AN AEROMAGNETIC SURVEY OF THE NENY FJORD AREA, GRAHAM LAND, ANTARCTICA

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ASTRACT. The results of an aeromagnetic network over Neny Fjord (68° 16′ S, 66° 50′ W) are described. The survey was flown to investigate a possible offshore continuation of a topographic divide between Graham Land and Palmer Land, which may have structural significance. The data do not show any major geological disconformity but do reveal an active magnetic relief. Three-dimensional modelling indicates that near surface intrusions are responsible for two anomalies whose amplitudes approach 650 nT. The largest body has dimensions of 10 × 1.5 km and may extend from less than 2 km below sea level to depths of 20 km. Both bodies trend approximately north-east–south-west. The results imply magnetization contrasts of up to 9 A m^{-1} which are comparable with selected gabbros from Marguerite Bay. The anomalies all lie within a more extensive linear anomalous zone along the west coast of the Antarctic Peninsula.

INTRODUCTION

Neny Fjord (68° 16′ S, 66° 50′ W) lies on the Fallières Coast of south-west Graham Land (Fig. 1). The fjord (Fig. 2a, b) is fringed by mountains of varying relief from Mount Nemesis (788 m) to the distinctive Neny Matterhorn with its adjacent Little

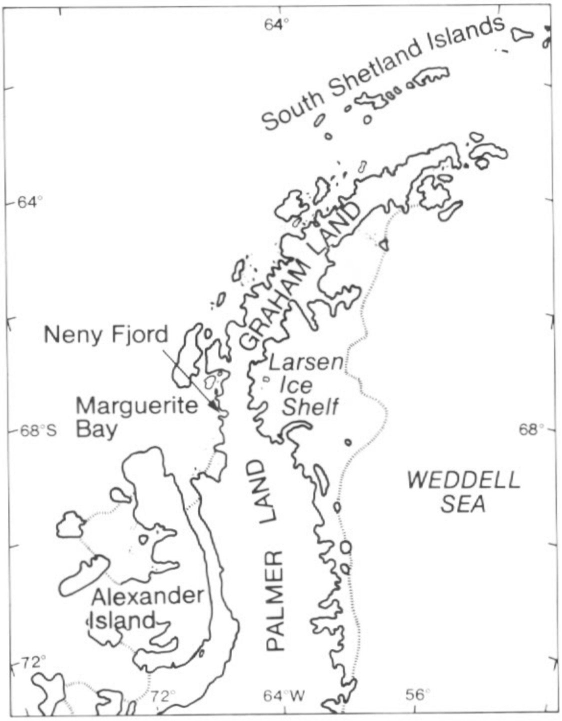
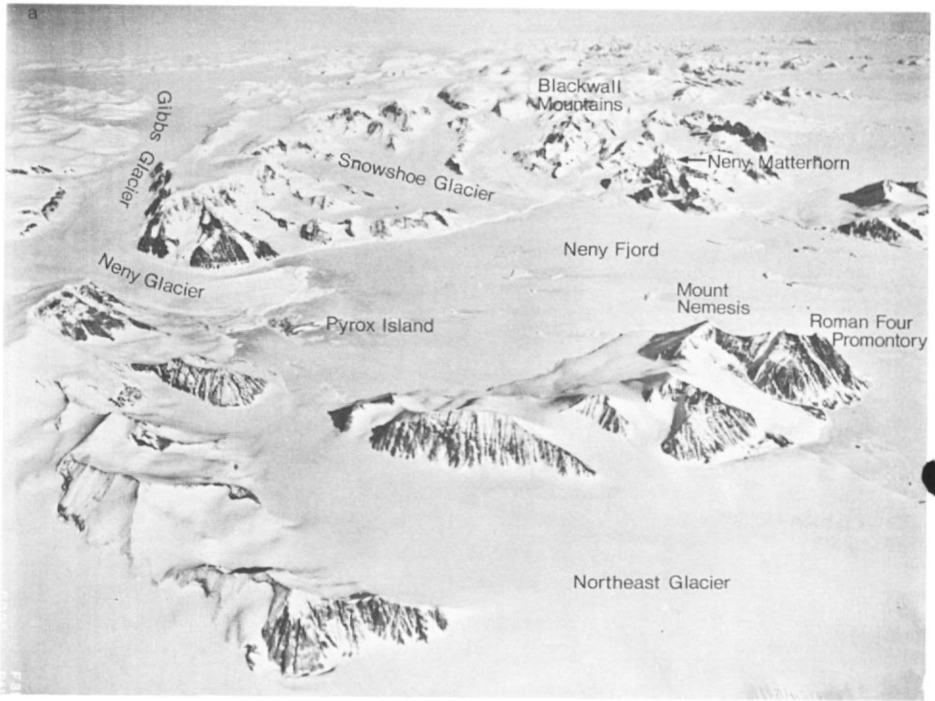


Fig. 1. Location of Neny Fjord aeromagnetic survey.



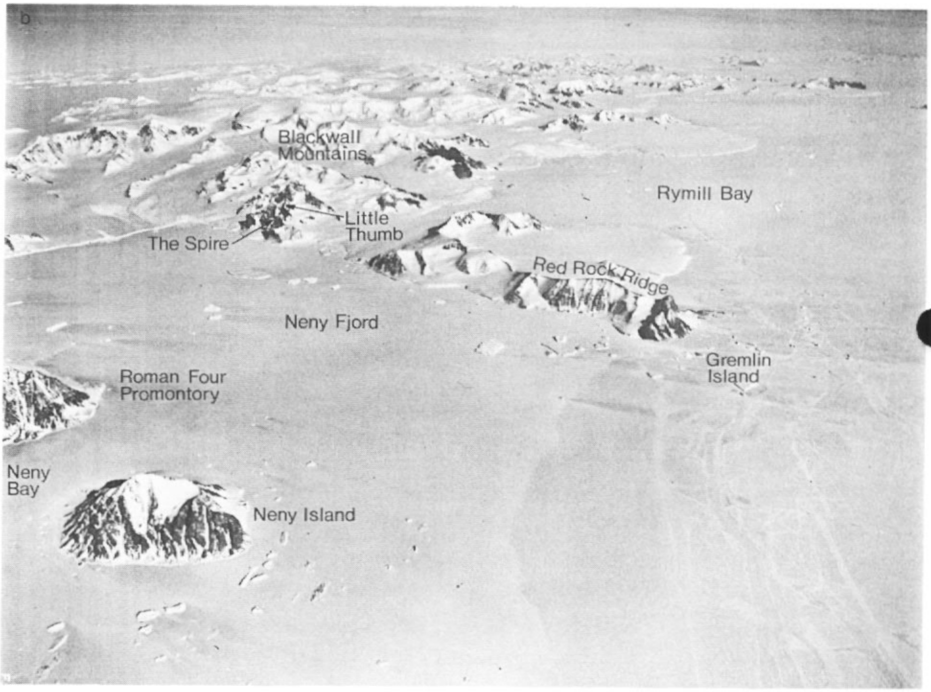


Fig. 2. Aerial photographs of Neny Fjord area looking south. Photograph identification: (a) TMA 1832, F31, 001. (b) TMA 1832, F31, 0035. Flight altitude 6200 m.

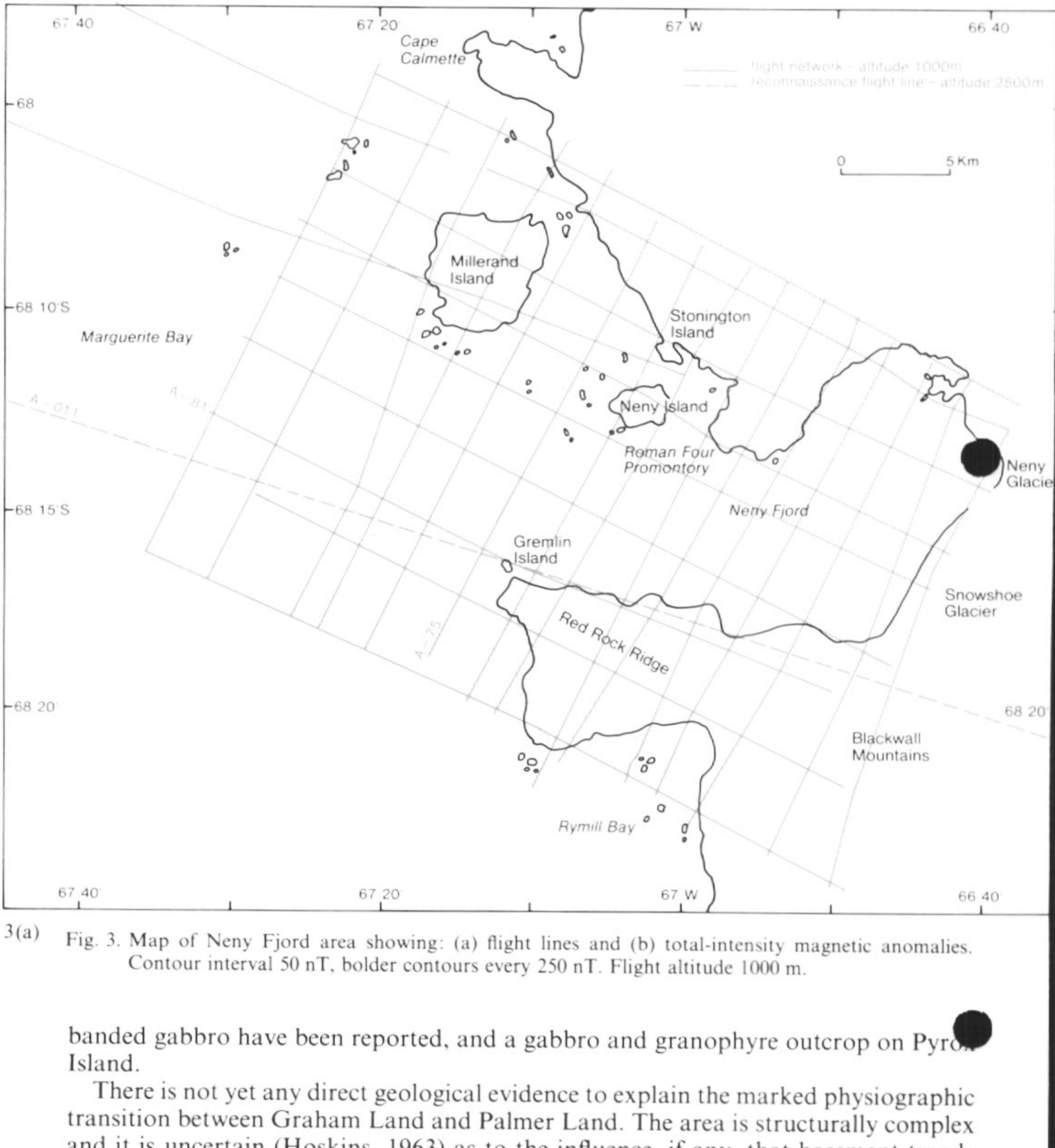
Thumb and The Spire. Two large glaciers calve into the fjord from the east, the highly crevassed Neny Glacier and the relatively smooth Snowshoe Glacier. North of a line joining the headlands of Roman Four Promontory and Red Rock Ridge lies a broken coastline of ridges, buttresses and glaciers with numerous offshore islands. The largest of the islands is Millerand Island (969 m), but many smaller ones reflect an irregular relief. The deepest sounding in the area is 481 m in Neny Fjord. The fjord lies at the western end of an obvious north-west–south-east topographic discontinuity. This extends across the breadth of Graham Land from Marguerite Bay to Larsen Ice Shelf by way of Neny Glacier and Gibbs Glacier, a distance of 90 km. Wyeth (1977) decribes the physiographic contrasts across this discontinuity which is considered to represent part of a 150-km wide transition zone between Graham Land and Palmer Land.

Geology

Graham Land forms the northern half of the Antarctic Peninsula, the latter being one of several possible continental fragments along the Scotia arc and in Lesser Antarctica. The fragments are believed to have occupied contiguous positions along the Pacific margin of Gondwana, thus uniting Greater Antarctica with South America (Dalziel and Elliot, 1982). Such a geographic continuity may have lasted until the mid-Tertiary (Woodburne and Zinsmeister, 1983). Subduction–accretion processes which were variously active along the continental margin of Gondwana during and subsequent to its fragmentation and component migration (Thomson and others, 1983; Storey and Garrett, 1985) are reflected in the geology of the Antarctic Peninsula. The exposed rocks largely consist of calc-alkaline plutonic rocks of Mesozoic–Cenozoic age and associated volcanic rocks (Antarctic Peninsula Volcanic Group) intruded by, and through, an evolving magmatic arc. There was a gradual cessation of subduction from south to north along the western margin of the Antarctic Peninsula, although there is indirect evidence (Barker, 1982) that some subduction is occurring today off north-west Graham Land.

The basement in the region is diverse, comprising deformed metasedimentary and gneissose rocks of Late Palaeozoic–Triassic age (Thomson and others, 1983). However, much of what was once believed to be a Precambrian–Palaeozoic basement may be pre-Middle Jurassic metamorphic and sedimentary rocks of an accretionary prism (Pankhurst, 1983). The rocks of the Neny Fjord and Marguerite Bay area are typical of those found elsewhere along the Antarctic Peninsula. The pre-volcanic basement consists essentially of gneisses with scattered schists (Adie, 1954; Hoskins, 1963). *Ortho*-gneisses which crop out near Millerand Island, on Neny Island and Roman Four Promontory range in composition from granite–gneiss to diorite–gneiss and are probably derived from early Jurassic igneous rocks (Pankhurst, 1983). The foliation of the metamorphic rocks strikes approximately north-west–south-east (Hoskins, 1963).

The Antarctic Peninsula Volcanic Group represented at Millerand Island and Little Thumb includes agglomerates, tuffs, andesites and dacites (British Antarctic Territory Geological Map, 1:500000 BAS 500G, Sheet 3, Edition 1, 1981). Andesites are also found in the western Blackwall Mountains. However, the predominant mainland rocks encircling Neny Fjord are those belonging to the plutonic suite of the magmatic arc. Red Rock Ridge is characterized by granites, quartz diorites and quartz gabbros, and Blackwall Mountains by granites. Rb–Sr ages of 92 ± 2 Ma and 113 ± 2 Ma have been given (Pankhurst, 1982) for plutonic rocks from Red Rock Ridge and Blackwall Mountains respectively. A pink granite from Millerand Island yielded a date of 82 ± 8 Ma. Between Snowshoe Glacier and Neny Glacier, adamellite, diorite and



3(a)

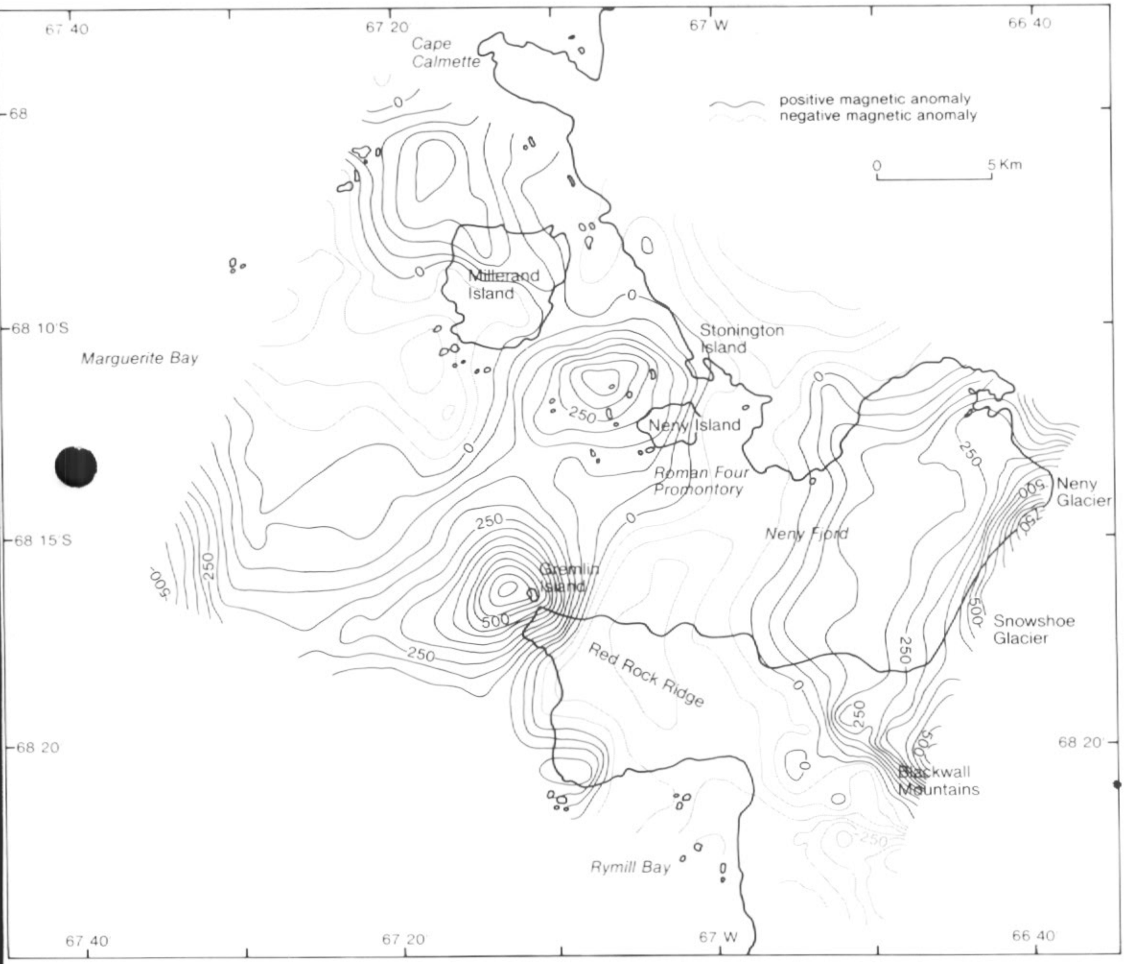
Fig. 3. Map of Neny Fjord area showing: (a) flight lines and (b) total-intensity magnetic anomalies. Contour interval 50 nT, bolder contours every 250 nT. Flight altitude 1000 m.

banded gabbro have been reported, and a gabbro and granophyre outcrop on Pyr[illegible] Island.

There is not yet any direct geological evidence to explain the marked physiographic transition between Graham Land and Palmer Land. The area is structurally complex and it is uncertain (Hoskins, 1963) as to the influence, if any, that basement trends had on the later plutonic emplacement. However it would appear that block faulting, with a north-east–south-west trend, was associated with the Mesozoic–Cenozoic plutonic activity.

AEROMAGNETIC SURVEYS

Prior to 1973, BAS geophysical surveys consisted of oversnow reconnaissance gravity and magnetic traverses (Renner, 1980). In 1973, however, the acquisition of an aeromagnetic system enabled a systematic regional survey to be initiated. The results from 1973 to 1985 were compiled as a 1 : 1 500 000 aeromagnetic anomaly map



3(b)

of the Antarctic Peninsula (Renner and others, 1985). In addition to the regional survey, which had an average flight line separation of 25 km, areas of specific local geological interest were surveyed in greater detail. These included Horseshoe Island (Herrod and Renner, 1983), Staccato Peaks (Crawford and others, 1986) and Neny Fjord.

The trough filled by Gibbs Glacier and Neny Glacier (Fig. 2) represents part of a major tectonic boundary but unstable winter sea ice and logistic complications have so far prevented ground access and geophysical investigation. Kennett (1966) undertook a local magnetic survey in Neny Bay but it did not extend south of Roman Four Promontory. Our aeromagnetic survey was to determine whether there was any extension beneath Neny Fjord of the discontinuity seen on land. Tracks (Fig. 3) covering an area of 35 × 25 km were flown on 31 December 1973 in one of the Survey's de Havilland Twin Otter aircraft. A constant barometric altitude of 1000 m was maintained although turbulence caused minor fluctuations in heading and altitude. A total of 686 line km of data were recovered in a 2–3 km grid; flight directions were approximately parallel and perpendicular to the axis of the peninsula. Data were sampled at one-second intervals at an indicated airspeed of 120 kn (222 km h^{-1}); this equates to a reading every 62 m of ground covered. The equipment included a Geometrics G-803 proton precession magnetometer, a Geometrics G704 digital data acquisition system and a Mars-six analogue recorder. A wing-tip sensor was employed for which heading errors were determined to be less than ± 10 nT. Navigation was visually controlled by vertical fixes, bow and beam fixes and position lines. A Shackman 35 mm auto-camera was mounted in the cockpit and was available for a line-ahead photographic record.

Throughout the survey the transient variations of the Earth's magnetic field were monitored at the BAS geomagnetic observatory at Faraday (65° 15′ S, 64° 16′ W). Despite its position 370 km north of Neny Fjord the observatory records should be applicable (Renner, 1980).

DATA REDUCTION

The data had a noise envelope approaching 25 nT and to remove high frequen[illegible] components due to aircraft interference a low-pass digital filter was applied whic[illegible] effectively attenuated all anomalies of less than 2 km full wavelength. Subtraction of the International Geomagnetic Reference Field (IGRF) for epoch 1974.0 was accomplished for each data point using the relevant IGRF coefficients (Barraclough, 1981). Diurnal activity during the survey was stable with a maximum range of 32 nT.

Once the data were plotted mis-ties were relaxed at each of the 127 intersection points. This reduced the root mean square value for the mis-ties from 58 nT before line levelling to 4 nT. To produce the computer-contoured residual map (Fig. 3) a 500-m grid was superimposed on the data set and weighted values were calculated for each point from a maximum search radius of 8 km. A grid filter was then applied to eliminate anomalies with wavelengths less than the flight-line separation.

Description of anomalies

The aeromagnetic contour map shows that the area has strong magnetic features. The most significant anomaly is centred over Gremlin Island, 2 km west of Red Rock Ridge. The anomaly has a maximum amplitude approaching 650 nT. A further anomaly, also indicated by Kennett (1966), is seen 4 km north-west of Neny Island and has an amplitude of 350 nT. It is possible that both maxima represent parts of a single more extensive anomaly which trends north-east–south-west for 18 km and has a width of 8 km. A further strong anomaly is suggested inland from the Blackw[illegible] Mountains, although its peak lies east of the survey limit. Whilst the survey is o[illegible] limited extent there could be structural control along orthogonal directions 030° and 120° (Fig. 3). This gives magnetic trends parallel and perpendicular to the continental margin.

Interpretation of the magnetic anomalies

The Neny Fjord local survey was undertaken during the first season of systematic aeromagnetic reconnaissance of the Antarctic Peninsula. At that time the magnetic fabric of the area was unknown but as a result of the subsequent regional survey (Renner and others, 1985) the Neny Fjord anomalies can be seen as a small but integral part of the extensive West Coast Magnetic Anomaly (WCMA). The WCMA may be traced along the length of the Antarctic Peninsula and then via the continental blocks of the Scotia arc to southern South America (Garrett and others, in press). Over the

Antarctic Peninsula the WCMA may be divided into a western and eastern component and consists of a series of moderate wavelength (20 km) anomalies of 200–600 nT amplitude superimposed on a broader (80–120 km) magnetic spine. Interpretation of the WCMA (Garrett and others, in press) using complementary gravity, seismic refraction and geological evidence indicates that mafic source rocks belonging to an extensive linear Mesozoic–Cenozoic batholith are responsible.

The Gremlin Island magnetic anomaly

A section of the reconnaissance survey profile A-011 (unsmoothed) is shown in Fig. 4. This crosses Gremlin Island and Blackwall Mountains and shows their associated anomalies relative to the WCMA, here exhibiting distinct western and eastern components. The regional gradients imposed by the WCMA obviously influence the signature of the local anomalies, so an interpretation of the WCMA was essential to display the geological background to the Neny Fjord local anomalies. Garrett and Storey (in press) successfully modelled a similarly shaped WCMA profile, also unsmoothed, from latitude 70° 40′ S in northern Palmer Land. This indicated a composite source body whose upper surface approached to within 2 km of sea level, a near-vertical magnetization and intensities of magnetization of up to 2 A m^{-1}. The application of a two-dimensional interpretative program (Lee, 1979) to profile

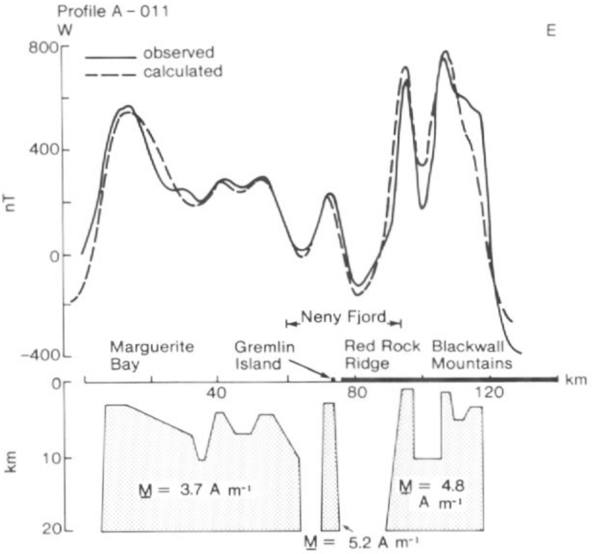


Fig. 4. Two dimensional interpretation of aeromagnetic reconnaissance profile A-011 across the WCMA. Flight altitude 2500 m.

A-011 produced a similar subsurface distribution (Fig. 4) although higher intensities of magnetization were required. For the anomaly over Gremlin Island an intensity of magnetization of 5.2 A m^{-1} gave a body with an upper surface at 2.5 km depth, a width of 3 km and a vertical extent of 20 km. The variations in the intensities of magnetization along the interpreted section are compatible with recent volume susceptibility measurements (S. W. Garrett, pers. comm.) on 22 gabbros from Marguerite Bay. These show gabbros with intensities of magnetization of between 0.2

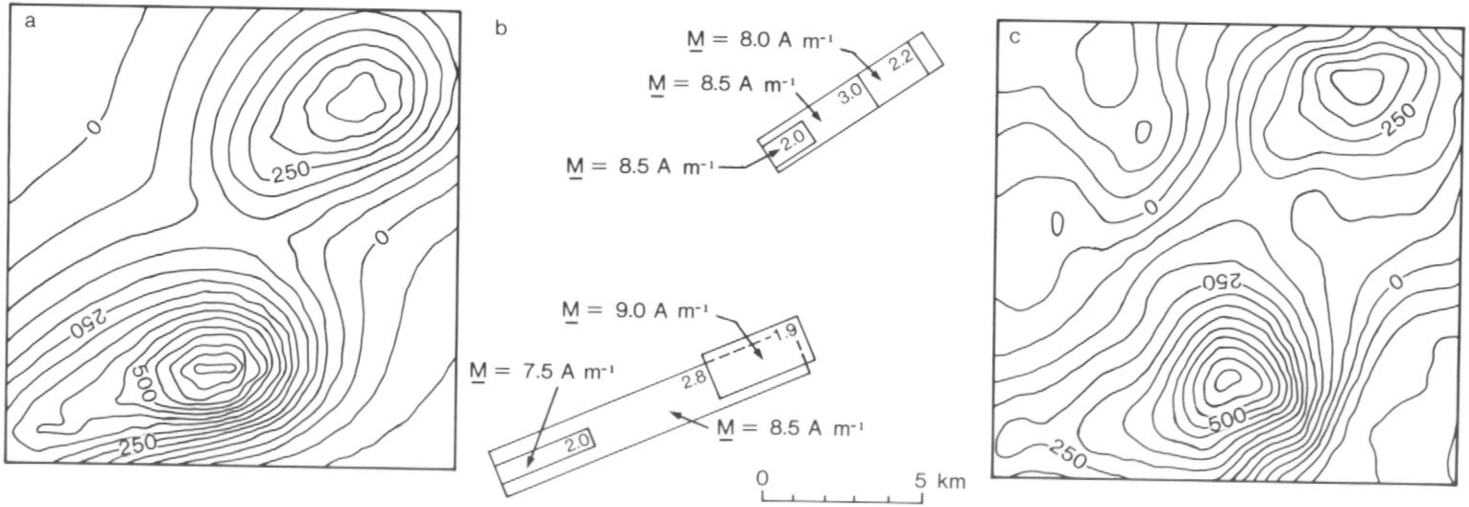


Fig. 5. Three-dimensional interpretation of the Gremlin Island magnetic anomaly. (a) The observed total field anomaly; (b) plan view of model; values represent elevation of upper surface (km) relative to sea level; (c) computed total-field anomaly. Bodies extend to 20 km depth.

and 6.7 A m^{-1} with a mean of 1.98 A m^{-1}. Whilst there are no rock samples available from Gremlin Island, measurements on gabbros collected on an island 2 km to the south gave intensities of magnetization of up to 1.6 A m^{-1} and diorites from the headland of Red Rock Ridge gave a maximum value of 1.3 A m^{-1}.

The two-dimensional interpretation was then applied to two profiles from the local survey; flight lines A-81 and A-75 (Fig. 3). An acceptable solution gave a body 1.2 km wide in the vicinity of Gremlin Island at a depth of 1.2 km and with a total intensity of magnetization of 8.5 A m^{-1}. Keeping the intensity constant at 8.5 A m^{-1} requires a body 1 km wide at a depth of 1.4 km to account for the anomaly distribution north-west of Neny Island.

The two-dimensional solutions were used as a basis for a three-dimensional interpretative program (Coles, 1974). This was based on the method of Bhattacharyya (1964) where a magnetic field is calculated for a series of rectangular prism-shaped bodies with magnetization at a given declination (D) and inclination (I), here assumed to be parallel to the Earth's present field with values of $D = 21°$ E and $I = -60°$. An additional constraint was provided by sea depths, for which soundings in the immediate area ranged between 17 and 80 m. After successive modifications to improve the correlation between observed and calculated fields an acceptable model (Fig. 5) was resolved with upper surfaces at approximately 2 km depths. Therefore the causative bodies do not necessarily outcrop at seabed. Composite intensities of magnetization of between 7.5–9.0 A m^{-1} were required for the source rocks.

Throughout the modelling it was necessary to assume a large north–south aligned intrusion centred by the Blackwall Mountains, 20 km east of Gremlin Island with an intensity of magnetization of 4.8 A m^{-1}. The body is believed to be responsible for the easterly decrease in the magnetic field across the survey area.

CONCLUSIONS

The aeromagnetic survey over Neny Fjord has not added to our understanding of the relationship between Graham Land and Palmer Land partly because subsequent reconnaissance surveys revealed the geophysical complexity of the region which was not fully appreciated when the local network was undertaken. The area lies within the extensive WCMA which reflects a composite linear batholith of Mesozoic–Cenozoic age. Garrett and Storey (in press) believe that Cenozoic block-faulting resulting from the slowing and cessation of subduction along the Pacific margin led to the separation of the western and eastern components of the WCMA. The same faulting may have controlled the magnetic trends along 030° parallel to the continental margin. The north-east–south-west alignment also parallels faulting proposed by Hoskins (1963).

Whilst our results do not indicate any magnetic contour offset in Neny Fjord, they do reveal an intense magnetic field. Two- and three-dimensional interpretations of anomalies centred over Gremlin Island and offshore Neny Island indicate composite bodies whose upper surfaces approach to within 2 km of sea level. The proposed body beneath Gremlin Island has dimensions 10 × 1.5 km, extends to a depth of 20 km and trends north-east–south-west. The maximum required intensity of magnetization for the body is 9.0 A m^{-1} which is comparable with measurements made on some gabbros from Marguerite Bay. The body causing the less pronounced anomaly off the west coast of Neny Island has a similar trend but is smaller. The two bodies may be united at depth and thus may have a common origin.

Any future investigations into the Graham Land–Palmer Land boundary will require detailed aeromagnetic networks complemented with oversnow techniques and covering the breadth of the transition zone.

ACKNOWLEDGEMENTS

The authors are grateful to B. J. Dikstra who contributed much to the aeromagnetic data collection, and to the pilot B. J. Conchie. They also wish to thank BAS field personnel at Adelaide Island for their assistance and for the inspiration given by colleagues at Stonington Island.

Received 6 November 1986; accepted 22 January 1987

REFERENCES

Adie, R. J. 1954. The petrology of Graham Land. I. The Basement Complex; early Palaeozoic plutonic and volcanic rocks. *Falkland Islands Dependencies Survey Scientific Reports*, No. 11, 22 pp.

Barker, P. F. 1982. The Cenozoic subduction history of the Pacific margin of the Antarctic Peninsula: ridge crest–trench interactions. *Journal of the Geological Society of Lond*, **139**, 787–801.

Barraclough, D. R. 1981. The 1980 geomagnetic reference field. *Nature*, **294**, 14–15.

Bhattacharyya, B. K. 1964. Magnetic anomalies due to prism-shaped bodies with arbitrary polarization. *Geophysics*, **29**, 517–31.

British Antarctic Survey. 1981. British Antarctic Territory Geological Map, scale 1:500000, Southern Graham Land, Series BAS 500G, Sheet 3, Edition 1. Compilers J. W. Thomson and J. S. Harris. British Antarctic Survey, Cambridge.

Coles, R. W. 1974. Two magnetic interpretation methods using rectangular prisms. Department of Energy, Mines and Resources, Ottawa, Ontario. Report No. 74–3.

Crawford, I. A., Girdler, R. W. *and* Renner, R. G. B. 1986. An aeromagnetic study of the Staccato Peaks area, Alexander Island, Antarctica. *British Antarctic Survey Bulletin*, No. 70, 41–53.

Dalziel, I. W. D. *and* D. H. Elliot. 1982. West Antarctica: problem child of Gondwanaland. *Tectonics*, **1** (1), 3–19.

Garrett, S. W., Renner, R. G. B., Jones, J. A. *and* McGibbon, K. J. 1987. Continental magnetic anomalies and the evolution of the Scotia arc. *Earth and Planetary Science Letters*. (In press.)

Garrett, S. W. *and* Storey, B. C. 1987. Lithospheric extension of the Antarctic Peninsula during Mezozoic basin formation and the closing stages of Cenozoic subduction. Geological Society of London Special Publication. (In press.)

Herrod, L. D. B. *and* Renner, R. G. B. 1983. Interpretation of magnetic anomalies over Horseshoe Island, Graham Land. *British Antarctic Survey Bulletin*, No. 58, 1–13.

Hoskins, A. K. 1963. The basement complex of Neny Fjord, Graham Land. *British Antarctic Survey Scientific Reports*, No. 43, 49 pp.

Kennett, P. 1966. Magnetic survey of the Neny Bay area, Marguerite Bay. *British Antarctic Survey Bulletin*, No. 8, 97–9.

Lee, M. K. 1979. *Two dimensional gravity and magnetic interpretation (version 2). Program GAM 2D2. Computer Program Report Series. Report No. 32.* Applied Geophysics Unit, British Geological Survey, Keyworth, Nottingham. 30 pp.

Pankhurst, R. J. 1982. Rb–Sr geochronology of Graham Land, Antarctica. *Journal of the Geological Society of London*, **139**, 701–11.

Pankhurst, R. J. 1983. Rb–Sr constraints on the ages of basement rocks of Antarctic Peninsula. (*In* Oliver, R. L., James, P. R. *and* Jago, J. B. *eds. Antarctic earth science*. Canberra, Australian Academy of Science and Cambridge, Cambridge University Press, 367–71.)

Renner, R. G. B. 1980. Gravity and magnetic surveys in Graham Land. *British Antarctic Survey Scientific Reports*, No. 77, 99 pp.

Renner, R. G. B., Sturgeon, L. J. S. *and* Garrett, S. W. 1985. Reconnaissance gravity and aeromagnetic surveys of the Antarctic Peninsula. *British Antarctic Survey Scientific Reports*, No. 110, 50 pp.

Storey, B. C. *and* Garrett, S. W. 1985. Crustal growth of the Antarctic Peninsula by accretion, magmatism and extension. *Geological Magazine*, **122**, 5–14.

Thomson, M. R. A., Pankhurst, R. J. *and* Clarkson, P. D. 1983. The Antarctic Peninsula – a late Mesozoic–Cenozoic arc (review). (*In* Oliver, R. L., James, P. R. *and* Jago, J. B. *eds. Antarctic earth science*. Canberra, Australian Academy of Science and Cambridge, Cambridge University Press, 289–94.)

Woodburne, M. O. *and* Zinsmeister, W. J. 1983. A new marsupial from Seymour Island, Antarctic Peninsula. (*In* Oliver, R. L., James, P. R. *and* Jago, J. B. *eds. Antarctic earth science*. Canberra, Australian Academy of Science and Cambridge, Cambridge University Press, 320–2.)

Wyeth, R. B. 1977. The physiography and significance of the transition zone between Graham Land and Palmer Land. *British Antarctic Survey Bulletin*, No. 46, 39–58.