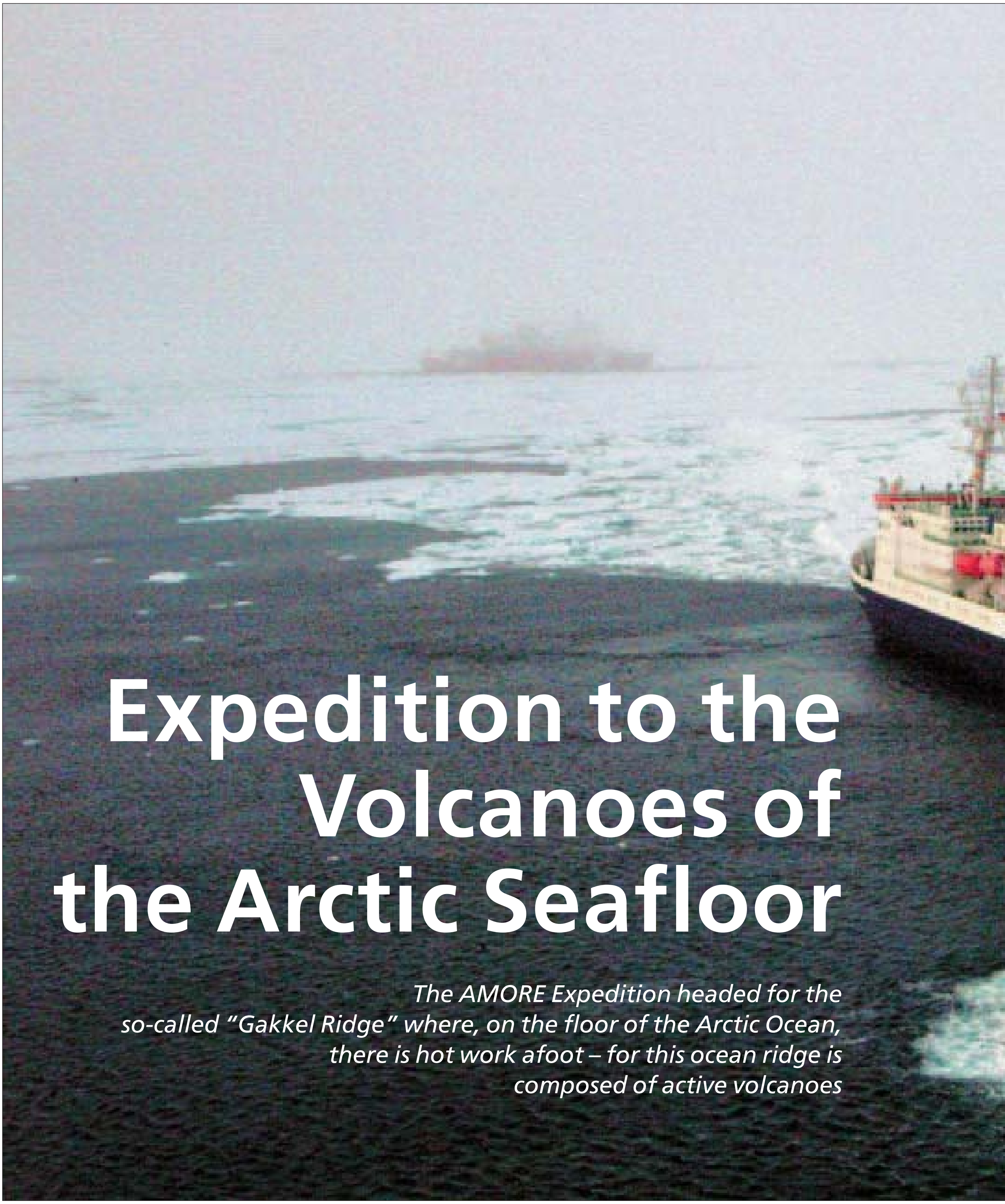


Expedition to the Volcanoes of the Arctic Seafloor

The AMORE Expedition headed for the so-called "Gakkel Ridge" where, on the floor of the Arctic Ocean, there is hot work afoot – for this ocean ridge is composed of active volcanoes

Three research vessels meet in the Arctic Ocean: The RSV “Polarstern” and “USCGC Healy” have yet to ply their way to the Pole through the icy water, the Swedish “Oden” (foreground) has already completed its mission.

When Jules Verne made his imaginary journey of exploration to the centre of the earth through the vents in an Icelandic volcano over a hundred years ago, he assumed that all volcanoes are interlinked in a subterranean system. But even his imagination failed to visualise the worldwide system of submarine volcanoes that extends over a distance of over 60,000 kilometres and only breaks the surface of the ocean at Iceland. This mid-oceanic ridge, which spans the entire world ocean, has evolved along the boundaries between the tectonic plates of the Earth's crust. Gakkel Ridge, in the central eastern Arctic Ocean is the northern most spur of the plate boundary between Eurasia and North America, and at the same time the most slowly opening ridge segment in the world, opening only a few millimetres each year.

In October 2001, the research vessel RSV "Polarstern" and the ice-breaker USCGC "Healy" from the U.S. Coastguard returned to port bringing dramatic data from an expedition to the Gakkel Ridge which lasted over four months. The AMORE 2001 (Arctic Mid-Ocean Ridge Expedition) marks a milestone in Arctic Ocean exploration in that scientists have for the first time accurately charted, surveyed and sampled the western part of the Gakkel Ridge.

Geophysical surveys were conducted to determine the thickness of the crust along the Gakkel Ridge and its adjacent ocean basins. Initial evaluation of the data shows that the crust thickness along the Gakkel Ridge, which varies between six kilometres and a few hundred metres, does not accord with existing model concepts. In contrast to previous assumptions, it now appears that there are magmatic centres spaced at regular intervals along the ridge, where clearly greater accumulations of basalt have formed than in the other parts.

Probes measure ice and melt-water. The data recount the climatic changes in the Arctic

Magnetic measurements made from helicopters indicate that these submarine volcanoes were active over very lengthy geological periods. The geophysical measurements undertaken along the Gakkel Ridge, and especially studies of the adjacent basins, revealed that not only does the thickness of the sediments under the ocean floor, otherwise so level, vary greatly, but also that a part of this sedimentary cover has been transported into the ocean basins from the neighbouring continental shelf edges by dramatic slides.

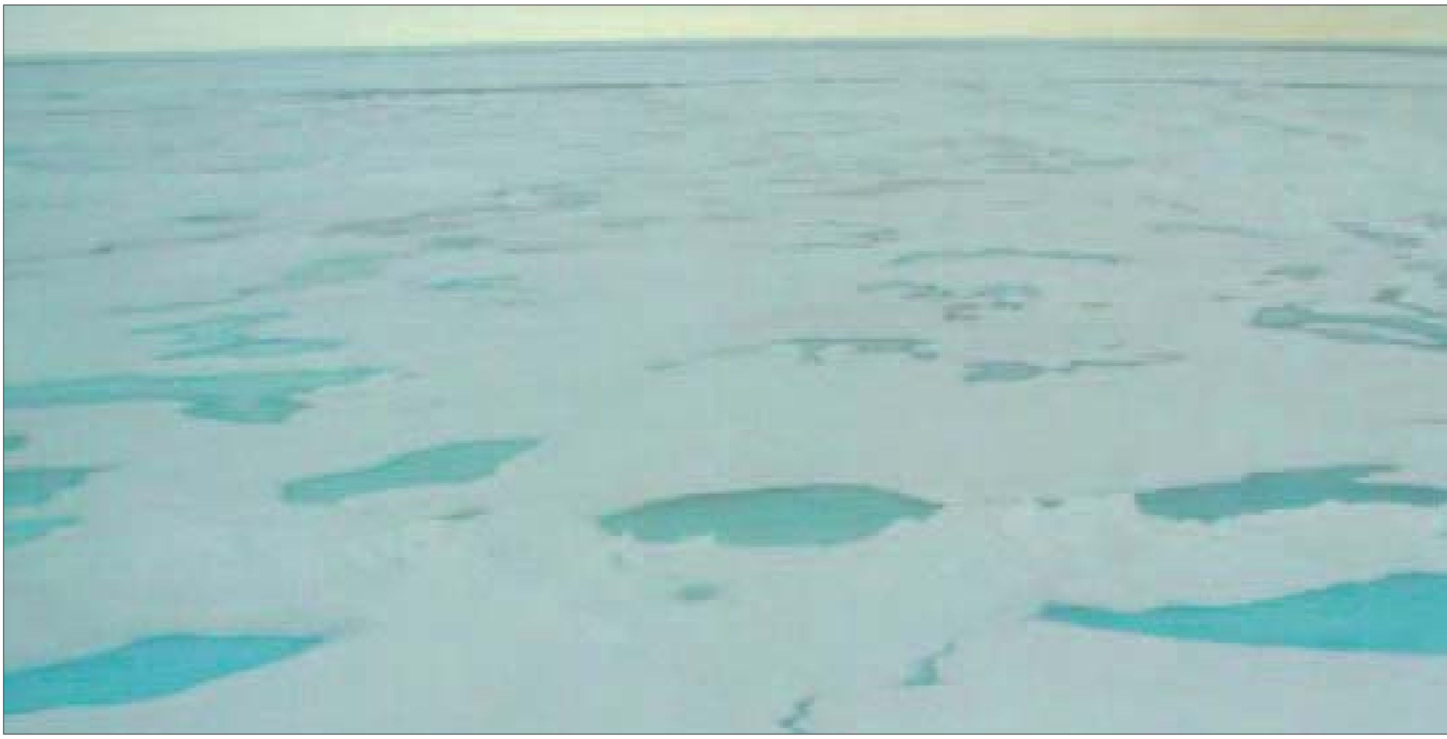
Under the two-metre layer of ice and the 4,000-metre-deep Arctic Ocean lay the volcanoes from which the samples were to be taken using TV-controlled grabs and dredges. These basic tools returned with loads of up to three tonnes of rock from the ocean floor to the surface in one lift. Initially, we had expected that this submarine ridge would most probably have been the result of extrusion caused by tectonic movements rather than by any volcanic processes, and so we had expected to find a majority of peridotites and gabbros in the samples. Peridotites deep-seated rocks from the earth's upper mantle, and gabbros form in the lower oceanic crust, so that both types of rock can only be brought to the surface of the ocean floor by tectonic movements. And these rocks were indeed found in many locations.

The majority of the rock samples, however, were found to contain basalts, the solidified products of volcanic eruptions from submarine volcanoes. The shapes of the samples reflected the violence of the clash of red-hot lava with ice-cold sea water during these submarine eruptions. The freshly expelled lava solidifies to a thick, black, tubular glass periphery into which the lava flows, rather like blowing up a balloon. In the course of this process, so-called basalt pillows are created to form the upper 2,000 metres or so

A helicopter flying at an altitude of 20 metres measures the thickness of the ice cover beneath it using a helicopter electromagnetic probe ("HEM-Bird"). Left: Magnetic fields are also probed. Above: A basalt sample from the ocean floor. The "giant pillow" weighs several tonnes.

of the oceanic crust. These basalts contained a variety of types, which we had not expected to meet on the Gakkel Ridge. In particular, the high proportion of interspersed crystals in the rock can only be explained by the presence of large magma chambers, and stands in clear contrast to the conventional wisdom that the extremely slowly spreading Gakkel Ridge simply doesn't produce enough magma to keep such chambers in operation. After the initial assessment of the rock samples, thin sections were prepared on board ship. Microscopic measurement of the optical properties of these sections enabled us to make precise statements regarding the composition and origin of a sample only a few hours after the rocks were recovered. The composition of the rocks measured on board coincided roughly with what had been expected. However, as these studies point to the existence of a thin crust along the entire Gakkel Ridge, and thus stand in contrast to the violent volcanic activity observed, more detailed studies must now be undertaken to elucidate the ratio between the rate of spreading and the thickness of the ridge crust.

Examination of the "hot springs" under the Arctic Ocean was also on the expedition's agenda – springs, whose chemical composition is rather more reminiscent of a witch's cauldron. Mid-oceanic ridges are the scenes of broadly spread and quantitatively very significant hydrothermal exchange processes between the rocks of the oceanic crust and the water columns. Where these springs discharge, at their so-called "vents", highly specialised communities of invertebrates are often found which, to judge by their external appearance, should not actually dwell in the ocean depths. They include, for example, large



Smaller-sized air guns towed through the ice behind the ship generate acoustic signals to obtain geophysical reflections. Above: Gigantic ice flows with blue pools of melt water. The weathered surface is typical of the summer. Right: A TV-controlled "grab" brings samples up to the surface from the ocean floor.

tube worms and mussels which have adapted to a very specific form of metabolism. Back in 1998, the "Polarstern" had collected vent fauna of this sort along the continental shelf of the Laptev Sea off Siberia, from the immediate prolongation of the Gakkel Ridge. They testify to the possible presence even more of them further to the west, and are the best proof of the broad distribution of hydrothermal springs further along the Gakkel Ridge.

Every exploration of the ocean floor demands accurate charting. Although such charts are a matter of course for seas in temperate latitudes, knowledge of ocean floor morphology of the Arctic Ocean up to this point had been very broad brush, having been passed on to a very restricted circle of people by the U.S. Navy, which had from time to time made nuclear submarines available. These submarines are able to ravel submerged under the ice and make a continuous depth profile, and thus to compile a chart. However, due to the relative inaccuracy of the navigation facilities in the submarines, this proved to be somewhat problematic, as much of the planning for the AMORE Expedition was based on this chart. However, the "Polarstern" and the "Healy", working independently and over long distances under favourable ice conditions, were able to survey the northern and southern flanks of the Gakkel Ridge respectively while satellite navigation facilities allowed them to make highly accurate fixes of their positions. One very valuable result of this expedition was the resulting detailed and extremely precise cartographic record made of the morphology of a stretch of the Gakkel Ridge extending over a distance of almost 900

km. One of the purposes of the expedition was to observe changes in the thickness and distribution of the ice and to compare the results with previous measurements made by "Polarstern" in the central Arctic Ocean in 1991 and 1998. In summer 2001, no extensive areas of water were encountered at the North Pole. Over 90 per cent of the surface was covered by large flows of multi-year ice measuring several kilometres in diameter. Interspersed between these were narrow channels already bearing a covering of new ice. Comparisons with 1991 revealed marked changes in the observed thickness of the ice. Whereas the typical thickness in 1991 was 2.5 metres, this year it lay between 1.9 and 2.1 metres. These measurements were for the most part made using an electromagnetic probe carried on a sledge that was dragged over the frequently rough terrain presented by the ice. In this manner a total of 52 ice flows were surveyed over a distance of 100 kilometres. However, new types of probe were also employed which enabled the thickness of the ice to be measured from a moving ship or a helicopter. In particular, the new "HEM-Bird", a geophysical probe drawn along under a helicopter on a 20-metre cable, enabled the acquisition of data of surprisingly high quality. These measurements of the ice thickness also served as preparation for the European Space Agency's (ESA) "Cryo-Sat" satellite mission, due to map the Arctic and Antarctic ice cover beginning in 2004. Measurement of the sea ice also included determination of the physical and biological properties of the ice and melt pools. In addition to this, we drilled ice cores, evaluated satellite and aerial photographs, and determined the reflective capacity of diverse types of surface. Observing the feeding habits of minor invertebrates which had adapted to the extreme living conditions in brine channels in the ice flows, and whose body fluid did not freeze, proved very exciting.

The northern Arctic Ocean is permanently covered by pack ice today, even though the exchange processes with the adjacent seas and the seasonal melting processes ensure that this sea ice never lasts for more than a few years. The task of the marine geologists was to take sediment cores from the region off the great Siberian shelf. As terrestrial sediment sequences are often subject to major errors in dating we are hoping that these submarine cores will help to throw further light on chronological processes. Major ice shields on the adjacent land areas can be identified in the Arctic Ocean sediments through coarse and fine rock residues carried by the icebergs. The sediment cores from the Gakkel Ridge at 70 degrees East, which had never previously been subject sampled, were indeed found to contain a number of layers of coarse sand and stones, typical sediments from the melting phases of great glaciers. From the variously coloured layers in the sedimentary cores we were able to estimate that these were around 200,000 years old. Laboratory studies are now expected to provide more precise dating and to reveal the extent of the glaciation in Northern Siberia in its individual phases, the role played by the transport of moisture from ephemeral stretches of open water in the build-up of the ice, and the points in time when the melt water of the warm phases of melting glaciers reached the ocean.

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