Kara Sea Expedition Yields Insight into LGM Ice Sheet Extent

Extensive efforts have been made in recent years to improve the knowledge of Pleistocene glaciations in the Arctic and related climatic changes. Special interest is focused on the Last Glacial Maximum (LGM) in northern Eurasia – an issue of a long-standing debate involving a discrepancy between minimal and maximal reconstructions of at least double the size of the modern Greenland ice sheet. Critical evidence lies on the continental shelf of the Barents and Kara seas that contained much of the grounded ice in northern Eurasia and was itself a significant center for ice growth. Ice sheets on the Barents-Kara shelf dramatically diminished the exchange of water and air masses between the Arctic and North Atlantic and dammed the discharge of Eastern European and, possibly, Siberian rivers into the Arctic Ocean.

Despite much progress achieved recently in delineating the LGM limits in northern Eurasia (e.g., Svendsen et al., 1999), there are significant unanswered questions associated with the distribution of ice masses and their effect on sea level, atmospheric circulation, and the hydrological system. One of the key questions is: What was the fate of Siberian rivers – were they blocked by grounded ice and prevented from discharging into the Arctic Ocean during the LGM, as is inferred for earlier glaciations (Mangerud et al., 2001), or was their flow unhindered? This question is important for understanding the Arctic hydrological change, in which the Siberian rivers play a prominent role. Climate modeling suggests that even a small variation in their budget can affect climate through changing sea-ice coverage and freshwater discharge into the North Atlantic (Rahmstorf and Ganopolsky, 1999). Meanwhile, hydrologic modeling shows a potentially dramatic difference in river network configuration and pooling of water in proglacial lakes, depending on the eastern extent of the Barents-Kara Ice Sheet (Lammers et al., 2000). The most reliable way to address this problem is to investigate whether ice sheets expanded across the northern Kara Sea and thus impinged on the West-Siberian drainage that provides almost half of the total Arctic runoff today (Figure 1). However, this approach has been practically unattainable because of heavy ice conditions and logistical constraints that severely limit the accessibility of the northern Kara Sea.
A data-collection breakthrough was attained in 2001. The expedition onboard r/v *Gidrolog*, organized by the Research Institute Okeangeologia (St.Petersburg, Russia) in collaboration with the Moscow State University and the Byrd Polar Research Center (Ohio State University, USA) performed extensive seismic, subbottom sonar, and sidescan sonar profiling, as well as sediment coring in the northern Kara Sea (Figure 1). Numerous sediment cores accompanied by continuous echosounder profiling were also collected by a neighbour Russian-German expedition in the central Kara Sea on r/v *Boris Petrov* (Stein and Stepanets, 2002). The use of a sparker (electrical-source) seismic system, combining a sediment penetration of 100+ m with a resolution of better than 5 m, is especially important for mapping glacigenic sediments that have a high acoustic impedance and are thus impenetrable for higher-resolution acoustic profilers. The dual application of continuous sparker and subbottom-sonar profiling provided a comprehensive characterization of Quaternary strata along the *Gidrolog* study track, comprising ~4,000 km. Sidescan sonar was used at selected sites to investigate sea-floor bedforms that may be related to glacigenic processes. A preliminary investigation of the new data allowed us to elucidate major seismo-stratigraphic features of the Quaternary deposits and, thus, to outline the LGM ice-sheet limits and patterns of riverine drainage in the northern Kara Sea. A rigorous age control is now needed to verify and detail this new stratigraphy.

**New results and preliminary interpretation**

Bedrock (pre-Quaternary) strata appear to be widely truncated throughout the study area, similar to the glacially-eroded Upper Regional Unconformity of the Barents Sea. Glacigenic diamictons are widespread atop the truncation, especially in the northern part of the study area. Diamictons are mostly readily identified by their irregular geometry, sharp erosional bottom and rough top surface, lack of coherent internal reflectors, and high impedance. We recognize several generations of diamicton that were likely formed during at least two major glaciations. The oldest diamicton discontinuously occurs at the bottom of the Quaternary sequence throughout the study area. A better preserved diamicton, up to 100 m thick, that appears to be stratigraphically younger is limited to the northern sectors (Figure 2A). In the deep St. Anna and Voronin troughs, which open northwards to the Arctic Ocean, both the diamicton and bedrock are often shaped into large-scale drumlin-like bodies, longitudinally oriented. A similar orientation characterizes smaller-scale lineations mapped by sidescan sonar in the St. Anna Trough (Figure 1; Polyak et
al., 1997). We infer that these bedforms, both buried and exposed, were largely formed by erosional and/or molding action of ice and can be thus used for reconstructing the patterns of ice-sheet flow.

In shallow areas further south, the Quaternary sequence is largely represented by a seismo-stratigraphic unit with a complex reflection pattern including common discontinuous, hummocky reflectors and prograding structures (Figure 2B). This unit, of up to 100 m thick, is interpreted to be formed by propagation of nearshore/prodeltaic facies during the sea-level fall. Numerous distortions of seismic reflection may be attributed to the action of permafrost on the emergent seafloor. An erosional surface is widely recognized on top of the regressional unit and can be traced in adjacent basin-fill deposits as a strong reflector (Figures 2C-D). This surface, obviously related to the last minimal sea-level stand, is an important regional stratigraphic marker which can be correlated as far as the Pechora Sea in the southwest and the Laptev Sea in the east (Gataullin et al., 2001; Kleiber et al., 2001). Glacigenic diamictons or bedforms characteristic of glacial erosion are not found on top of the regressional unit, which indicates that these areas were not overridden by grounded ice during the LGM.

A prominent feature associated with the regressional unit is a presence of multiple channels, up to 50 m deep and 5 km wide, both filled and unfilled with sediment (Figure 2B). The latter are clearly reflected in seafloor topography and have been recognized for a long time. We also note at least two generations of filled channels with the youngest generation grading laterally into deposits that overlie the regressional unconformity. The oblique reflection of channel fills, together with a meandering shape identified for some channels, indicate that they were formed by rivers during their extension on the continental shelf. Areas adjacent to channel mouths contain accumulations of laminated deposits up to 100-m thick (Figure 2C). These prodeltaic depositional basins merge into a large basin-fill unit south of the Voronin Trough and expand northwards over the margin of the young diamicton (Figure 2A). Further north, this sedimentary unit thins out to negligible thicknesses.

Because direct age determination for glacial diamictons is unattainable, the stratigraphy of overlying sediments and its relationship with deposits from non-glaciated areas is critical for establishing the timing of glacial events. Post-glacial sediments in the north (e.g., Figure 2A) bear no evidence for sea-level fall, therefore we infer that they are correlative to deposits above the LGM regressional surface further south. This interpretation is consistent with the stratigraphy
of sediment cores from the St.Anna and Voronin Troughs implying that diamictons in these areas were emplaced during the LGM (Polyak et al., 1997, 2002). The resultant proposed LGM margin would likely connect to the youngest ice limit mapped on the Taymyr Peninsula (Fig. 1; Alexandersson et al., 2001), thus completely blocking the West-Siberian rivers in the Kara Sea. We suggest that filled channels and correlative deposits above the regresional unconformity south of the proposed ice margin were related to the damming of rivers. The unfilled channels could be then formed by an instantaneous drainage of proglacial basin(s) due to ice break-up at a still relatively low sea level, with a subsequent rapid inundation of the shelf. However, if sediments overlying the diamicton in the Voronin Trough area prove to be older than the LGM, that will indicate a northerly outlet for water from prodeltaic basins. A detailed correlation and mapping of key stratigraphic boundaries is needed to definitively determine the LGM relationships between ice sheets, riverine network, and proglacial basins (lakes). Although the incomplete nature of the stratigraphic record in shallow areas may prevent us from mapping the lake levels comprehensively, we should be able to evaluate at least their minimal configuration - an important boundary condition for paleohydrologic modeling.

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References


Figure Captions

Figure 1. Study area showing the Gidrolog-2001 data location and tentative reconstruction of LGM ice-sheet margin. Also shown are prior data (Polyak et al., 1997, 2002, and unpublished). LGM ice-limit data on Taimyr are from Alexandersson et al., 2001. Bathymetry is from navigational charts on scales 1:200,000 to 1:500,000, detailed using seismic-reflection data. Also shown is location of Figures 2A-D (boxed). Insert shows circum-arctic river network of drainage (thickness of rivers represents relative runoff) with the study area and catchment for the Kara Sea highlighted (R-ArcticNET, 2001; base map courtesy of R.Lammers).

Figure 2. Selected sparker (A-C) and sonar profiler (D) records (Fig. 1 for location). Major stratigraphic boundaries are highlighted. Sparker data were recovered using a single-channel system with a source energy of 600 J and registration frequency of 100-1000 Hz. Vertical scales are in pulse two-way travel time (ms, left) and in depth below sea level estimated from sound speed in water 1500 m/s (m, right); actual thickness of sediment may be larger. Note differing horizontal scales and a compressed vertical scale in C. Sonar data (D) have a swept frequency range of 3-14 kHz. (A). Morainic wedge with overlain basin-fill deposits. Note the continuation of glacigenic unconformity beyond the diamicton edge. (B). Regressional unit, exposed during the LGM sea-level fall, with a system of channels cut into its surface. Base of the younger filled channel correlates to subaerially eroded unit’s surface. At the channel mouth, channel fills grade into basin-fill deposits (cf. C). Glacially eroded bedrock with small remnants of an older diamicton (?) is seen at the bottom of regressional unit. (C and D). Transition from regressional unit to basin-fill deposit, both resting upon the eroded bedrock. Subaerially eroded (LGM) surface of regressional unit is traced to some distance basin-ward as a strong reflector, unattainable for a sonar signal (D), which is presumably related to action of permafrost and/or gas migration during low sea-level stand. Erosion or non-deposition of basin fill near its termination on the right in C is possibly related to currents. Record is obscured beneath a thick regressional unit. Approximate position of the sonar record (D) is shown by box in C.