A Geomorphologic, Seismic and Magnetic Study of the Astrid Ridge, Dronning Maud Land, Antarctica

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ABSTRACT

Astrid ridge rising from a depth of about 4000 m to 1000 m is a prominent feature on the continental margin of Dronning Maud Land. The ridge was studied by a six E-W and one N-S tracks comprising 458 1km of echosounding, 405 Ikm of seismic profiling and 452 Ikm of magnetics. The crest of the ridge in the area surveyed trends N-S in the south but veers to NNW-SSE afabout 68°S Lat. and is reported to change to NNE-SSW at about 67°S Lat. The crest of the ridge in the south is marked by a flat area at about 1500 m which deepens to 1700 to 1900 at about 68° Lat. The western flanks of the ridge in the south are gently sloping while the eastern flanks are marked by NNE-SSW trending scarps of about 80-280 m. The northern area is marked by a NW to NNW-SE to SSE trending valley about 5-15 km wide and 240-380 m deep. The seismic profiles of the ridge show a top transparent or layered sediments (50 ms to 0.4 s) underlain by a prominent reflector (50 to 100 ms) and the acoustic basement between 0.4 to 0.6 s. The sediments dip away from thecrest.of the ridge to the flanks. The magnetic data indicate.that the basement in the.area occurs at a depth of 3.0 to 3.4 km. The seismic profiles indicate that the NNE-SSW trending scarps on the eastern flanks represent faults which affect only the younger sediments and are not reflected in the magnetics and thus are not deeper structures. The major NNE-SSW trending fracture reported by earlier workers is not conspicous in the area and perhaps occurs further to the east. The NW-NNW to SE-SSE trending narrow valleys are grabens where the basement and associated sediments have been faulted down. The grabens are marked by a series of magnetic anomalies of about 100 to 400 nannoteslasuperimposed over the peak of a broad high amplitude anomaly which indicates an uplift of the magnetic basement and appears to be a deep crustal feature. The graben appears to be a major tectonic feature of the area and marks a change in the trend of the ridge at about 68°S Lat.

INTRODUCTION

The Internationa] Indian Ocean Expedition in the early 1960s considerably enhanced the knowledge of the marine geology and geophysics of the Indian Ocean and to a large extent of the continental margins. The expedition provided an impetus to marine geological and geophysical studies of the continental margins of the countries bordering the Indian Ocean. However, because of the ice cover and hostile environment, the continental margins of Antarctica still remain poorly studied. The study of the marine geology and geophysics of the Antarctic continental margins is of considerable value in the breaking, drift and reconstruction of the Indian, Antarctic and Australian plates.

A large volume of the work on the geology and geophysics of the Antarctic continental margin was carried out during the various oceanographic expeditions to the Antarctica as a part of International Geophysical Year. The results of these studies have been summarized in the Soviet Atlas of the Antarctica (Bakaiv, 1966). Bergh (1977) identified the Mesozoic anomalies Ml to M9, the Mesozpic seafloof and a major NNE-SSW trending fault scarp which is popolar to the fault scarp in the Mozambique basin. Hinz (1978) carried out seismic profiling on the Astrid Ridge and observed a buried fault scarp on the eastern margin and over 1 sec. thick sediments on the ridge. Johnson, Vanney, Elverhoi and La Brecque (1981) synthesized the available data on the morphology of the Weddell Sea and the South West Indian Ocean which included the continental margin of Dronning Maud Land and the Astrid Ridge. They concluded that the eastern flanks of the Maud bank, Astrid Ridge and the Gunners Ridge represent a fracture zone. Most of the workers place the Maud bank adjacenet to Agulhas plateau and Astrid Ridge to Mozambique'Ridge (Bergh, 1977; Norton andScalter, 1979; Veevers, Powels and Johnson, 1980; Goslin, Segoufin, Schlich and Fisher 1980; Johnson, Vanney, Elverhoi, and La Breque 1981).

The First Indian Expedition to the Antarctica carried out an extensive marine geological and geophysical survey'of the Antarctic continental margin comprising echosounding-(3509 km), magnetics (2900 km) and seismics (450 km) and 7 seabed samples. The areas covered by the expedition included the

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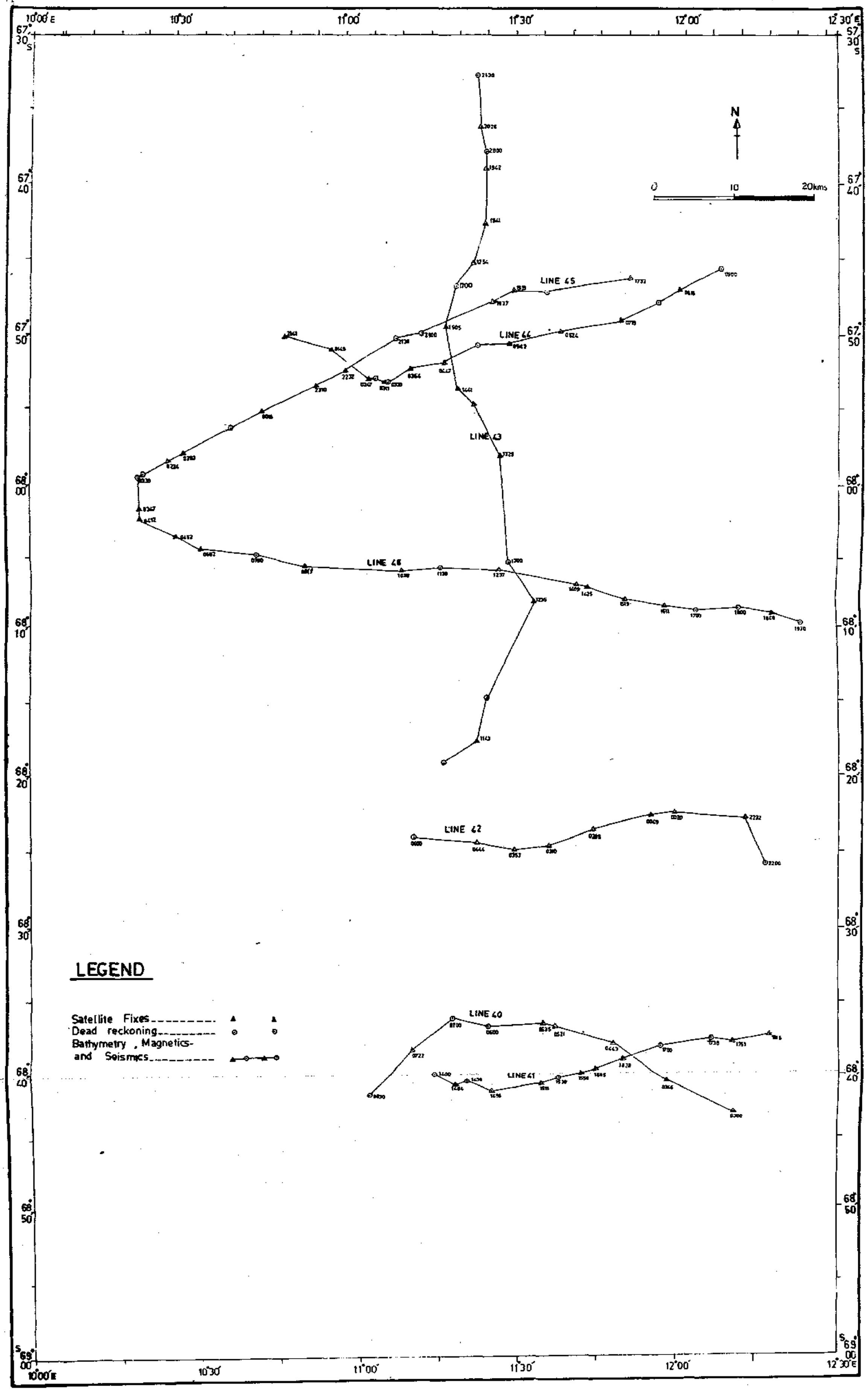

Fig. 1. Map showing the positions of the lines surveyed on the Astrid Ridge, Dronning Maud Land, Antarctica.

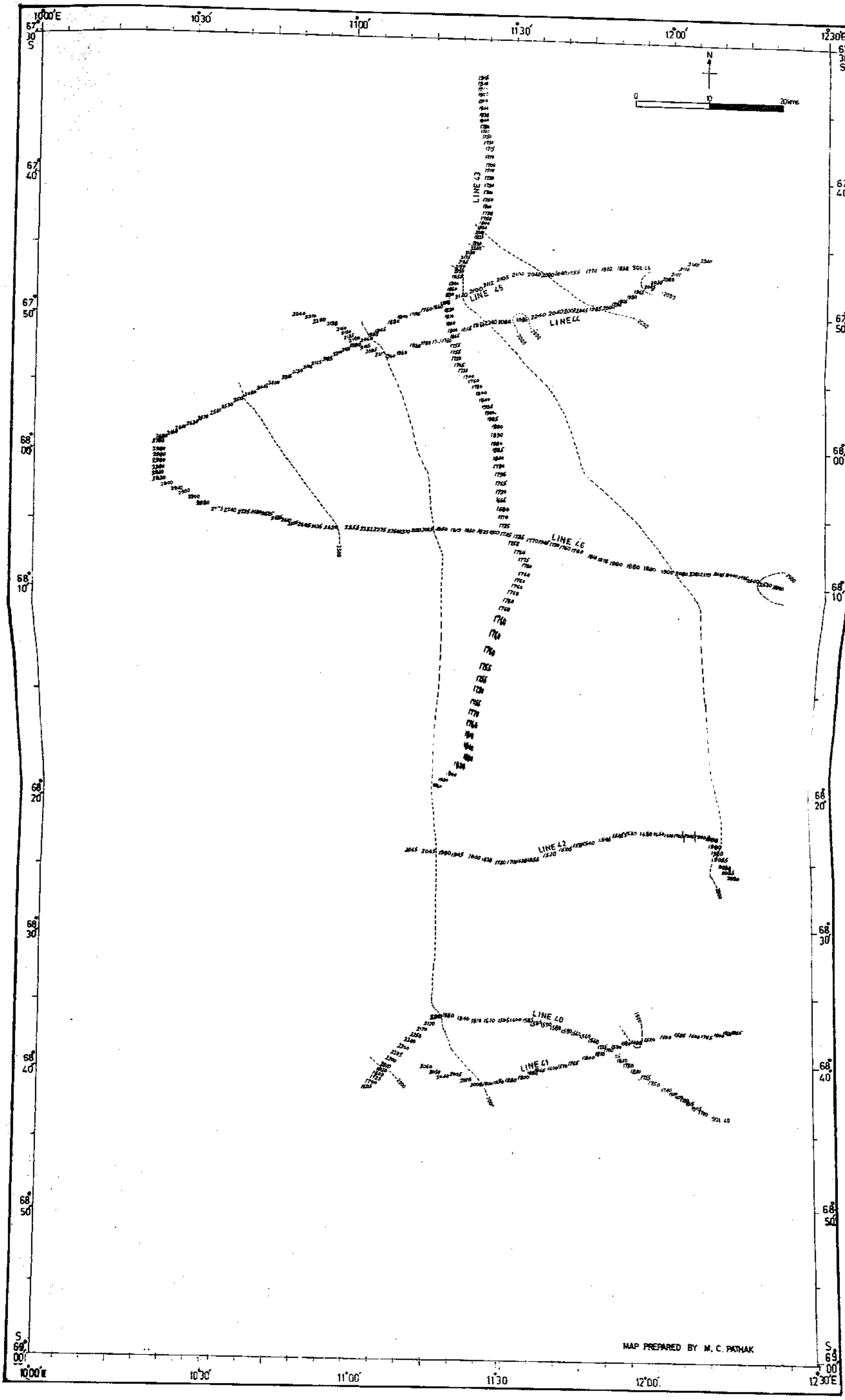

Fig. 2. Map showing the bathymetry of the Astrid Ridge, Dronning Maud Land, Antarctica (Contour interval 500 m). (Map prepared by M. C. Pathak.)

Gunners Ridge, approaches to Rui Boudin station, Astrid Ridge and the approaches to the Indian Station, *Dakshin Gangotri.* Since the processing of the large volume of data would take some time, the processing of the data for some areas of scientific interest was assigned a priority and this included the Astrid Ridge. The surveys on the Astrid Ridge comprised (Fig. 1) echosounding (458 km), seismics (405 km) and magnetics (452 km). The continental margin during the period of the surveys i.e., January, 1982, was still covered with ice and most of the shallow areas could not be surveyed. In the case of some tracks, a straight course could not be followed because of the drifting ice or rough seas. The magentic data collected during the cruise could not be corrected for diurnal variations because of the unavoidable delays in obtaining the data from the adjacent magnetic observatories in Antarctica.

RESULTS

Geomorphology

The topographic map published by Johnsons *et al.* (1981) shows that the Astrid Ridge in the south trends N-S and changes to NNE-SSW in the north at about Lat. 67°S. The ridge rises from a depth of over 4,000 m to about 1,000 m in the south and deepens to more than 2,500 m in the north at Lat. 67°S. The echosounding tracks in the present surveys were widely spaced and did not cover the entire width of the ridge to the east and west. Inspite of this limitation the data provide some additional and new information and are, therefore, being presented here.

The ridge perhaps comprises of a number of parallel or sub-parallel crests separated by intervening low valleys. The crest of the ridge in the area surveyed trends N-S in the south and veers to NNW-SSE in the north at Lat. 68°10'S (Figs. 2 & 3). The crest in the south is marked by a flat area at about 1,500 m (Lines 40, 41 and 42) which deepens in the north to 1700-1900 m at Lat 68°S (Line 46). The flat area perhaps does not extend farther north as north of Lat. 68°S (Lines 43,44 and 45) the crests of the ridge are clearly identifiable and are separated by a NNW-SSE trending valley. Since the east-west tracks were incomplete, the exact depth of the base of the ridge is not known but Lines 42 and 46 indicate some flattening on the eastern flanks of the ridge. The western flanks of the ridge in the south are gently sloping while the eastern flanks have a number of NNE-SSW trending scarps (relative elevation 80 to 280 m) with steps marked by progressive deepening of the seabed to the east (Fig. 3 and Fig. 4, F and H). The scarps in the north trend NW to NNW — SE to SSE and form well-defined valleys 240 to 380 m deep and 5 to 15 km wide (Fig. 3 and Fig„4, A, C and E). The valley with steep scarps may perhaps have a bearing on the change of direction of the ridge at about 68°S.

The scarps and valleys are marked by a number of hyperbolic reflectors indicative of lateral extension of uneven topography over a wider area and possibly exposures of hard rock.

Seismic Profiling:

An EG & G Single Channel Seismic Reflection Profiling System comprising of Power Supply (Model 232 A), Trigger Capacitor banks (Model 231), Krohn-hite variable filter (Model 3750) and an EPC 3200 graphic recorder was used for the surveys. The reflection pattern configurations on seismic records were studied to identify the acoustic basement; overlying sedimentary layers and subsurface discontinuities in the basement and also the sedimentary strata, the major structural elements and the tectonic events. The results of these are analyses are presented below (Fig. 5).

The seismic profiles comprised six E-W tracks across the ridge and one N-S track approximately along the crest of the ridge. The profiles provided a maximum penetration down to 0.6 s and in some cases the acoustic and even the crystalline basement was recognisable. On the ridge itself an acoustic transparent or layered sequence (thickness ranging from 50 ms to 0.4 s) was identified which is underlain by a prominent

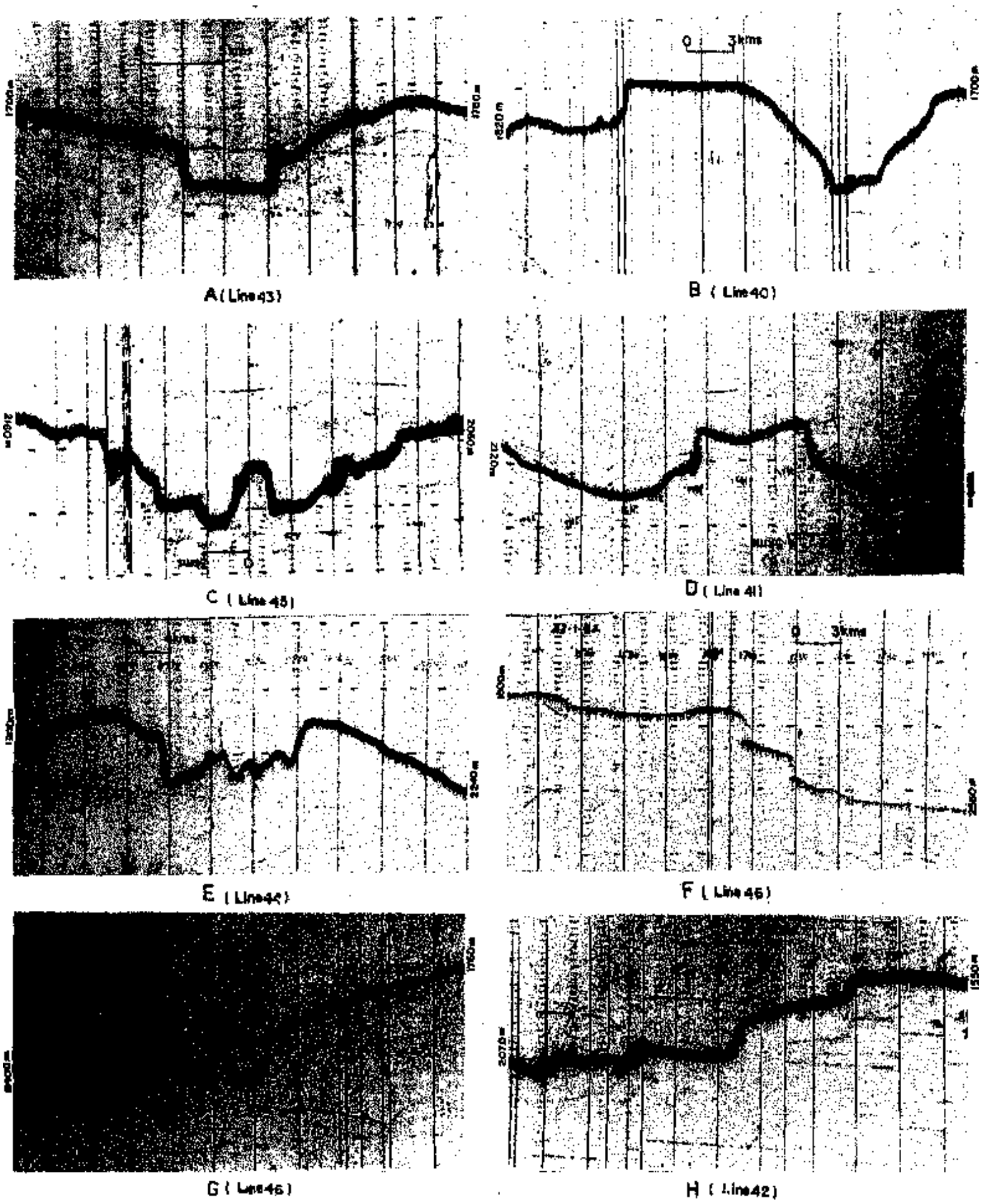

Fig. 4.: Echograms of the seabed showing, scarps/faults, canyons and valleys/graben.

A, C and E: The scarps on the crest of the ridge form the graben. The seismic profiles show faulting along the scarps and a magnetic high is also observed.

B: The seismic profiles show faults along the scarps but apparently no magnetic anomaly is observed.

D: Almost vertical scarps define a prominent topographic feature but the seismic profiles do not indicate any disturbance and apparently there is no magnetic anomaly. Could it be a canyon-like feature described by earlier workers?

G: The almost vertical sides of the scarps suggest a tectonic feature but the seismic profiles do not indicate any fault.

F and H: The scarps are clearly shown as faults in the seismic profiles but are not associated with a magnetic anomaly.

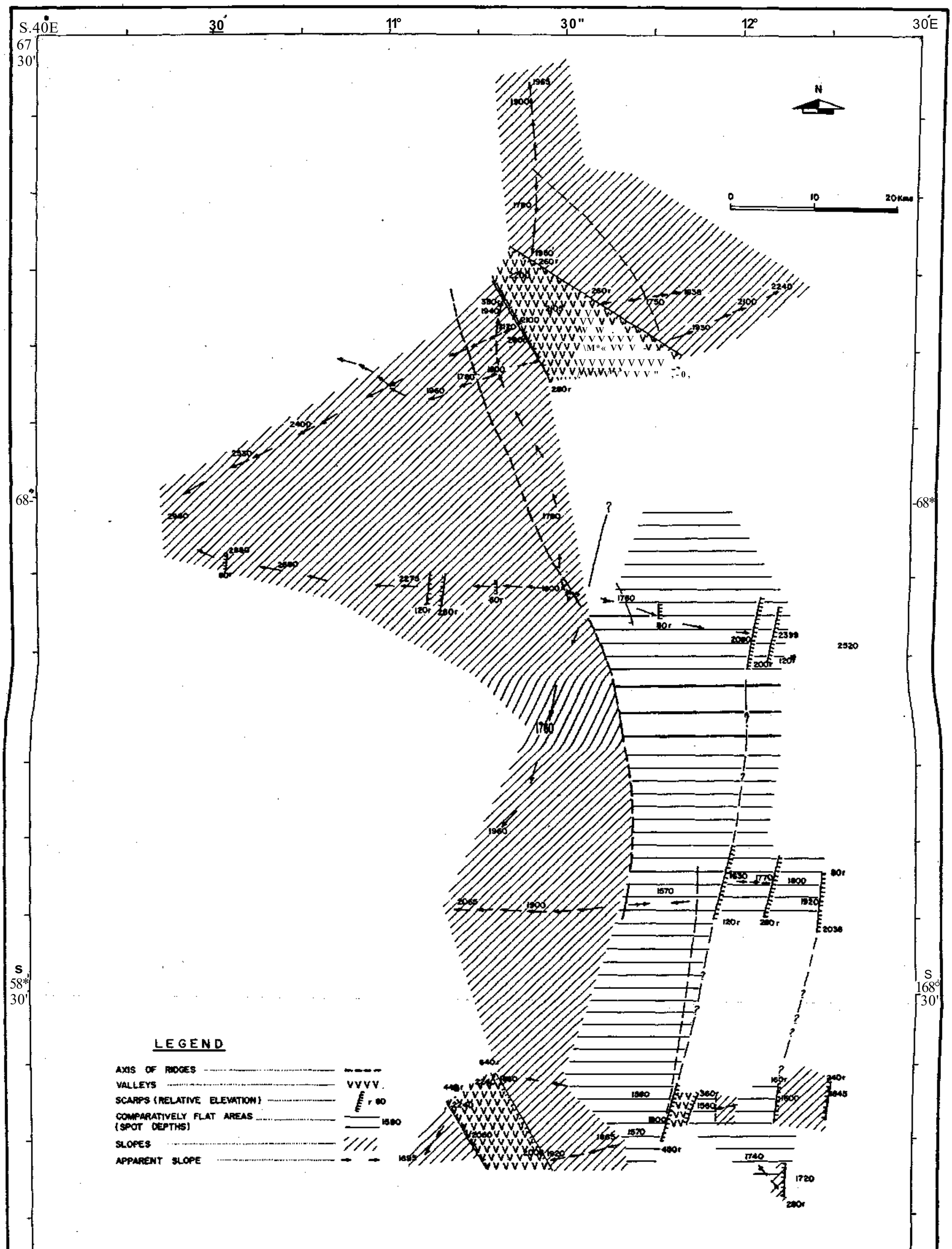

Fig. 3. Schematic map showing the geomorphology of the Astrid Ridge.

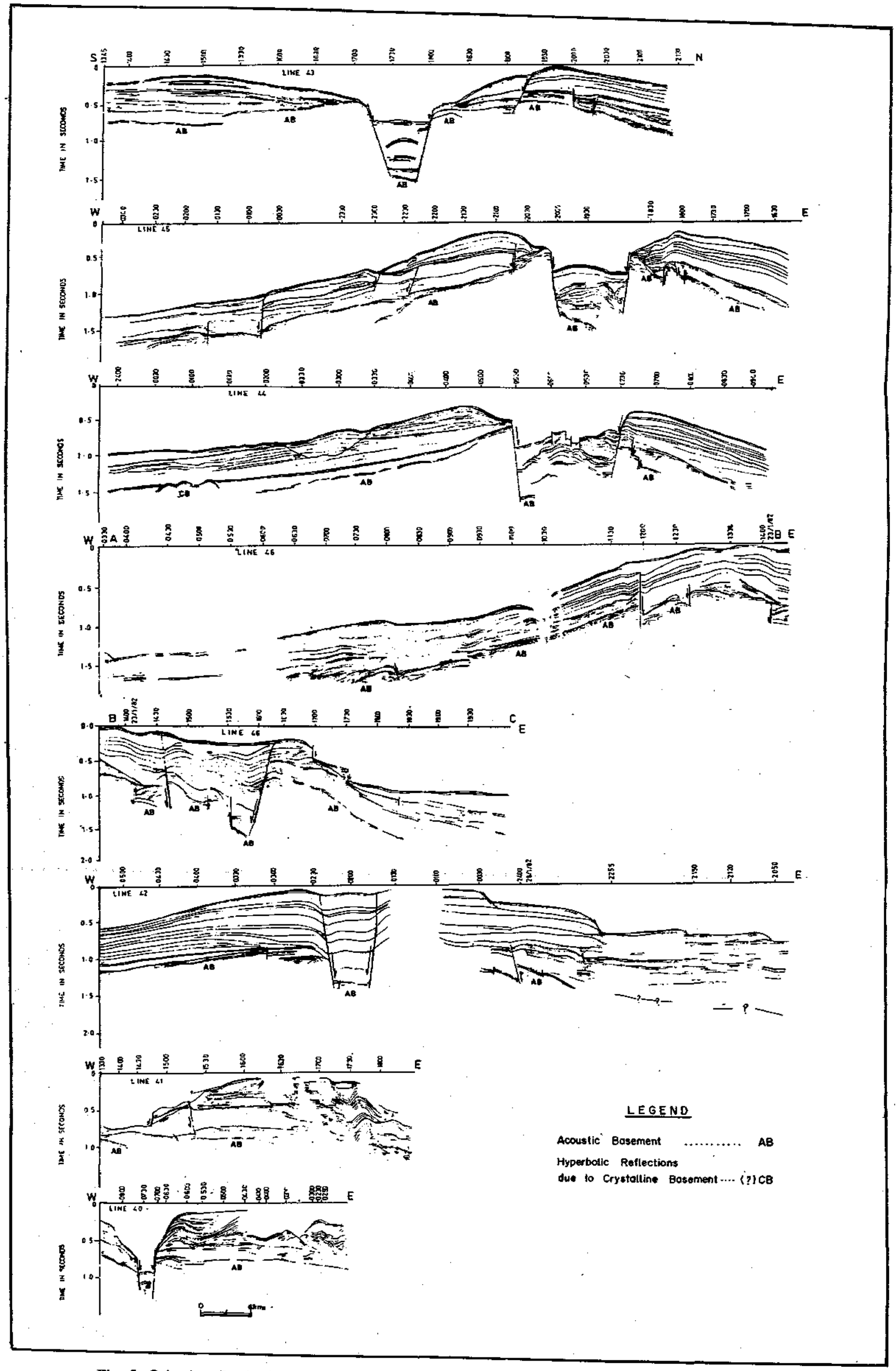

Fig. 5. Seismic reflection profiles over the Astrid Ridge. Two ways travel time in seconds, acoustic basement (AB), and crystalline basement (CB) are indicated.

reflector (thickness few tens of ms to 0.1 s). The prominent reflector just overlies the acoustic basement at depths ranging from 50 ms to 0.6 s. The eastern flanks of the ridge show (Lines 44 and 45) a thick overlapping/onlapping sequence (0.2 to 0.25 s) which covers the ridge sediments and perhaps represents a deep sea facies.

Line 40

The profile shows a maximum penetration of 0.5 s below the seabed. The seabed is covered with 0.4 s acoustically transparent sediments. Parallel to sub-parallel reflections typical of layered sediments are common in the lower part of the transparent sediments. The wavy reflections in parts of the sequence perhaps indicate under compaction and lateral inhomogeneities. The reflectors within the upper strata are abruptly truncated for about 20 to 22 kms (Fixes 0300 and 0445) and a depth of 0.2 s below the seabed which may be due to erosion on the seabed subsequent to the deposition of the sediments.

The western part of the profile shows two major faults forming a graben which has displaced the sediments and the acoustic basement. The sides of the graben are marked by abrupt truncation of reflectors and steel dips due to faulting while in the graben the sediments show contortion and considerable disturbance.

Line 41

The profile shows a maximum penetration of about 0.5 s below the seabed which marks a discontinuous acoustic basement. The parallel and sub-parallel reflectors within the top 0.4 s thick acoustic transparent sediments in the west are similar to those along Line 40. The sediments are homogeneous in the west while to the east these are wavy due to folding or differential compaction.

The central part of the section (Fix 1630) shows an abrupt lateral truncation of the upper sedimentary strata extending over 5 to 6 km and down to 0.2 s. The sediments on the sides do not show any disturbance or dislocation, therby indicating that the feature is sedimentary (erosional) rather than tectonic. In the west, a fault with a throw of about 0.05 s extends from almost the topmost sediments to the prominent reflector above the basement. A major fault displaces the prominent reflector above the basement and another along a scarp the younger sediments.

Line 42

The profile shows a maximum penetration of 0.6 s down to a discontinuous acoustic basement. About 0.4 s thick acoustic transparent sediments cover the seabed, the parallel to sub-parallel reflections within the sediments indicate homogeneous layered sediments. The acoustic basement is overlain by two prominent reflectors at 0.4 to 0.6 s. The basement is affected by number of faults of magnitude 0.01 to 0.15 s which do not extend to the younger overlying sediments. However, two major faults have a down thrown the entire sedimentary column and even the acoustic basement to about 0.25 s (Fixes 0130 to 0230). The seismic section indicates an uplift of the basement on the crest of the ridge and the overlying sediments gently slope along the flanks of the ridge to the east and west. The basement has also been uplifted due to some of the faults. The sediments have prograded and on lap against the uplifted basement while some pinch out towards the ends, which are faulted. The scarps in the east also show an abrupt termination of sedimentary strata which may be due to faults in the area. Thus there are ages i. e. those affecting the basement and the immediatly overlying prominent reflactor, those affecting the younger sediments and those affecting the entire sedimentary column including the acoustic basement.

The seabed is carpeted with acoustic transparent sediments varying in thickness from 0.3 s in the west to 0.35 s towards the middle end east. These are underlain by a prominent reflector at about 0.4 s depth. In the central part of the profile, the upper transparent sediments are wavy which may be due to differential compaction or due to structural disturbances. In the east, a prominent reflector at 0.1 to 0.15 s depth

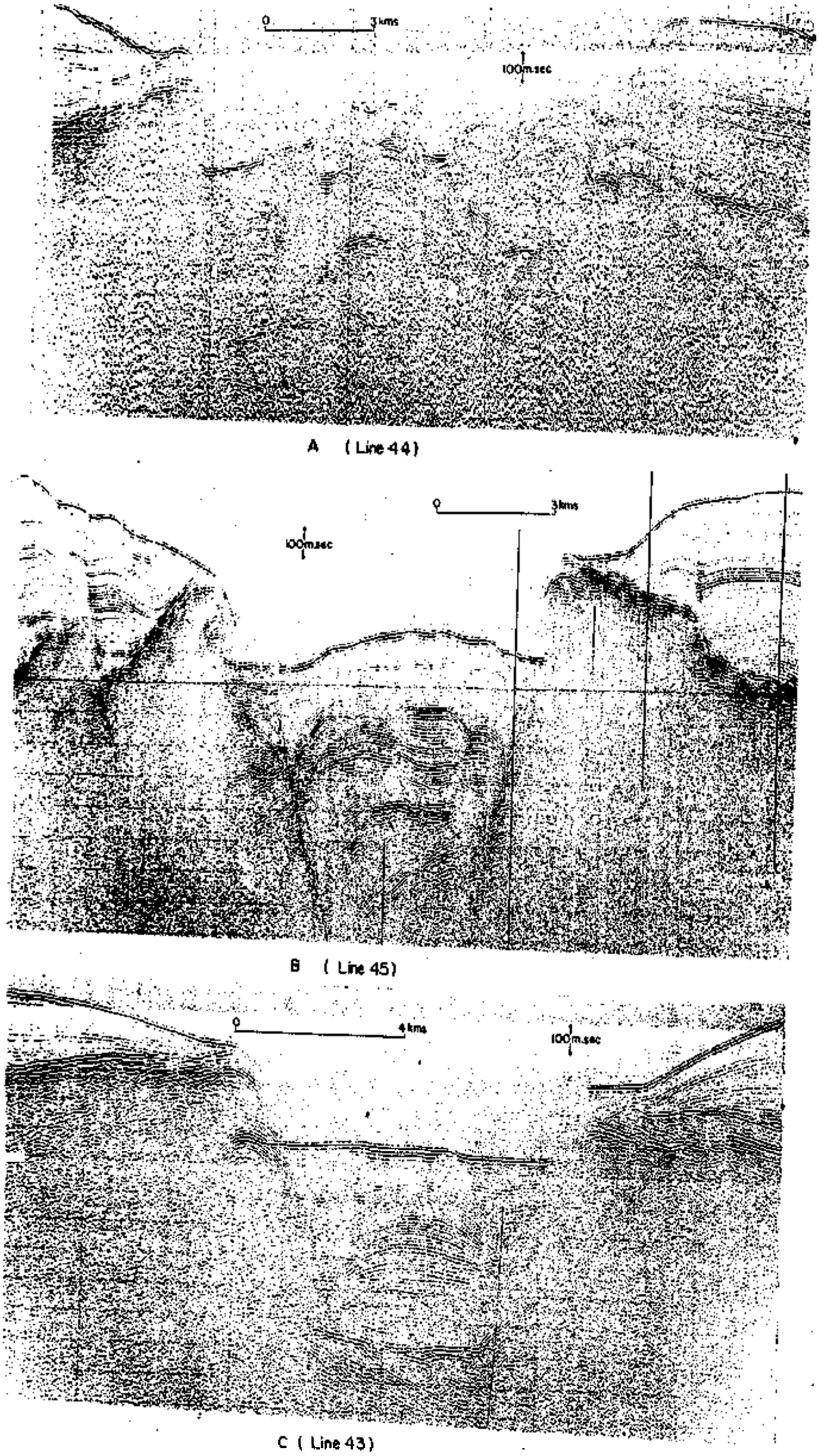

Fig. 6: Seismic records of the graben in the northern area.

within the transparent sediments dips steeply to the east and against the uplifted basement. Further in the east the older sediments of the ridge are overlapped by the younger deep sea facies.

Line 43

The N-S line along the crest of the ridge provided information for correlation of topographic, structural and tectonic features observed in the E-W lines.

The profiles give a penetration down to 0.45 s below the seabed, which, as in the other profiles, is almost down to the acoustic basement. The acoustic basement is intermittently seen throughout the entire length excepting in some part to the north. The characteristic feature of the profile as in the case of the Lines 44 and 45 is a graben (Fig. 6C) in which the sediments and the acoustic basement has been displaced down to a depth of almost 0.35 to 0.5 s, within the graben the sediments have been badly disturbed and domed up. It appear that the acoustic basement on the south has been comparatively more, even though marginally, uplifted than in the north. Another fault to the north with a displacement of 0.5 s has affected the entire sedimentary column while the two faults to the north affect the acoustic basement and the overlying prominent reflector.

Line 44

The seismic profile shows a maximum penetration down to 0.4 s which defines the acoustic and in one case even the crystalline basement. The acoustic basement is well defined on the western flanks but east of Fix 0530, the basement is faulted down and further east (Fix 0730), repeated faults have thrown down the basement, perhaps much deeper.

The acoustic transparent sediments of about 0.35 s thickness with parallel to sub-parallel reflection cover the ridge almost continously, excepting at the crest where these have been faulted down and badly disturbed. A prominent reflector within the ATS at a depth of about 0.25 s is seen in the east. The transparent sediments are underlain by two prominent reflectors at 0.3 and 0.4 s depth. The reflection from these are parallel to the sub-parallel and are even discordant The dips of the sediments are comparatively steeper to the east than the west. The sediments show a progradation and sediment build up along the flanks. The sediments gradually thin towards the uplifted basement at the crest of the ridge. The central part of the western flank defines a feature which has perhaps been filled later by younger sediments.

The characteristic feature of the profile is the graben at the crest of the ridge in which the sediments and the acoustic basement has been displaced down to 0.35 s (Fig. 6A). The sediments within the graben are highly disturbed, faulted and folded. The basement on the western side appears to have been uplifted higher and then on the eastern side of the block where it appears to have been faulted down by a series of step faults.

Line 45

The profiles show a maximum penetration down to 0.4 s which define the prominent reflector and in some cases the just underlying acoustic basement also.

The major features of the seismic section are the two faults on the crest of the ridge which have displaced the entire sedimentary column and the basement to 0.4 s forming a graben (Figs. 6B and 10). The sediments and the acoustic basement in the graben are badly disturbed, folded and faulted. The . acoustic basement rises steeply both on the eastern and western sides of the graben and perhaps the basement rocks are exposed on the walls of the graben. The basement, as in the Line 44, is comparatively more disturbed on the eastern than on the western flanks. Some faults disturb the acoustic basement and

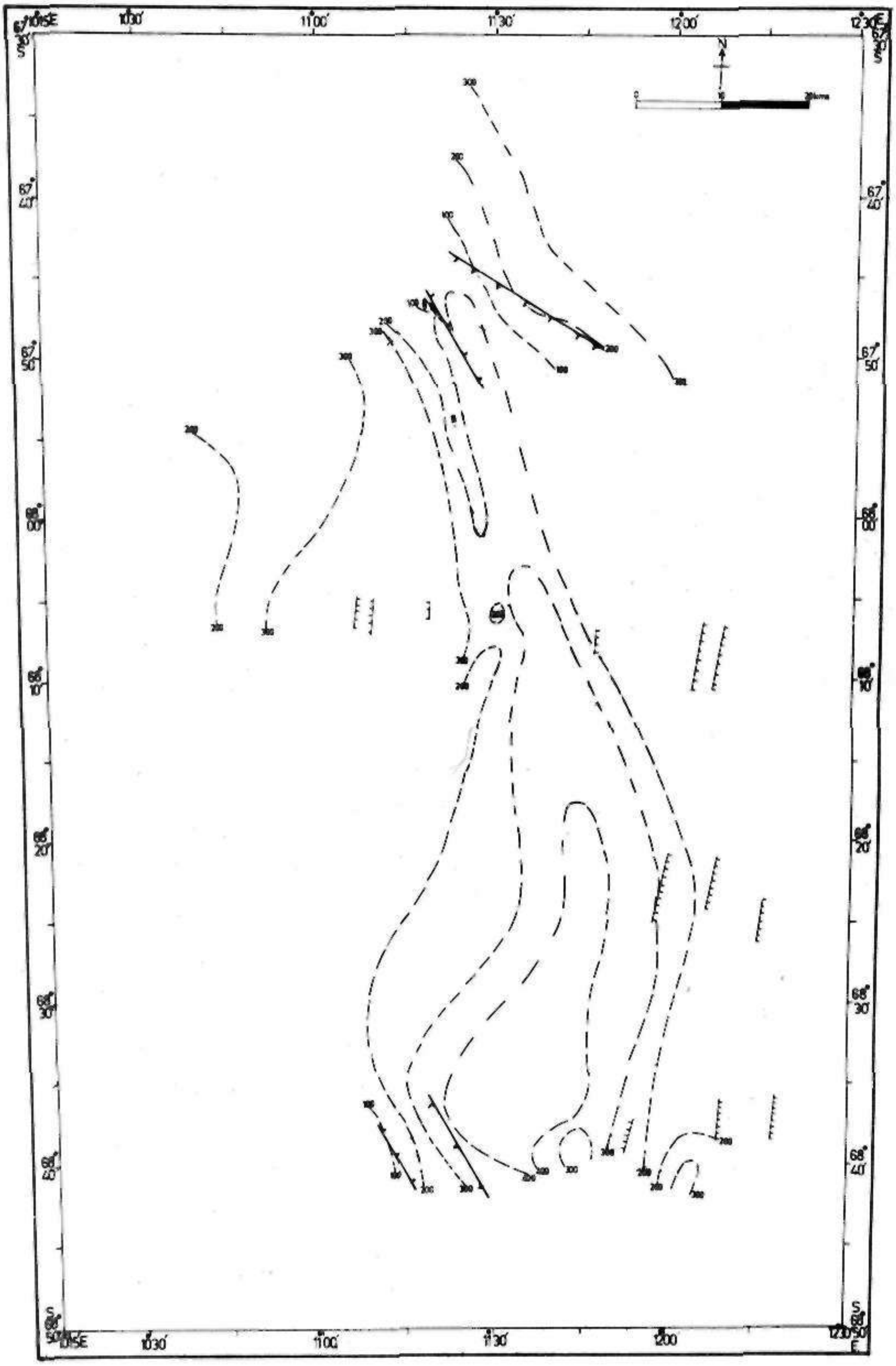

Fig. 7 : Isopach of the acoustic transparent sediments on the Astrid Ridge (Contour interval 100 ms).

the overlying prominent reflector only. However, some faults including the one on the western flank ana the graben affect the entire sedimentary column as also the acoustic basement. The faults in this seismic section could be related to three different ages.

The seabed in the area is covered by about 0.3 s of acoustic transparent sediments underlain by reflectors at 0.3 and 0.4 s in the east and a reflector at 0.3 s in the west. The reflections from the prograded sediments are noted as lenses on the flanks and these onlap against the lifted basement. The topmost sediments forming a lens (2030-2300) represent a similar younger sedimentary facies as on Line 44. Parallel to sub-parallel reflections in the tranaparent sediments indicate homegeneity in the sediment layers.

Line 46

The seismic profiles shows a maximum penetration of 0.5 s. The maximum penetration is almost limited down to the acoustic basement which is well defined even though intermittently in the profiles. The acoustic basement and the overlying prominent reflector have been affected by faults of the magnitude of about 0.4 s which do not affect the younger sediments. The basement shows a gradual uplift towards the crest of the ridge and the younger sediments thus slope to the east and west towards the flanks. Two major faults have down thrown the sedimentary column and even the acoustic basement to 0.2 s depth and has led to minor warping and folding in the overlying sediments and those of the adjacent area. The scarps on the east represent faults which however do not extend deeper and are perhaps confined to the younger sediments only.

About 0.25 s thick acoustically transparent sediments with parallel reflection overlie two prominent reflectors at 0.25 and 0.35 s depth. The sediments appear to be relatively horizontal to subhorizontal in the south and in the north from Fixes 1930 and 2000 dip to the south to the graben and to the northern flank of the ridge. Thick prograded sediments are seen along the flanks of the uplifted basemnt.

Magnetics

The total magnetic intensity measurements were carried out with a Geometrics 801 Proton Precession Magnetometer.. Analog records of the total magnetic intensity values at a sampling interval of 3 seconds were collected and these were prepared after subtracting the regional background field empirically (Fig. 9) as diurnal variations are not available immediately. Anomaly signatures were correlated with structures indicated from seismic records and depth to magnetic crystalline basement was computed following the infleption points and half slope method of Peter (1949).

The magnetic values in the area range from 38550 to 40195 nannotesla. The anomaly signatures along the Lines 40 and 41 are smooth except for a broad low on the Line 40 spreading over 15 km (Fixes 0346 to 0521) towards the east. The causative source for this anomaly was estimated to be at about 3.4 km depth. On Line 42, a well resolved anomalous high (Fixes 0353 & 0100) and a low (Fixes 0050 to 2232) are observed. The depth estimated from the anomalies revealed magnetic crystalline basement at about 3.1 km. In contrast to the southern lines, the anomalies on the northern Lines 43,45 and 46 are well resolved in the east. The magnetic anomalies are almost smooth in the west except on Lines 46 (Fixes 0412 to 0700) and 44 (Fixes 2341 to 0330) where broad anomalous highs varying from 1200 to 2000 nT amplitudes (peak to peak) are noted. A significant feature of the anomalies in the east is a series of high frequency anomalies superimposed overttTe peak of another distinct broad high amplitude anomaly (Fig 10: Line 45 Fixes 0447 - 0719, Line 44 Fixes 1732 - 2310 and Line 43 Fixes 1632 - 1930). The peak to peak amplitude of the anomaly is around 400 to 1000 nT. The widths and the amplitudes (peak to peak) of these high frequency anomalies range from 4 to 10 kms and 100 to 400 nT respectively. A comparison and correlation of these anomalies will reveal a NW-SE to WNW-ESE strike of the broad anomaly and a widening of the anomaly from about 18 km on Line 43 to 24 km on the Line 44 to the SE. The eastern flanks of the anomaly dip steeply and the high frequency anomalies are more pronounced on the Lines 43 and 44.

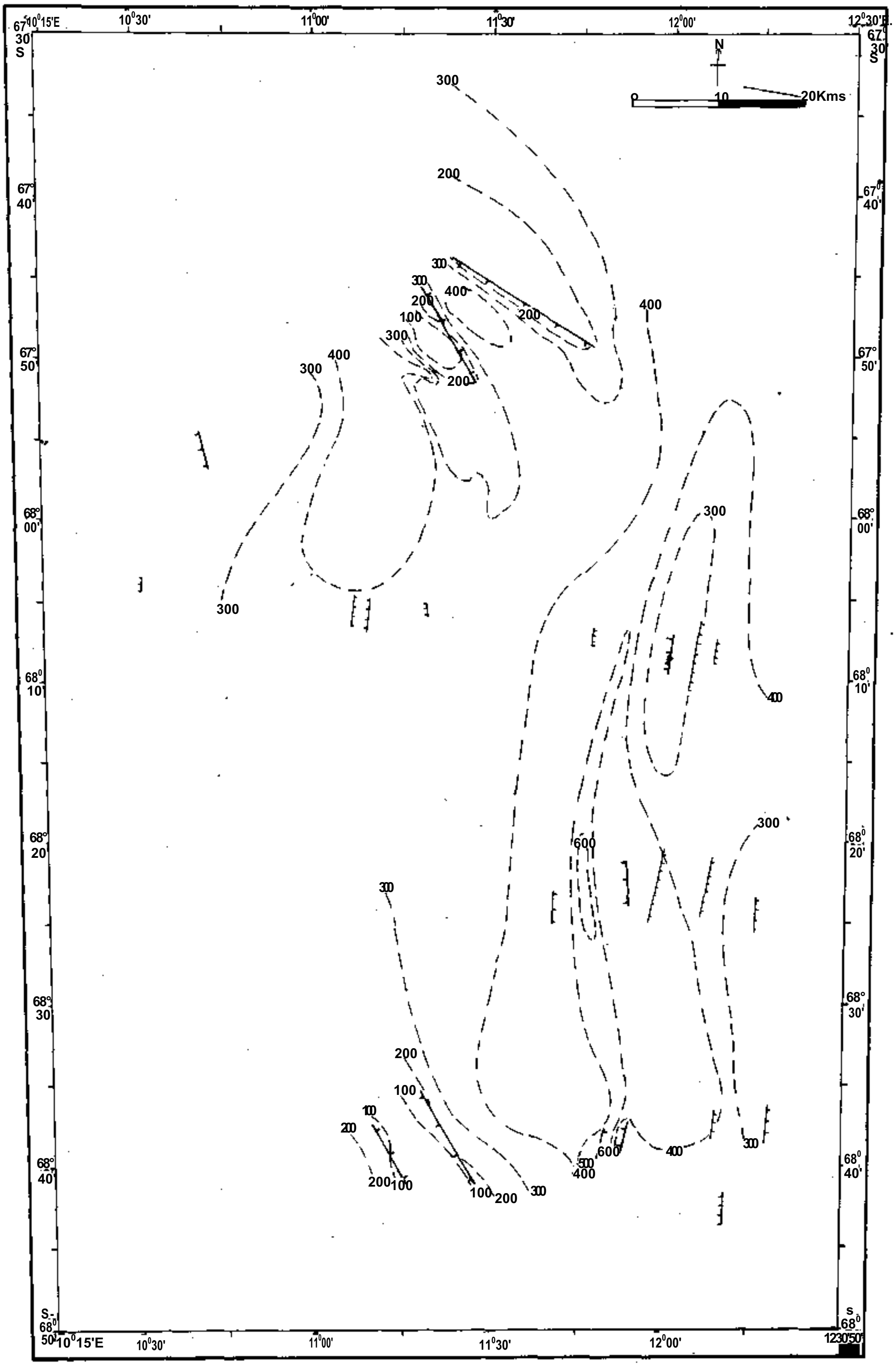

Fig. 8: Isopachs of sediments on the Astrid Ridge (Contour interval 100 ms)

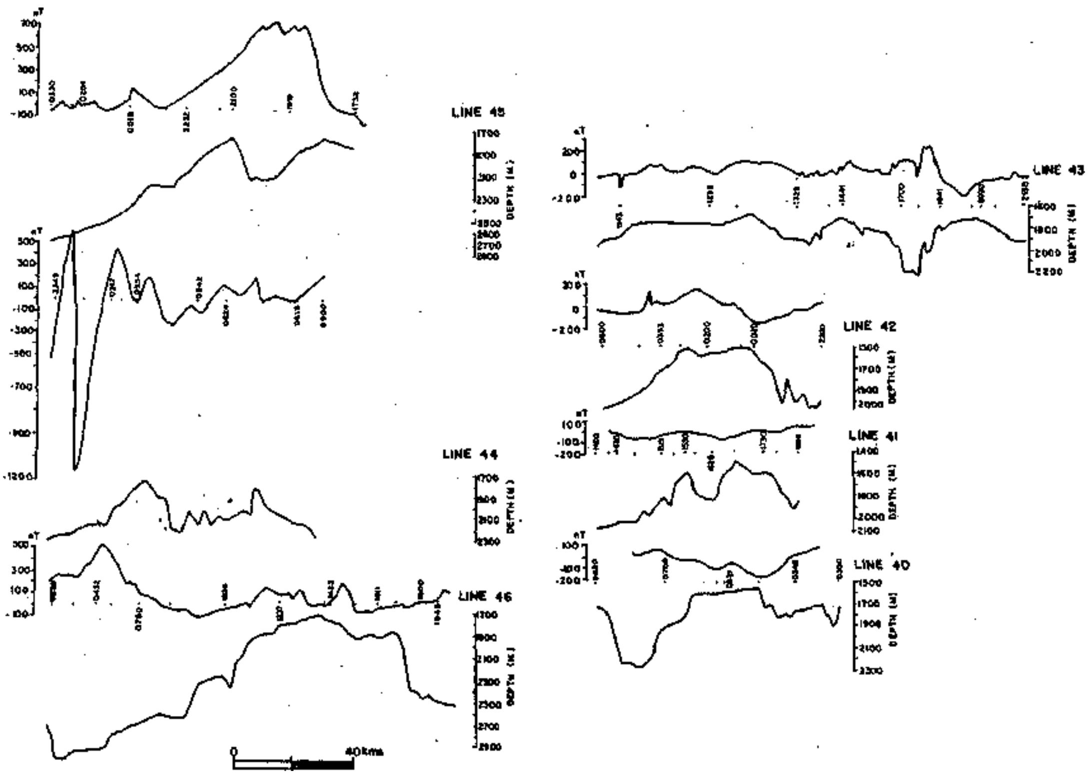

Fig.9 Topography of the sea bed and total intensity residual magnetic anomalies along the lines surveyed.

DISCUSSIONS

The geomorphology shows that the ridge trends N-S in the south-and veers to NNW-SSE around 68°S Lat and further north changes to NNE-SSW at about 67°S Lat. The crest of the ridge in the south is marked by a flat area at about 1500 m which deepens to 1700 -1900 km at about 68°S Lat.

The seismic profiling indicates that the sediments on the ridge can be broadly divided into a top transparent or layered sequence (50 ms thick), underlain by a prominent reflector (About 100 ms to 0.4 s) and the acoustic basement (100 ms to 0.6 s) marked by hyperbolic reflectors. The sediments dip away from the crest to the flanks of the ridge to the east and west. On the eastern margin of the ridge a deep sea sedimentary facies is also recognised (maximum thickness 900 m). The isopach maps show (Figs. 7 and 8) that the sediments are thicker (0.6 ms) in the south and thin farther to the north and along the flanks to the east and west.

The southernmost profiles show extensive folding and faulting which is comparatively less in the northern profiles. The profiles of the southern part of the ridge show that the eastern flanks of the ndge are marked by NNE-SSW scarps (80-280 m) and faults (upto 0.15 s) while the western flanks slope gently. These faults do not affect the older sediments and the basement and are not reflected in the magnetics also. The fracture zone reported by the earlier workers (Bergh 1977) as marking the eastern flank of the ridge perhaps does not extend to the area and lies farther to the east.

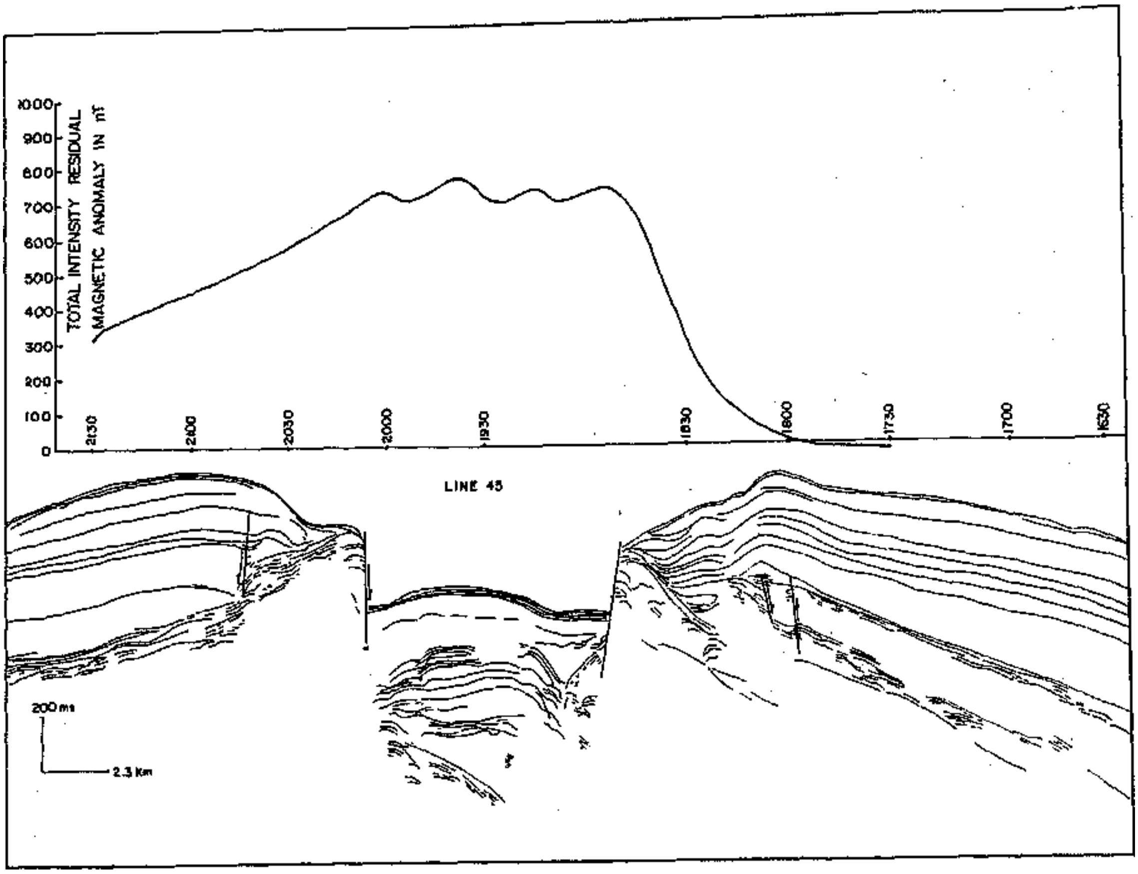

Fig. 10: Bathymetric and seismic section and magnetic anomalies (total intensity residual magnetic anomaly thick line) across the graben (Line 45).

The characteristic feature of the geomorphology, seismic profiles and magnetics of the area is a NNW-SSE trending graben (7 to 11 km broad and 240 to 280 m deep) which has displaced the entire sediments to a depth of 0.6 s. The rift apparently coincides with the crest of the ridge in this area and the western faults appear to have uplifted and the basement more than the eastern ones. The sediments and the basement in the graben are badly disturbed and show contribution and doming. The graben is associated with a prominent magnetic high of 700 to 800 nannotesla and therefore, marks an uplift of the magnetic basement and is a deeper crustal feature.

The faults in the area appears to belong to three ages: (1) those affecting the younger sediments only, (2) the entire sedimentary column and the acoustic basement, and (3) affecting the acoustic basement the overlying older sediments only. Based on the geomorphology and tectonics, the area can be divided into two different domains north and south of Lat. 68°S. It appears that the graben separates the two domains and marks a change in the trend of the crest of the ridge from N-S to NE-SW.

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