Polarforschung 48 (1/2): 20—30, 1978

Arctic Basin Morphology*

By G. L. Johnson, P. T. Taylor, P. R. Vogt and J. F. Sweeney **

Abstract: The geomorphology of the Arctic is complex. Major features found within the Arctic Basin include a spreading center (Nansen Ridge); a continental fragment (Lomonosov Ridge); marginal plateaux (Morris Jesup, Yermak and Chukchi); and a large ridge complex of unknown genesis (Alpha-Mendeleev). However, enough geophysical data are now known to partially unravel the history of the Arctic Basin: 38 mybp Yermak and Morris Jesup Plateaux separated; 60 mybp Lomonosov Ridge was rifted away from the Eurasia continental block; 70—80 mybp Alpha-Mendeleev Ridge was probably shifted away from near Lomonosov Ridge by sea floor spreading; and in the late Jurassic-early Cretaceous the Arctic Alaska plate rotated away from the Canadian Arctic Archipelago to create the Canada Basin.

Zusammenfassung: Die Geomorphologie der Arktis ist komplex. Die wichtigsten Hauptstrukturen, die im Arktischen Becken gefunden wurden, umfassen ein Ausweitungs-Zentrum (Nansen-Rücken), ein kontinentales Bruchstück (Lomonosow-Rücken), randliche Plateaus (Morris Jesup, Yermak und Tschuktschen Pl.) und einen großen Rücken-Komplex unbekannter Entstehung (Alpha-Mendelejew). Jetzt liegen jedoch genügend geophysikalische Daten vor, um die Geschichte der Entstehung des Arktischen Beckens teilweise zu enträtseln: vor 38 Mill. Jahren wurden die Yermak- und Morris-Jesup-Plateaus abgetrennt. Vor 60 Mill. Jahren wurde der Lomonosow-Rücken vom eurasischen Kontinentalblock abgespalten. Vor ca. 70 Mill. Jahren wurde möglicherweise der Alpha-Mendelejew-Rücken vom nahe gelegenen Lomonosow-Rücken durch Meeresboden-Ausweitung abgetrennt. In der Oberjura-Unterkreide-Zeit drehte sich die arktische Alaska-Platte vom kanadisch-arktischen Archipel weg, wobei sich das Kanadische Becken bildete.

INTRODUCTION

The morphology of the Arctic Basin is slowly being revealed by data from drifting ice island expeditions, icebreakers working the peripheral edges, under-ice nuclear submarines, ice landings by aircraft, and by inference from aeromagnetic surveys.

Under the auspices of the International Hydrographic Organization and the Intergovernmental Oceanographic Commission of Unesco, a fifth edition of the General Bathymetric Chart of the Oceans (GEBCO) is under construction. Fig. 1 is an abstract of the Arctic Basin section sheet 5.17 of the GEBCO series. Sheet 5.17 is a polar projection and extends to 64°N as its southern border ***.

In this paper, we shall consider only the abyssal morphology; the bordering continental shelf areas and Norwegian Greenland Sea have generally been more extensively studied. Representative marginal seas studies include: (1) Barents Sea (KLENOVA, 1960; ELDHOLM & TALWANI, 1977); (2) Norwegian/Greenland Sea (JOHNSON et al., 1975; ELDHOLM & SUNDOVER, 1978; PERRY et al., 1977; GRONLIE & TALWANI, 1978); (3) Baffin Bay and the Northwest Territories (PELLETIER, 1966; SOBCZAK & SWEENEY, 1978); (4) Beaufort Sea (PRATT & WALTON, 1974); (5) Chukchi Sea (CREAGER & MCMANUS, 1965); (6) Laptev Sea (LOCKERMAN, 1968); and (7) Kara Sea (JOHNSON & MILLIGAN, 1967).

---

* Paper presented at the „Conference on Geophysics, Geology, Geomorphology and Geodesy of Spitsbergen", held by the German Society of Polar Research in Hamburg, October 2—3, 1978.
Earth Physics Branch Contribution No. 782

** Dr. G. L. Johnson, Office of Naval Research, Arlington, Virginia 22217 (USA).
Dr. P. T. Taylor, NORDA, Bay St. Louis, Mississippi 39529 (USA).
Dr. P. R. Vogt, Naval Research Laboratory, Washington, D. C. (USA).
Dr. J. F. Sweeney, Earth Physics Branch, Department of Energy, Mines & Resources, Ottawa, Ont. K1A OY3 (Canada).

*** These charts are available from the Hydrographic Chart Distribution Office, Department of Fisheries and the Environment, 1675 Russell Road, Ottawa, Ontario, Canada KlG 3H6, for cost of $ 5.

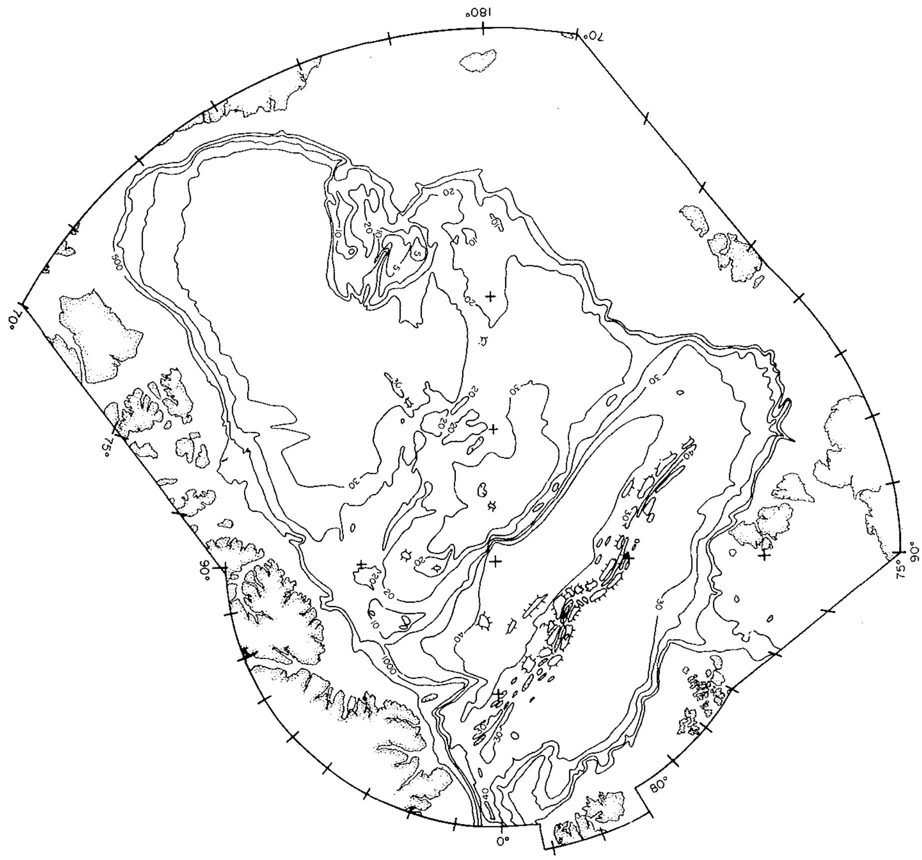

Fig. 1: Bathymetric chart of the Arctic Basin. This is a simplification of the GEBCO sheet 5. 17. Contour are in meters at 1000 meter interval except for the 500 m isobath.

Abb. 1: Tiefenlinienplan des Arktischen Beckens. Dies stellt eine Vereinfachung des GEBCO-Blattes 5.17 dar. Umrisse sind in 1000-m-Abständen mit Ausnahme der 500-m-Tiefenlinie eingetragen.

ABYSSAL GEOMORPHOLOGY

Continental Slope

The Arctic Ocean is unique among the oceans of the world in that 49% of its area is underlain by continental shelf (SOBCZAK & SWEENEY, 1978). The shelf is not of uniform extent, being several times wider off the Eurasian coast than off the North American coast. Seaward of Alaska, Canada and Greenland, the shelf is 100—200 km wide, whereas the East Siberian Shelf and the Barents and Kara Sea shelves range from 500 to 1700 km in width (OSTENSO, 1962). As noted by PELLETIER (1966) well developed northward drainage systems existed during the Tertiary in the Canadian Arctic.

The continental slope is generally defined by the 200 m isobath except seaward of Greenland where the shelf is up to 500 m deep, and its slopes are often cut by large canyon systems. Barrow Canyon incising the shelf 150 km west of Pt. Barrow underlies axis of a surface current flowing northward through Bering Strait and along the Alaskan Coast (LEPLEY, 1962). Many other canyons are known on the continental slope north of Alaska (CARSOLA, 1954). Farther east, Mackenzie Canyon extends across the shelf beyond the Mackenzie Delta and then descends down the continental slope. Many other canyons cross the Canadian Shelf in the vicinity of the straits between islands of the Northwest Territories (PELLETIER 1966). Fig. 1 also suggets that large canyons are present along the Eurasian continental margin between 65° E and 130° E longitude.

Marginal Plateaux

The Chukchi Plateau (Fig. 2) is used in this paper to refer to the entire Plateau complex between 150° and 170° E. The Plateau flanks the southern end of the Canada Basin and extends north from the Chukchi Shelf. The Plateau is divided into two parts by a

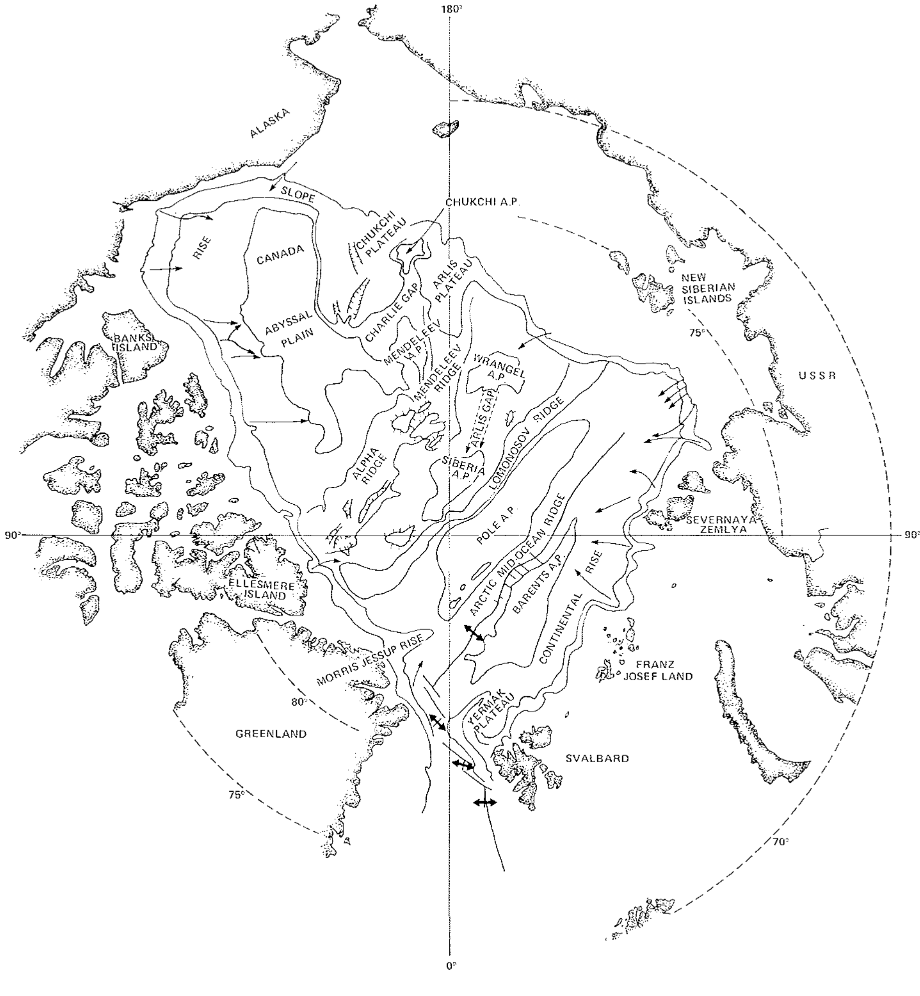

Fig. 2: Physiographic province chart of the Arctic Basin. Thin arrows denote possible submarine canyons, heavy arrows active spreading centers.

Abb. 2: Physiographische Gliederung des Arktischen Beckens. Pfeile bedeuten mögliche untermeerische Canyons.

northerly striking deep of apparent structural origin which contains a local perched plain (Northwind Plain) (AMERICAN GEO. SOC., 1975) (Fig. 2). The western portion of the Chukchi Plateau is crowned by the Chukchi Cap which has a diameter of about 100 km and an average depth of about 300 m. The surface is marked by small-scale relief of 5 to 30 m which is probably the result of ice gouging at lower sea levels (HUNKINS, 1968). Southeast of the Chukchi Cap, across the Northwind Plain, is the Northwind Cap. It is somewhat deeper (contained by the 1000 m isobath) than the Chukchi Cap. This region has been described as a "continental borderland" by FISHER et al. (1958). The Chukchi Plateau apparently is continental in origin and represents a subsided block. At 180° the Arlis Plateau forms the junction between the Mendeleev Ridge and the continental shelf. This Plateau is separated from the Chukchi Plateau by the Chukchi Abyssal Plain. The Plateau appears to be broken into at least two segments generally defined by the 1500 m isobath (Fig. 1).

The two other marginal plateaux are the Morris Jesup Rise seaward of northern Greenland and the Yermak Plateau north of Svalbard (Fig. 2). FEDEN et al. (1979) postulated that these plateaux represent paired aseismic ridges composed of anomalous (Iceland-like) oceanic crust. Magnetic lineations northeast of the plateaux suggest they were formed primarily between 55 and 38 m. y. b. p. and probably were emergent until about early Miocene time. The Yermak and Morris Jesup plateaux may thus reflect the existence of a mantle hot spot. This Yermak hot spot may still be active, to judge from late Cenozoic volcanism in northwest Svalbard and high amplitude magnetic lineations on the Nansen Ridge between the plateaux (FEDEN et al., 1979).

Continental Rise and Abyssal Plains

Arctic continental rises are generally wide and well developed. Seaward of Canada the rise is up to 500 km wide and north of the Barents Sea 200 km wide. As noted by HUNKINS (1968), submarine channels are common in those few areas that have been surveyed. This is not surprising considering the drainage patterns which must have existed during lower sea levels and the Tertiary (PELLETIER, 1966).

An abyssal plain is defined as a flat portion of the sea floor with gradients less than 1:1000 (HEEZEN et al., 1959).

The existence of the Barents Abyssal Plain (AP) (Fig. 2) was predicted by HEEZEN & LAUGHTON (1963). This plain fills the depression between the Mid-Oceanic Ridge and the Eurasian Continental Shelf. The plain lies at depths of 3500 to 3900 m with the deeper portions found at the southern and western extremities. The principle sources of terrigenous material forming the Barents AP must be the Ob and Yenisey rivers which have built an extensive delta system in the Kara Sea (JOHNSON & MILLIGAN, 1967). During glacial ages sediment was probably discharged from ice-front deltas along the shelf edge.

The Pole Abyssal Plain first discovered by U. S. nuclear submarine Nautilus (DIETZ & SHUMWAY, 1961) lies between the Mid-Oceanic Ridge and the Lomonosov Ridge (Figs. 1 and 2). This abyssal plain is on the average several hundred metres deeper than the Barents AP, and lies enclosed by the 4000 m isobath (AMERICAN GEO. SOC., 1975). Therefore, the Mid-Oceanic Ridge which separates these basins has evidently acted as a dam to sediment originating on the shelves of the Kara Sea and Barents Sea. The greatest depth of the Pole Abyssal Plain (4300 m) occurs near the North Pole, suggesting that the primary sediment sources are from the two landward ends. The Lena river must be a major contributor of sediment (Fig. 1). JOHNSON (1969) noted prominent sub-bottom layers, usually three in number, on 12 kHz echograms from the deepest portion of this abyssal plain. Seismic reflection data indicate a sediment thickness of 500 to 1500 m (KISELEV, 1966).

The Siberia AP (Fig. 2) (also known as Fletcher AP) lies between the Lomonosov and Alpha Ridges at a depth of 3900 m. It is fed by the shallower perched Wrangel AP which lies at 2800 m. A complex series of sea channels connect the two plains in the Arlis Gap region and presumably act as the sediment conduit (KUTSCHALE, 1966). Arlis Gap is a northwest striking structural high which has dammed a thick sequence of sediments to form the perched Wrangel AP. KUTSCHALE (1966) estimated that at least 3.5 km of sediments are present and DE LAURIER (1978a) suggests 4 km.

The Mendeleev AP lies seaward of the perched Chukchi AP and is presumably fed by it. The Mendeleev AP lies at depths of about 3300 m and the Chukchi at 2200 m (HALL, 1970). Hall measured more than 2 kilometers of sediment beneath Mendeleev AP with no indication of basement.

The largest abyssal plain is the Canada AP (Fig. 2) which covers an area of about 254,000 km^2 (HUNKINS, 1968). Its deepest point is slightly in excess of 3800 m. The Canada AP may be connected and fed by inter-plain channels from the Mendeleev AP.

Mid-Oceanic Ridge

The morphology of the Eurasian Arctic basin is dominated by the Mid-Oceanic Ridge (Nansen Ridge). The Soviets have named the Arctic portion of the Mid-Oceanic Ridge Gakkel Ridge and have applied two names to different portions of the central rift valley (Sedov and Hydrographer valleys) (JOHNSON, 1969; TRESHNIKOV et al., 1967). An extension of this world-encircling ridge through the Arctic Basin was first suggested on the basis of a well-defined pattern of earthquake epicentres and a few soundings (GAKKEL, 1962; HEEZEN & EWING, 1961). Present knowledge of the ridge morphology is based on echograms obtained by submarines operating beneath the sea ice cover (DIETZ & SHUMWAY, 1961; JOHNSON & HEEZEN, 1967; VOGT et al., 1979; FEDEN et al., 1979).

The Arctic Mid-Oceanic Ridge abruptly commences seaward of the continental margin of Greenland. The base of the Greenland Continental Slope shows no topographical expression of the Mid-Oceanic Ridge, however, the relatively thick sedimentary blanket of the Greenland continental margin may mask the pertinent underlying tectonic trends. This abrupt appearance suggests the existence of a fracture zone parallel to the Spitsbergen and Molloy Fracture Zones (Fig. 2) (FEDEN et al., 1979; PERRY et al., 1977).

Within 10° of the Greenwich meridian, the ridge has a width of approximately 270 km (Fig. 1).Flanking topographical highs border a depressed axial region interpreted as a graben or central rift valley. This valley is distinctly developed in the area north of Spitsbergen with the adjacent rift mountains rising 2 km above the 4 to 5 km deep rift valley floor.

The Nansen Ridge between 0° W and 30° E is typified by segments of the crestal zone alternating with: (1) relatively shallow rift valley floor (3500—4000 m) and well developed elevated rift mountain provinces (shallower than 2500 m); and (2) a deep rift valley floor (4700—5300 m) and deeper, more subdued flanking rift mountains (2500—3000 m). The former type of spreading axis is associated with a relatively intense axial magnetic anomaly and the latter with very low axial anomaly amplitudes. VOGT et al.

(1979) suggest that the higher magnetic anomaly amplitudes and shallower valley floors may be the result of greater basalt productivity and a thicker magnetic layer. The Mid-Oceanic Ridge seaward of the Laptev and Kara Seas (Fig. 1) becomes a relatively subdued feature. The most likely interpretation seems to be that the sediment which poured into the Arctic Basin from the Lena, Ob and Yenisey rivers have been sufficient, in quantity, to bury the very slowly spreading Laptev end of the ridge (JOHNSON, 1969).

The presence of fracture zones is hard to prove with present fragmentary data. Aeromagnetic data suggest that the axis has few significant offsets contrary to some earlier interpretations (AMERICAN GEO. SOC., 1975). In Fig. 2, a large fracture zone or series of fracture zones is probably present at about 90° E in order to explain the abrupt offset in the otherwise remarkably straight ridge axis and associated epicenter pattern.

Lomonosov Ridge

Lomonosov Ridge is a flat-topped ridge extending some 1800 km from the continental shelf north of Ellesmere Island to the continental shelf of Eurasia, north of the New Siberian Islands. Its width varies from almost 200 km at its approach to the continental shelves but narrows to about 20 km near the north pole where the ridge appears to be dextrally displaced by about 80 km.

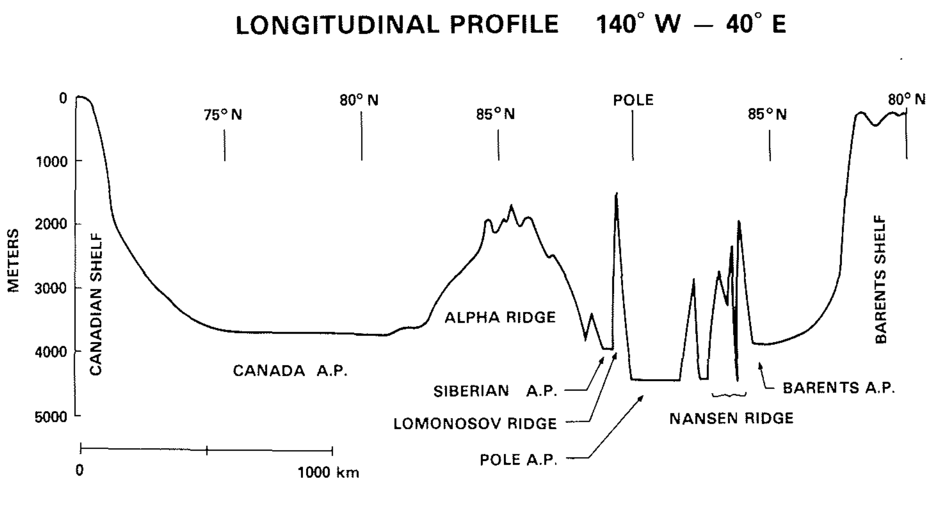

Fig. 3: Idealized profile across the Arctic Basin.

Abb. 3: Idealisiertes Profil durch das Arktische Becken.

The Lomonosov Ridge is outlined by the 2000 m isobath (Fig. 1). There is a sill approximately 1600 meters deep which separates Lomonosov Ridge from the continental margin of Ellesmere Island; whereas on the Soviet side however, the ridge appears morphologically to merge with the continental margin. This may reflect the burial of tectonic features by a prograding continental shelf. In the central region the shallowest recorded depth is 954 m (GORDIENKO & LAKTIONOV, 1960). The Canadian end of the ridge is triangular in shape and is enclosed by the 1000 m isobath. The minimum known depth of 373 m was recorded by HMS SOVEREIGN (GEBCO sheet 5. 17).

WILSON (1963) was the first to postulate that crustal growth along the present Arctic Mid-Oceanic Ridge has gradually separated the aseismic Lomonosov Ridge from the Eurasian continent. Morphologically, this ridge resembles the Jan Mayen Ridge which JOHNSON & HEEZEN (1967) postulated to be a fragment of the Greenland shelf that was split off during the most recent episode of sea floor growth.

The low amplitude of magnetic anomalies over much of the Lomonosov Ridge (COLES et al., 1978) suggests either a weakly magnetic crystalline basement or a deeply buried basement beneath the ridge crest. Seismic refraction studies (KISELEV, 1970; GRAMBERG & KULAKOV, 1975) indicate that the ridge is composed of two main structural units with different seismic velocities: a 1.8 to 2.0 km/s surface layer up to 1.0 km thick overlying a 3.0 to 4.0 km/s layer 2.5 to 3.0 km thick. Both units appear to be stratified. The upper unit may represent pelagic sediments of Tertiary (post rifting) age. Rocks of the lower unit do not possess seismic velocities similar to those either of crystalline basement or of oceanic layer 2 (KISELEV, 1970; SWEENEY et al., 1978a). Instead the 3.0—4.0 km/s-layer may represent Mesozoic platform rocks like those beneath the Barents Sea.

VOGT et al. (1979) analyzed aeromagnetic data from the Eurasia Basin. They were able to date the magnetic lineations and the separation of Lomonosov Ridge from Eurasia at or before anomaly 24 time (60 m. y. b. p., according to the HEIRTZLER et al., 1968 chronology, but probably about 55 m. y. b. p.). They do note that there is space for anomalies 25—27 between 24 and the continental margin and that a broad, low amplitude magnetic negative exists in their place. They hypothesize with KARASIK (1974) that either (a) anomalies 25—27 were either suppressed or erased by thick sediment fill, or by some other process associated with initial rifting, or (b) that the associated crust is subsided continental material.

Alpha Ridge

The Alpha-Mendeleev Ridge is a broad, rugged arch, which lies between the Lomonosov Ridge and the Canada Abyssal Plain (Figs. 1 and 2). The 200 meter isobath delineates its crestal region. It is a broader feature than the Lomonosov Ridge, ranging from 250 to 800 km in width. The Ridge strikes east-west from the Canadian continental margin to approximately 165° E longitude. At this point it joins or is continuous with the southeastward striking Mendeleev Ridge. It is unknown whether these two ridges are the same feature or two separate structures with coterminal ends. The 2500 meter isobath does include both the Alpha and Mendeleev Ridges. The Mendeleev Ridge, too, is a broad fractured arch although apparently not as rough in the crestal region as Alpha Ridge. HALL (1973), using seismic reflection records obtained over the Alpha Ridge from T—3, reported that up to 1200 m of sediments cover a mountainous 4.4 km/s to 5.5 km/s basement. Topographically the blocky relief of Alpha is lineated parallel to the regional trend, but the local ridges and valleys do not continue for any distance. The same is true of its magnetic signature (VOGT et al., 1979), which locally correlates directly with the bottom relief implying a highly magnetized basement of normal polarity (or induced magnetization). Satellite data over Alpha Ridge (LANGEL et al., 1975) reveal a long wavelength (> 1,000 km) magnetic anomaly similar to that reported by REGAN et al. (1975) over continental shields such as northern Greenland, as well as continental fragments such as the Seychelles (SWEENEY et al., 1978a).

TAYLOR (1978) reported that in the Siberia (Fletcher) Abyssal Plain linear sea floor spreading type magnetic anomalies may be present, suggesting this sea floor was formed by sea-floor spreading separating the Alpha and Lomonosov Ridges. We conclude the Alpha-Mendeleev Ridges are older features once closer to the Lomonosov Ridge. This does not solve the problem of origin of the Alpha-Mendeleev Ridges, although a continental origin (KING et al., 1966) is definitely not excluded. Difficulties with the "extinct spreading axis" hypothesis are discussed by VOGT & AVERY (1974) and DE LAURIER (1978b). Other workers have suggested that the ridge is an extinct spreading center (VOGT & OSTENSO, 1970), an extinct island arc/subduction zone (HERRON et al., 1974); or a hot spot trail (VOGT et al., 1979). Recent reviews of the various schools of thought are found in VOGT & AVERY (1974), CLARK (1975, 1979), VOGT et al. (1979), and SWEENEY et al. (1978a).

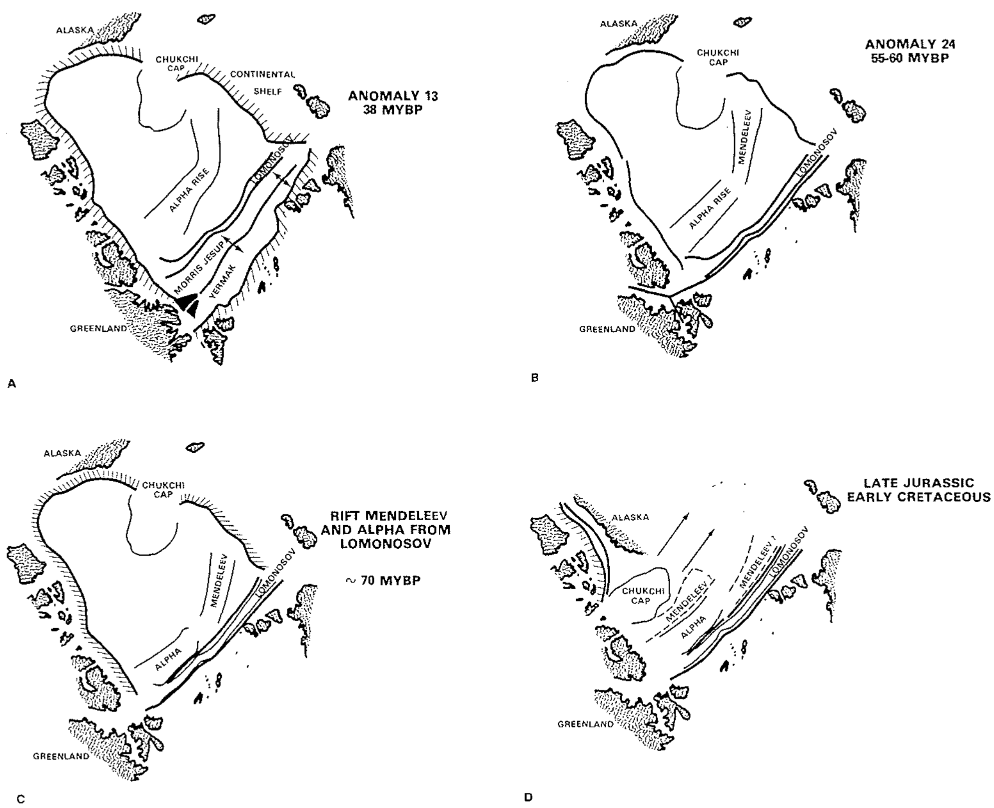

Fig. 4: Possible sequence of events in the evolution of the Arctic. A is based on FEDEN et al, 1979. B on SRIVASTAVA, 1978.

Abb. 4: Mögliche Abfolge der Ereignisse in der Entwicklung der Arktis. Skizze A basiert auf FEDEN et al. 1978, Skizze B auf SRIVASTAVA 1978.

Origin

Since the morphology reflects the origin as well as subsequent history of the sea floor, it is appropriate to summarize the present state of knowledge of the origin of the Arctic Basin and to make a few speculations.

The Eurasia Basin is well defined by magnetic anomalies which date the separation of the Yermak and Morris Jesup Plateaux at anomaly 13 time (38 m. y. b. p.) (FEDEN et al., 1979) and the separation of Lomonosov Ridge from Eurasia at or just before anomaly 24 time (60 m. y. b. p.) (VOGT et al., 1979). This is shown in Fig. 4, A and B. Alpha Ridge remains enigmatic in origin. However, following the suggestion of TAYLOR (1978) that there are sea-floor spreading-type anomalies between the Lomonosov and Alpha Ridges we infer the two ridges were at one time closer together (Fig. 4C). It is possible that the Alpha-Mendeleev massif is like the Lomonosov continental crust. However, the magnetic signatures and morphology of the two ridges are radically different (VOGT et al., 1979) and do not support a common origin. The generic relationships between the Alpha and Mendeleev Ridges are not clear. It would seem most likely that Mendeleev Ridge was a part of the Alpha Ridge although it may have been semi-detached. Mendeleev Ridge is assumed in Fig. 4C to be a part of the Alpha Ridge. Another possibility (Fig. 4D) is that it was a separate continental sliver lying between the Chukchi Plateau and the Alpha Ridge and due to a translation was moved contiguous with the termination of Alpha Ridge. This latter option is considered less likely. The date of the presumed rifting of Alpha Ridge from Lomonosov Ridge is uncertain (Fig. 4C). It might coincide with the initial rifting between Greenland and North America which according to SRIVASTAVA (1978) started during the lower Cretaceous and continued through anomaly 32 (75 m. y. b. p.). Anomaly 32 is the oldest anomaly that can be indentified in the Labrador Sea (SRIVASTAVA, 1978), and therefore, is a favorable time to rift Alpha Ridge from the Eurasian continental margin. Srivastavas' pole of opening at anomaly 32 time was located at 70.80° N 150.93° E and therefore allows the Arctic to be under a condition of tensional tectonic stress; contrary to earlier claims by PITMAN & TALWANI (1972) and HERRON et al. (1974).

If the speculations are correct, the linear anomalies reported by TAYLOR (1978) from the Siberia AP should be some portion of the sequence 25 to 32 with an axis of symmetry representing the extinct spreading center. Morphologic evidence for such an extinct axis awaits detailed reflection profiling.

Paleomagnetic data and evidence from regional structural and stratigraphic relationships in northern Alaska (NEWMAN et al., 1977) suggest that the rotation of the Arctic Alaska plate away from the Canadian Arctic Archipelago to create the Canada Basin began during the late Jurassic or earliest Cretaceous time. This rotation may have been a consequence of the earliest opening of the North Atlantic Ocean (SWEENEY et al., 1978b). Rotation would then be followed by southward translation of the entire rotated block away from the Alpha and Mendeleev Ridges. The inception of rotation may have been as early as the Triassic (NEWMAN et al., 1977; SWEENEY et al., 1978b), but no direct evidence of faulting of this age is seen in northern Alaska. YORATH & NORRIS (1975) also suggested spreading parallel to the Northwest Territories continental margin.

TAILLEUR (1973) and BOUCHER (1978) both support the rotation of Alaska away from the Canadian Archipelago. This conflicts with the schematic model of HERRON et al. (1974) for the Paleozoic and Mesozoic history of the Canada Basin. Their model requires, among other things, that the Kolymski Massif, now part of Siberia, slid into the Canada Basin in the early Paleozoic and collided with Arctic Canada in order to form the Franklinian fold belt. Kolymski supposedly then slid back out again in the Jurassic. The presence of Alaska adjacent to Arctic Canada obviates the necessity to slide the Kolymski Massif into the Canada Basin and then out again, as Alaska assumes the role of the land mass needed to form the Franklinian fold belt by collision against the Canadian land mass as implied by TAILLEUR (1973). SWEENEY et al. (1978b) suggested that the rotation of Alaska and the Chukotak Peninsula was complete by mid-Cretaceous time (100 m. y. b. p.).

If these recent speculations have merit then magnetic lineations of the late Jurassic-early Cretaceous Keathley (M) sequence (155 to 115 m. y. b. p.) would not be unexpected in parts of the Canada Basin.

The Arctic region, as revealed by reconnaissance magnetic and bathymetric data, is an area of complex volcanic and tectonic origins and subsequent modification. Continental fragments lie between regions with abyssal depths that were produced by sea floor spreading. The mechanisms producing the sea-floor where: (1) early rotation between two continental masses (Alaskan and Canadian) similar to the creation of the Bay of Biscay (WILLIAMS & MCKENZIE, 1971); (2) sea floor spreading in the Siberian (or Fletcher) abyssal plain; (3) an active spreading axis (Nansen Ridge). The mid-ocean ridges responsible for the first two spreading episodes have presumably subsided and their morphologic remains are deeply buried beneath abyssal plain sediments. Obviously, until we are able to obtain geologic samples from these older regions our knowledge of the Arctic must remain largely speculative.

References

American Geographic Society (1975): Map of the Arctic Region. — New York, N. Y.

Boucher, G. (1978): Rotation of Alaska and the opening of the Canada Basin. — USGS open file report: 78—96.

Carsola, A. J. (1954): Submarine canyons on the Arctic slope. — J. Geol. 62: 605—610.

Clark, D. L. (1975): Geological history of the Arctic Ocean Basin. — In: C. J. Yorath, E. R. Parker & D. J. Glass, eds., Canada's Continental Margins and Offshore Petroleum Exploration, Can. Soc. Petrol. Geol. Mem. 4: 501—524.

Clark, D. L. (1979): Geology and geophysics of the American Basin. — In: A. E. M. Nairn & F. Stehli, eds., The Ocean Basins and Margins, Vol. 5, The Arctic, in press.

Coles, R. L., Hannaford, W. & G. V. Haines (1978): Magnetic anomalies and the evolution of the Arctic. — In: J. F. Sweeney, ed., Arctic Geophysical Review, Pub. Earth Phys. Br. 45 (4): 51—66.

Creager, J. S. & D. A. McManus (1965): Bathymetry of the Chukchi Sea: Drainage Patterns on the Floor of the Chukchi Sea. — Marine Geology 3: 279—290.

De Laurier, J. M. (1978a): Arctic Ocean sediment thicknesses and upper mantle temperature from magnetotelluric soundings. — In: J. F. Sweeney, ed., Arctic Geophysical Review, Pub. Earth Phys. Br. 45 (4): 35—50.

De Laurier, J. M. (1978b): The Alpha Ridge is not a spreading centre. — In: J. F. Sweeney, ed., Arctic Geophysical Review, Pub. Earth Phys. Br. 45 (4): 87—90.

Eldholm, O. & E. Sundvor (1978): The Continental Margins of the Norwegian — Greenland Sea: Recent results and outstanding problems. — Phil. Trans. Royal Soc. London, in press.

Eldholm, O. & M. Talwani (1977): Sediment distribution and structural framework of the Barents Sea. — Geol. Soc. of Am. Bull. 88: 1015—1029.

Fisher, R. L., Carsola, A. J. & G. Shumway (1958): Deep-sea bathymetry north of Pt. Barrow. — Deep-Sea Res. 5: 1—6.

Feden, R. H., Vogt, P. R. & H. S. Fleming (1979): Magnetic and Bathymetric evidence for the "Yermak" hot spot northwest of Svalbard in the Arctic Basin. — Earth Planet. Sci. Lett, in press.

Gakkel, Ya. Ya. (1962): The exploration and development of polar lands. — In: C. D. Harris, ed., Soviet geography, accomplishments and tasks, 265—274, Am. Geo. Soc. Occ. Publ. 1, New York.

Gordienko P. A. & C. D. Laktionov (1960): Principal results of the latest oceanographic research in the Arctic Basin. — Akad. Nauk. SSSR. Investiga, Geog. Series 5: 22—35 (Tr. by E. R. Hope, Canada DRB T 350 R.)

Gramberg, I. S. & Yu. N. Kulakov (1975): General geological features and possible oil and gas provinces of the Arctic Basin. — In: C. J. Yorath, E. R. Parker & D. J. Glass, eds., Canada's Continental Margins and Offshore Petroleum Exploration, Can. Soc. Petrol. Geol. Mem. 4: 525—529.

Gronlie, G. & M. Talwani (1978): Bathymetry of the Norwegian-Greenland Sea. — Tech. Rep. Lamont-Doherty Geol. Obs., Palisades, N. Y.

Hall, J. K. (1970): Arctic Geophysical Studies, the Alpha Cordillera and the Mendeleev Ridge. — New York, Columbia Univ. Ph. D. dissert., 125 pp.

Hall, J. K. (1973): Geophysical evidence for ancient sea-floor spreading from Alpha Cordillera and Mendeleev Ridge. — In: M. G. Pitcher, ed., Arctic Geology, Am. Assoc. Petrol. Geol. Mem. 19: 542—561.

Heezen, B. C. & M. Ewing (1961): The Mid-Oceanic Ridge and its extension through the Arctic Basin. — In: G. O., Raasch, ed., Geology of the Arctic, Toronto, vol. 1: 636—638.

Herron, E. M., Dewey, J. F. & W. C. Pitman III (1974): Plate tectonics model for evolution of the Arctic. — Geology 2: 377—380.

Hunkins, K. (1968): Geomorphic Provinces of the Arctic Ocean. — In: J. E. Sater, ed., Arctic Drifting Stations, 365—376, Montreal, Arctic Institute of North America.

Hunkins, K., Herron T., Kutschale H. & G. Peter (1962): Geophysical Studies of the Chukchi Cap, Arctic Ocean. — J. Geophys. Res. 67: 235—247.

Johnson, G. L. (1969): Morphology of the Eurasian Arctic Basin. — Polar Record 14: 619—628.

Johnson, G. L. & B. C. Heezen (1967): Morphology and evolution of Norwegian-Greenland Sea. — Deep-Sea Res. 14 (6): 755—771.

Johnson, G. L., McMillan, N. J. & J. Egloff (1975): East Greenland Continental Margin. — In: C. J. Yorath, E. R. Parker & D. J. Glass, eds., Canada's Continental Margins and Offshore Petroleum Exploration, Can. Soc. Petrol. Geol. Mem. 4: 205—224.

Johnson, G. L. & D. B. Milligan (1967): Some geomorphological observations in the Kara Sea. — Deep-Sea Res. 14 (1): 19—28.

King, E. R., Zeitz, I. & L. R. Alldredge (1966): Magnetic data on the structure of the central arctic region. — Geol. Soc. Am. Bull. 77: 619—646.

Karasik, A. M. (1974): The Euro-Asian Basin of the North Polar Ocean from the standpoint of plate tectonics. — In: Problems of the Geology of the polar regions of the Earth, Leningrad, 23—31 (in Russian).

Kiselev, I. G. (1966): [Several features in the contemporary, morphological tectonic structure of the Lomonosov Ridge according to seismic data]. — Nauchno-Issledovatel'skaya Komissiya Morskoyu Geofiziki (Gelendzhik) [Research Commission on Marine Geophysics (Gelendzhik)] (Unpublished manuscript).

Klenova, M. V. (1960): Geologiya Barentsova morya [Geology of the Barents Sea]. — Moscow, Izdatel'stvo Akademii Nauk SSSR.

Kutschale, H. (1966): Arctic Ocean Geophysical Studies. The Southern Half of the Siberia Basin. — Geophysics 31: 793—710.

Langel, R. A., Bensusen, S. J., Regan, R. D., Davis, W. M. & J. C. Cain (1975): High latitude magnetic anomaly maps (abs). — EOS, Trans. Am. Geophys. Union 56: 356.

Lepley, L. K. (1962): Submarine topography of the head of Barrow Canyon. — Deep-Sea Res. 9: 214—217.

Lockerman, R. C. (1968): Some summer oceanography features of the Laptev and East Siberia Seas. — U. S. Naval Oceanographic Office [Unpublished manuscript].

Newman, G. W., Mull C. G. & N. D. Watkins (1977): Northern Alaska Paleomagnetism, Plate Rotation and Tectonics. — Alaska Geol. Soc. Symposium, Anchorage, Alaska: 16—19.

Ostenso, N. A. (1962): Geophysical investigations of the Arctic Ocean Basin. — Research Report, University of Wisconsin, Geophysical and Polar Research Center, No 4 [Unpublished manuscript].

Pelletier, B. R. (1966): Development of Submarine Physiography in the Canadian Arctic and its relation to crustal movements. In: G. D. Garland, ed., Continental Drift, Toronto: 77—101.

Perry, R. K., Fleming, H. S., Cherkis, N. Z., Feden, R. H. & J. V. Massingill (1977): Bathymetry of the Norwegian-Greenland and Western Barents Sea. — Geol. Soc. Am. Map Ser. 21: Boulder, Col.

Pitman III, W. C. & M. Talwani (1972): Sea floor spreading in the North Atlantic. — Geol. Soc. Am. Bull. 83: 619—646.

Pratt, R. & F. Walton (1974): Bathymetric Map of the Bering Shelf. — Geol. Soc. Am. Inc., Boulder, Col.

Regan, R. D., Cain, J. C. & W. M. Davis (1975): A global magnetic anomaly map. — J. Geophys. Res. 80: 794—802.

Sobczak, L. W. & J. F. Sweeney (1978): Bathymetry of the Arctic Ocean. — In: J. F. Sweeney, ed., Arctic Geophysical Review, Pub. Earth Phys. Br. 45 (4): 7—14.

Sweeney, J. F., Coles, R. L., DeLaurier, J. M., Forsyth, D. A., Irving, E., Judge, A. S., Sobczak, L. W. & R. J. Wetmiller (1978a): Arctic geophysical review — a summary. — In: J. F. Sweeney, ed., Arctic Geophysical Review, Pub. Earth Phys. Br. 45 (4): 101—108.

Sweeney, J. F., Irving, E. & J. W. Geuer (1978b): Evolution of the Arctic Basin. — In: J. F. Sweeney, ed., Arctic Geophysical Review, Pub. Earth Phys. Br. 45 (4): 91—100.

Srivastava, S. P. (1978): Evolution of the Labrador Sea and its bearing on the early evolution of the North Atlantic. — Geophys. J. Royal Astr. Soc. 52: 313—357.

Taylor, P. T. (1978): Low level aeromagnetic data across the western Arctic Basin. — Trans. Am. Geophys. Union 59: 268—269.

Tailleur, I. L. (1973): Probable rift origin of the Canada Basin, Arctic Ocean. — Am. Assoc. Petrol. Geol. Mem. 19: 526—535.

Treshnikov, A. F., Balakshin, L. L., Belov, N. A., Demenitskaya, R. M., Dibner, V. D., Karasik, A. M., Shpasker, A. O. & N. D. Surgayeva (1967): Geograficheskiye naimenovaniya osnovnykh chastey rel'yefa dna arkicheskogo basseyna [Geographical names of the main features of the floor of the Arctic basin]. — Problemy Arktiki i Antarktiki 27: 5—15.

Vogt, P. R. & O. E. Avery (1974): Tectonic history of the Arctic Basins: Partial solutions and unsolved mysteries. — In: Y. Herman, ed., Marine Geology and Oceanography of the Arctic Seas, New York: 83—117.

Vogt, P. R. & N. A. Ostenso (1970): Magnetic and gravity profiles across the Alpha Cordillera and their relations to Arctic sea-floor spreading. — J. Geophys. Res. 75: 4925—4937.

Vogt, P. R., Taylor, P. T., Kovacs, L. C. & G. L. Johnson (1979): Detailed aeromagnetic investigation of the Arctic Basin. — J. Geophys. Res., in press.

Wilson, J. T. (1963): Hypothesis of earth's behaviour. — Nature 198 (4884): 925—29.

Williams, C. A. & D. McKenzie (1971): The evolution of the north-east Atlantic. — Nature 232: 168—173.

Yorath, C. J. & D. K. Norris (1975): The tectonic development of the southern Beaufort Sea and its relationship to the origin of the Arctic Ocean basin. — In: C. J. Yorath, E. R. Parker & D. J. Glass, eds., Canada's Continental Margins and Offshore Petroleum Exploration, Can. Soc. Petrol. Geol. Mem. 4: 589—611.