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From Exploratory to Process-Oriented High-Latitude Marine Geophysical and Geological Research

Kurzfassung

L. Johnson hat eine Schlüsselrolle inne in der Erforschung des norwegischen Teils der Grönland-See und des eurasischen Beckens. Die heutige Forschung konzentriert sich zunehmend auf prozessorientierte Themen. Viele Herausforderungen bleiben bestehen, besonders bezüglich der Ablagerung bei extrem geringer Geschwindigkeit, hinsichtlich der Wanderung der Platten im Grenzbereich und was die Existenz von einem oder mehreren großen Eruptivgebieten (LIPs) betrifft.

Abstract

L. Johnson has had a key role in the exploration of the Norwegian-Greenland Sea and Eurasia Basin contributing to the present model of lithospheric breakup followed by ~55 m.y. of sea floor spreading. Within this framework, current research is increasingly directed towards process-oriented topics. Many challenges remain, particularly related to crustal accretion at ultra-slow rates, plate boundary migration, and the existence of one or more Arctic LIPs.

Résumé

L. Johnson occupe une position-clé dans l'exploration de la partie norvégienne de la mer autour du Groenland et du bassin eurasien. La recherche d'aujourd'hui se concentre de plus en plus sur des thèmes qui s'orientent vers le mode de procédure. Il reste beaucoup de défis, particulièrement à l'égard de la sédimentation à vitesse très réduite, à l'égard du déplacement des plateaux limitrophes et quant à l'existence de plusieurs régions éruptives arctiques.

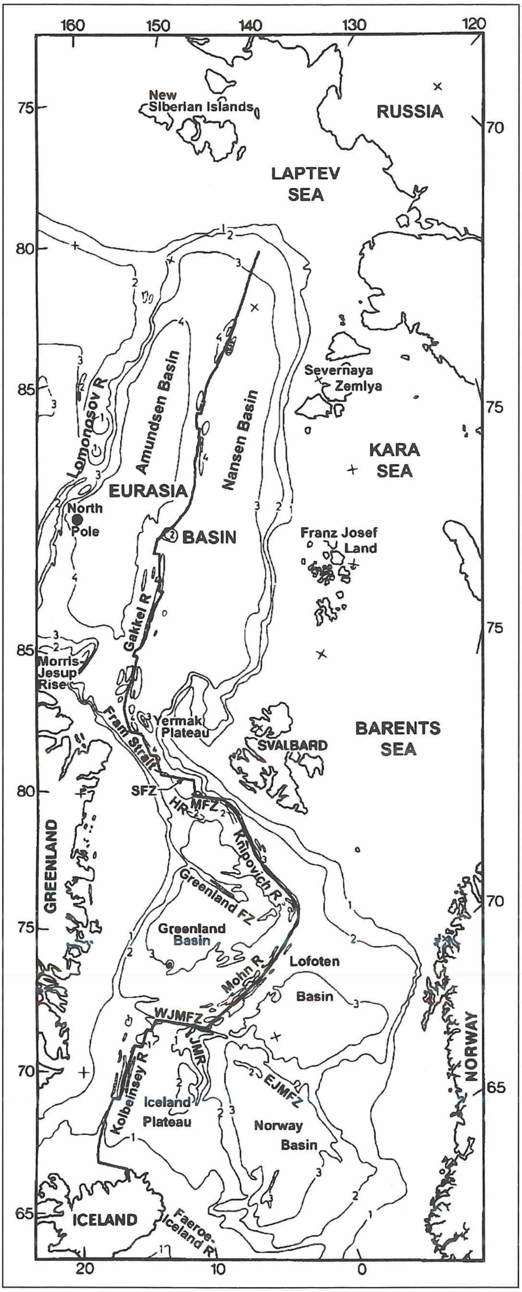
Keywords

Norwegian-Greenland Sea, Eurasia Basin, Plate Tectonics, Large Igneous Provinces

1. Introduction

For more than a 30-year period L. Johnson has made major research contributions to high-latitude marine geology and geophysics. The many visionary ideas, suggestions and models, commonly arrived at from meager data of variable quality, make him a progenitor of high-latitude research. Later, in the capacity as science administrator he has been instrumental in providing research opportunities for scientists from many countries.

We acknowledge his efforts by using three of his papers as an introduction to a brief summary of current knowledge and remaining, or poorly resolved, problems related to the plate tectonic evolution of the Norwegian-Greenland Sea and Eurasia Basin and to large episodic emplacements of mafic rocks in the Arctic realm (Fig. 1, Table 1).



2. Mid-Oceanic Ridge

Two papers by JOHNSON & HEEZEN (1967a,b), mainly based on analysis of sea floor morphology, provided the first comprehensive description of the mid-oceanic ridge (MOR) between Iceland and the Laptev Sea continental margin (Fig. 1). The MOR is an ultra-slow spreading ridge whose half-rate decreases from 1.1 cm/yr north of Iceland to 0.26 cm/yr in the eastern Eurasia Basin where it terminates at the lower continental slope, changing into a wide continental rift zone in the Laptev Sea (e.g. GRACHEV et al., 1999).

Fig. 1: Plate boundary (solid line) and regional physiographic provinces in Norwegian-Greenland Sea and Eurasia Basin. Bathymetry in km. EJMFZ, WJMFZ, MFZ, SFZ: East Jan Mayen, West Jan Mayen, Molloy and Spitsbergen FZ, respectively. HR, Hovgaard Ridge; JMR, Jan Mayen Ridge.

South of Molloy Fracture Zone (FZ), the MOR has three main segments; the Kolbeinsey, Mohn and Knipovich ridges. Although the plate boundary farther north is still the least known on Earth, new data sets have become available, including: 1) bathymetric maps; 2) densely spaced aero-gravity and magnetic profiles; 3) an Arctic seismicity data base; and 4) some detailed, local surveys. This has led to a division into three regional MOR provinces, each containing a series of small-offset transforms: the Spitsbergen Transform System shifting the plate boundary into the Eurasia Basin; and the West and East Gakkel ridges characterized by different axial morphologies (ENGEN et al., in prep.).

In a regional sense, the plate boundary exhibits a number of typical features. Among these are: asymmetric ridge mountains (e.g. VOGT 1986); deepening of the rift valley away from Iceland; greatly varying ridge azimuth; and variable amounts of oblique spreading (e.g. ELDHOLM et al., 1990). A most spectacular feature is the partly sediment-filled, continuous, 10-km-wide, and 3.2-3.3-km-deep Knipovich rift valley which is without a continuous central magnetic anomaly and major transforms. The ridge approaches the continental slope northward; in fact, the rift valley is entirely buried by slope sediments near the intersection with the Molloy FZ.

A main research challenge is to continue the regional mapping and sampling north of the Knipovich Ridge to obtain an improved plate boundary geometry including the transition into continental crust on the Laptev margin; and to date the crust to determine the longevity of the present transforms. Furthermore, both regional and local studies will focus on the relationship of ridge morphology, composition and venting to the mode of crustal accretion at ultra-slow rates. Finally, the Knipovich Ridge may become a laboratory for studying obliquely spreading ridges where sedimentation keeps pace with accretion.

3. Plate Tectonic Evolution

JOHNSON & HEEZEN (1967b) described the basin morphology and regional structural features in the Norwegian-Greenland Sea and suggested an evolutionary model, of which the main features are still retained. Subsequently, the acquisition of marine geophysical data, aeromagnetic measurements and sea floor sampling and drilling led to an increasingly more comprehensive data base covering the areas of open waters, whereas the ice-covered Eurasia Basin and NE Greenland continental margin are still poorly explored. Subsequent studies have shown that the first quantitative plate tectonic model of the Norwegian-Greenland Sea (TALWANI & ELDHOLM 1977) provides a robust, space-time regional framework for the post-Paleocene ocean history.

At the onset of the Eocene, the Arctic realm comprised two mega-lineaments which reflect a long history of structural inheritance: the Reykjanes-Mohn and De Geer lineaments. The former is predominantly a zone of crustal extension associated with massive igneous activity during breakup, whereas the latter is a shear zone shifting the nascent plate boundary into the Arctic.

The ultra-slow sea floor spreading ridge north of Iceland, continuing as a continental rift into Siberia, is the result of a complex plate tectonic evolution characterized by axial migration and formation of at least three microcontinents, the Jan Mayen, Hovgaard and Lomonosov ridges. In terms of plate geometry the region constitutes four provinces separated by major fracture zone systems (Fig. 1). The temporal history is characterized by two periods, ~55–34 Ma and ~34 Ma to present, of different relative plate motion associated with the amalgamation of Greenland and North America plates at ~34 Ma.

The evolution of the province south of the Jan Mayen FZ, comprising the deep Norway Basin and the shallow Iceland Plateau, reflects an unstable, stepwise westward

Plate tectonics – Crustal structure	Processes
General • Detailed mapping and sampling of MOR • Mapping of COB on ice-covered margins • Consequences for plate reconstructions of continental extension prior to microcontinent separation	• MOR migration into continental crust
Faeroe-Iceland Ridge • Crustal age and subsidence history	• Plume tail history
Southern Province • COB on conjugate margins • Magnetic anomalies: breakup-to-A6 time • Duration of Jan Mayen microplate • Structure and evolution of Jan Mayen fracture zone system and Jan Mayen Ridge microcontinent	• Fan-shaped spreading • Nature and emplacement of Iceland Plateau opaque horizon
Central Province • Pre-anomaly-23 plate boundary • Anomaly pattern during slowest spreading (A18-6 time)	
Northern Province • Detailed plate tectonic history • Nature of Greenland FZ and Hovgaard submarine ridges (microcontinents?) • Onset of oceanic crustal accretion in Fram Strait • Onset of complete continental separation in Fram Strait	• Low-amplitude magnetic field and lack of Knipovich Ridge central anomaly • Initiation and consequences of Fram Strait deep water passage
Eurasia Basin • Detailed plate boundary geometry • Structure of Morris-Jesup Rise/ Yermak Plateau • Transition of plate boundary into continental lithosphere – Laptev sheared margin	• Formation of Morris-Jesup Rise/ Yermak Plateau • Ridge morphology changes along Nansen-Gakkel Ridge • Mode(s) of crustal accretion during ultra-slow spreading
Arctic LIPs • Improved dating and volume/rate estimates • Nature of Alpha Ridge • Existence of underplated LIP crust • Arctic LIP or LIPs	• LIP vs plate tectonics • LIP vs leaky transforms and triple junctions • Transient vs persistent LIP components

Tab. 1: Un- or poorly resolved problems relating to crustal structure and plate tectonic evolution

migrating plate boundary. It includes the short-lived Jan Mayen microplate between areas of fan-shaped spreading resulting in complete separation of the Jan Mayen microcontinent from Greenland ~22 Ma. In contrast, spreading along Mohn Ridge, has mostly been regular and symmetric except for minor plate boundary adjustments during the first few million years after opening.

Farther north, the southern Greenland Sea opened in the early Eocene, whereas the continents moved past each other along a major transformation in the north. Here, plate separation was first achieved by crustal extension delaying the accretion of oceanic crust until the late-to-middle Miocene. A sliver cut off the Svalbard margin moved west as the Hovgaard Ridge microcontinent. In the Arctic Ocean, separation of the Lomonosov Ridge from the Eurasia margin at ~55 Ma, followed by mostly regular spreading along the Gakkel Ridge, developed the Eurasia Basin (e.g. KRISTOFFERSEN 1998).

Further refinement of the plate tectonic space-time framework will mainly arrive from improved boundary conditions, particularly on determining a better continent-ocean boundary off Greenland, in the Eurasia Basin and around the microcontinents.

Another challenge is the development of a detailed and consistent evolutionary model for the Greenland Sea and westernmost Eurasian Basin which accounts for the present plate boundary asymmetry, ocean basement relief, and the conjugate Morris Jesup Rise and Yermak Plateau. This model will also elucidate the onset of the deep water passage through the Fram Strait, a key paleoenvironmental boundary condition.

Finally, one has to develop a reconstruction procedure to account for lithospheric extension prior to microcontinent separation. In terms of processes, the focus is on the geodynamic mechanisms both responsible for crustal accretion and composition at very low rates, and for microcontinent formation and fan-shaped spreading.

4. Arctic LIPs

JOHNSON & RICH (1986) suggested that Arctic volcanism had pulsed maxima at about 30-million year-intervals, reflecting a global periodicity of similar duration. Although they stressed uncertainties in rock ages, they hoped the observation would spur others to pursue the subject. In fact, the topic became the focus some years later under the common denominator. "Large Igneous Provinces" (LIPs), i.e. broad areas, $>10^5$ km^2, of mafic volcanic and plutonic rocks erupted over $\sim 10^6$ yr (e.g. COFFIN & ELDHOLM, 1994). LIPs form both in plate interiors and at plate boundaries and originate in the mantle, via mass and energy transfer both independently of, and in conjunction with steady-state sea floor spreading. The massive igneous activity is commonly attributed to mantle plumes. Whereas a global, cyclic LIP nature is not proven, the episodic nature of LIP formation is clearly recognized, and the process may be extended far back in Earth history.

The transient LIPs include continental flood basalt provinces, volcanic passive continental margins, oceanic plateaus and ocean basin flood basalts. An example is the North Atlantic Igneous Province which shows initial small-scale activity in a wide region from Baffin Bay to the UK since ~63 Ma, culminating with large-scale massive transient volcanism during breakup between Greenland and Eurasia 56–55 Ma. Huge extrusive and intrusive constructions onshore and along the rifted margins remain from this important event.

The Arctic realm farther north contains several post-Jurassic volcanic provinces, i.e. onshore Canadian Arctic, North Greenland, Svalbard, and Franz Josef Land. Compared to LIPs elsewhere, these provinces are poorly mapped and dated, and the understanding of Arctic LIPs is still in its infancy. Present dating appears to indicate two potential events in early and late Cretaceous in the eastern and western Arctic, respectively. Moreover, the origin of the Alpha Ridge is still controversial and a key question is whether it is coeval with the Canadian Arctic volcanism, possibly constituting a LIP.

One also has to consider its relationship with the 30–40 m.y. older event in Svalbard and Franz Josef Land, the nature of post-Eocene Yermak Plateau-Morris Jesup Rise events, as well as the Neogene volcanism in Svalbard. As more data emerge, the Arctic may figure prominently in the global LIP inventory.

5. References

COFFIN, M. F. & ELDHOLM, O. (1994): Large Igneous Provinces, Crustal structure, dimensions, and external consequences. – Rev. Geophys., **32**: 1–36

ENGEN, Ø., ELDHOLM, O. & BUNGUM, H. (in prep): The Arctic plate boundary

ELDHOLM, O., KARASIK, A. M. & REKSNES, P. A. (1990): The North American plate boundary. – In: GRANTZ, A., JOHNSON, G. L. & SWEENEY, J. (Eds.): The Arctic Ocean Region, v. L, The Geology of North America, Geol. Soc. Am., Boulder/Colo.: 171–184

GRACHEV, S. S., JOHNSON, G. L., LAXON, S. W., MCADOO, D. C. & KASSENS, H. (1999): Main structural elements of eastern Russian continental margin derived from satellite gravity and multichannel seismic reflection data. – In: KASSENS, H. et al. (Eds.): Land-Ocean systems in the Siberian Arctic; dynamics and history, Berlin: 667–682

JOHNSON, G. L. & HEEZEN, B. C. (1967a): The Arctic Mid-Oceanic ridge. – Nature, **215**: 724

JOHNSON, G. L. & HEEZEN, B. C. (1967b): Morphology and evolution of the Norwegian-Greenland Sea. – Deep-Sea Res., **14**: 755–771

JOHNSON, G. L. & RICH, J. E. (1986): A 30 million year cycle in Arctic volcanism? – J. Geodyn., **6**: 111–116

KRISTOFFERSEN, Y. (1998): The Eurasia Basin, An update from a decade of geoscientific research. – Polarforschung, **68**; 11–18

TALWANI, M. & ELDHOLM, O. (1977): Evolution of the Norwegian-Greenland Sea. – Geol. Soc. Am. Bull., **88**: 969–999

VOGT, P. R. (1986): Geophysical and geochemical signatures and plate teconics. – In: HURDLE, B. G. (Ed.): The Nordic Seas, New York: 237–410

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