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Detailed Aeromagnetic Investigation of the Arctic Basin

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Systematic low-level aeromagnetic surveys conducted during 1974–1975 reveal details of the magnetic fabric in two parts of the Arctic Basin. These profiles extend coverage of the Nansen (Gakkel: Mid-Arctic) Ridge from 85.3°N, 13°E to 86°N, 50°E, where these new data overlap previous Soviet aeromagnetic coverage. Prominent magnetic lineations can be identified despite spreading half-rates as low as 0.3 cm/yr about 25–35 m.y. B.P. The separation of Lomonosov Ridge from Eurasia occurred at or before anomaly 24 time (55 m.y. B.P.). Although there is 'room' for anomalies 25–27 between 24 and the continental margin, a broad magnetic negative exists in their place. Either anomalies 25–27 were suppressed or erased by thick sediment fill or some other process associated with initial rifting, or the associated crust is subsided continental material. All anomalies, particularly the central anomaly, exhibit dramatic variations of amplitude along their strike. It is the low values of amplitude that are anomalous with respect to the Mid-Atlantic Ridge to the south. Bathymetric data demonstrate that the high central anomaly amplitudes correlate with shallower rift valley floors (3500–4000 m) and higher rift mountains. We propose that the pillow basalt layer (2a) is thicker in the magnetic high amplitude zones. There is no bathymetric evidence for sediment gaining access to the valley floor in the area examined. A second survey was flown across the northern Canada Basin and Alpha Ridge. Complex, but lineated, anomalies of 1500 to 2500 nT relief parallel the crest of Alpha Ridge. A crestal valley, 2500 m deep and 30 km wide, flanked by ridges with crests 1200–1500 m deep, correlates well with magnetic and gravity anomalies: this suggests that prominent Alpha Ridge magnetic anomalies are caused by basement topography of high magnetization (20–30 A/M) and normal polarity. If the Alpha Ridge is floored by an anomalous type of oceanic crust, it probably originated during the long mid-Cretaceous period of normal polarity. In the northern Canada Basin, several prominent linear anomalies cross the surveyed swath on strikes of 040°T to 065°T, subparallel to the Alpha Cordillera. If these lineations reflect sea-floor spreading and geomagnetic reversals (possibly during the lower Cretaceous to upper Jurassic), the spreading axis cannot have paralleled either the Canadian continental margin or the Alpha Ridge as has been proposed, but instead, lay parallel to the Northwind Escarpment.

1. INTRODUCTION

Geological knowledge of the central Arctic [*Demenitskaya and Hunkins*, 1970; *Ostenso*, 1974; *Vogt and Avery*, 1974; *Clark*, 1975, 1978] has not advanced as rapidly as in other ocean basins, primarily because the ice pack has kept out surface research vessels, including the *Glomar Challenger*. The potential of the nuclear submarine as a marine geophysical research platform remains unexplored. The Arctic, therefore, demands a greater reliance on magnetic data for crustal studies, since only the magnetic field can be readily charted by air. In this paper, we present new, detailed aeromagnetic studies of parts of the Arctic Basin.

From a plate tectonic viewpoint, the Arctic Basin between Eurasia and Lomonosov Ridge—the Eurasia Basin—has been considered relatively well understood. The Nansen (also Mid-Arctic or Gakkel) Ridge bisects this basin and represents an extension of the world-encircling, Mid-Oceanic Ridge (MOR) system [*Heezen and Ewing*, 1961]. As a rifted ocean basin, the Eurasia Basin was first thought to have opened 40 m.y.b.p. [*Vogt and Ostenso*, 1970]. More recent work suggests an age of ~60 m.y. [*Pitman and Talwani*, 1972; *Karasik*, 1974]. One of our objectives was to verify the latter age and expose details of the spreading history and present tectonic fabric not revealed by the earlier data. Of particular interest is the opportunity to study an exceptionally slow spreading (~0.5 cm/yr) branch of the MOR. By contrast, the Amerasia Basin has so far defied all attempts to ferret out its evolution [*Vogt and Avery*, 1974; *Clark*, 1978]. Our aeromagnetic work would, it was hoped, constrain the wide range of speculations so far entertained, which ranged from Mesozoic spreading [*Fujita*, 1978; *Herron et al.*, 1974] to subsided crystalline shield [*King et al.*, 1966; *Demenitskaya et al.*, 1973; *Taylor*, 1978].

In this paper, we present an interpretation of recently acquired aeromagnetic swaths across parts of the Amerasia and Eurasia basins (Areas A and B, Figure 1). Further analysis (for example, depth-to-source maps) is in progress. The aeromagnetic work constitutes a continuing NORDA-NRL joint project to map the magnetic anomalies of the Arctic Basin and thereby decipher its tectonic evolution.

The two survey swaths (Figure 1) were chosen to extend the detailed aeromagnetic coverage by the Naval Research Laboratory [*Phillips et al.*, 1978, and unpublished data]. Our tracks were oriented normal to the regional strike of the Nansen and Alpha cordilleras, and were spaced close enough, compared to anomaly wavelengths, that relatively unambiguous correlation and contouring could be attempted.

Both of these swaths overlap previous reconnaissance flights reported by *Ostenso and Wold* [1971], *Vogt et al.* [1971], and *Vogt and Ostenso* [1970]. The Eurasian Basin swath overlaps Soviet data of unknown quality and line spacing, thus far published only in 'zebra-stripe' residual form [*Karasik*, 1974]. Another of our objectives was to assess the quality of the Soviet data relative to our recently acquired measurements. High-level (3 km) relatively wide spaced (100 km) aeromagnetic data were also collected over a larger region, including our Areas A and B, by *Riddihough et al.* [1973] and *Coles et al.* [1976].

2. DATA COLLECTION AND PROCESSING

Two aircraft, both RP-3's, were employed in these surveys, Birdseye and Project Magnet. The Birdseye flights were executed in July–August, 1974, and October, 1975. The Project Magnet aircraft was used to collect profiles 1–8 and 19–28 (Figure 2) in the Summer of 1973. The flight specifications

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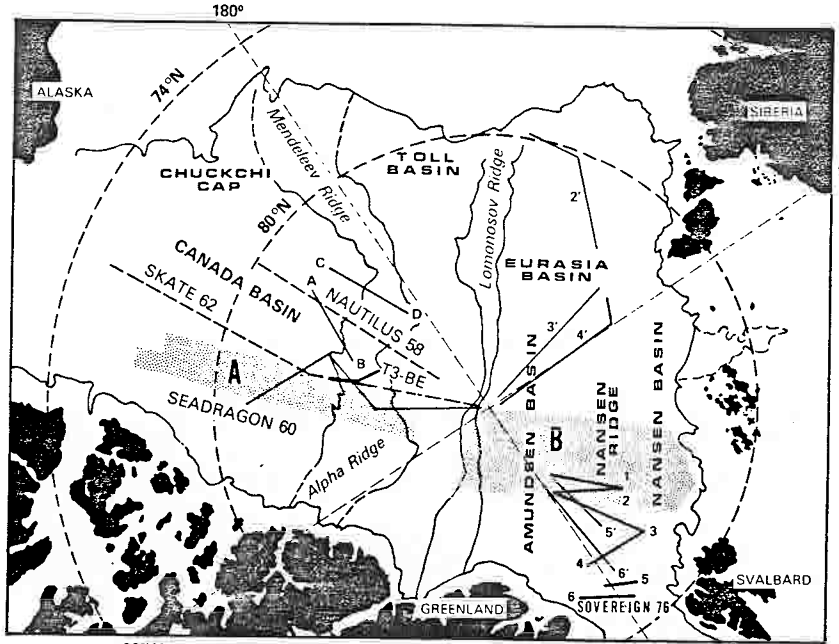

Fig. 1. Areas of detailed aeromagnetic surveying by the U.S. Naval Oceanographic Office over the Alpha Cordillera (A) and Eurasia Basin (B). Also shown are several of the topographic profiles collected by U.S. submarines over the Alpha Cordillera (Skate-62, Nautilus-58, Seadragon-60; Figure 17, from data of *Beal* [1968]) and in the Eurasia Basin (2'–6', Figure 8, from *Johnson and Heezen* [1967]); profiles 1–6, recently collected by British submarine HMS Sovereign (Figure 9); and three profiles (T3–BE [*Hall*, 1973] and CD, AB [*Hunkins*, 1961]) constructed from ice island data (Figures 16 and 17).

given here are modal values and may differ slightly in the surveyed areas. All magnetic data were recorded with cesium-vapor magnetometers on analog charts at a sampling rate of one measurement per second. Aircraft speeds were approximately 440 km/hr. Thus, the sampling rate is about one data point per 0.25 km. All tracks were flown at a nominal elevation of 300 m; line spacing varied from 9 to 17 km (Figures 2, 11). An inertial navigation system (LNT-51) was used throughout these surveys. Positions were recorded at intervals of five minutes or less. From base checks after each flight, the average drift rate was found to be less than 0.23 km per hour. Removal of the earth's main magnetic field differed between the Nansen Ridge and Alpha Cordillera areas. For the latter we used the IGRF [*Zmuda*, 1971] appropriate to the survey area and time. For the Nansen Ridge data, we used the IGRF for profiles 9–18 and the American World Chart (AWC) of *Peddie and Fabiano* [1976] for the remainder. No significant temporal magnetic disturbances occurred while experiments were underway.

3. THE NANSEN (MID-ARCTIC) RIDGE AND EURASIA BASIN

a. *Geological Interpretation*

When the magnetic anomaly profiles are plotted along the flight tracks (Figure 2), it becomes evident that the Eurasia Basin displays a pattern of linear magnetic anomalies such as characteristically produced by sea-floor spreading and geomagnetic reversals. Prominent lineations (1, 2, 5, 6, 13, 18, and 20–24 of the Cenozoic reversal pattern [*Heirtzler et al.*, 1968]) can be identified on most tracks and traced across the survey area (Figure 3). No major transform faults or other disruptions of the anomaly pattern (for example, seamount chains,) occur in this part of the Eurasia Basin. All lineations (1 through 24) execute a broad bend, concave toward the North Pole. The overall spreading geometry has thus remained unchanged since the Lomonosov Ridge separated from Siberia at or just before anomaly 24 time. In detail, there are minor irregularities in the anomaly pattern, some of which may be transform faults of short offset. Thus, three small fracture zones of 5 to 15 km displacement apparently exist along the present spreading axis in the eastern part of the survey area (Figure 3). Other researchers also found only small transform faults (less than 25 km offset) along the Nansen Ridge [*Karasik*, 1968; *Demenitskaya and Hunkins*, 1970]. On the whole, however, the Nansen Ridge-Eurasia Basin lineation pattern is remarkable for its continuity and simplicity, quite unlike the pattern of fracture zones predicted apparently on the basis of the limited bathymetric data, on the 1975 AGS chart (Figure 2). The AGS chart suggests fracture zones spaced about every 50 km, with rift valley offsets of about 20–40 km. Our magnetic data, however, do not confirm such a tectonic fabric. The position of the rift axis as revealed by the magnetic data lies some 70–90 km north of the AGS rift valley along the eastern and western thirds of the survey, but only 0 to 20 km to the north of the hypothesized rift valley in the middle of the area (Figure 2).

Earthquake epicenters (Figure 2) are too scattered and too few in number to confirm the detailed rift axis configuration indicated by the magnetics. In general, however, the epicenters lie closer to the magnetic axis than to the rift valley indicated on the AGS chart.

Having identified the most prominent lineations (5, 6, 13, and 20–24), we plotted them as a function of distance from the present spreading axis (anomaly 1). These distances are displayed as frequency histograms along the distance axis (Figure 4). Identified lineations generally lie within ±5 to 10% of their average distance from the axis. Some of this scatter may arise from anomaly misidentification. Such errors would tend to give rise to bimodal distributions, such as that for anomaly 20 (Figure 4). Despite the scatter in distances and the possibility

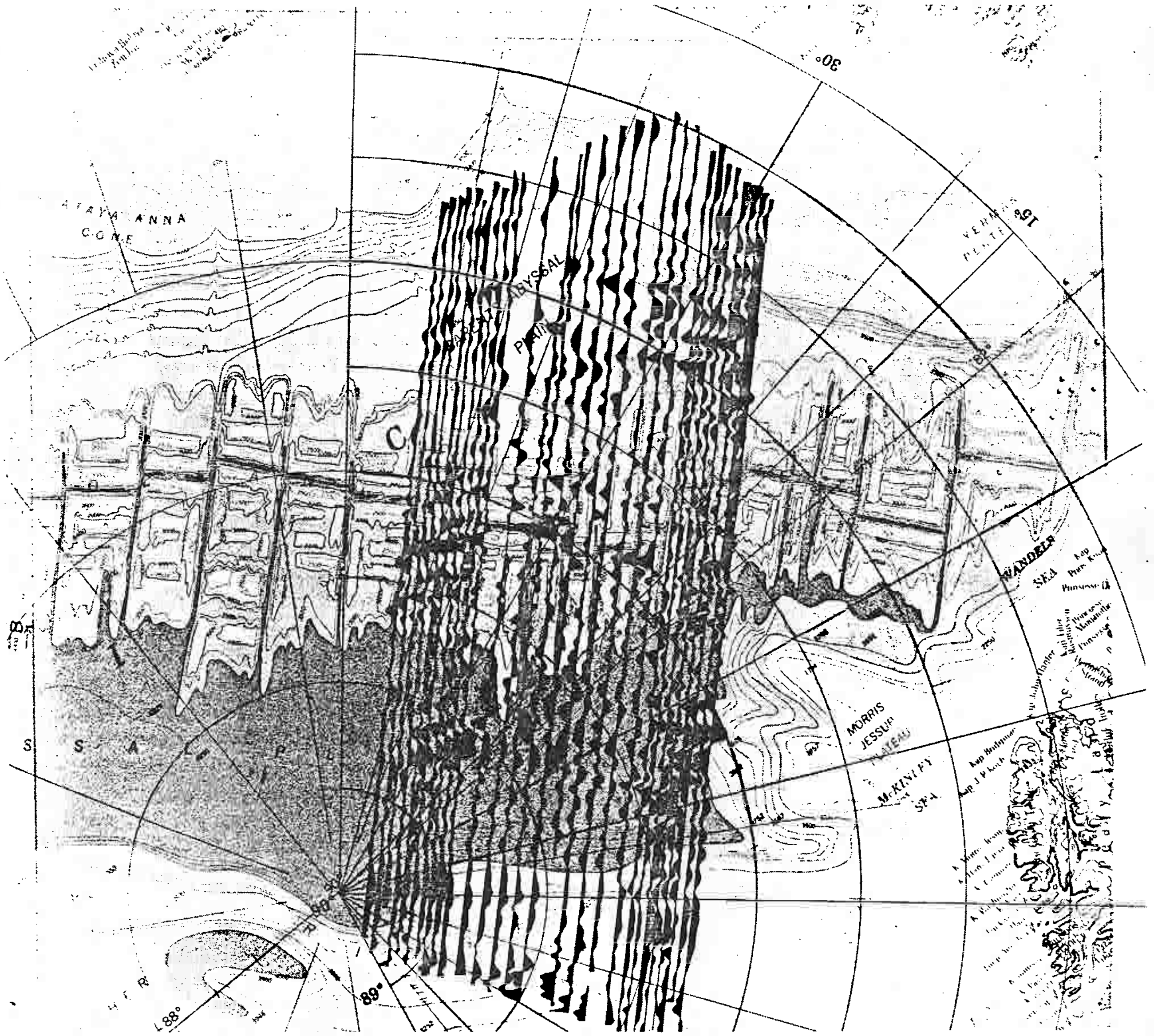

Fig. 2. Residual profiles plotted along flight tracks and superposed on *American Geographical Society* [1975] bathymetric chart (polar stereographic projection). Since subtraction of the IGRF (or the field of *Peddie and Fabiano* [1975]) leaves regional anomalies of −120 to −220 nT when averaged over pairs of adjacent tracks, such averages were added back to the anomaly profiles before plotting. White dots are earthquake epicenters, from the Environmental Sciences Services Administration (1970), 1961–1969, and updated through 1971 from data of the National Oceanic and Atmospheric Administration. Note difference between magnetically determined spreading axis (continuous white line) and rift valley axis previously hypothesized from widely spaced submarine tracks [*American Geographical Society,* 1975] such as those published by *Johnson and Heezen* [1967] and *Beal* [1968].

of occasional misidentifications, it is generally true that anomalies on the north (Lomonosov Ridge) flank lie closer to the spreading axis than do anomalies on the south (Siberian) flank. This relatively slight, but significant, asymmetry of spreading can be seen already for anomalies as young as 5 and 6, and becomes greater on older anomalies (anomaly 20 is the only exception, possibly because of misidentification on some profiles). The asymmetric spreading implied by age versus distance curves (Figure 4) confirms the results published by Soviet authors [*Karasik,* 1974].

Apparently this 'asymmetry' has persisted throughout the 60 m.y. history of spreading in the Eurasia Basin. The Lomonosov or north limb of the ridge spread at half-rates of around 80–95% the south flank half-rates. These estimates are not very accurate, since they are based on the slopes of the age-distance curves (Figures 4 and 5). The cumulative effect of spreading asymmetry is to leave the present axis somewhat closer to the Lomonosov Ridge than to the continental margin of Eurasia (as defined by the 2 km isobath). Asymmetric spreading in the Eurasia Basin is significant, but somewhat less in magnitude, compared to areas such as the Southeast Indian Ridge (up to 70–75%; *Hayes* [1976]) or in the Famous area (53%, 0–1.7 m.y., and 80%, 1.7–8.3 m.y. [*MacDonald,* 1977]). We cannot determine from our Arctic data whether or not the magnitude of spreading asymmetry changed abruptly, as in the Famous and southeast Indian areas. We also have not investigated the variation in asymmetry along the strike of the ridge. We note, however, that *Karasik* [1974] found the observed

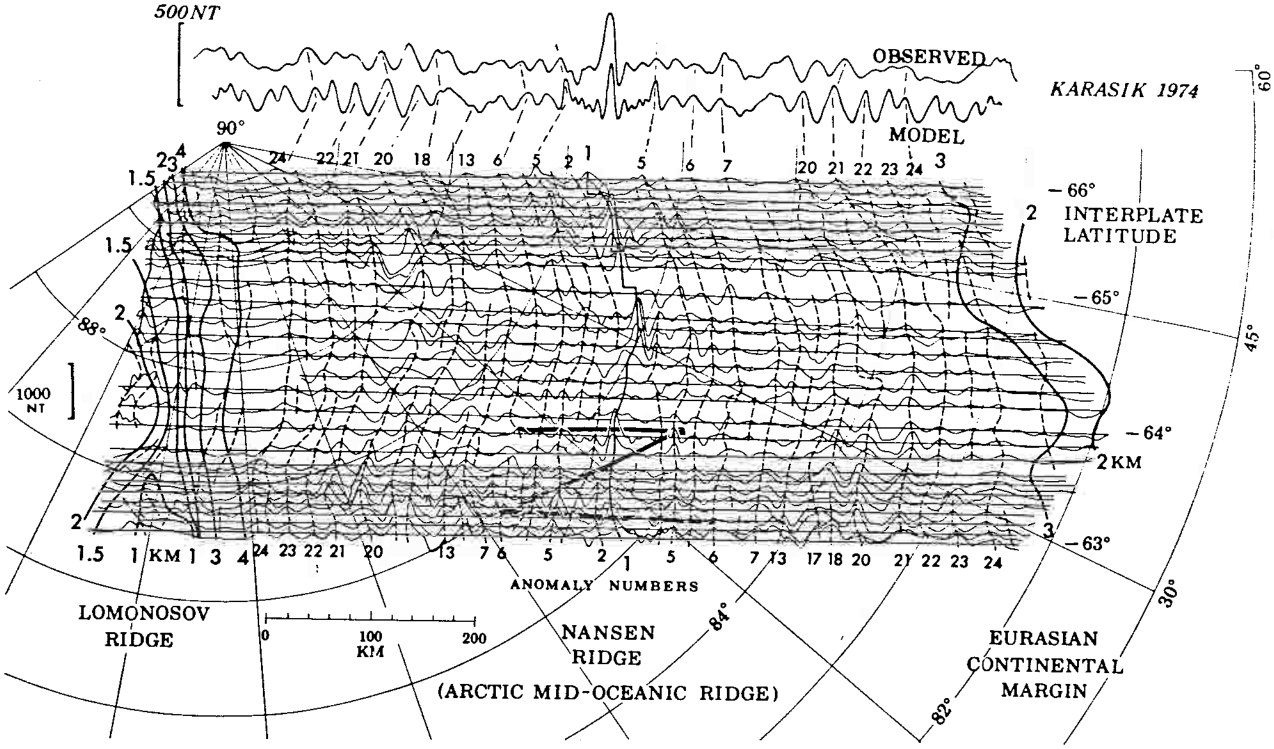

Fig. 3. Line traces of magnetic anomaly profiles across the Eurasian continental margin, Nansen and Lomonosov Ridges. The profiles have been adjusted upwards to make the average anomaly along each pair of adjacent tracks equal to zero (see Figure 2). Anomaly numbers after *Heirtzler et al.* [1968]; dashed lines connect similar anomalies across the survey area. Isobaths representing the Lomonosov Ridge and Eurasian continental margin are shown in kilometers; Nansen Ridge isobaths were omitted for the sake of clarity (see Figure 2). Observed and model profiles taken directly from *Karasik* [1974]; inferred anomaly correlations with the Soviet data are shown. Note different scale (500 nT) used to illustrate the *Karasik* [1974] profiles. Model spreading rate is plotted in Figure 5. Interplate latitudes refer to a post-10 m.y.b.p. opening pole at 65.5°N, 139.5°E [*Karasik*, 1974]. Heavy straight lines show locations of bathymetric traverses 1 and 2 (Figure 9).

spreading asymmetry (i.e., a faster southward half-rate) to be a general characteristic of the Eurasia Basin. If the asymmetry was accomplished by finite axis jumps, as documented along the Galapagos spreading axis [*Hey and Vogt*, 1977], then the jumps are probably too small to be resolved by near sea-surface magnetic data. Perhaps the asymmetric Arctic spreading is a continuous process, as suggested for the southeast Indian Ridge [*Hayes*, 1976].

The age versus distance data were visually fit by smooth curves rather than (as usually seen in the literature) linear segments connecting median or modal values for each anomaly. Our conclusions do not depend on which approach is used. As can be seen in Figure 4, the observed data cannot resolve high frequency information, if any, that might exist in the true age versus distance curve.

In constructing the age versus distance curves we used the anomaly ages given by *Heirtzler et al.* [1968]. Subsequent deep drilling in oceanic areas, and other data, led *Tarling and Mitchell* [1976] to propose a substantial revision in the Paleogene portion of the reversal sequence. Dashed curves in Figure 4 shows the age versus distance relation according to the reversal chronology of *Tarling and Mitchell* [1976]. Other proposed revisions of the reversal chronology [e.g., *Sclater et al.*, 1974; *LaBrecque et al.*, 1977] predict crustal ages intermediate between those derived from the Heirtzler et al. and Tarling-Mitchell scales.

Although anomaly 24 is the oldest identified lineation in the survey area (Figures 2, 3), there generally exists another 50 to 100 km between that anomaly and the physiographic margin of the Lomonosov Ridge (2 to 4 km isobaths) on the north and Eurasia to the south (1 to 3 km isobaths). However, a broad magnetic negative exists in the place of the anomalies 25–28, which would be expected over these marginal strips [*Karasik*, 1974]. There are at least three possible explanations: (1) the crustal strips beyond anomaly 24 represent deeply subsided and perhaps modified continental crust; (2) the strips are oceanic crust from an earlier episode of spreading, formed at a spreading rate high enough compared to the reversal frequency that no reversals are recorded; and (3) the strips are oceanic crust of anomaly 25–28 age, but whose magnetic expression has been erased by deep sediment burial and heating, or for some reason was not recorded in the earliest stages of spreading. We note that similar strips of pre-anomaly 24 'deep water' crust also exist in the Greenland-Norwegian Sea and between Reykjanes Ridge and the southeast Greenland margin [*Talwani and Eldholm*, 1977]. Perhaps marginal deep-water areas in these areas as well as the Eurasia Basin represent remnants of Mesozoic basins which controlled the line of initial spreading in a general way.

Because the Eurasia Basin is relatively close to the pole of opening for the rather slowly separating European and North American plates, the Nansen Ridge is one of the slowest spreading segments of the Mid-Oceanic Ridge. We first review the conclusions other authors have published on the basis of their aeromagnetic work [*Karasik*, 1974]. (The portion of the Soviet survey area overlapping ours is shown in Figure 6.) Averaged over the last 10 m.y., total opening rates at four sites on the Nansen spreading axis range from 1.05 cm/yr at

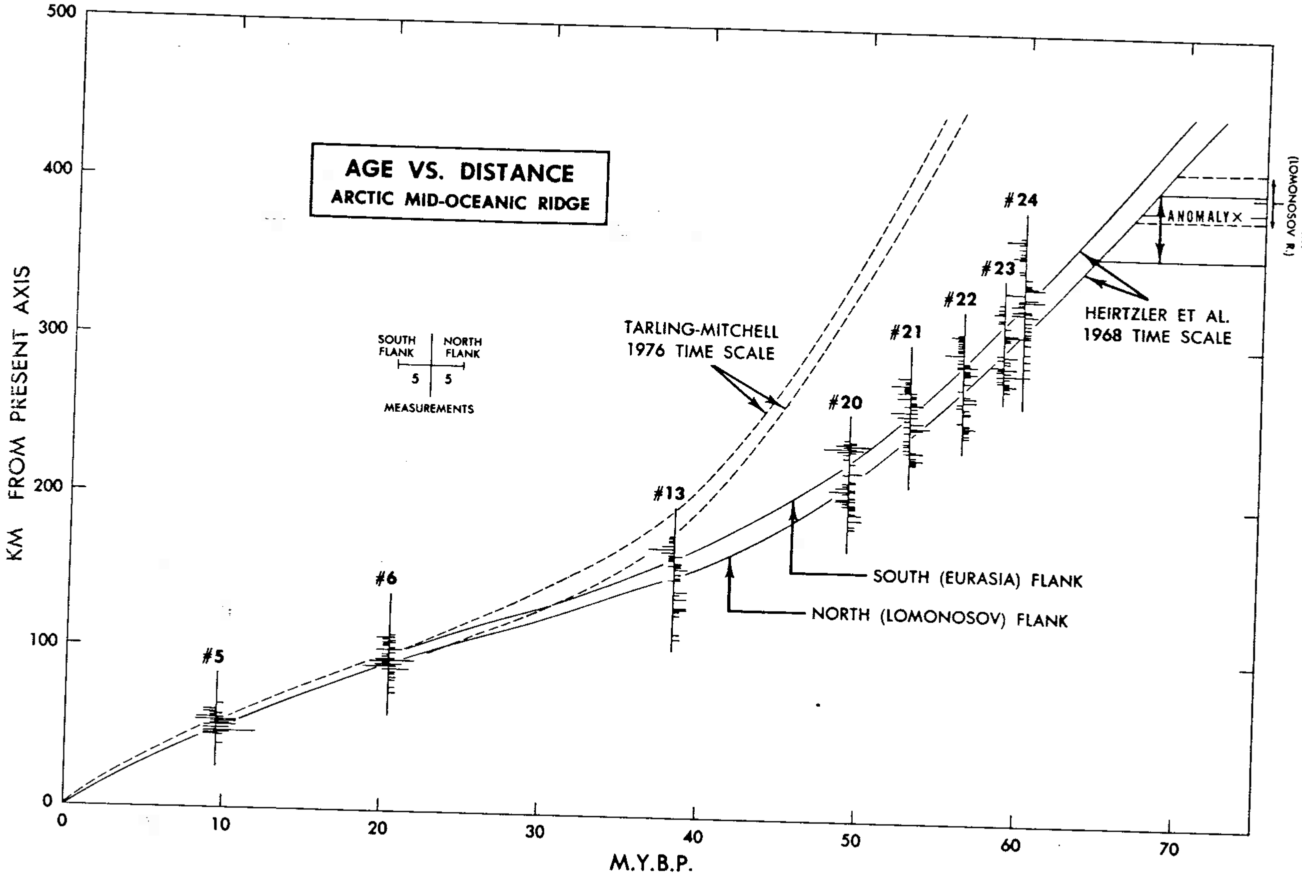

Fig. 4. Age of prominent magnetic lineations as a function of distance from present magnetic axis of Nansen Cordillera. Anomaly picks were plotted as bar histograms normal to vertical (time) lines giving age of anomaly according to scale of *Heirtzler et al.* [1968]. Values to the left of each vertical line represent anomalies on the south (Eurasia) flank of Nansen Ridge. Values to right represent anomalies on the north (Lomonosov Ridge) flank. Note that anomalies on north side of ridge are generally closer to axis than their counterparts on south side, thus indicating somewhat asymmetrical spreading. Dashed curve corresponds to anomaly ages proposed by *Tarling and Mitchell* [1976]. A curve generated from the *LaBrecque et al.* [1977] reversal chronology would lie between those plotted here. If ocean crust generated by spreading extends to 3 km isobath of Lomonosov Ridge, or to anomaly 'X' (Figure 3), the extrapolated age versus distance curve predicts crustal ages up to 68–70 m.y. on *Heirtzler et al.* [1968] scale, and 55 m.y.b.p. on Tarling-Mitchell scale.

86°39′N, 45°50′E (within the NAVOCEANO survey area) to 0.91 cm/yr at 80°36′N, 122°05′E. Half-rates, which are consistently 10–20% lower on the Lomonosov (Pole Abyssal Plain) flank of the Nansen Ridge, range from 0.35 to 0.57 cm/yr. The total opening rates of the Nansen Ridge are consistent (±10%), with numerous published values along the same plate boundary down to the Azores triple junction, provided the Eurasia/America plate rotation pole is near 65.5°N, 139.5°E [*Karasik,* 1974]. Using a model profile based on the reversal chronology of *Heirtzler et al.* [1968], Karasik computed average spreading half-rates of 0.5, 0.32, 0.30, 0.59, and 1.1 cm/yr for the time intervals bounded by 0, 10, 20, 38, 51, and 70 m.y.b.p. For the time interval between 60 and 70 m.y.b.p. (anomalies 25–29), the fit between Karasik's data (as well as our data) and the model profile is poor; thus, as discussed previously, the existence of ocean crust of this age remains problematical.

Our analysis confirms the conclusions of *Karasik* [1974]. Rather than fitting model profiles to the data by trial and error, we graphically differentiated the smooth age-distance curves of Figure 4. The resulting spreading rate history is shown in Figure 5. Since differentiation amplifies initial errors, we do not claim high accuracy for the spreading rate curves. In fact, it is not possible to distinguish between gradual and stepwise changes in spreading rate. However, we can draw three conclusions: (1) Spreading rate decreased from middle or early Paleogene time to a low in the middle Tertiary, and then increased once more in the late Tertiary. Absolute values depend on the reversal chronology used; however, the overall shape of the curve seems well-established and parallels the history of the same plate boundary in the Greenland-Norwegian Sea [*Talwani and Eldholm,* 1977] and on the Reykjanes Ridge south of Iceland [*Vogt and Avery,* 1974]; (2) the spreading rate has been higher on the southern (Eurasian) side of the axis; and (3) the spreading rate history of *Karasik* [1974] is essentially indistinguishable from that derived in this paper (a detailed comparison between the Soviet and NAVOCEANO data, summarized in Figure 6, is discussed later).

So far, we have considered only the identification of spreading anomalies and the consequences for the history of opening of the Eurasia Basin. Amplitudes of the anomalies are another parameter of potential geologic significance. For example, where the central anomaly is well-developed, the magnetization that has to be assigned to the central block is twice that of the flanking blocks [*Karasik,* 1974; *Phillips et al.,* 1978]. Studies of other spreading axes indicate that one component of the crustal magnetization experiences a rapid decay—to $1/e$ of its original value, within less than 0.6 m.y.—as a result of seawater alteration of titanomagnetite [e.g., *MacDonald,* 1977]. An unexpected result of the present survey, however, is the

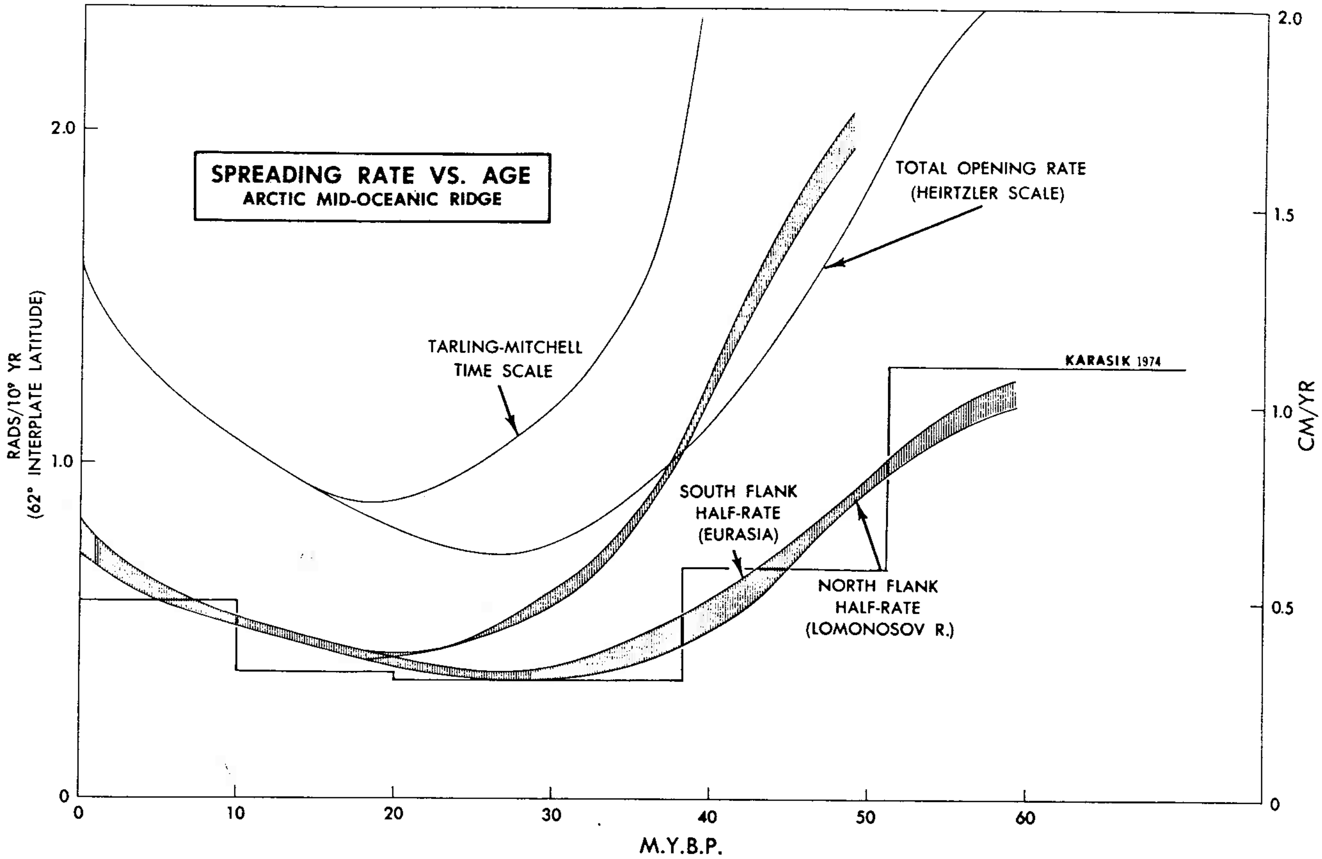

Fig. 5. Spreading half-rate (lower curves) and total opening rate (upper curves) as a function of time for segment of Eurasia Basin reported here. Curves were derived by graphically differentiating age versus distance curves (Figure 4) fitted visually to identified magnetic lineations and their distance from axis. Prior to 15–20 m.y.b.p., absolute values of spreading rate depend increasingly on whether *Heirtzler et al.* [1968] (lower branch of each group of curves) or more recent *Tarling and Mitchell* [1976] reversal chronology is used. Approximate plate rotation rates (left scale, in radians per 10^9 years, assume constant interplate (rotation) latitude of 62°N for center of survey area. Note persistently slower spreading on north (Lomonosov Ridge) flank of Nansen Cordillera. Rate history (average for both flanks) deduced by *Karasik* [1974], shown by stepped curve, is in general agreement.

dramatic along-strike amplitude variations of the ±50 to 500% and 50 to 100 km wavelength that affect all identifiable lineations (Figures 2, 3, and 7). This amplitude modulation is especially prominent for the central anomaly, whose amplitude varies from nearly zero to +500 nT, with an average of about 250 nT. Comparison with the Mid-Atlantic Ridge (MAR) to the south suggests that the Nansen Ridge 'high' amplitude sections are typical; it is the lows that need explaining. We first thought that small transverse fracture zones are somehow responsible for the reduction of the central anomaly amplitude. However, there is no general association between anomaly offsets and amplitude lows. Further, the magnetic lows are generally too broad compared to the expected widths of minor transverse fracture zones. In any case, any fracture zones could not exceed 5 or 10 km in offset, otherwise, they would stand out in the anomaly pattern (Figures 2 and 3).

Since geophysical data (other than aeromagnetic) are very limited, and rock samples nonexistent, we can only speculate about the possible significance of the amplitude fluctuations. It was suggested some years ago [*Johnson and Heezen*, 1967] that sediment from the Barents Abyssal Plain is locally gaining access to the rift valley. If so, the intensity of basalt magnetization might tend to be reduced by metamorphic effects [*Vogt et al.*, 1970; *Irving et al.*, 1970].

To test this hypothesis, we would ideally require seismic reflection profiles across both low-amplitude and high-amplitude segments; a thicker sediment fill would be expected to correlate with low axial magnetic amplitudes. Although reflection data are lacking, several bathymetric profiles crossing the Nansen Ridge at random angles have been collected by U.S. nuclear submarines [*Johnson and Heezen*, 1967; *Beal*, 1968; Figures 1, 8). Further, in early 1977, the British nuclear submarine HMS Sovereign made six additional bathymetric traverses of the Nansen Ridge in the area of NRL aeromagnetic coverage [*Phillips et al.*, 1978; *Feden et al.*, 1978] and in the NAVOCEANO survey area reported in this paper. The sounding lines were designed, with the aid of the aeromagnetic results, to identify any topographic difference that might exist between spreading segments with low-amplitude and high-amplitude axial anomalies.

The results of the submarine-based bathymetric survey (Figures 1, 9, 10) are relatively unambiguous: The profiles crossing H-type (high amplitude) spreading segments (numbers 1, 5, and 6; and 5′, Figure 8) reveal a relatively shallow rift valley floor (3500–4000 m depth), and well-developed elevated rift mountain provinces. Profiles crossing low-amplitude segments (numbers 2–4, Figure 9; and 6′, Figure 8) reveal deep rift valley floors lying at 4700–5300 m. Where the rift valley floor is deeper, so are the flanking crestal mountains (Figures 9 and 10).

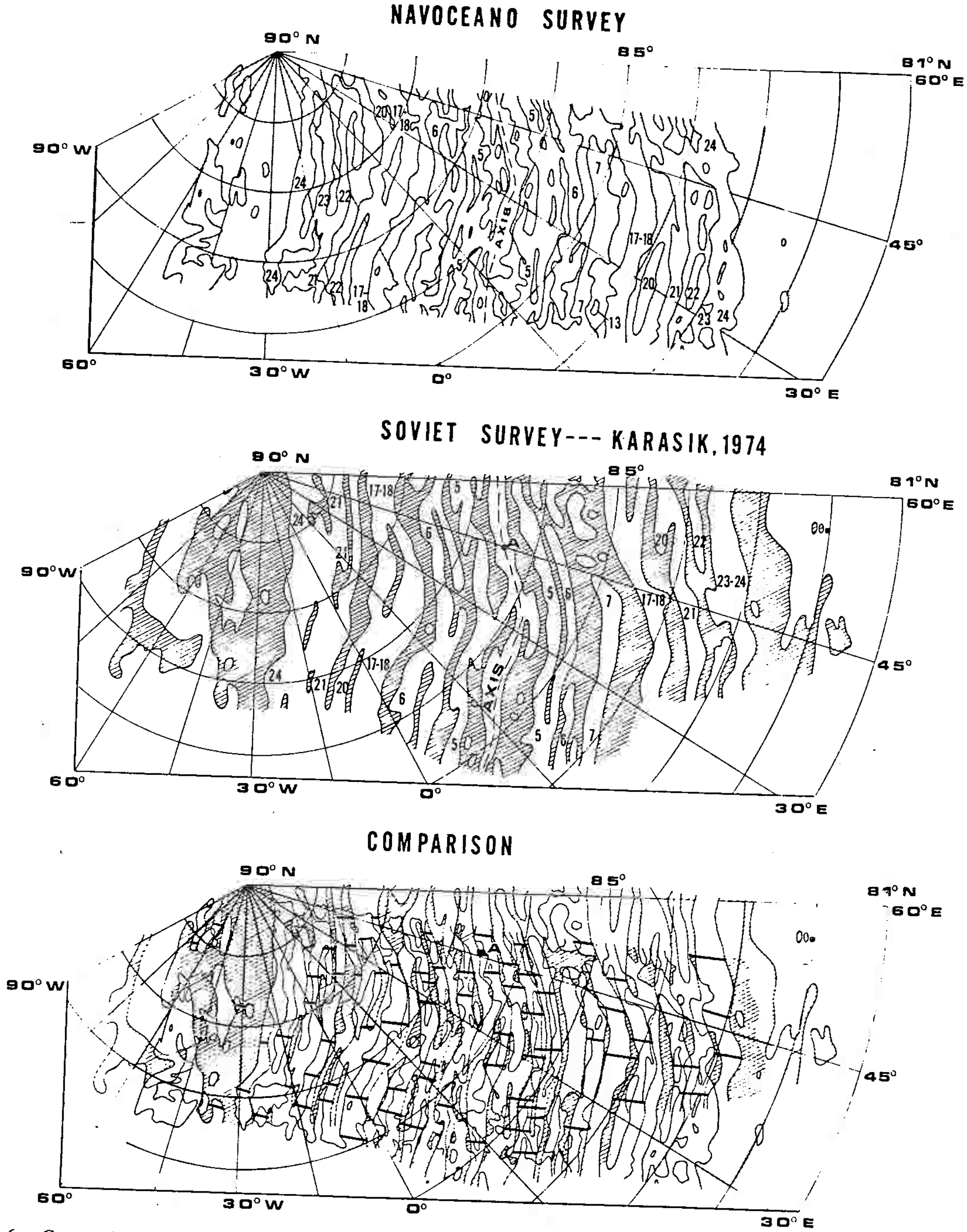

Fig. 6. Comparison with Soviet data. The upper zebra striped anomaly map (fine stippling indicates negative anomalies, with respect to the arbitrary datum) illustrates the recently acquired measurements presented here. *Karasik*'s [1974] diagram is shown in the middle of the figure (ruled diagonal indicates negative anomalies and white indicates positive). The latter magnetic map represents a compilation of several different, but overlapping, surveys. The bottom figure shows the two maps superposed. Bars indicate the relative shift (all toward the left!) required in the Soviet chart to match the NAVOCEANO chart. 'A' shows one actual position of axis given by Karasik.

Since sediment in-filling would raise the rift valley floor, the observed amplitude depression, which is associated with a deep rift-valley floor, also cannot be explained by the mechanism of *Vogt et al.* [1970] and *Irving et al.* [1970]. Sedimentation may still explain the amplitude asymmetry between older lineations on opposite sides of the spreading axis. In the Nansen Basin, anomalies number 7 and older have characteristically of the order one-half the amplitude they exhibit in the Amundsen Basin (Figure 7). Since the Nansen Basin contains 3–5 km sediment versus only 2.5 km in the Amundsen Basin [*Gramberg and Kulakov*, 1975], we propose that the thick sediment blanket in the Nansen Basin may have allowed heat flow to destroy some of the basalt remanence in the ocean crust below that basin.

Basalt chemistry, rock magnetization, and deep-tow data suggest that these high-amplitude zones are due to highly fractionated FeTi (iron-titanium) enriched—hence, more intensely magnetized—basalt [*Vogt and Johnson*, 1973; *Anderson et al.*, 1975; *Vogt and de Boer*, 1976; *Vogt and Byerly*, 1976; *Byerly et al.*, 1976]. A different 'compositional' mechanism has been advanced by *Prevot and Lecaille* [1976] to explain the occurrence of relatively more magnetized basalts in a narrow

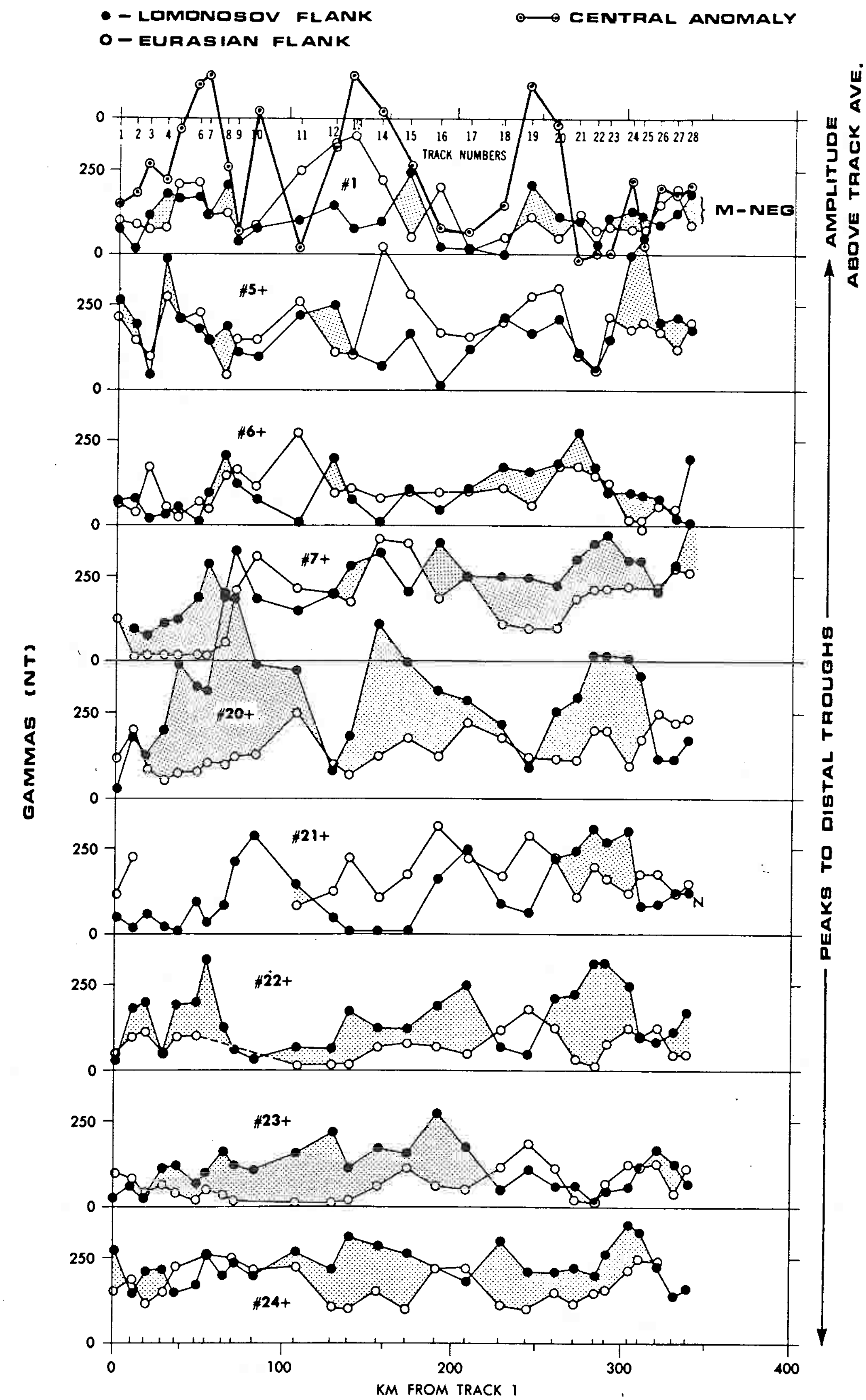

Fig. 7. Anomaly amplitudes plotted along strike of magnetic lineation pattern, as a function of distance from southwesternmost profile, number 1. Track numbers are indicated at top. Amplitudes of anomalies 5 to 24 are peak-to-trough, from indicated anomaly to next older magnetic negative. Open and closed circles denote Eurasian and Lomonosov flanks, respectively. Stippled zone shows anomaly excess of Lomonosov flank (Amundson Basin) over Eurasian flank (Nansen Basin). For anomaly 1 amplitudes (top row), central anomaly is plotted with respect to average along track (see text), and flanking magnetic troughs ('M-Neg,' M for Matuyama) are plotted similarly, but with sign reversed. Note dramatic along-strike variations in amplitude on most profiles, particularly central anomaly.

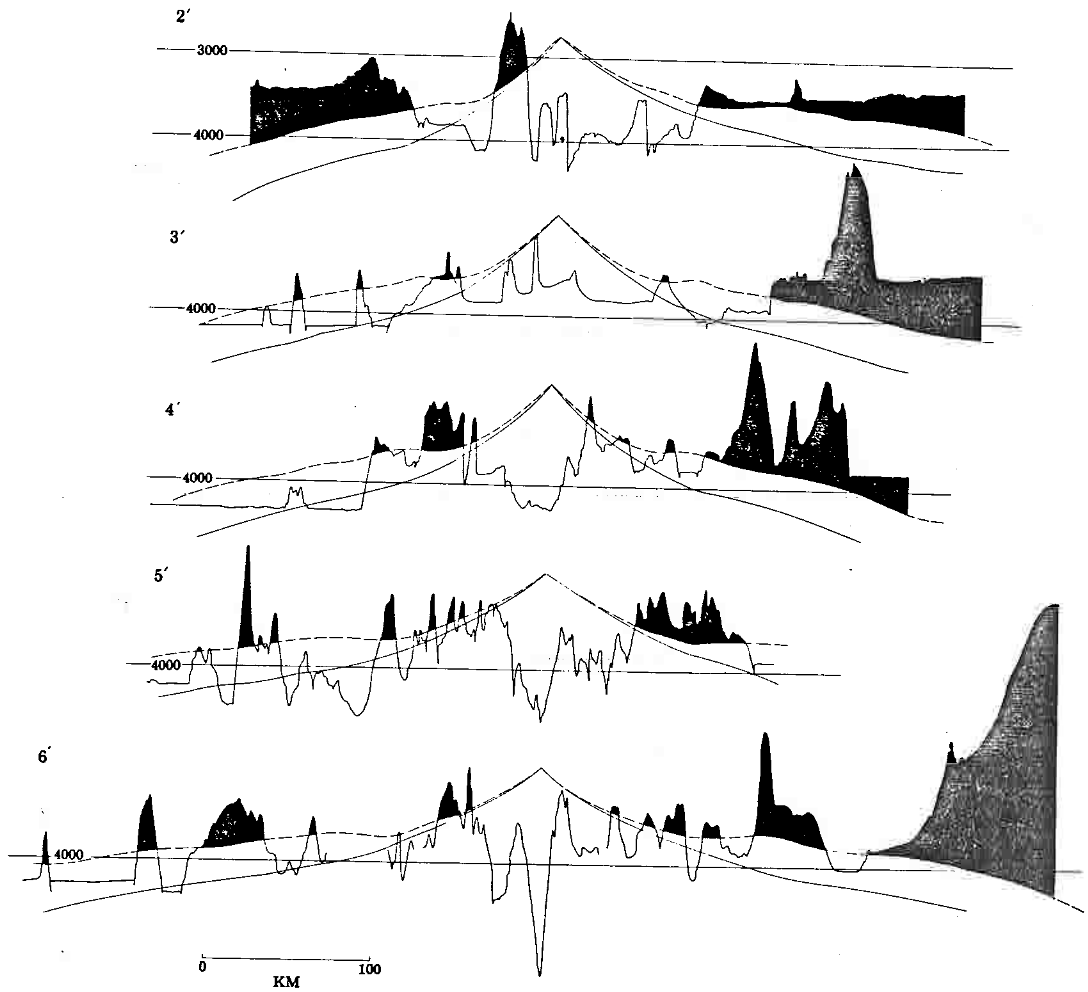

Fig. 8. Bathymetric profiles collected by nuclear submarines on random tracks crossing the Nansen Ridge at various angles (Figure 1), modified from *Johnson and Heezen* [1967]. Profiles were projected onto sections normal to the rift axis. Sloping unbroken profiles indicate standard North Pacific age versus depth profiles [*Sclater et al.*, 1971]. Dashed curve illustrates adjustment for average sediment overburden [*Demenitskaya and Hunkins*, 1970] and consequent isostatic depression. Area shaded black illustrates amount of oceanic crust above the standard North Pacific subsidence curve [*Sclater et al.*, 1971]. Note that the slow-spreading Nansen Ridge is generally deeper than the North Pacific 'standard,' which is, itself, deeper than most of the North Atlantic, at least for crust younger than 10 m.y.

strip along the floor of the MAR rift valley at 37°N (Famous area). Olivine or picritic basalts tend to have smaller grain-size titanomagnetites, and therefore higher magnetization, compared to plagioclase-rich basalts.

b. Comparison With Soviet Survey

Many conclusions published in the literature have been based on the Soviet aeromagnetic survey [e.g., *Demenitskaya and Hunkins*, 1970; *Karasik*, 1974; *Phillips et al.*, 1978]. But these data have been published only in a 'zebra-stripe' (zero-anomaly contour) format. It was decided to make a detailed comparison between our data and that part of the Soviet 'zebra-stripe' chart which our data overlap (Figure 6).

Comparison of the two charts (Figure 6) shows overall agreement in lineation trends and patterns. The Soviet contours are somewhat smoother, presumably because the track separation (Figure 4 of *Karasik* [1974]) is somewhat wider (10–35 km) than that used on the NAVOCEANO survey (9–17 km).

A major difference arises when the two zebra charts are superposed (bottom of Figure 6). In order to bring *Karasik*'s [1974] lineation pattern into agreement with the NAVOCEANO chart, the Soviet data must be shifted toward the Lomonosov Ridge by distances that decrease systematically from 35–50 km over the Barents Abyssal Plain (nearer Siberia) to 10–20 km over the Pole Abyssal Plain. The reason for this systematic misfit is not clear. If the misfits is due to Soviet navigation uncertainty, then we must conclude that their tracks have been adjusted for internal consistency. The remaining systematic errors of 10 to 50 km are not unreasonable if the Soviet aeromagnetic flights were entirely dead-reckoned. Using only the published 'zebra' chart, we find it necessarily difficult to estimate misfit paralleling the lineation pattern. However, the lineation pattern executes a broad 'bend' whose location along the strike of the Nansen Ridge does not differ significantly from one survey to the other. Based on this observation, along-strike positioning differences are judged to be less than 30–40 km. Until the Soviet aeromagnetic data are published in a more complete form, it is not possible to make a better estimate of their accuracy.

4. MAGNETIC ANOMALIES OVER THE AMERASIA BASIN

If the origin and evolution of the Eurasia Basin can now be regarded as rather well understood in terms of plate tectonics,

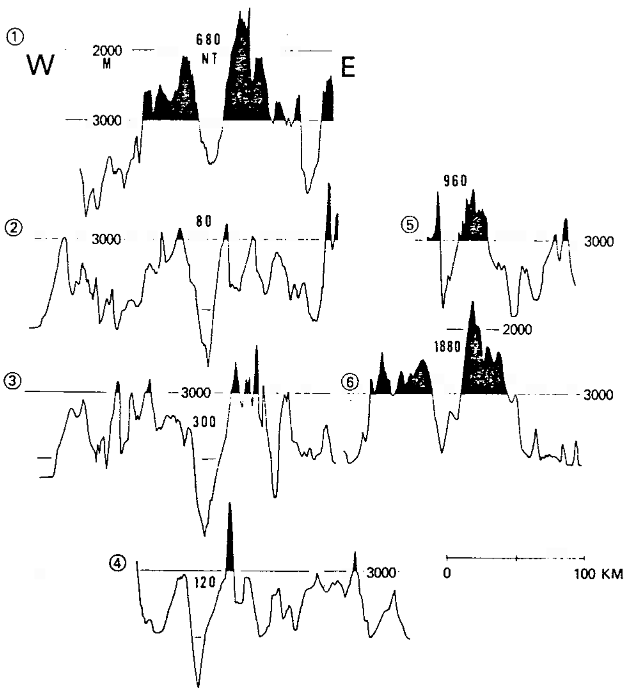

Fig. 9. Bathymetric profiles across Nansen Ridge recently collected by the British nuclear submarine, HMS Sovereign (Figure 1). Profiles 1, 5, and 6 cross spreading segments with high-amplitude axial anomalies; the others cross segments with low amplitudes. Peak-to-trough amplitude of central anomaly taken from data of Figure 1 and adjacent NRL survey [*Phillips et al.*, 1978].

then quite the opposite is true for the Arctic Basin beyond the Lomonosov Ridge—the Amerasia Basin. Tectonic theories ranging from subsided continental shields [*Eardley*, 1961; *King et al.*, 1966; *Taylor*, 1978] to permanent ocean basins [*Meyerhoff and Meyerhoff*, 1973], as well as Paleozoic [*Churkin*, 1973; *Vogt and Avery*, 1974] and Mesozoic sea-floor spreading origins [*Vogt and Ostenso*, 1970; *Hall*, 1970, 1973; *Tailleur*, 1973; *Herron et al.*, 1974; *Fujita*, 1978; *Sweeney et al.*, 1978], including crustal subduction along the Alpha Ridge [*Herron et al.*, 1974] have been suggested in recent years for all or parts of the Amerasia Basin. These various and occasionally conflicting speculations cover almost the entire range of crustal types and ages found on the earth's surface! Recent reviews of the various schools of thought are found in *Vogt and Avery* [1974], and *Clark* [1975, 1978]. In the following paragraphs, we review only the salient points, and then evaluate the detailed magnetic data (swath 'A' in Figure 1) as possible tests for the hypotheses.

The only bathymetric feature crossing the entire Amerasia Basin is the Alpha-Mendeleev Cordillera, hereafter simply referred to as 'Alpha Ridge' [*Vogt and Avery*, 1974; Figure 11]. With the advent of plate tectonics, this ridge was identified as a possible extinct spreading axis [*Beal*, 1968; *Vogt and Ostenso*, 1970]; tentative correlation of the high-amplitude, rather irregular anomalies over the crest of the Alpha Ridge with the Cenozoic reversal sequence [*Heirtzler et al.*, 1968] suggested an age of 60–40 m.y.b.p. for the crestal area [*Vogt and Ostenso*, 1970]. This hypothesis was developed further by other authors [e.g., *Churkin*, 1973; *Hall*, 1973]. *Hall* [1973] noticed that with its rough basement topography, the Alpha Ridge resembled the Mid-Atlantic Ridge. He further interpreted the scattered ice island geophysical data in terms of a spreading axis offset by transform faults at numerous sites. A major difficulty with the 'extinct spreading center' hypothesis is the shallow depth of the Alpha Ridge basement [*Herron et al.*, 1974; *Vogt and Avery*, 1974]. If spreading ceased in the early Tertiary [*Vogt and Ostenso*, 1970], or Cretaceous [*Clark*, 1974], then the thermal and topographic anomaly associated with this spreading axis should have virtually vanished. Instead, basement peaks on the crest of the Alpha Ridge locally rise above −2000 m [*Hall*, 1973]; the average crestal basement, about −2500 m, is 2–3 km above the norm for Cretaceous basement. By contrast, if there is roughly 2–3 km sediment in the basins flanking the Alpha Ridge [*Hall*, 1973; *Kutschale*, 1966], the crust there could be 'normal' Cretaceous ocean crust as far as basement depths are concerned, as also inferred by *Fujita* [1978].

Herron et al. [1974] suggested that the Alpha Ridge is an extinct island arc/subduction zone. The observed shallow basement poses no difficulties for this hypothesis. Neither an arc-like chain of seamounts nor an arcuate fossil trench trace have been identified, although a line of small (1 km high)

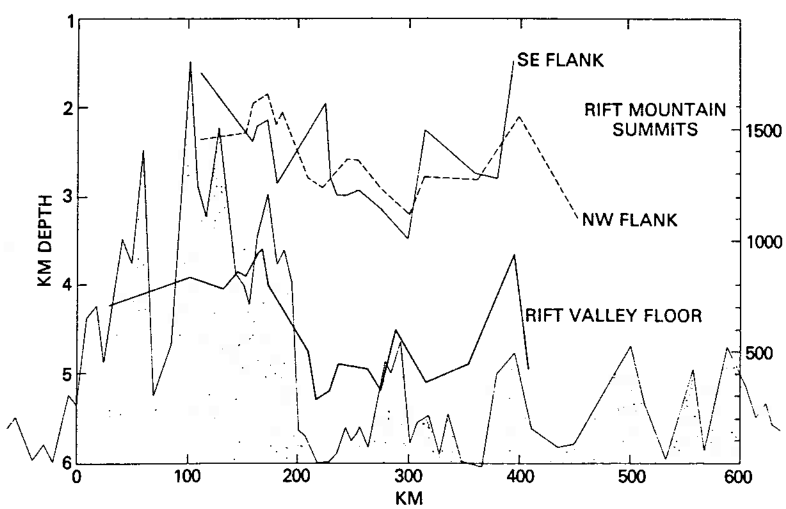

Fig. 10. Longitudinal topographic and magnetic profiles, measured northeastward along spreading axis from an origin at 85°N, 20°W. Area below central magnetic anomaly is stippled. Deepest points of rift valley floor were constructed from profiles in Figures 8 and 9, together with other data [*Feden et al.*, 1978; *Beal*, 1968]. Profiles labeled 'Rift Mountain Summits' were constructed from shoalest soundings encountered on each bathymetric profile and on each flank of Nansen Ridge [*Feden et al.*, 1978].

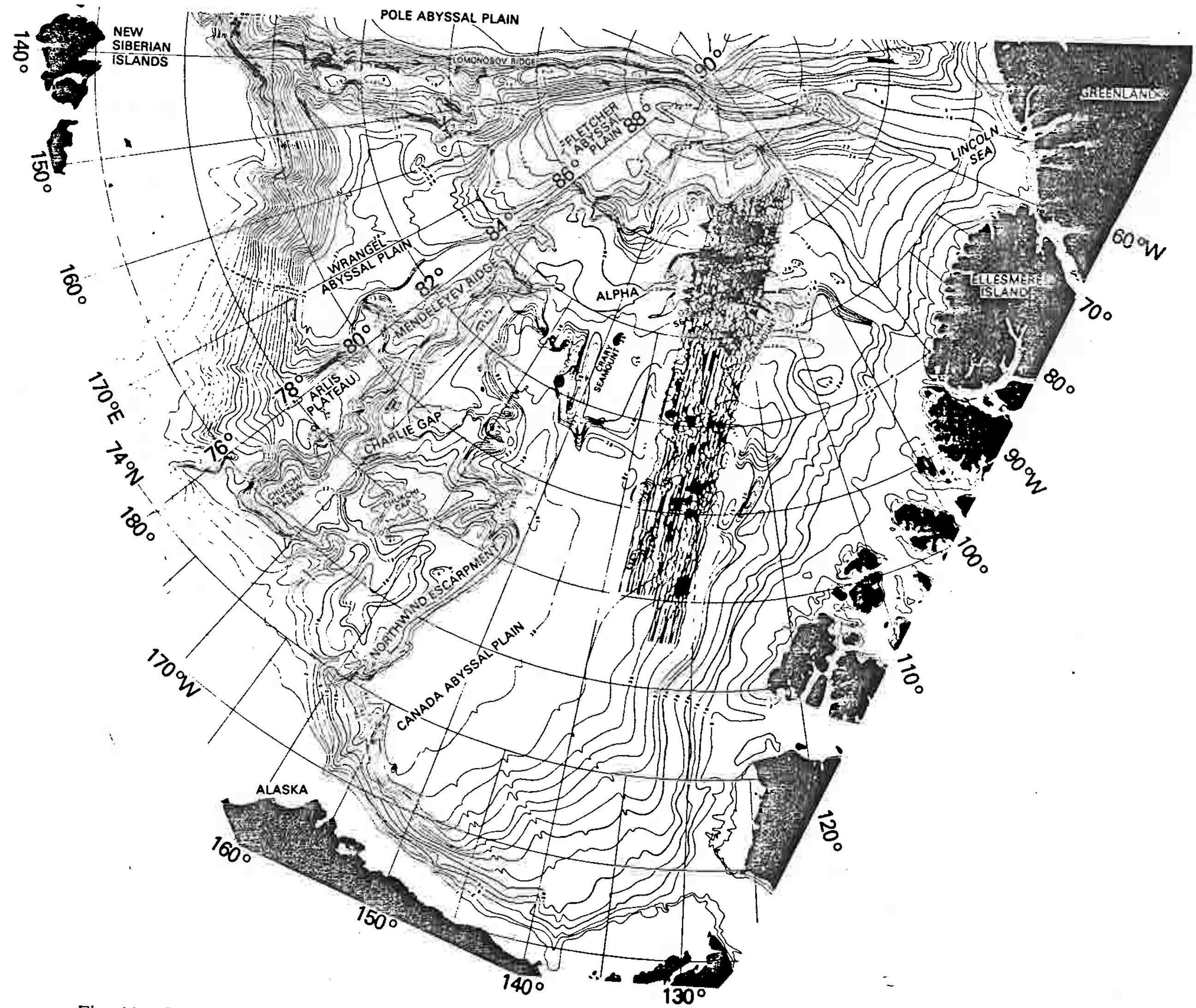

Fig. 11. Residual magnetic anomaly profiles plotted along aircraft tracks, Alpha Cordillera, and adjacent part of Canada Basin (Figure 1). Because of higher magnetic relief in this area, vertical exaggeration is less than that used in plotting Nansen Ridge profiles (Figures 2 and 3). Bathymetric base chart, adpated from *American Geographical Society* [1975], is substantially in error over the North American half of the Lomonosov/Alpha Ridge area [*Sobczak*, 1977].

seamounts paralleling the Alpha Ridge lies north of it [*Sobczak*, 1977]. The recovery of tuffaceous sediment of Maestrichtian and Eocene age at two sites on the Alpha Ridge [*Clark*, 1974; Figure 14] does not prove the subduction zone hypothesis, since explosive volcanism also occurs locally along shallow parts of the MOR—for example, Iceland. Moreover, the thinning wedge of sediments lapping onto the flanks of the Alpha Ridge would argue in favor of a ridge being a former spreading axis rather than a subduction zone [*Ostenso and Wold*, 1977]. The seamounts associated with the Alpha Ridge (Figures 11, 14, 17 [*American Geographical Society*, 1975; *Beal*, 1968]) and in the Fletcher Abyssal Plain [*Sobczak*, 1977] could equally well be either 'island arc,' like the Aleutians, or 'mid-plate,' like the Azores Islands or Kelvin Seamounts.

The greatest uncertainty attends the age and origin of other parts of the Amerasia Basin, for example, the Canada Basin. Some authors have related the origin of this basin to that of the Alpha Ridge [*Ostenso and Wold*, 1971], but most regard it as older and formed by different mechanisms of plate tectonic geometries.

According to *Churkin* [1973, 1972], the crust below the Canada Basin may be Early Paleozoic because of relationships of Paleozoic geosynclines along its southern margin. Along similar lines, *Vogt and Avery* [1974] suggested that the basin was, like the Aleutian and Sea of Japan basins, formed by back-arc spreading, only much earlier. *Ostenso and Wold* [1973] and *Hall* [1973], following *Vogt and Ostenso* [1970], suggested the modern Amerasian Basin is of Mesozoic age, its crust having been generated by spreading from the Alpha Cordillera. According to another variant, the Canada Basin was formed by spreading in the Jurassic and Cretaceous, but from an axis perpendicular to the present North Slope of Alaska [*Tailleur*, 1973; *Churkin*, 1973]. This would move the topographically elevated Chukchi complex (Figure 11), a presumed fragment(s) of continental crust, from an original position along the Alaskan continental shelf east of Pt. Barrow, as originally suggested by *Shaver and Hunkins* [1964] and *Hunkins* [1966].

A somewhat different hypothesis for the evolution of the Amerasia Basin by plate tectonics is that of *Herron et al.* [1974]. According to their model, the present area of the Amerasia Basin was occupied by the Siberian Kolyma block

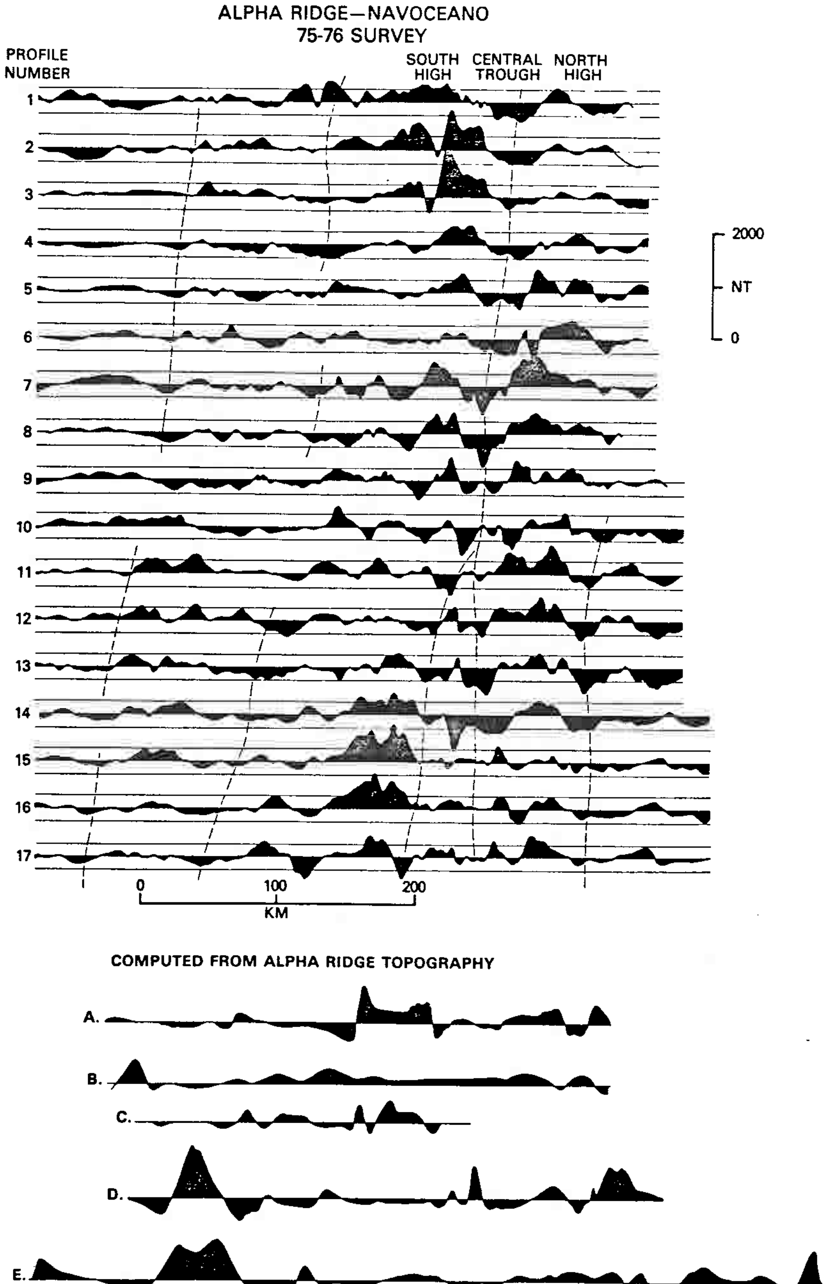

Fig. 12. Detailed magnetic residual profiles across Alpha Ridge and immediately adjacent Canada Basin. Left end of each profile corresponds to 83°N.

(or plate). Collision of this block with North America produced the Parry Island fold belt of the present Canadian Arctic Archipelago during the Middle Paleozoic. In the mid-Mesozoic, the Kolyma block once more separated from North America and collided with Siberia to form the Verkhoyansk fold belt. The Amerasia Basin opened by spreading in the wake of the Kolyma block; thus, its crust would be Mesozoic in age.

An entirely different, non-mobilist school of thought attributes the Amerasia Basin primarily to subsidence of a continental platform, a 'hyperborean shield' [*Eardley*, 1971; *Kiselev and Demenitskaya*, 1974; *Gramberg and Kulakov*, 1975].

Detailed aeromagnetic data would—or so it was hoped—provide conformation of a sea-floor spreading origin. Characteristically linear anomalies, perhaps displaced here and there by transform fractures, would be expected whatever the age of the crust, so long as it was created by axial accretion at spreading rates and reversal frequencies suitable for the generation of magnetic anomalies. Since Maestrichtian sediments were recovered from the Alpha Rise, and from many other considerations [*Churkin*, 1973; *Tailleur*, 1973], it is unlikely that any crust in the Amerasia Basin is younger than early Tertiary. Several authors suggest a Mesozoic [*Ostenso and Wold*, 1971], more specifically, 'Jurassic-Cretaceous' [*Tailleur*, 1973; *Churkin*, 1973; *Fujita*, 1978; *Irving and Morel*, 1978], or 'mid-Mesozoic' age [*Herron et al.*, 1974]. If the crust was generated during this time frame at typical spreading rates of a few cm/yr, we should expect to find anomalies associated with the Keathley (or 'M') reversal sequence [*Vogt et al.*, 1971] most recently dated as late Jurassic to early Cretaceous in age

(155–110 m.y.b.p. [*Larson and Hilde*, 1975]). If some of the crust is as young as late Cretaceous, anomalies 34 to 29 of the *Heirtzler et al.* [1968] sequence might be expected (63–80 m.y.b.p. on the time scales of *Tarling and Mitchell* [1976] or *LaBrecque et al.* [1977]). Crust of mid-Cretaceous age (80–110 m.y.b.p.) would not be expected to show lineations—other than effects of linear basement topography—since this period was of almost constant normal polarity. Crust of lower Jurassic age might also exhibit a 'magnetic smooth zone,' and similarly for any older periods of constant geomagnetic polarity.

The new aeromagnetic data from the Amerasia Basin (Area A, Figure 1) are shown in profile form (Figure 11); the data collected over the crest and flanks of the Alpha Ridge (north of 83°N) are also shown separately in profile (Figure 12) and 500 nT contour form (Figure 13).

a. Alpha Ridge

Consider first the Alpha Ridge magnetic pattern. The anomalies are of high amplitude (ranging from less than −1000 nT to over +2000 nT) and rather irregular, with long-wavelength (30–50 km crest to crest, ±1000 nT amplitude) and superposed shorter wave-length (~10 km crest to crest ± 100–200 nT amplitude) components. Despite the complexity of this pattern, many of these long-wavelengths and at least some of the shorter wavelength magnetic features are demonstrably lineated in a direction paralleling the regional strike of the Alpha Ridge (Figures 11 and 13).

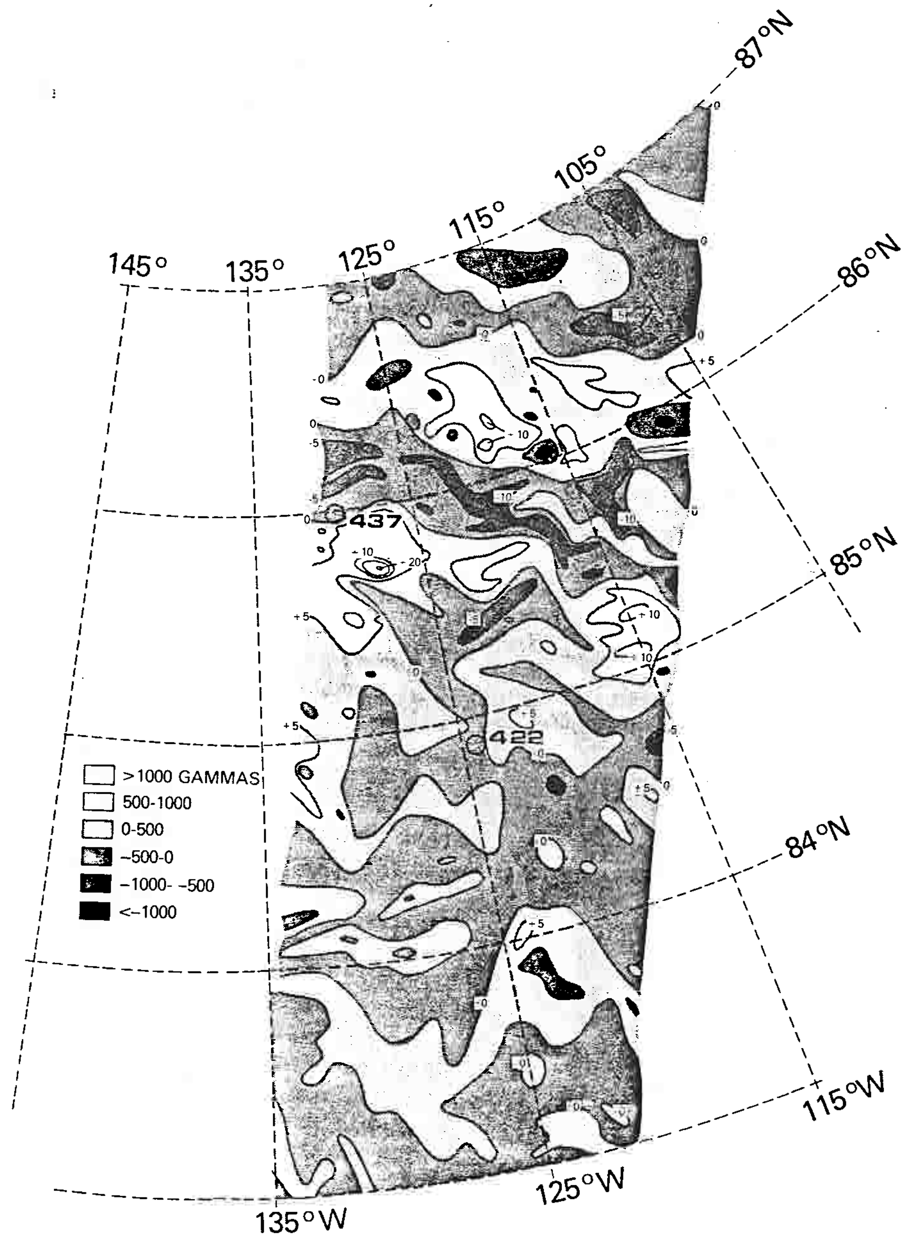

Fig. 13. 500 (nanotesla) contour of Alpha Ridge data profiled in Figure 12. Note central magnetic trough and flanking highs as well as one suggested 'fracture' trend. Numbered circles are locations of cores recovering Eocene (422) and Maestrichtian (437) sediment [*Clark*, 1974].

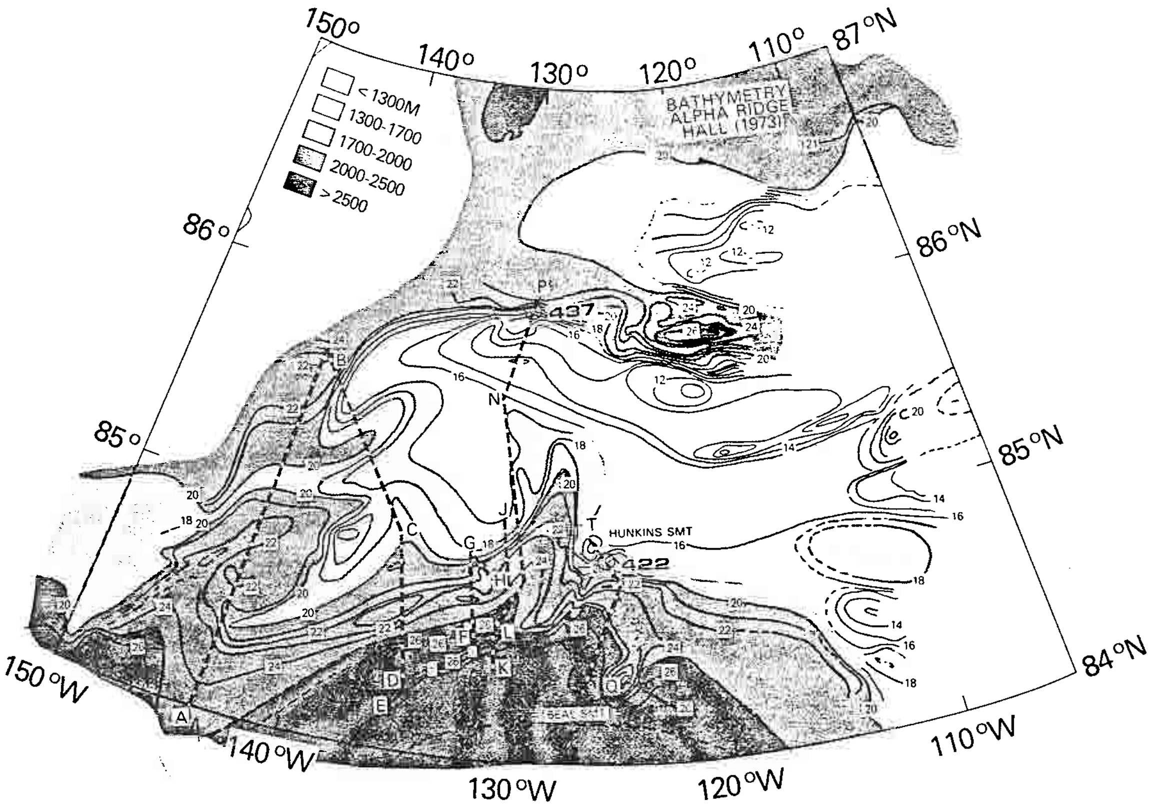

Fig. 14. Bathymetry of Alpha Ridge in area of aeromagnetic survey, at 100 m contours. Redrawn from *Hall* [1973]. Note good correlation between prominent WNW-trending valley, flanked by major ridges, and central magnetic trough with marginal highs (Figures 12 and 13). Apparently this crestal part of Alpha Ridge is strongly magnetized with a normal polarity. Core locations (422 and 437) from *Clark* [1974]. Hunkins Seamount is also known as Ostenso Seamount (see Figure 11).

The most prominent magnetic anomalies are labeled 'central trough,' 'north high,' and 'south high' in Figure 12. Comparison of the contour chart (Figure 13) with the more limited bathymetry (Figure 14) and free-air gravity (Figure 15) data collected primarily by the drifting ice island T-3 [*Hall*, 1973] reveals a strong correlation between the magnetic 'central trough' and a valley 2200–2700 m deep and ~30 km wide. In this paper, we call this feature the Central Valley. Similarly, the magnetic 'north high' and 'south high' correlate with flanking topographic highs whose crests lie at ~1200–1500 m depth. Seismic reflection data collected along the drift path of ice island T-3 show that below the bottom topography of the Alpha Ridge lies a considerably rougher basement topography whose ~1000 m relief has been partly masked by sediments preferentially ponded in basement lows [*Hall*, 1973].

Barring a fortuitous occurrence of reversely magnetized crust in the Central Valley, we conclude that the principal magnetic anomalies of the Alpha Ridge, at least in this area, are topographic effects. More precisely, the anomalies are caused by normally magnetized basement topography. Since the ~500 m thick sediment cover on the Alpha Ridge is thicker in basement lows [*Hall*, 1973; Figure 16], the basement trough below the central valley probably lies at depths of 3000–4000 m, while sediment on the crest of the flanking ridges is only ~200–600 m thick. Unfortunately, T-3 reached only the southern edge of the central valley at one location (Point P, Figure 14).

A topographic origin for these anomalies invalidates the original identification of the same and similar features, observed on widely spaced reconnaissance flights as early Tertiary spreading-type anomalies [*Vogt and Ostenso*, 1970]. In order to attribute the anomalies to basement topography, it is necessary to assign a rather high magnetization intensity to the basement (20–30 A/M; Figures 16 and 17). Oceanic basement topography so intensely magnetized is found at the floor of the Mid-Atlantic Ridge rift valley, but only in crust a few hundred thousand years old (e.g., *MacDonald*'s [1977] discussion of the Famous area). The Alpha Ridge basement is not younger than early Tertiary, and possibly much older [*Clark*, 1974, 1978]. Allowance for the higher dipole intensity over the Alpha Ridge (40% higher than for the Famous area for crustal ages of the order 10^7 years or less) does not suffice to reduce the Alpha Ridge basement magnetization to reasonable values (about 5 A/M).

Without discarding the idea that the Alpha Ridge is oceanic crust, we can offer three explanations for the high basement magnetization: (1) the magnetized layer, presumably mainly pillow basalt, is several times thicker than normal; (2) the geomagnetic dipole intensity was several times greater at the time the Alpha Ridge crust was magnetized: this hypothesis is not supported by the existing data, which, if anything, suggest a progressive increase of dipole intensity through the Phanerozoic [*McElhinney*, 1973]; (3) the Alpha Ridge basement is relatively rich in FeTi basalt of relatively high remanent magnetization (and susceptability). *Vogt and Johnson* [1973] noticed that sections of spreading axis, several hundred kilometers length and located near hot spots (for example, the Juan de Fuca and Galapagos hot spots) exhibit magnetic anomalies

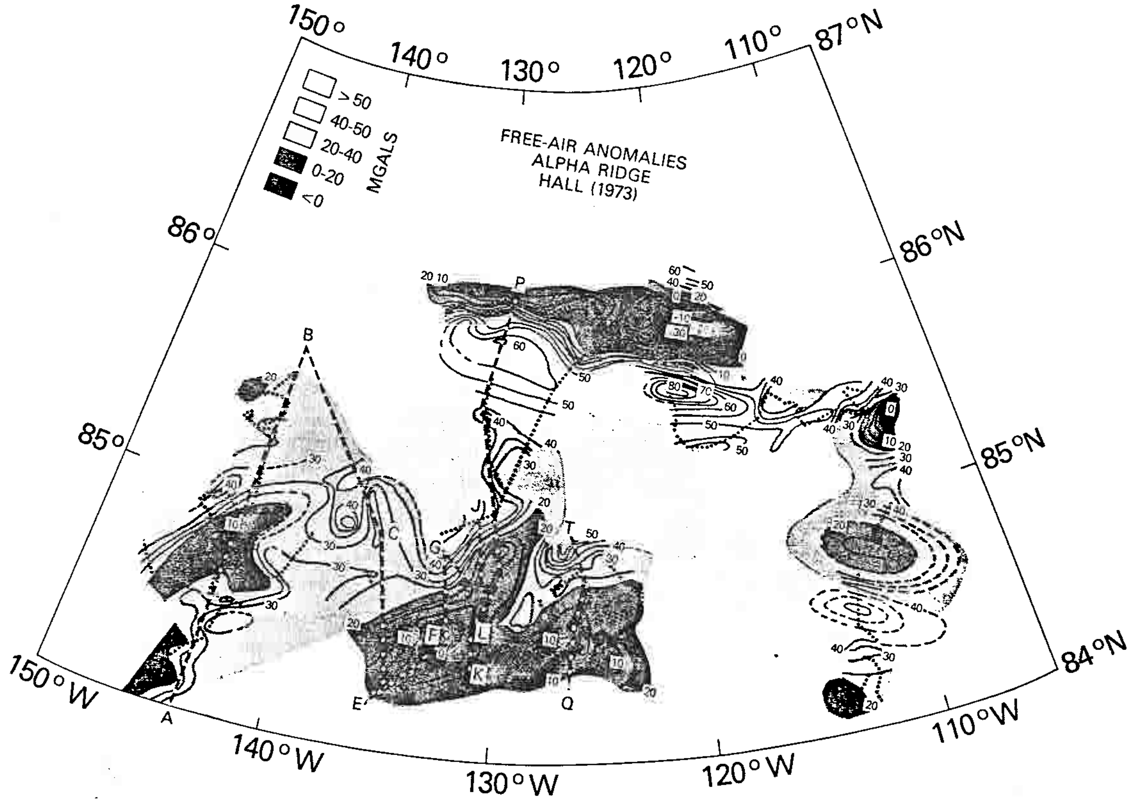

Fig. 15. Free-air gravity anomalies (10 mgal contours) over Alpha Ridge in area of aeromagnetic survey. Redrawn from *Hall* [1973] and based on Ice Island data. Note good correlation of gravity with both bathymetry (Figure 14) and magnetic anomalies (Figure 12).

two or three times the normal amplitude. Subsequent investigations confirmed that this 'H' type oceanic crust is relatively rich in TiO_2 and FEO^T, and therefore, titanomagnetite concentration and average remanence [*Byerly et al.*, 1976; *Vogt and Byerly*, 1976; *Vogt and de Boer*, 1976; *Anderson et al.*, 1975]. Thus, the Alpha Ridge basement magnetization is no more anomalous than these observed examples. The observed high magnetic amplitudes (Figures 16 and 17) do not rule out an origin by spreading; both the elevated topography and high magnetization might suggest that the accretion process was disturbed by one (or more) Iceland-like hot spots located near or on the axis of the ridge.

Since in the central part of the Alpha Ridge there is a band at least 200 km wide (Figures 13 and 14), magnetized with normal polarity, a spreading-type origin for this crust requires formation during a period of predominantly normal geomagnetic polarity. If spreading rates were relatively low, i.e., 1 cm/yr, then the period of normal polarity would have had to be long, at least 20 m.y. Formation of the Alpha Ridge basement during the long Cretaceous normal (Mercanton) period, 80–110 m.y.b.p., would not violate any of the meager data about the age and origin of the Amerasia Basin [*Clark*, 1974, 1978]. If the Alpha Ridge was a spreading center, it is tempting to identify the prominent WNW-trending valley at 86°N (Figure 14) as the extinct median graben, similar to the Aegir Ridge fossil rift valley west of Norway [*Talwani and Eldholm*, 1977]. By contrast, *Hall* [1973] chose an axis associated with topographic and basement lows crossed by the ice island midway between A and B, midway between B and C, and just south of N (Figure 14). Hall further postulated a large number of parallel transform fractures offsetting the axis (and hence, any spreading-type magnetic lineations) of the Alpha-Mendeleev Cordillera. In our magnetic survey area, the anomalies are so irregular that offsets in the pattern, small in this part of the Alpha Ridge [*Hall*, 1973], would not be easy to verify. However, there does appear to be one transverse trend, normal to the strike of the Alpha Ridge and thus possibly a transform fracture zone such as those postulated by *Hall* [1973].

As pointed out by *Vogt and Avery* [1974], it is also possible that the Alpha Ridge was uplifted and block-faulted subsequent to crustal formation, perhaps like the Bermuda Rise. In that case, the magnetic anomalies are largely inherited from the episode of crustal deformation, even though the crust may have originally been formed by axial accretion.

Unfortunately, our detailed magnetic data are not definitive. The island arc/subduction zone hypothesis [*Herron et al.*, 1974] is not excluded; the conspicuous central valley (Figure 14) might then be interpreted as a narrow marginal basin, perhaps like the Lau-Havre or Okinawa troughs in the western Pacific.

Nor can we use the magnetic data alone to rule out the hypothesis of *King et al.* [1966] that the Alpha Ridge is a subsided shield area. The irregular, sublinear character of the anomalies resemble those observed over crystalline shields; however, if the Alpha Ridge stands too high to be an acceptable extinct spreading axis [*Herron et al.*, 1974; *Vogt and Avery*, 1974], then it is too deep to be a subsided shield. At least there are no documented examples of extensive shield areas sunken to depths of several kilometers. Furthermore, a shield origin explains neither the oceanic crustal structure

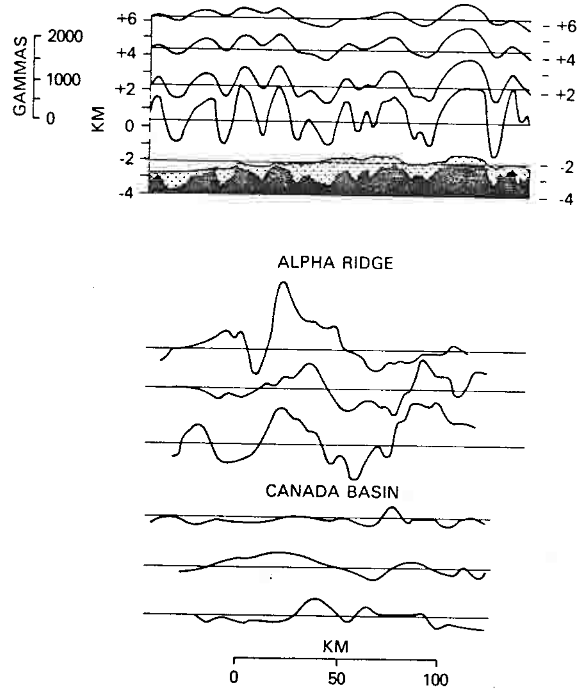

Fig. 16. Top, magnetic anomalies computed from a model basement derived from the seismic reflection profile of *Hall* [1973] (labeled T3–BE in Figure 1). Kilometer scale indicates height of 'observation level' above sea level. Model profiles were computed for elevations of 0.3, 2.3, 4.3, and 6.3 km above sea level. Magnetization intensity adjusted so that amplitudes observed over Alpha Ridge match 0.3 km profile. Basement magnetization is 22.9 A/M, with a dip of 85° and striking at an angle 40° to the Alpha Ridge. Middle and bottom of figure, representative sections of magnetic profile crossing Alpha Ridge crest (top) and adjacent Canada Basin (bottom) (Figure 1) at 0.3 km above sea level. Comparison of profiles indicates that difference in anomaly character between Alpha Ridge and Canada Basin can be accounted for by source depth differences no less than 5 km.

reported by *Hunkins* [1961] nor the Eocene and late Cretaceous volcanic activity indicated by piston cores [*Clark*, 1974]. Finally, the geological structure of shields is commonly so complex that simple correlations between topography and magnetic anomalies (Figures 13 and 14) would be unexpected.

b. Canada Basin

The magnetic anomalies on the lower flanks of the Alpha Ridge and adjacent Canada Basin are more subdued than those over the ridge crest. The anomaly profiles are smoother, with less short-wavelength 'noise.' To test the hypothesis that these observed differences simply reflect a magnetic source layer deepening away from the axis of the Alpha Ridge, residual anomalies were computed at various heights above the basement topography observed by *Hall* [1973] and over the crest of the ridge. The lowest profile (Figure 16) corresponds to what would be observed over the Alpha Ridge if the anomalies are entirely topographic effects. The upper profiles show what would be seen over the lower flanks and over the Canada Basin for various assumed basement depths. Based on observed bathymetric differences and reasonable estimates of sediment thickness [*Clark*, 1978], the magnetic basement should be 1–4 km deeper in the southern survey area. The attenuation and smoothing suggested by the computed profiles are a substantial part of what is actually observed (Figures 11 and 12); the rest could reflect the three-dimensional character of the sources, which would cause a more dramatic attenuation than calculated from the two-dimensional model (Figure 16). The hypothesis that most of the anomalies of Figure 11 result simply from basement topography is further supported by the association of an area of relatively high amplitude anomalies, 80°–82.5°N, with an unnamed topographic rise.

Some of the more linear magnetic anomalies could represent the Keathley (or 'Mesozoic') reversal sequence, at least in the southern part of the surveyed swath. Some anomalies are quite linear, particularly between 80° and 82°N. However, on the whole, the pattern is considerably more complex than observed in the large ocean basins, even at slow spreading rates [*Vogt et al.*, 1971]. If these Amerasia Basin anomalies are due to spreading and reversals, their complex character requires frequent shifts in the orientation of the accretion axis. The dominant SW strike of the more conspicuous lineations may be important, for this is also the strike of the Northwind Escarpment (Figure 11). The origin of this part of the Amerasia Basin is thus structurally related to the Chukchi complex, which could have rifted away from the Canadian margin sometime about 110–150 m.y.b.p. The Northwind Escarpment is then a rifted continental margin and the 'spreading' lineations would parallel these margins, as observed. This would be true even if the lineations represent spreading-related basement topography. The exact relation of such a spreading axis (more or less parallel to the ones proposed by *Tailleur* [1973] and implied by *Carey*'s [1955] orocline concept) to the Alpha Ridge is unknown; around 83°N, the lineations change from a strike resembling that of the Alpha Ridge to one paralleling the Northwind Escarpment. South of 83°N, however, some magnetic anomalies retain a strike parallel to the Alpha Ridge (Figure 11). We recommend that gravity data be collected to discriminate between reversals and basement relief as a source of the Canada Basin anomalies.

5. CONCLUSIONS

In the Eurasia Basin, we were able to accomplish the following: The conclusions of *Karasik* [1968, 1974] regarding the detailed spreading history of the basin were verified, while earlier views of the Nansen and Amundsen basins as not created by spreading hopefully laid to rest.

The origin of 50–100 km wide strips of crust lying between anomaly 24 and the Lomonosov (or Eurasian) margins remains obscure. We would recommend gravity and deep seismic reflection (or refraction) traverses across these marginal strips to determine if the crust is oceanic, continental, or intermediate, or if buried marginal basement ridges or escarpments (such as those described in the Greenland-Norwegian Sea by *Talwani and Eldholm* [1977]), also exist in the Eurasia Basin 'landward' of anomaly 24. If these crustal strips were formed by spreading just prior to anomaly 24, then an explanation must be found for the absence of anomalies 25–27. In this light, we note that the oldest identifiable anomalies (22–24) of the Nansen Basin are generally below 100 nT, locally below 50 nT, in peak-to-trough amplitude (Figure 7).

The initial detachment of Lomonosov Ridge from the Eurasian margin occurred no later than anomaly 24 time, and possibly as early as anomaly 27 time. The spread of published age scales for these anomalies [*Heirtzler et al.*, 1968; *Sclater et al.*, 1971; *Tarling and Mitchell*, 1976; *LaBrecque et al.*, 1977] then allows absolute ages ranging from 50 to 70 m.y.b.p.

Although our work basically confirms the published conclusions of *Karasik* [1968, 1974], there appear to be systematic navigation errors (or plotting errors) in the Soviet data (Figure 6). If magnetic lineations identified on these 'zebra' charts are used in plate kinematic syntheses, errors will be introduced.

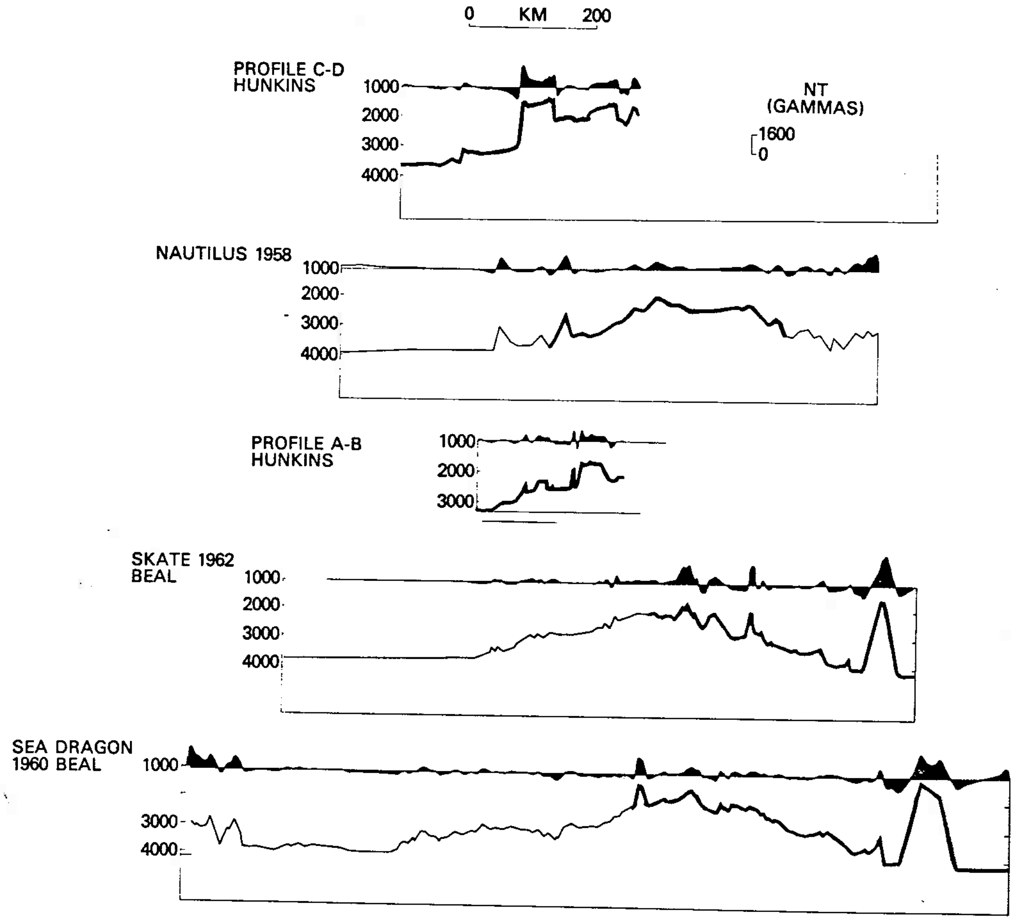

Fig. 17. Magnetic anomaly profiles computed from bathymetric lines (Seadragon-60, Nautilus-58, and Skate-62, from *Beal* [1968]; AB and CD from *Hunkins* [1961]) on assumption of constant magnetization intensity (34.4 A/M), direction (Figure 16), and sediment overburden (0.5 km). Observation level assumed to be +0.3 km. Compare with observed profiles across Alpha Ridge (Figure 12).

In the part of the Eurasia Basin investigated by us, the magnetic data do not agree with published bathymetric charts [e.g., *American Geographical Society,* 1975] in two respects (Figure 2). Contrary to prediction, the magnetic lineations are relatively continuous and execute smooth bends (Figure 3). The anomaly pattern suggests transform faults at only a few spots. Elsewhere, sharp offsets attributable to transform faults would have to be of small enough displacement (~10 km or less) to escape resolution. The second discrepancy with the bathymetry concerns location of the median valley. Using newer submarine data and re-evaluating the old, we find no reason not to correlate the median rift valley with the central anomaly in the entire survey area. If our results are generally true of the entire Nansen Ridge, we predict (1) far fewer transform faults than suggested in the AGS chart, and (2) an actual rift valley position that may be up to 50 km displaced from that predicted from the chart. The observed discrepancies are not surprising, considering the scanty data previously available, and underscore the value of aeromagnetic mapping to improve bathymetric charts in the Arctic.

An unpredicted phenomenon, also useful for 'aeromagnetic bathymetry,' is the along-strike variation in anomaly amplitude (Figures 7 and 10). The effect is most pronounced for the central anomaly, whose amplitude varies by an order of magnitude. Correlation with several sounding lines collected by nuclear submarines shows that both rift mountains and rift valley floor are substantially shallower where the axial magnetic amplitudes are high. The floor of the median valley lies at 4.7–5.3 km depth in the low-amplitude, but 3.5–4.0 km in the high-amplitude zones.

The magnetic profiles across the Alpha Ridge and adjacent Canada Basin unfortunately do not revolutionize our understanding of the Amerasia Basin. Perhaps the most significant finding is that the complex, sublinear, high-amplitude anomalies over the Alpha Ridge correlate with topography (Figures 13 and 14), and hence, not surprisingly, with free-air gravity (Figure 14). Apparently the Alpha Ridge, at least in the area investigated, has a highly magnetized basement (20–30 A/M) below its sediment cover. Thus, the anomalies are not due to polarity reversals as once suggested [*Vogt and Ostenso,* 1970]. Although the correlation between magnetics and topography makes aeromagnetic surveys useful for 'remote bathymetric sensing,' the magnetic anomalies cannot be used to assign crustal ages. If the Alpha Ridge crust was formed by spreading—which is far from certain [*Herron et al.,* 1974; *Vogt and Avery,* 1974], it may date from the long mid-Cretaceous interval of normal polarity; this would explain the normal magnetization of the basement. However, the magnetic data by themselves do not rule out either the 'subsided shield' theory [*King et al.,* 1966] or the 'subduction zone' theory [*Herron et al.,* 1974].

Relatively high-amplitude sublinear anomalies continue under the flanks of the Alpha Ridge and nearby Canada Basin (Figure 11). We showed that these anomalies could result from

Alpha Ridge crestal-type basement topography buried under several kilometers of sediment; if that is their origin, gravity anomalies would be expected in direct correlation with the magnetics. Alternatively, some of the Keathley ('M') anomalies of Upper Jurassic–Lower Cretaceous age [*Vogt et al.*, 1971; *Larson and Hilde,* 1975] may be present (Figure 10). In this case, our data would support a Jurassic-Cretaceous opening of the Canada Basin by spreading [*Tailleur,* 1973; *Herron et al.*, 1974; *Fujita,* 1978; *Irving et al.*, 1978], but from an axis paralleling the Northwind Escarpment.

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