Eos, Transactions, American Geophysical Union, Vol. 80, No. 40, October 5, 1999, Pages 465, 472–473

Expedition Gives Fresh View of Central Arctic Geology

Important new information has been collected on the structure and evolution of the main geological features of the central Arctic Ocean. An expedition in July 1998 to the Alpha and Lomonosov Ridges produced the first multichannel seismic (MCS) profiles ever along Alpha. Biological probes, ice and aerosol sampling, and the collection of sediment cores also took place.

One intriguing finding was that, while Lomonosov is biologically rich, Alpha is a benthic desert. Alpha proved to be one of the poorest benthic environments ever investigated in the Arctic Ocean.

A submarine mountain chain, Alpha Ridge was discovered almost 40 years ago by American ice drift stations [*Hunkins*, 1961]. Last year's expedition, known as Arctic-98, demonstrated that it is possible to reach the ridge with surface ships and perform reasonable research. However, difficult ice conditions were encountered and were believed to be typical for the region. The support of an icebreaker, which was on hand in this case, is therefore essential.

Conducted with the German R/V *Polarstern* and the Russian nuclear ice breaker *Arktika*, the expedition was designed to collect new geophysical data and samples to increase understanding of Alpha and of changes in the region in Recent Quaternary climate, ocean circulation, productivity, and sea ice distribution. Also planned was the delineation of the long-term history of the Mesozoic and Cenozoic Arctic Ocean and its evolution from a warm polar ocean to an ice-covered polar ocean. A description of the distribution and activity patterns of zooplankton and zoobenthos in the context of seafloor morphology and the hydrological regime also was envisioned.

Some Findings

The MCS profiles showed a more or less constant sediment thickness of 800 to 1200 m along the strike of Alpha Ridge (Figure 1, profile 98530). Overall more than 1200 km of MCS data were collected, 320 km from Alpha and 920 km from Lomonosov and the adjacent Makarov and Amundsen Basins. Lomonosov Ridge actually was investigated with shipborne seismic methods for the first time, between 85° and 80° north latitude. Bathymetric and gravity data also were acquired along the entire track.

Eleven cores provided new information on the paleoenvironment of the central Arctic

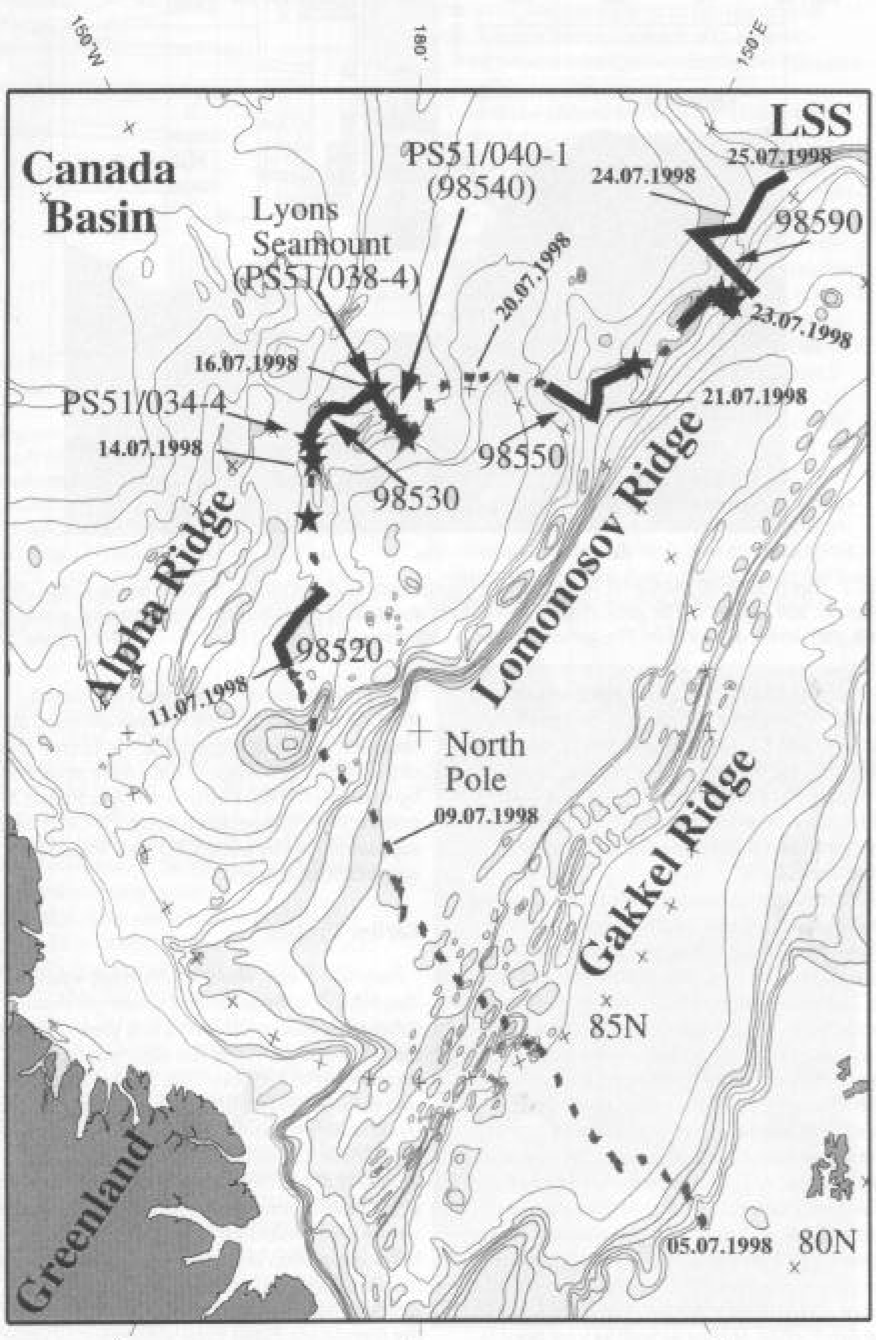

Fig. 1. Cruise track of the Arctic-98 expedition (dashed line). The solid parts of the tracks indicate the acquired seismic lines, and the stars indicate the location of the geological and biological coring stations. LSS = Laptev Sea Shelf.

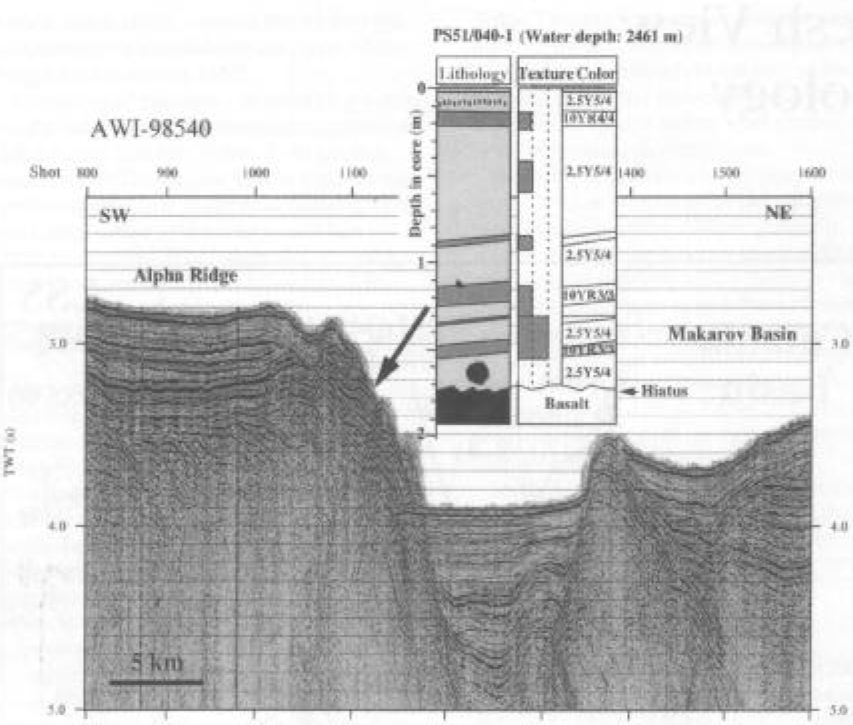

Fig. 2. Part of seismic profile 98540 across an escarpment at the northern flank of Alpha Ridge. For location, see Figure 1. The gray shaded lithology is dominated by clayey to silted material, while the dark gray layers are sandier. The general lithology, however, is similar to Core PS51/034-4 (Figure 3).

Ocean back to 2-3 Ma. Sediment cores from the Lyons Seamount (Figure 1) provided critical stratigraphic information. Basalt in PS51/040-1 from a steep escarpment north of this seamount might give the first good age constraints on the evolution of the Alpha Ridge. Samples from other expeditions have been difficult to date.

All investigated parameters of the biological probes revealed low benthic productivity on Alpha, in strong contrast to Lomonosov. Zooplankton was also poor but not as obviously so. The ecosystems of the ice-covered deep Arctic basins and ridges, especially their benthic components, generally suffer from a shortage of organic matter produced in situ.

The richness along Lomonosov Ridge may be explained mainly by advection of particulate organic matter produced in the northeastern Laptev Sea. A current-driven crushing of sea ice immediately above the ridge also opens leads and polynyas [*Gordienko and Laktionov*, 1969] and may stimulate primary production in this area. On the other hand, Alpha Ridge appears to be remote from any supporting production source as well as very poor in in situ production because of the very heavy ice cover there.

Aerosol sampling, ice sampling, and ice thickness measurements were carried out along almost the entire ship track. After July 10, the thickness of the ice floes increased from 2-3 m to 4-6 m. Dirty ice was sampled at several localities to determine the source areas of the floes. Hydrological data were obtained by expendable (X) bathythermograph and X-conductivity-temperature-depth (X-CTD) casts, supplemented by a few CTD and "Rosette" water bottle samples.

Earlier Probes

Forty years ago, when Alpha ridge was first discovered, soundings and sparse published submarine tracks allowed a first view of the extent of the ridge. While the adjacent basins were found to be more than 3000 m deep, Alpha rose to 1200 m. In large areas the seafloor over the ridge was very rugged.

In 1983, a Canadian ice island expedition [*Jackson et al.*, 1985] conducted an extensive geoscientific program on Alpha for a look at its nature and evolution. Carried out was the first large-scale deep seismic sounding experiment to investigate the velocity structure of the deeper crust. Forsyth et al. [1986] interpreted the travel-time curve to be similar to the velocity-depth functions found around Iceland and suggested that Alpha Ridge represents a hot spot trail. Several hundred sediment cores during U.S./Canadian ice island experiments were collected, but only a few contained material documenting the Mesozoic paleoenvironment of the ridge some 80 Myr ago. The existing old sediment samples clearly show that the Arctic Ocean was ice free at that time. However, the available geoscientific information is not sufficient to derive a complete model for the geodynamic and paleo-oceanographic evolution of the ridge.

Last summer, on July 4, the *Polarstern* rendezvoused with the *Arktika* at the boundary of the Norwegian-Russian exclusive economic zone (EEZ) east of Svalbard, and the two ships operated in a convoy. Ice conditions were severe north of 81° north latitude, and almost no open leads were present for easy navigation. However, with the support of the ice breaker, the ships were able to move with a mean velocity of about 9-15 km/h toward Alpha Ridge. About 180 kilometers south of the Canadian part of the ridge, the ships encountered such extremely difficult ice that even *Arktika* could not move. Satellite images and helicopter reconnaissance flights showed that the main area of interest could not be reached within the time frame of the expedition.

However, satellite images suggested that ice conditions were not as severe toward the west and after 2 days, on July 14, the ships were able to move southward onto Alpha Ridge on its central part. Geological and biological samples as well as geophysical lines were acquired during the next 5 days over the western part of the ridge. On July 19-20, the ships left the ridge and steamed towards the Laptev Sea through an area of favorable ice conditions observed on satellite images along the Lomonosov Ridge.

Geophysical Experiments

Three seismic profiles were collected on Alpha Ridge. A streamer with an active length of 200-300 m and an airgun cluster with a total volume of 24 L were used. Sonobuoys were deployed along the profiles to acquire more accurate seismic velocity information. The longest profile (Figure 1, 98530), which was 192 km, was acquired along the strike of the westernmost part of the ridge. Three sonobuoys were deployed, providing signals up to a distance of 30 km, and showing the 800-1200 m sediment thickness variation. The basement was imaged along most parts of profiles 98530 and 98540 (Figure 1) and was characterized by seismic velocities of 4.5 to 4.7 km/s.

At deeper levels, seismic velocities of 5.0, 5.1, and 5.4 to 5.7 km/s, which can be interpreted as the uppermost basaltic layer of oceanic crust, were identified on two sonobuoys on profile 98530. On line 98540 (Figure 2), which runs almost perpendicular to the ridge, the sediments thin toward the north, and an escarpment of 800 m high was found at approximately 85°30′ north latitude, 175° west

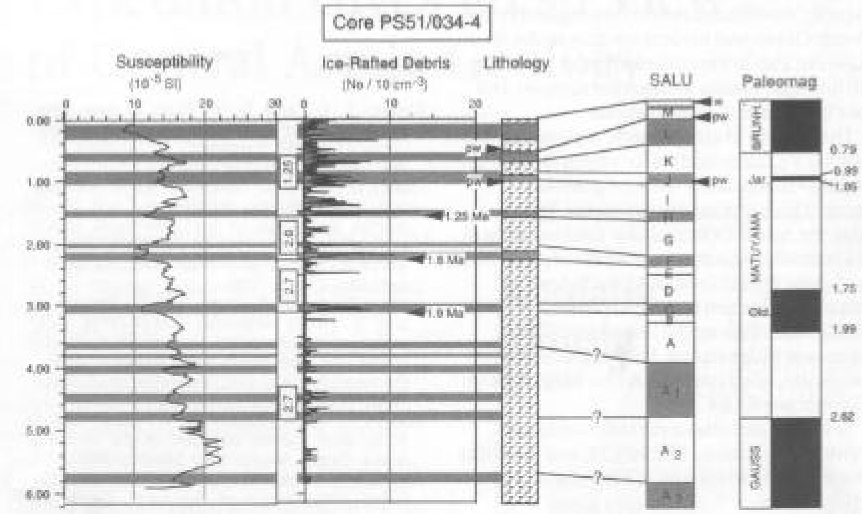

*Fig. 3. Lithostratigraphy of Core PS51/034-4, based on magnetic susceptibility, content of ice-rafted debris (IRD), and lithological core description. Gray intervals in the lithology column indicate sandier intervals. In general, low magnetic susceptibility values correlate with increased amounts of IRD. The records of Core PS51/034-4 are correlated with Standard Arctic Lithological Units and the paleomagnetostratigraphy [*Clark et al., *1980;* Mudie and Blasco, *1985;* Jones, *1987;* Darby et al., *1989]; paleomagnetic timescale is according to Cande and Kent [1992]. Units A3, A2, C, F, H, J, and L, and parts of M are more sandy intervals. The initials "w" and "pw" indicate white and pink-white layers that can be used for core correlation. Sedimentation rates (in mm/ky) are shown as vertical numbers between the susceptibility and IRD records. For more details, see R. Stein et al., unpublished manuscript (1999).*

longitude. Geological coring recovered several basalt samples from the escarpment. North of the escarpment the basement is more rugged.

Additional MCS data could be acquired along most parts of the track, where the ships sailed along the strike of Lomonosov Ridge toward the Laptev Sea. Profile 98550 (Figure 1) starts at the southern flank of Lomonosov Ridge at 84°30′ north latitude. In contrast to its structure at 88°, the ridge topography shows variations up to 1000 m in its central part along line 98550. This topography might be caused by basement structure formed during the rifting of either the Makarov Basin or the Eurasian Basin away from Lomonosov Ridge. Line 98590 at 81°30′ north latitude, almost 450 km to the south, shows a similar basement structure but more pronounced.

Based on velocities from three sonobuoys, a sediment thickness was calculated of 600 to 800 m along profile 98590. At greater depths, seismic velocities between 4.1 and 4.8 km/s were found. It is not clear if these velocities represent compacted sediments or basement rocks. For further details, see Jokat [1999].

Geological Investigations

Surface and subsurface sediment samples were taken by the giant box corer, the multicorer, the kastenlot corer, and the gravity corer. In general, coring positions were carefully selected using PARASOUND, a sediment echosounding system, to avoid areas of sediment redeposition and erosion. These records also allowed us to characterize the different structural elements in terms of ridge morphology and sedimentary patterns.

Snow fields, dirty sea ice, melt ponds, and the upper 75 m of the water column were also sampled. During transit times, aerosols were routinely collected using a pump installed on the uppermost deck of the vessel.

Several long sediment cores with a recovery between 4.5 and 7.2 m were obtained along the northern flank of the western Alpha Ridge. The predominant lithology of Alpha Ridge sediment cores is silty clay, colored brown, light to dark yellowish brown, and light olive brown. Sandy intervals and mud clasts occur in the upper 0.5 to 1.4 m of the cores, approximately. The most prominent feature in the cores are color cycles of light olive brown and brownish yellow/yellowish brown sediments, which occur down to the bottom of the cores.

Seismic profile 98540 (Figures 1 and 2) suggested that older sediment strata or basaltic basement crop out on the steep slope of a graben-like structure in the westernmost part of Alpha Ridge, and so a coring program was carried out to sample the basement. In one of the cores (PS51/040-1), a large piece of black basalt, 7 cm in diameter, was found at 160-166 cm below the seafloor, and the core catcher contained additional pieces of basalt (Figure 2). The overlying sediments are dark brown, with light olive brown to yellowish brown silty clays with sand and mud clasts in the uppermost part. A major hiatus is assumed to have occurred between the Quaternary/upper Pliocene sediments and the basalt.

Two of the sediment cores (PS51/034-4 and PS51/038-4) were studied in some detail onboard *Polarstern*. Based on grain size (silty clay versus sandier intervals), specific marker horizons (pink-white and white layers), and magnetic susceptibility values, the new sedimentary records were correlated with existing sediment cores from Alpha Ridge (see, e.g., *Clark et al.* [1980], *Darby et al.* [1989]). Using the cited authors' stratigraphic framework, our sediment cores probably represent the last 3 Myr, approximately, as shown by core PS51/034-4 (Figure 3), for example. Resulting sedimentation rates vary between about 1 and 3 mm/kyr.

The distinct changes in sediment color, physical property records (wet-bulk density, porosity, magnetic susceptibility), and mineralogical composition suggest distinct changes in the terrigenous sediment source area, input of ice-

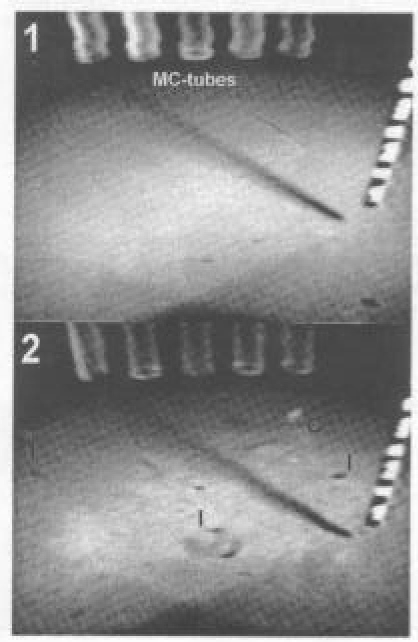

Fig. 4. Multicorer video shots from Alpha Ridge (top) and Lomonosov Ridge (bottom). In the upper part, five tubes of the multiple sediment corer (MC) can be seen. On the right side a scale (10 cm divisions) is visible. I = Isopoda dwellings; C = Crinoidea.

rafted debris (IRD), oceanic circulation patterns, and paleoclimate occurring on Alpha Ridge during the last 3 Myr.

Intensity and frequency of ice-rafting events on the ridge probably increased stepwise near 1.9, 1.6, and 1.25 Ma (Figure 3). In general, maxima in IRD coincide with minima in magnetic susceptibility, suggesting differences in the composition of the coarse- and fine-grained material. [For further details, see *R. Stein et al.*, unpublished manuscript, 1999].

Zooplankton and Benthos

Many areas in the central Arctic appear to a high degree to be dependent on horizontal advection of particulate organic matter from the more productive marginal Arctic seas. As the Eurasian Basin is under the strong influence of Atlantic water masses and the Transpolar Drift, while the Amerasian Basin contains a number of recirculating systems, we expected to learn something about the significance of such differences by comparative studies in both areas.

A few stratified mesozooplankton samples from the entire water column were obtained from Alpha Ridge with a new multiple deep sea closing net. Preliminary analyses indicated the copepod community there is similar to that in the Eurasian Basin. The upper and the Atlantic-influenced deeper water layers were dominated by *Calanus hyperboreus* and *C. glacialis*.

Larger zoobenthos were collected with a box corer. For the investigation of smaller benthos, especially meiofauna, sediment samples were taken with a multiple sediment corer (MC). The cores were also used for measurements of microbial metabolic activities and of total sediment oxygen uptake rates.

The MC video screenshots from Alpha and Lomonosov Ridges (Figure 4) show clear differences in animal densities. While the Lomonosov Ridge station is fairly populated by filter feeders (*crinoidea*) and burrowing *isopoda*, almost no trace of any animal was visible on Alpha Ridge. That the ridge was among the poorest benthic environments ever investigated in the Arctic Ocean was evident not only in the images but also in the collected fauna (less than 10 tiny macrofauna animals per sample) and our biochemical investigations.

The content of chloroplastic pigment equivalents (CPE) as indicators for phytoplankton material available at the seafloor generally ranged from low to very low levels. This was also the case for extracellular turnover rates of fluoresceindiacetate as measures of microbial activities. On the crest of Alpha Ridge, the maximum content of CPE was more than two times lower than on the investigated Lomonosov Ridge station. Bacterial activities were also much lower on Alpha Ridge than on Lomonosov Ridge.

Scientific activities were terminated just north of the Russian EEZ July 24, and the cruise ended about 70 km east of Tiksi at the Lena delta July 26.

Acknowledgments

We thank the captains and crews of RV *Polarstern* and the Russian nuclear ice breaker *Arktika* for their excellent support during the expedition. The good cooperation with the ice breaker *Arktika* was essential for the success of the cruise. The financial support by the Ministry for Education, Science, Research and Technology within the bilateral Russian-German multidisciplinary research project "System Laptev Sea 2000" is gratefully acknowledged. This is Contribution No. 1643 of the Alfred Wegener Institute for Polar and Marine Research.

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