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The Arctic Ocean: An Unique Tectonic Laboratory

Kurzfassung

Das Nördliche Eismeer, umgeben von passiven kontinentalen Randgebieten, ist als kleines Ozeanbecken einzigartig. Innerhalb seines kleinen Gebietes bietet es eine Vielfalt tektonischer Besonderheiten, von denen einige als solche ungewöhnlich sind, während andere wegen ihrer Lage interessant sind. Einige der interessantesten Phänomene sind der Gakkel Ridge, der sich am langsamsten ausbreitende aktive Grat mitten im Ozean, der Alpha Ridge, den man für einen vulkanischen Grat hält, der Lomonosov Ridge, ein schmales kontinentales Fragment, und die Beckenränder, die scheinbar unmagmatisch sind.

Abstract

The Arctic Ocean is unique as being a small oceanic basin surrounded by passive continental margins. Within its small area it encompasses a variety of tectonic features, some of which are unusual in themselves, while others are of interest because of their setting. Some of the major features of interest are the Gakkel Ridge, the slowest spreading active mid-ocean ridge; the Alpha Ridge, believed to be a mantle plume track; the Lomonosov Ridge, a narrow continental fragment; and the basin margins, which appear to be amagmatic.

Résumé

L'océan Arctique est unique en tant que petit bassin entouré de régions limitrophes continentales entièrement passives. A l'intérieur de sa petite région il offre une grande diversité de particularités tectoniques dont quelques-unes sont extraordinaires, tandis que d'autres sont intéressantes à cause de leur site. Quelques-uns des phénomènes les plus intéressants sont le Gakkel Ridge, la crête active se déployant le plus lentement au milieu de l'océan, l'Alpha Ridge qui passe pour une crête volcanique, le Lomonosov Ridge, un fragment étroit continental, et les bords des bassins qui ne semblent pas être magmatiques.

Keywords

Arctic, Tectonics, Ridges, Margins

1. Introduction

The Arctic Ocean is unique among the world's oceans in that it is a small ocean basin entirely surrounded by continents and by passive continental margins, apart from the narrow link to the North Atlantic, which lies between Svalbard and Greenland and, as well as being an oceanographic connection, is an active tectonic link along the Spitzbergen Fracture Zone. It is perhaps interesting, although presumably entirely coincidental, that this structure is mirrored by the Antarctic, where a small continent is surrounded by spreading oceans. Because of this anomalous character, a study of its various structural and tectonic features, and especially of their similarities and dissimilarities with those elsewhere, can provide valuable insights into tectonic process in general. Here we illustrate this by a brief review of some of the major features and their significance, although it must be emphasized that the selection lays no claim to being either comprehensive or objective. Fig. 1 shows the location of the features mentioned here.

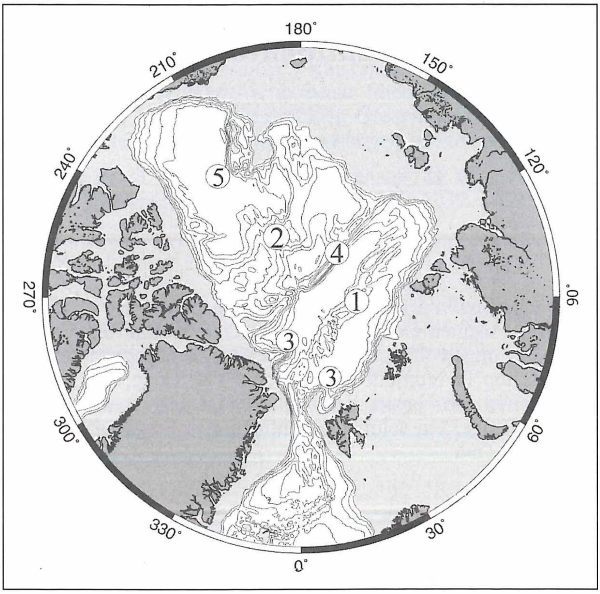

Fig. 1: The Arctic Ocean, with structural features discussed: (1) Gakkel Ridge; (2) Alpha Ridge; (3) Morris Jesup/Yermak Plateau; (4) Lomonosov Ridge; (5) Northwest Ridge

2. Gakkel Ridge

First and foremost, perhaps, the Gakkel Ridge is an active center of sea-floor spreading. Its importance and peculiarities follow from its very slow rate of spreading: 3 mm/year as compared with up to 150 mm/year for some Pacific ridges (FEDEN et al. 1979). Because of the slow spreading, the upwelling of mantle beneath the Gakkel Ridge is also anomalously slow, which allows the hot rising material to be cooled by conduction from above. As a result, there is relatively little melting and segregation of basaltic magma to form the oceanic crust, so that this crust is much thinner (2 km) than normal oceanic crust (JACKSON et al. 1982), and its chemistry also reflects the low degree of melting. In addition, the cold material is rigid and brittle, so that the Gakkel Ridge is characterized by rough, strongly faulted topography. The dependence of oceanic crustal thickness on spreading rate (REID & JACKSON 1982) is now fairly well established and accepted, but the detection of thin crust formed at the Gakkel Ridge was the first time it had been observed experimentally, and was important in providing the basis for theoretical quantitative models of melting and cooling at mid-ocean ridges.

3. Alpha Ridge

The Alpha Ridge, by contrast, owes its existence to an excess of igneous activity. Its crustal structure (FORSYTH et al. 1986) appears to be most consistent with formation by a mantle plume or hot spot. Its breadth and general character suggest an association with a spreading center, as in the case of Iceland, rather than mid-plate volcanism such as Hawaii. The Alpha Ridge may therefore be associated with the opening of the Canada Basin. Indeed, the deep crustal structure beneath the Alpha Ridge shows a strong similarity (Fig. 2) to that of the plume trace between Greenland and Iceland (REID et al. 1997), and the plume that generated the Alpha Ridge may be related to the subsequent volcanism in Davis Strait and the current activity of Iceland. However, the relation between the plume, basin opening, and the adjacent continental margins, is still obscure. If the plume was associated with spreading in the Canada Basin, did it cease activity when the spreading stopped? There is also a minor, still-active zone of enhanced volcanism, or H-zone, at the southern end of the Gakkel Ridge, where the crustal thickness is greater, and magnetic anomalies are stronger, than elsewhere along the ridge. At the beginning of the rifting in the Eurasian Basin, this zone formed the small but nonetheless significant conjugate oceanic plateau of the Morris Jesup Rise and Yermak Plateau (JACKSON et al. 1984). It may be associated with the plate tectonic triple junction between the Gakkel Ridge, Spitzbergen Fracture Zone and the supposed Nares Strait Fracture Zone, but whether the excess volcanism was in some way caused by the triple junction, or the position of the junction was determined by a pre-existing hot spot, is unknown.

4. Lomonosov Ridge

Another interesting and unusual feature of spreading in the Eurasian Basin is the Lomonosov Ridge. This is a thin sliver of continental material that was rifted away from the wide Barents shelf when sea-floor spreading at the Gakkel Ridge was initiated (FORSYTH & MAIR 1984). We may speculate that at the time of propagation of the rift into the Arctic region, it was easier for rifting to occur within the continental lithosphere than in the adjacent stronger oceanic lithosphere. A related situation exists in western North America, where the transform boundary between the North American and Pacific plates has shifted inside the continent, resulting in the rifting and motion of Baja California, but the case where extension and rifting have occurred along a parallel toa pre-existing continental margin seems to be unique to the Lomonosov Ridge.

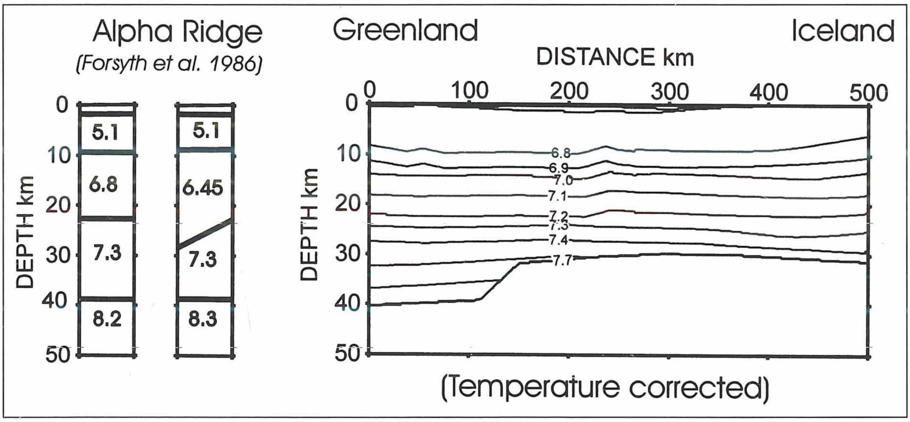

Fig. 2: Similarity of crustal structure of the Alpha Ridge and the Greenland-Iceland Ridge. Seismic velocity in km/s.

5. Conclusion

We also note that the continental shelves around the Arctic Ocean, particularly those of Eurasia, are unusually wide. The detailed structure of the margins has been relatively little studied. One interesting result was obtained in a study of the crust of the Canada Basin, immediately adjacent to the continental escarpment of the Northwest Ridge (JACKSON et al. 1995). The structure here does not show typical crustal seismic velocities overlying well defined mantle, but rather an apparent high crustal velocity at relatively shallow depth. This is very similar to what has been observed at some continental margins elsewhere, where the seismic velocity structure has been interpreted to show little or no igneous crust formed during and immediately after rifting, with the basement or immediate subbasement material being mantle that has been largely serpentinized to reduce its seismic velocity. While typical of nonvolcanic continental margins, it also raises an interesting question as to the crust of the Canada Basin, away from the igneous regime of the Alpha Ridge: was this also formed at a very slow spreading rate, as at the present Gakkel Ridge, and is the crust therefore also anomalously thin. A combination of thin crust and the relative age of the Canada Basin might well have provided conditions for widespread mantle serpentinization throughout the basin itself, and it would perhaps be of interest to test this hypothesis experimentally some time in the future.

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