauna (Nesis, 1983).
- occurrence of botanical refugiums at the Novaya Zemlya and other shelf islands.
- the discovery of mammoth remains on Oktyabr'skaya Revolyutsiya Island dated at 11-25 Ka.
- preservation of endemic lemmings within the Scandinavian region.
- alpine flora and fauna of lakes and, especially, of the Baltic Basin.
- continuous section of peat soil at Taimyr Lake dated at 11.6-34.5 Ka.
- knowledge of Dryas flora migration in the Arctic (Kozhevnikov, 1990).
- the spatial distribution of late Pleistocene overconsolidated sediments.
- contour lines of the hypothetical pan-Arctic glacier shield.
- palynological reconstructions at Novaya Zemlya (Malyasova, 1990).
- mapping of a continuous section of marine sediments dated at 10-38 Ka in the fjords of Spitzbergen (Grigoriev and Musatov, 1982).
- the comparison of scales of glaciation with the Canadian Arctic (Velichko et al., 1988; Evans, 1990).
- absence of the glacial morpholithogenesis elements in the regions of the supposed occurrence of thick glacier sheet, e.g., on the Yamal and Gydan peninsula (Makeev et al., 1989).

A 250-m-thick Pliocene-Quaternary marine section contains Late Quaternary marine sediments (Musatov and Musatov, 1992) in a geological section along the Yuribei River valley 70 km away from its mouth, based upon a salinity of 1.5 percent. This example illustrates the disagreement in the comparison of the sea-level marks and,

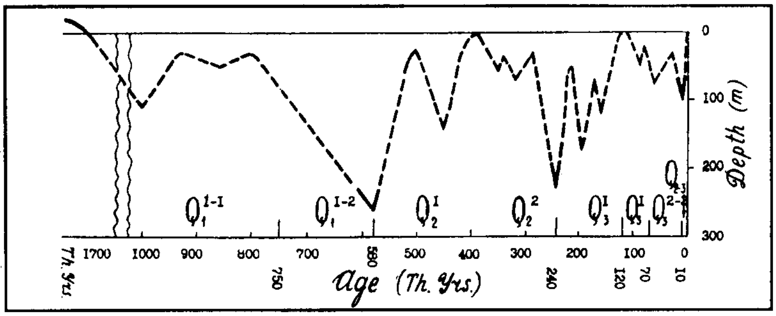

Fig.9. Late Cenozoic sea-level change in the Barents Sea.

more importantly, underwater synchronous sea terraces of the glacial and nonglacial regions.

Defenders of the pan-Arctic concept seem to be confused at times by mistranslation of foreign literature. For instance, when the latest papers discuss the continuous Late Würm Ice Age of the Barents shelf, we should understand the evolution of the continuous ice field, not from the glaciers lying on the present sea bottom, but from the congelation or hydropagetal ice that is verified by Hald et al. (1990). They showed that Holocene sediments in the southwestern part of the Barents Sea overlie glaciomarine deposits dated at 15-27 Ka, which formed in a Polar shelf environment but not in a region occupied by an ancient glacier for many thousands of years.

The term "glacial shelf" should be rejected because the glacial factor was not the prime one acting in the formation of these shelves. Similar to the onshore environment, it is logically correct to distinguish regions affected by this or that type of glacial regime, or to speak about the shelves of glacial regions.

Fig.10. Barents Sea paleogeography at the glacial maximum (18,000 Yr.): 1-glacier sheet frontiers, known; 2-same, assumed; 3-shelf glacier frontiers; 4-pack ice cover; 5- the same, one-year ice; 6-shoreline for 18,000 Yr.; 7-Arctic tundra; 8-paleorivers; 9-glacial frontier.

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