

GEOLOGY AND STRUCTURE OF THE  
ASTRID RIDGE, DRONNING MAUD LAND,  
ANTARCTICA

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**Abstract.** Bathymetric (458 line km), Seismic reflection, higher energy sparker source (405 line km) and magnetic (452 line km) studies of the Astrid ridge, a prominent broad bathymetric feature in water depths of about 1520-2900 m on the continental margin of Dronning Maud Land, are carried out. The crest of the ridge in the area surveyed trends N-S in the south but veers to NNW-SSE at about 68° S Latitude and is found to change to NNE-SSW at about 67° S Latitude. 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 with steep gradients. The ridge is mantled by layered sediments of a top transparent layer (50 to 0.4 s) underlain by a prominent reflector (50 ms to 100 ms) and the acoustic basement. The basement occur at

0.4 to 0.6 s depth. The sediments dip away from the crest of the ridge to the flanks. The seismic records further indicated that the NNE-SSW trending scarps on the eastern flanks represent faults which extend only to the younger sediments. They are not reflected in the magnetics indicating that they are not deeper structures. The NW-NNW to SE-SSE trending narrow valleys with steep gradient walls occurring on the ridge crest in the study area are grabens where the basement and associated sediments have been faulted down. The graben in the north is marked by a series of magnetic anomalies of about 50 to 200 nT superposed over the peak of a broad high amplitude anomaly of a mafic material buildup and appears to be a deep crustal feature. The positive bathymetric feature of the ridge part in the south of the study area is not reflected in magnetic anomaly signatures, implying heterogeneity in composition. The magnetic basement is interpreted at depths to top of 1.8 km to 4.0 km. 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 Latitude.

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## INTRODUCTION

The study of the geology and geophysics of the eastern Antarctic continental margins offers unique opportunities to understand (1) the record of the tectonic processes since the fragmentation of the Gondwana Land under the relatively thin blanket of sediments and (2) the geodynamic processes and reconstruction of the Indian, Australian, and Antarctic plates. But the margins still remain poorly studied, and the mineral resources are unexplored due to difficult logistics, the ice cover and hostile environment. However, the recent geological and geophysical studies of the Antarctic continental margins during the various oceanographic expeditions to Antarctica as a part of the International Geophysical Year generated the data. The data are studied, and the results of these studies are summarized in the Atlas of Antarctica [Bakaiv, 1966]. The active seafloor spreading process of the Western Antarctic continental margin and passive eastern Antarctic continental margin are illustrated. Bergh [1977] identified the Mesozoic anomalies M1 to M9 (113 to 121 m.y.), the Mesozoic seafloor, and a major NNE-SSW trending fault scarp which is copolar 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 1.0 sec thick sediments on the ridge. Johnson et al., [1981] synthesized the available data on the morphology of the Weddell Sea and the Southwest 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 adjacent to Agulhas plateau and Astrid ridge adjacent to Mozambique ridge [Bergh, 1977;

Norton and Sclater, 1979; Veevers et al., 1980; Goslin, et al., 1980; Johnson et al., 1981; La Brecque and Keller, 1982; Martin and Hartnady, 1986].

## OFFSHORE DATA

The First Indian Expedition to Antarctica was lead in 1981-1982 on board M/V Polar Circle. Marine geological and geophysical surveys of the eastern Antarctic continental margin were carried out during the cruise (Figure 1). They include bathymetric (3509 line km) magnetic (2900 line km) and seismic reflection (450 line km) surveys and seven seabed samples. The areas covered by the expedition included the Gunners ridge, approaches to the 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 priority and this include the Astrid ridge. The surveys on the Astrid ridge (Figure 2) comprised of echosounding (458 line km), seismic (405 line km) and magnetic (452 line km) along six E-W tracks (lines 40-42 and 44-46 across the ridge) and one N-S track (line 43 along the crest of the ridge). A Kelvin and Hughes echosounder was operated for bathymetric surveys. The Geometrics 801/3 model proton precession magnetometer was deployed for the magnetic surveys. The sensor of the magnetometer was towed astern twice the length of the vessel. An EG&G single-channel seismic reflection profiling system comprising of multi-electrode sparker (energy source 8 to 24 Kjl, a power supply (Model 232A), a Trigger capacitor bank (Model 231), a Krohnrite variable filter (Model 3750)) and an EPC 3200 graphic recorder was used for the surveys. The continental margin during the period of the surveys, i.e., January 1982, was still covered

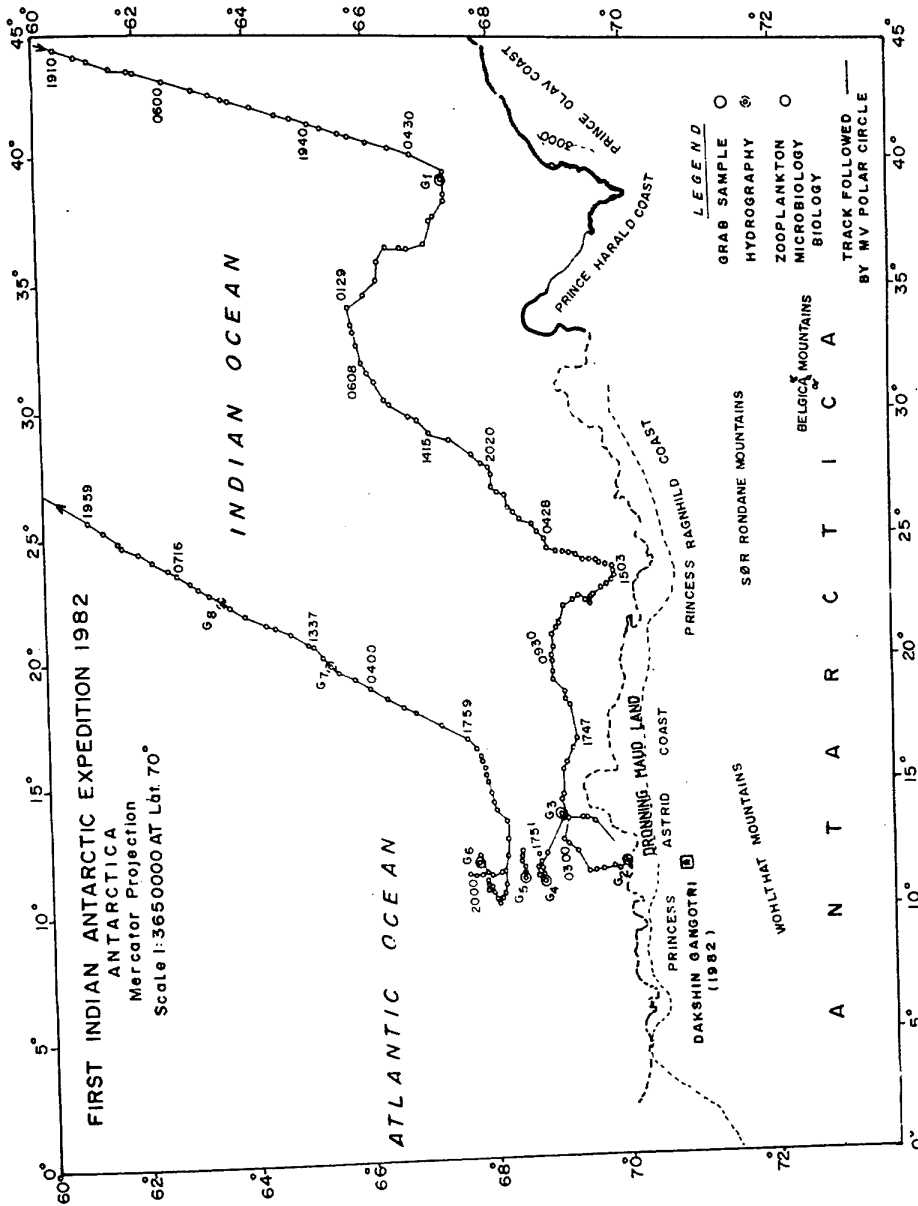


Fig. 1. Tracks along which multidisciplinary oceanographic studies of the eastern continental margin of Antarctica were carried out during the First Indian Antarctic Expedition in 1982.

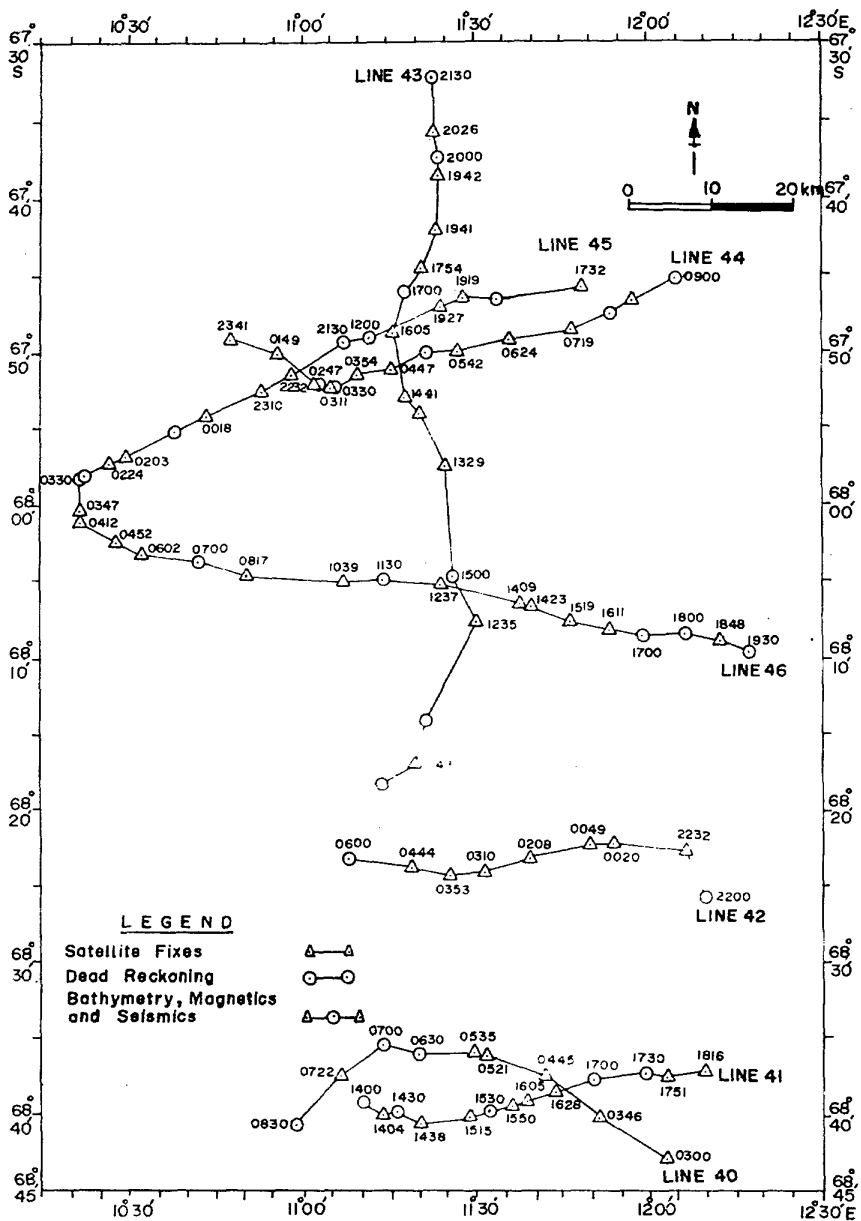


Fig. 2. Map showing the positions of the lines surveyed on the Astrid ridge, Dronning Maud Land, Antarctica.

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 magnetic

data collected during the cruise have been corrected for normal Earth's dipole magnetic field and diurnal variations. Two dimensional model studies for some of the well resolved anomalies are done.

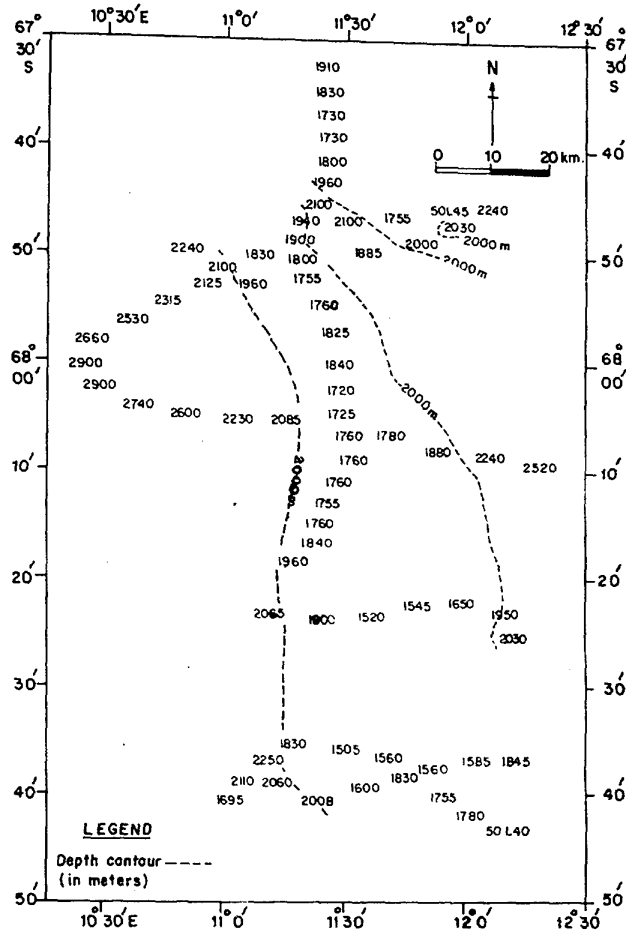


Fig. 3. Bathymetry of the Astrid ridge, Dronning Maud Land, Antarctica (contour interval 1000 m).

## RESULTS

### Geomorphology

The topographic map published by Johnson et al., [1981] shows that the Astrid ridge in the south trends N-S and changes to NNE-SSW in the north at about latitude 67°S. The bathymetric tracks in the present surveys were widely spaced and did not cover the entire width of the ridge to the east and west. In spite of this limitation the data provide some additional and new information.

The ridge apparently comprises 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 Latitude 68°10' S (Figures 3 and 4). The crest in the south is marked by a flat area at about 1500 m water depth (lines 40, 41 and 42) which deepens in the north to 1700-1900 m at Latitude 68° S (line 46). The flat surface perhaps does not extend farther north as north of Latitude 67°S (lines 43, 44 and 45), the crests

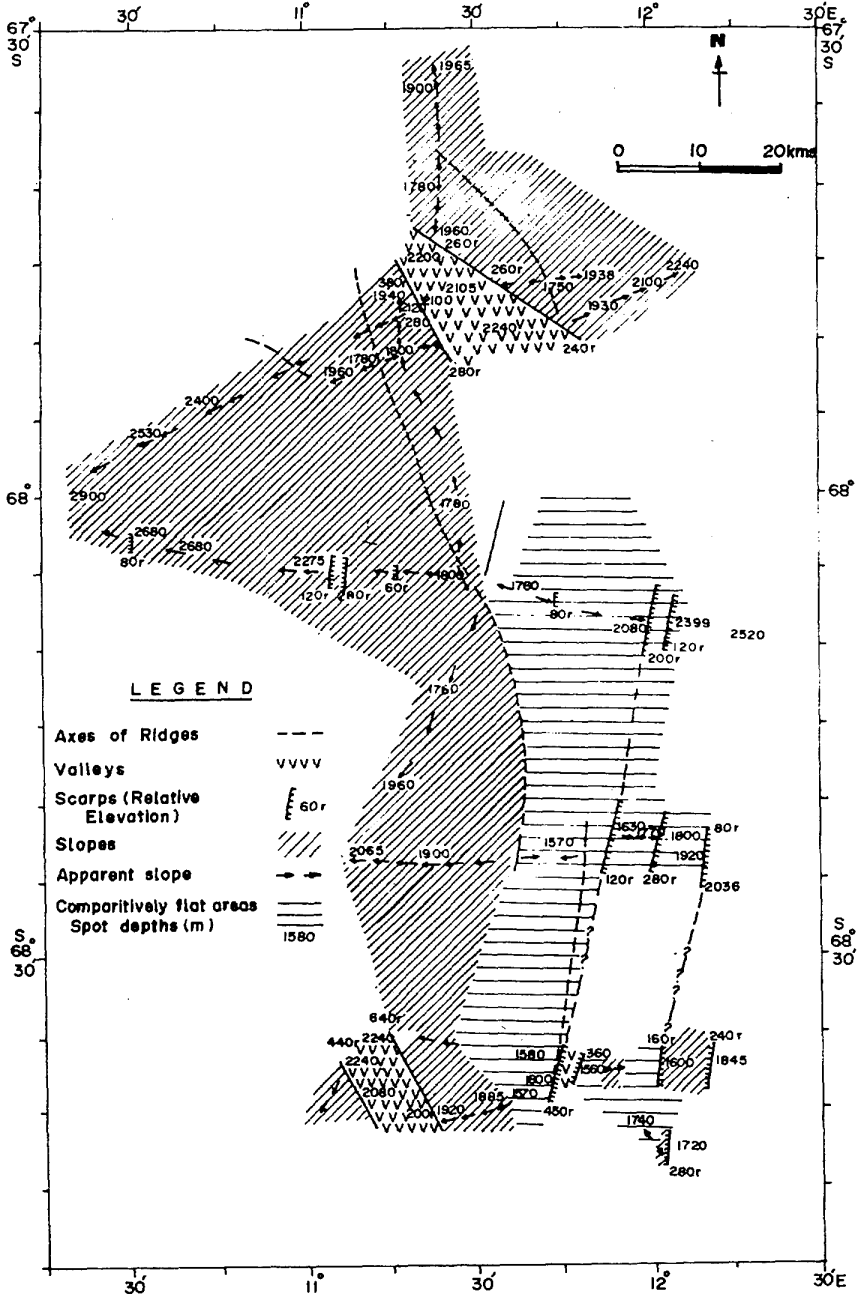


Fig. 4. Schematic map of the geomorphology of the Astrid ridge.

of the ridge are clearly identifiable and are separated by a NNW-SSE trending valley. Since the E-W tracks were incomplete, the exact depth of the base of the ridge is not well 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 (Figures 4, 5F and 5H). 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 (Figures 4, 5A, 5C, and 5E). The valley with steep scarps may have a bearing on the change of direction of the ridge at about 68° S.

#### Seismic Profiling

Seismic sequence analysis on the analog seismic reflection profiles of lines 40-46 is carried out. Results of these studies are presented in Figure 6. The profiles revealed a maximum penetration down to 0.6 s, and in some cases the acoustic and even the crystalline basement are recognizable (The acoustic basement in this case is mapped with the sparker energy source). The seabed is covered with acoustically transparent sediment sequence (thickness ranging from 50 ms to 0.4 s) which is underlain by a prominent reflector (thickness varying from a few tens of milliseconds to 0.1 s). The transparent sediment maximum thickness is around 0.4 s in the south (lines 40-42) and decreases to around 0.35 s in the north (lines 44-46). Parallel to subparallel reflections typical of the layered sediments are common in the lower part of the transparent sediments. The prominent reflector just overlies the acoustic basement at depths ranging from 50 ms to 0.6 s. The thick overlapping/onlapping

sequence (0.2 to 0.25 s) of the ridge sediments especially on the eastern flanks of the ridge (lines 44 and 45) perhaps represents a deep sea facies.

#### Line 40

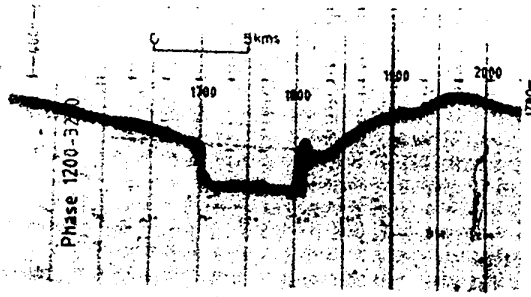
The wavy reflections are noticed in parts of the upper sediment sequence. And the reflectors within the 0.2 s upper strata are abruptly truncated for about 20 to 22 km (0300 and 0445). Two major fault scarps forming a graben which displaced the sediments and the acoustic basement are noticed in the west. The sides of the graben are marked by abrupt truncation of reflectors and steep dips due to the faulting while inside the graben the sediment show contortion and considerable disturbance.

#### Line 41

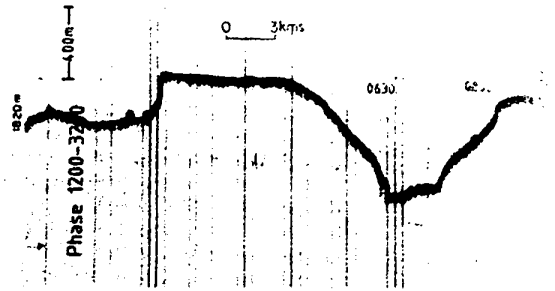
The seismic reflectors are parallel to subparallel in the west, and they are wavy in the east indicating relatively stratified sediments in the west. An abrupt lateral truncation of the upper sedimentary strata over a 5 to 6 km stretch and down to 0.2 s in the centre (around 1630) is noticed. The sediments on the sides do not show any disturbance or dislocation, thereby indicating that the feature is sedimentary (erosional) rather than tectonic. The wavy reflection sequence on lines 40 and 41 indicates folding or differential compaction, while the truncations of the sequence reflect erosion subsequent to deposition. 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.

#### Line 42

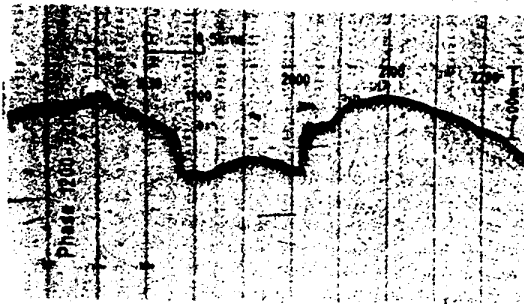
The profile shows a maximum penetration of 0.6 s down to a discontinuous acoustic basement and is overlain by prominent reflectors. It is affected by a



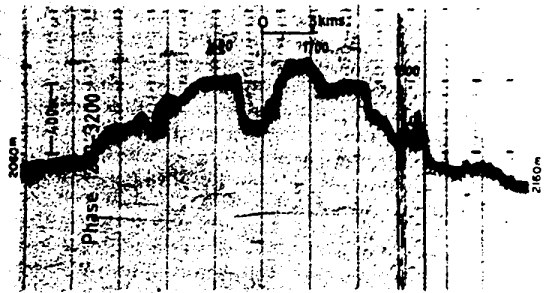
A ( Line 43)



B ( Line 40)



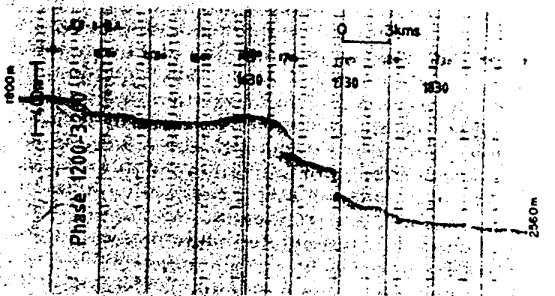
C ( Line 45)



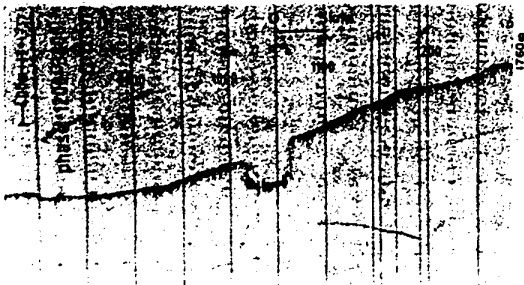
D ( Line 41)



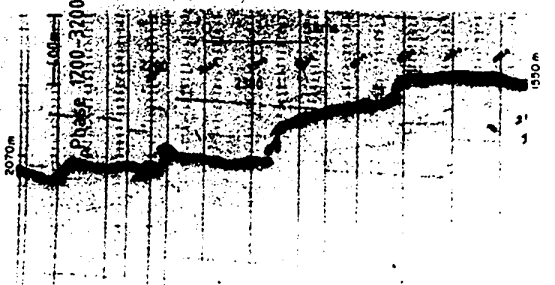
E ( Line 44)



F ( Line 46)



G ( Line 46)



H ( Line 42)



number of faults with magnitude 0.01 to 0.15 s which do not extend to the younger overlying sediments. However, two major faults have downthrown the entire sedimentary column and even the acoustic basement to about 0.25 s (0130 to 0230). The seismic section indicates a raised acoustic base-ment on to the ridge crest, and the overlying sediments gently slope along the flanks of the ridge to the east and west. 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 three ages, i.e. those affecting the basement and the immediately overlying prominent reflector, those affecting the younger sediments, and those affecting the entire sedimentary column including the acoustic basement.

In the central part of the seismic profile, the seismic reflectors of the upper strata are wavy which indicates folding or differential compaction, while the truncations of the sequence reflect erosion subsequent to deposition. 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 reflector along a scarp of the younger sediments. On these lines, maximum subbottom penetration around 0.5 s and discontinuous acoustic basement on line 41 are observed.

#### Line 43

The N-S line along the crest of the ridge provided information

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Fig. 5. (Opposite) Echograms of the seabed scarps/faults, canyons and valleys/graben. Figures 5A, 5C, and 5E show results for the scarp on the crest of the ridge and the graben. The corresponding interpreted seismic sections show faulting along the scarps and the associated magnetic anomalies. Figures 5B, 5D, 5F, 5G, and 5H show results for scarps in the south.

for correlation of topographic, structural, and tectonic features observed in the E-W lines.

The acoustic basement occurs at a maximum depth of 0.4 s below the seabed. It is intermittently seen throughout the entire length except in some parts to the north. The characteristic feature of the profile, as in the case of lines 44 and 45 is a graben (Figure 7C) in which the sediments and the acoustic basement have been displaced down to a depth of almost 0.35 to 0.5 s. Within the graben the sediments are disturbed and domed up. It appears that the acoustic basement in the south is 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 profile shows a well defined acoustic basement at a maximum depth of 0.4 s and in one case even shows the crystalline basement. The acoustic basement is clearly identified on the western flanks (east of 0530), even though it was faulted down to much deeper levels.

A prominent reflector within the acoustic transparent sediments 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 depths. The reflections from these are parallel to subparallel.

The dips of the sediments are comparatively steeper to the east than to the west. The sediments show a progradation and sediment buildup along the flanks. The ridge crest is mantled with thin veneer of sediments. The characteristic feature of the profile is the steep walled graben at the crest of the ridge in which the sediments and the acoustic basement have been displaced down to 0.35 s (Figure 7A). The sediments within the graben are highly

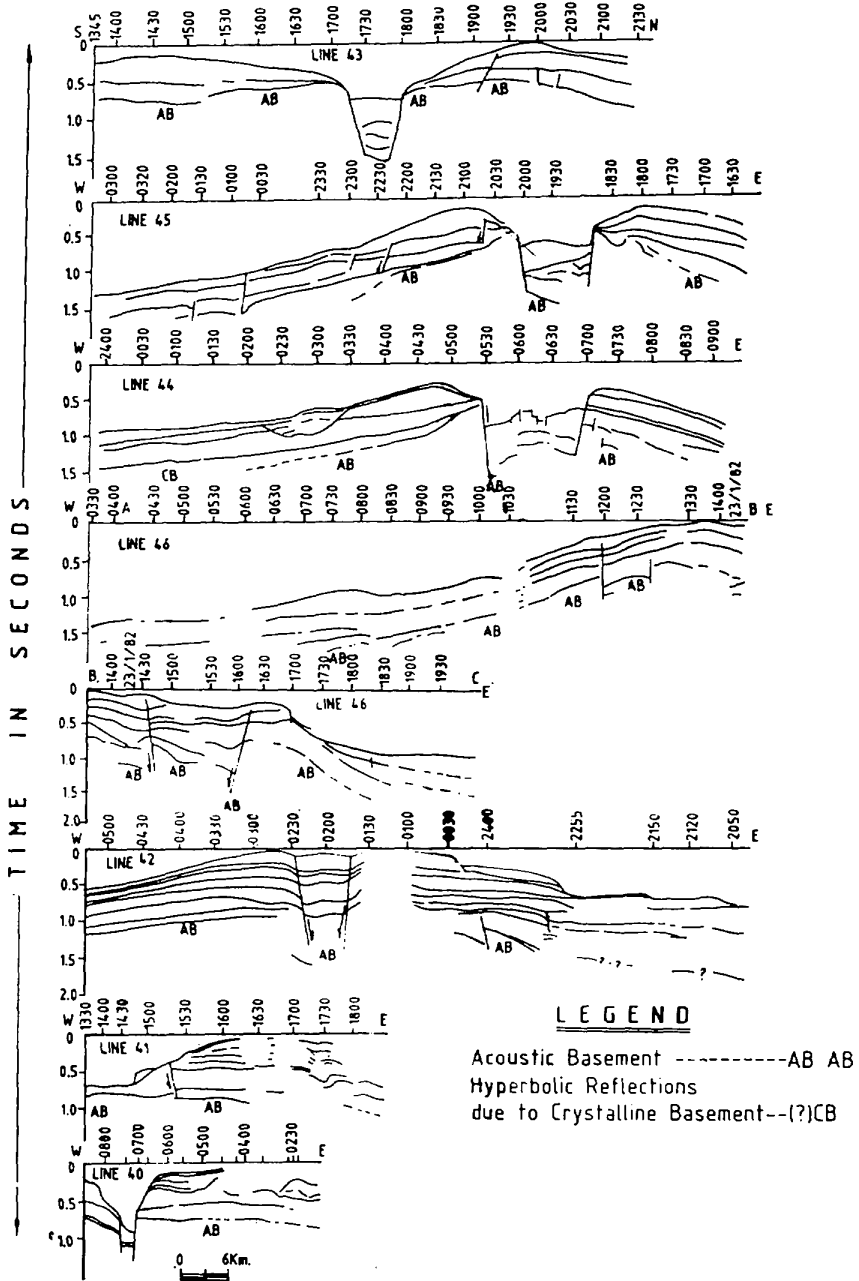
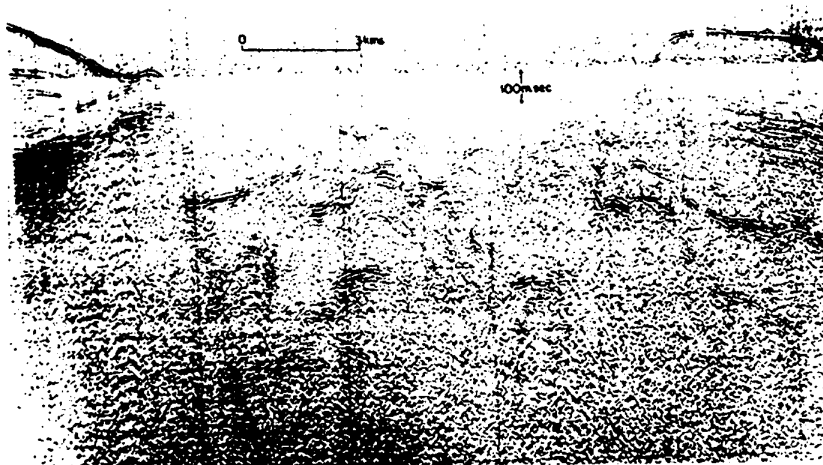
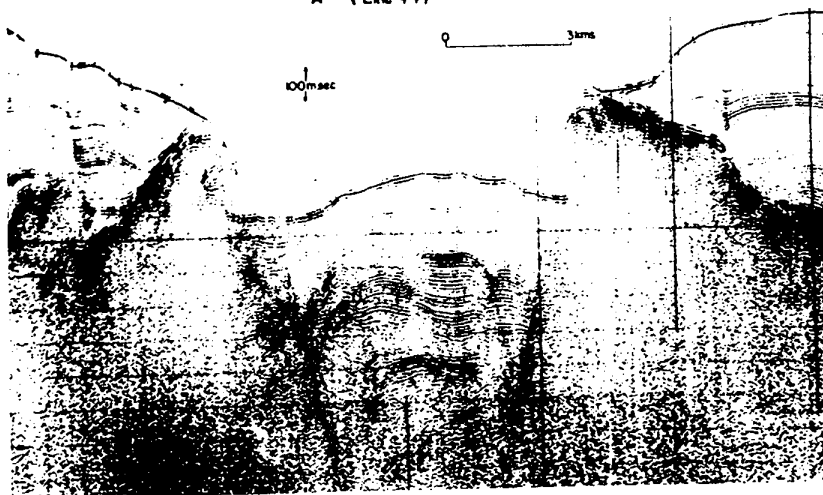


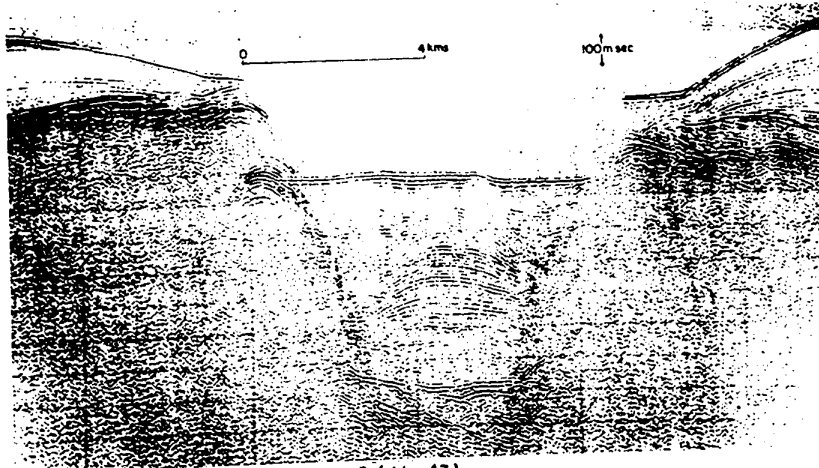
Fig. 6. Interpreted seismic section over the Astrid ridge. Two way travel time in seconds, acoustic basement (AB), and crystalline basement (CB) are shown.



A ( Line 44)



B ( Line 45)



C ( Line 43)

Fig. 7. Seismic records of the graben in the northern area.

disturbed, folded and faulted. The basement on the western side appears to have been uplifted higher than on the eastern side of the block, where it appears to have been faulted down by a series of step faults.

#### Line 45

The profile shows a maximum penetration down to 0.4 s which defines the prominent reflector and in some cases the just underlying acoustic basement. The major features of the 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 (Figure 7B). The sediments and the acoustic basement in the graben are folded and faulted. The basement rises steeply on both the eastern and the western sides of the graben, and perhaps the basement rocks are exposed on the walls of the graben. The basement and the overlying prominent reflector are affected by the presence of the faults and more disturbed on the eastern than on the western flanks. However, some faults, including the one on the western flank and the graben affect the entire sedimentary column and the acoustic basement. The faults in the seismic section could also be related to three different ages as mentioned in the line 42.

#### Line 46

On the profile a well defined acoustic basement which is seen intermittently occurs at a maximum depth of 0.5 s. The basement and the overlying prominent reflector have been affected by faults of magnitudes of about 0.4 s which do not affect the younger sediments.

The basement show a gradual uplift toward the crest of the ridge, and the younger sediments 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 have led to minor

warping and folding in the overlying sediments and sediments 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.

Comparatively, more parallel to subparallel reflectors in the north and wavy reflectors in the south are noticed in the study area. However, thick prograded sediments are seen along the flanks of the uplifted basement.

#### Magnetics

The total magnetic intensity values in the area range from 38,550 to 40,195 nT. The observed magnetic anomalies (Figure 8) are obtained after duly correcting the data for the geomagnetic reference field (IAGA (1) Working group for 1982 epoch) and diurnal observed at the geomagnetic observatory at Hermanus (Latitude 34° 25' S, Longitude 19 13' E).

The peak to peak anomaly signatures are smooth in the southern lines; 41, 42 and 43 except for a broad, 15 km wide low on line 40 (0346 to 0521) and a well resolved anomalous high (0353 to 0100) and low (0050 to 2232) on line 42. Varied amplitude anomalies occur on the northern lines. The anomalies on lines 43, 45 and 46 are almost smooth in the west, except on lines 46 (0412 to 0700) and 44 (2341 to 0330) where broad anomalous highs, 900 to 1000 nT amplitude are recorded. A significant feature of the anomalies in the east is a series of high frequency anomalies superimposed over another distinct broad high amplitude anomaly (Figure 9, line 45, 1732-2310, line 44, 0447-0719, and line 43, 1632-1930). The anomaly amplitudes are around 200 to 400 nT. The widths and the amplitudes of the high frequency anomalies range from 4 to 10 km and 50 to 200 nT, respectively. Correlation of these anomalies revealed a NW-SE to WNW-ESE strike of the broad anomaly and widening of the anomaly from about 18 km on line 43 to 24 km on line 44 to

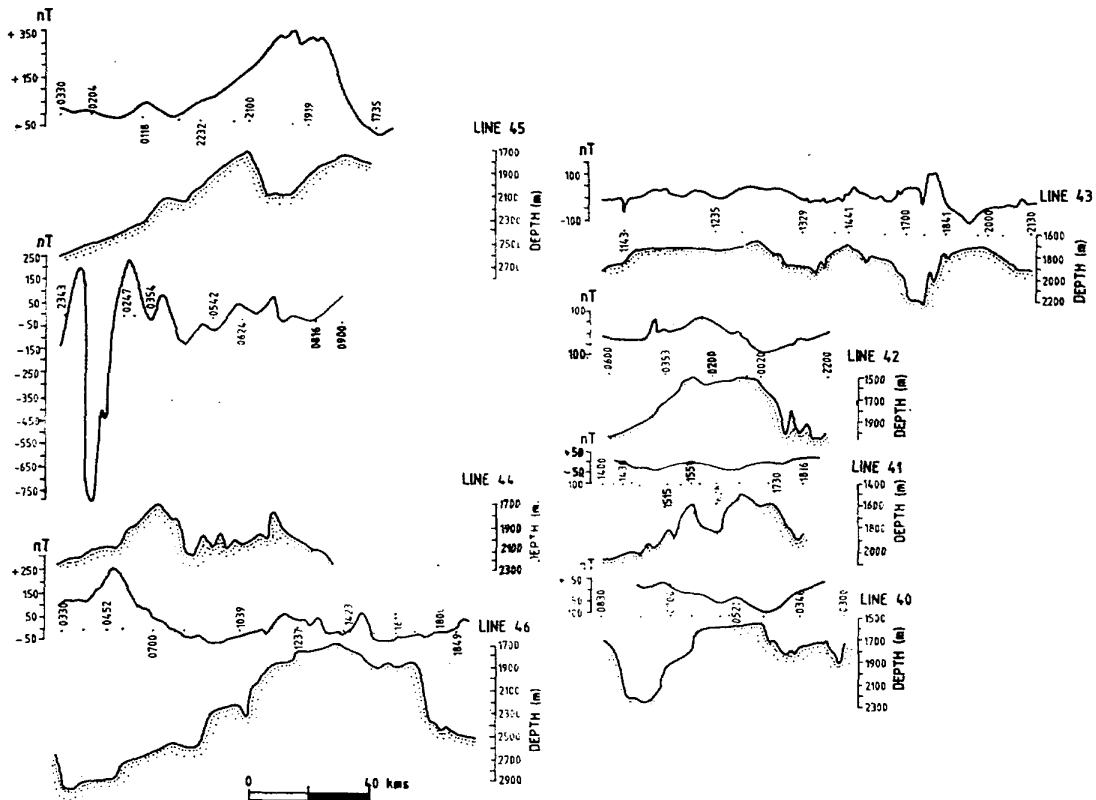


Fig. 8. Bathymetry and observed total magnetic intensity anomalies along the lines surveyed.

the SE. The eastern flank of the anomaly dips steeply, and the high frequency anomalies are more pronounced on lines 43 and 44.

The magnetic anomaly signatures correlated well with the structures identified from the geomorphic and seismic studies. These reveal that a distinct broad high amplitude anomaly occurs at the crest of the N-S to NNW-SSE trending Astrid ridge in the north. Two-dimensional model studies of the magnetic anomalies under constraints from the seismic reflection results (Figure 9) were carried out following Talwani and Heirtzler's method [1964]. In this method, model bodies bounded by polygonal surfaces were generated to explain the observed anomalies and the geological structure

contributing to anomalies. The magnetic anomalies very well reflect the riftlike features on the ridge as also some of the scarps/faults discussed. These appear to be deep crustal features which even affect the magnetic crystalline basement.

Model studies of the anomalies on the line where the rift is prominent revealed that a magnetic crystalline basement with a magnetization of about 3 A/M (Figure 9) contributes to the anomalies. The model at depths to top varying from 1.8 to 4.0 km revealed 16.4 km maximum thickness under the ridge crest and even represents the graben model noticed from seismic records. Some of the scarps/faults are not reflected in the magnetics and these do not appear to be deep crustal features.

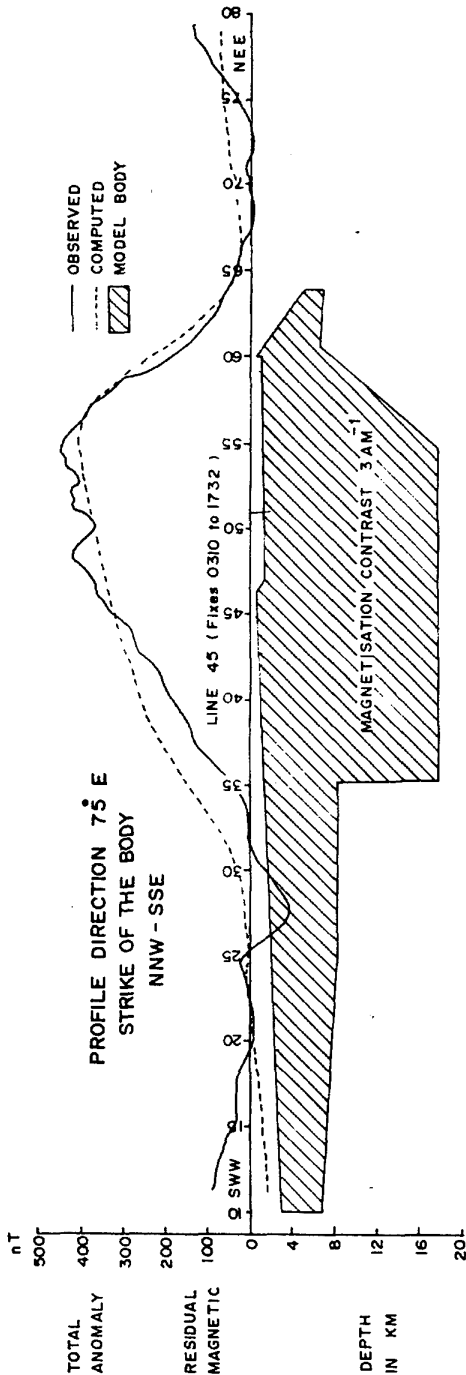


Fig. 9. Interpreted two dimensional magnetic block model.

Deep seismic sounding studies (DSS) of the Queen Maud Land coast [Kurinin and Grikurov, 1982] revealed the crustal structures and presence of a prominent crustal layer 17-20 km thickness under a thin veneer of sediments. It was interpreted as charnockite, based on velocity, (6.0-6.2 km/sec) and density, (2.90-2.95 gm/cm) structure. The fact that the Agulhas plateau especially in the southwest consists of continental crust [Laughton, et. al., 1971], and the Queen Maud land margin were juxtaposed near the triple Junction in Early Cretaceous reconstruction of Gondwana land [Bergh, 1970 and La Brecque and Keller, 1982] lead to comparison of the interpreted basement model from magnetic anomalies with the DSS crustal structure. It indicates that the present model parameters, i.e., depth and thickness, agree with the crustal layer from deep seismic sounding studies. Moreover, the magnetic parameter of the interpreted model helped in suggesting the nature of the basement is mafic charnockite, similar to the crustal layer in the adjacent onshore area.

#### DISCUSSION

The geomorphology shows that the ridge trends N-S in the south and veers to NNW-SSE around 68° S Latitude and further north changes to NNE-SSW at about 67° S Latitude. The crest of the ridge in the south is marked by a flat surface at about 1500 m water depth which deepens to 1700 - 1900 at about 68° S Latitude. The seismic profiles indicate that the sediments on the ridge can be broadly divided into a top transparent and layered sequence (50 ms thick), underlain by a prominent reflector (about 199 ms to 0.4 s) and the acoustic basement (100 ms to 0.6 s). 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 recognized (maximum thickness of 900 m). The isopach maps revealed (Figures

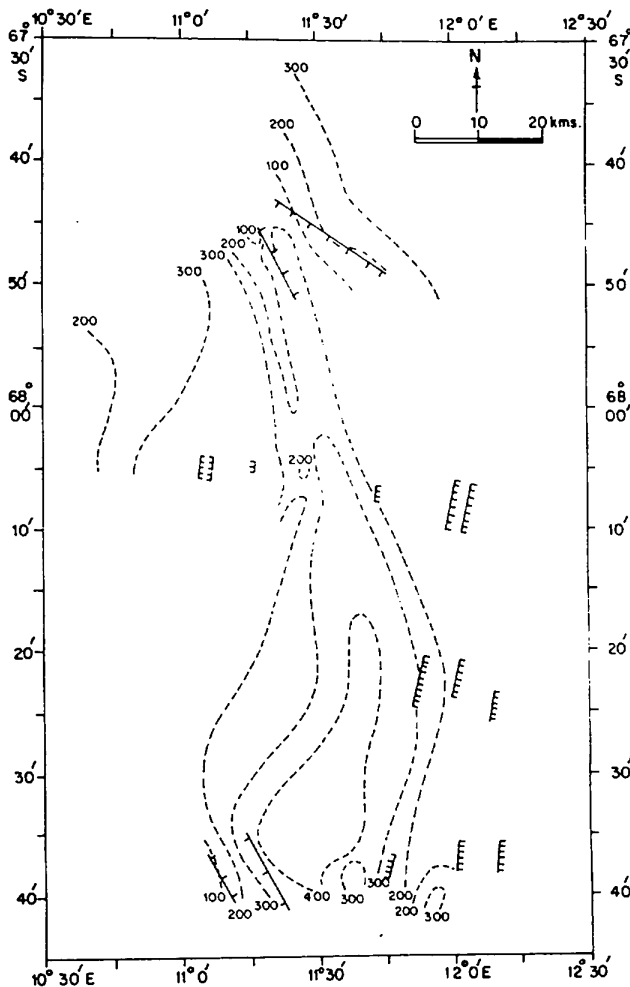


Fig. 10. Isopach of the acoustic transparent sediments on the Astrid ridge (Contour interval 100 ms).

10 and 11) 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 are comparatively less in the northern profiles. They, perhaps, reflect the compressional forces as a result of the tectonic processes in the area and the mainland orogenic episodes. The profiles of the southern part of

the ridge show that the eastern flanks of the ridge 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 also are not reflected in the magnetics. The abrupt truncations of the upper strata of the sedimentary sequence in the southwest could be the result of sediment erosion by current scour. The fracture zone

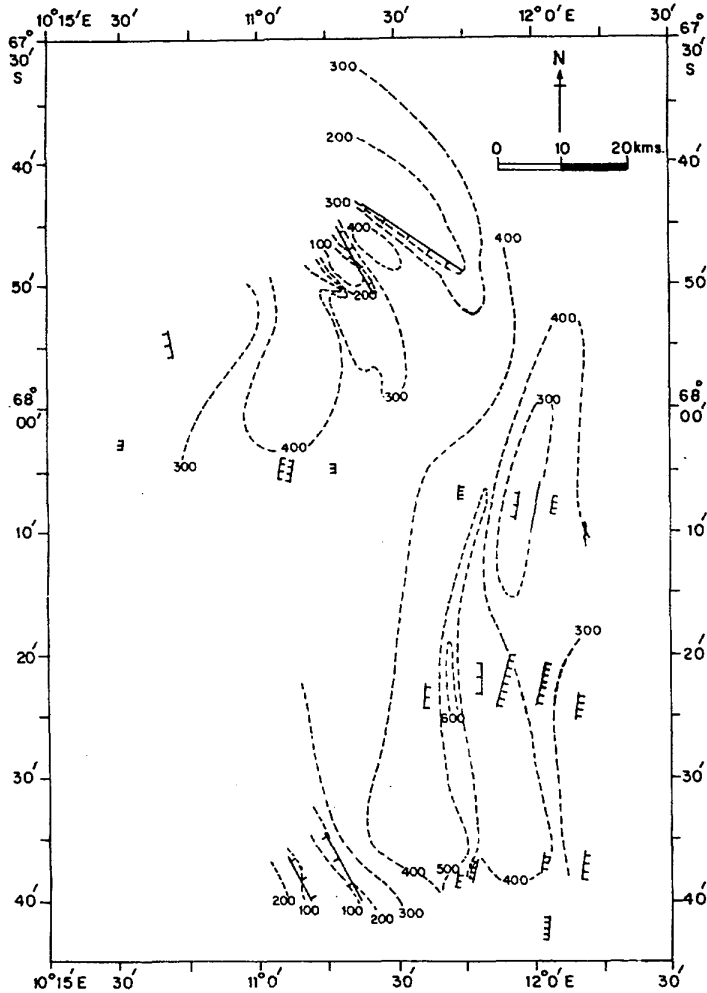


Fig. 11. Isopach of the sediments on the Astrid ridge (contour interval 100 ms).

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. The characteristic feature of the geomorphology, seismic profiles and magnetics of the area is a NNW-SSE trending graben, 7 to 11 km wide 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 the basement more than the eastern ones. The sediments and the basement in the graben are badly disturbed and show contortion and doming. The graben is associated with prominent magnetic anomalies of about 200 nT and therefore, marks an uplift of the magnetic basement and is a deep crustal feature.

The faults in the area appear to belong to three ages: (1) those affecting the younger



sediments only, (2) those affecting the entire sedimentary column and the acoustic basement, and (3) those affecting the acoustic basement and the overlying older sediments only. On the basis of the geomorphology and tectonics, the area can be divided into two different domains in the north and south of Latitude 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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