MAGNETIC ANOMALIES OVER THE BLACK COAST, PALMER LAND

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Abstract. Regional aeromagnetic data gathered over eastern Palmer Land reveal a north–south aligned cluster of short-wavelength (10–20 km), large-amplitude (800–2000 nT) anomalies which may be modelled using shallow bodies of 10 km width and high magnetization (> 5 A m^{-1}). A ground magnetic survey targeted on these features revealed complex anomaly patterns with high amplitudes (> 6000 nT) which were interpreted using three-dimensional techniques. The source bodies are a distinctive suite of mafic intrusions of (?)Cretaceous age.

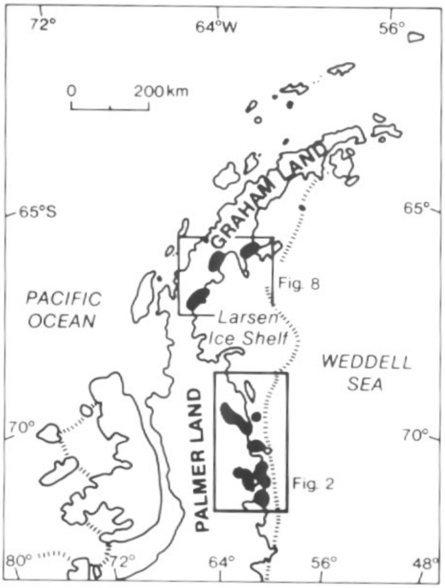

Fig. 1. The Antarctic Peninsula. Large magnetic anomalies on the east coast (Renner and others, 1985) are shaded. The areas of Fig. 2 and Fig. 8 are enclosed.

Introduction

The Antarctic Peninsula (Fig. 1) is over 1500 km long and lies between the Pacific Ocean and the Weddell Sea. Along the eastern edge of Palmer Land lies the Black Coast (Fig. 2a), situated between Cape Boggs (70° 30′ S, 61° 20′ W) and Cape Mackintosh (72° 55′ S, 59° 30′ W). The coastal topography is characterized by several east–west trending peninsulas, of which one of the largest is Eielson Peninsula approaching 40 km in length. To the east of this lies the Larsen Ice Shelf which is undulating and rifted near the shore but which becomes flatter towards the Weddell Sea.

During the last 200 Ma the Antarctic Peninsula has been the site of an active

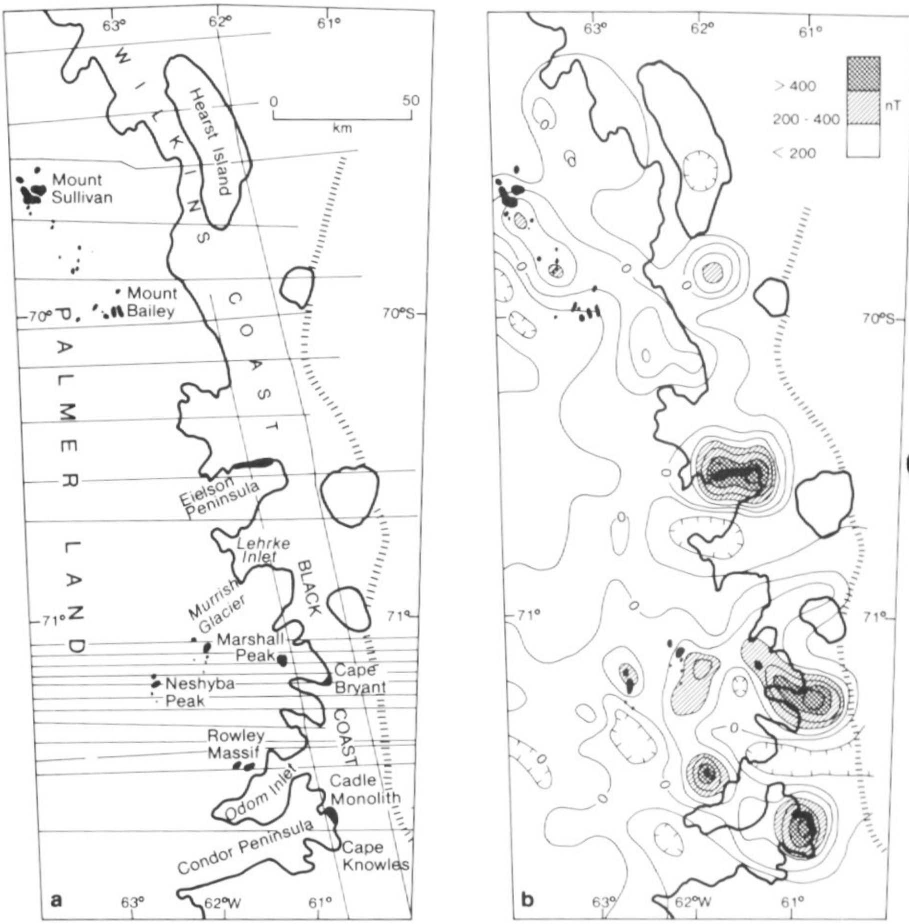

Fig. 2. (a) Regional aeromagnetic flight network over Black Coast and Wilkins Coast. Flight height 2500 m. Rock outcrops referred to in the text are shaded. (b) Regional aeromagnetic anomaly map of Black Coast and Wilkins Coast. Contour interval 100 nT. Large positive magnetic anomalies are shaded.

magmatic arc (Thomson and others, 1983; Storey and Garrett, 1985). Reconnaissance geological investigations in eastern Palmer Land have identified a (?)Palaeozoic basement complex, sedimentary and volcanic rocks associated with a Jurassic back-arc basin and Jurassic–Cretaceous plutonic rocks (Singleton, 1980; Anckorn, 1984; Davies, 1984; Meneilly and others, in press). Early Cretaceous granodioritic plutons are common (Singleton, 1980) but outcrops of metagabbro, gabbro and diorite have also been reported from scattered localities (Knowles, 1945; Adie, 1955; Singleton, 1980).

Reconnaissance aeromagnetic profiles across the Antarctic Peninsula were gathered during 1965 as part of the US Naval Oceanographic Office Project Magnet program (Bregman and Frakes, 1970). Renner (1980) examined these data and noted the presence of large (> 800 nT) magnetic anomalies over the Black Coast. These features were positioned with greater accuracy during subsequent aeromagnetic flights by the British Antarctic Survey (Fig. 2b) (Renner and others, 1985). An over-snow magnetic survey, executed by a two-man BAS party including one of the authors (K. J. M.), was targeted on the largest anomalies measured during the airborne surveys. This paper includes a detailed description of the anomalies, an interpretation of the geometry of the source bodies and a discussion of their tectonic significance.

Data Acquisition and Processing

Airborne survey

A BAS Twin Otter aircraft equipped with a wing-tip magnetic sensor was used for the regional aeromagnetic survey of the Antarctic Peninsula (Renner and others, 1985). A line spacing of 15–20 km was achieved, although a more detailed network at 4 km line interval was completed near latitude 71° S (Fig. 2a). The profiles were flown at a constant barometric elevation of approximately 2.5 km. The majority of the aeromagnetic data in eastern Palmer Land were gathered during 1975–76 field season (Dikstra, 1983) when a Bendix DRA-12 Doppler radar system was used for navigation and supplemented by a photographic record provided by a front-mounted auto-camera. Additional data were gathered during 1979–80 field season and by one of the authors (S. W. G.) during 1982–83 field season when a Decca Series 70 Doppler unit and Tactical Air Navigation System was employed. Corrected line positions are considered accurate to within 2 km.

Total-field magnetic measurements were made with a Geometrics G-803 magnetometer. Data were sampled at 1 s intervals which equates to a field reading every 62 m at 120 kt ground speed. Heading errors due to the undesirable magnetic effect of the aircraft were reduced to less than 10 nT by compensation procedures described by Renner and others (1985). Diurnal variations were monitored by base-station magnetometers.

Profile data were processed to remove diurnal variations and high-frequency noise caused by aircraft systems. The 1980 International Geomagnetic Reference Field (IGRF) (Barraclough, 1981) was used to remove the global component of the magnetic field. Automated production of the regional aeromagnetic anomaly map (Fig. 2b) involved the interpolation of a 3-km grid of magnetic values from the profile data and filtering of the grid to prevent spatial aliasing caused by the large line spacing (Renner and others, 1985).

Oversnow survey

Ground magnetic traverses were completed in 1984–85 field season by a two-man BAS party using snowmobiles and sledges. The severe coastal terrain prevented coverage of all of the anomalies located during the airborne survey. Nevertheless, a total of 280 km of profile data (Fig. 3) were gathered including over 1400 stations. Navigation relied upon dead reckoning techniques. The position of points distant from the magnetic anomalies was measured by compass resection from landmarks displayed on the BAS 250P map series (sheets SR 19–20/12 and SR 19–20/16) and the distance between intervening points on the traverses was measured using a sledge wheel. The absolute position of the profiles is considered accurate to ± 500 m but the relative positions of adjacent datapoints are probably accurate to within ± 30 m.

A Geometrics G-856 proton-precession magnetometer was used to determine the total field. The magnetometer was operated in auto-cycle mode at pre-selected time intervals at a constant speed of travel which resulted in an interval of 200 m between readings. For the majority of the survey, the sensor was mounted on an unladen

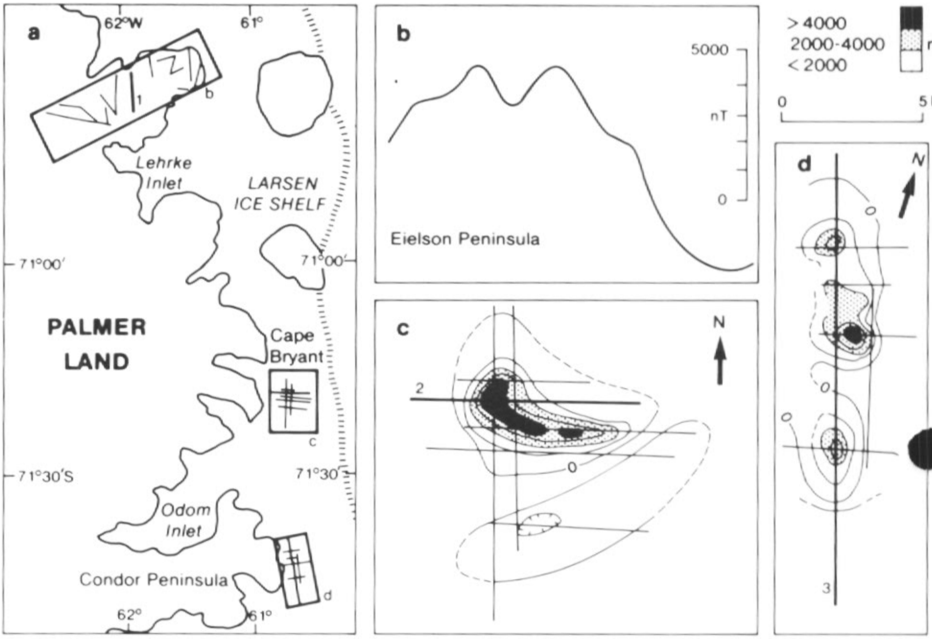

Fig. 3. Oversnow magnetic data gathered on Black Coast and Wilkins Coast. Contour interval 1000 nT. Large positive magnetic anomalies are shaded. (a) Location of the traverses. (b) Ground profile 1 over Eielson Peninsula. (c) Magnetic anomaly contour map for the area to the SE of Cape Bryant. Location of ground profile 2 is shown. (d) Magnetic anomaly contour map for the area to E of Cape Knowles and Cadle Monolith. Location of ground profile 3 is shown.

sledge towed 15 m behind a snowmobile upon which the magnetometer was mounted. Under these operating conditions, the magnetic effect of the snowmobile caused errors of less than 5 nT in the measured field with the exception of isolated spikes which were attributed to the influence of the engine on the magnetometer.

Diurnal variations were monitored by a Geometrics G-866 recording base-station magnetometer which was located within 10 km of the ground traverses. The average variation during the survey was less than 20 nT and the maximum recorded change of 68 nT represents only 1 % of the largest peak-to-trough amplitude of the anomalies surveyed. For this reason, diurnal corrections were not applied to the ground traverse data.

Magnetic noise was removed manually during data processing. The global component of the magnetic field defined by the 1980 IGRF was removed prior to plotting and interpretation of the anomalies. The irregular distribution of data points meant that manual contouring was preferred for the production of the ground magnetic anomaly maps (Fig. 3) but contouring could not be attempted for widely spaced profiles on Eielson Peninsula.

Magnetic Anomalies

The regional aeromagnetic anomaly map (Fig. 2b) shows a poor resolution of high-frequency components because of the filtering involved in its production. The following detailed description and interpretation of the magnetic anomalies therefore relies upon aeromagnetic profiles (Fig. 4) and oversnow data (Fig. 3).

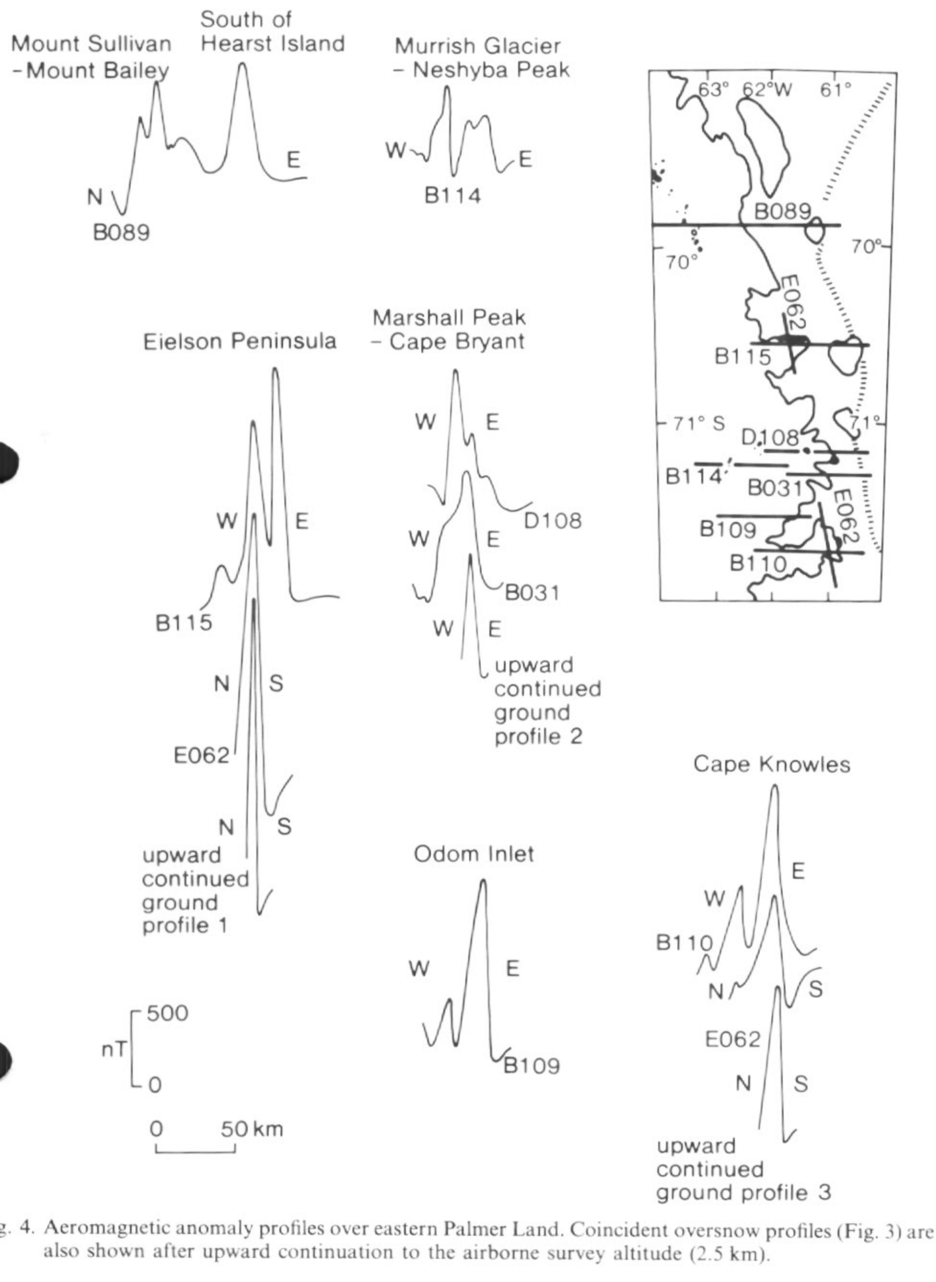

Fig. 4. Aeromagnetic anomaly profiles over eastern Palmer Land. Coincident oversnow profiles (Fig. 3) are also shown after upward continuation to the airborne survey altitude (2.5 km).

Two groups of positive aeromagnetic anomalies with wavelengths of 10–20 km are observed over eastern Palmer Land. The first includes anomalies of 300–900 nT over Mount Sullivan and Mount Bailey (Fig. 4, B089) and over Murrish Glacier and Neshyba Peak (Fig. 4, B114) which extend for up to 100 km along strike (Fig. 2b). The second includes the anomalies of 800–2000 nT over the Black Coast. This north–south aligned cluster of isolated anomalies comprises those to the south of

Hearst Island (Fig. 4, B089), over Eielson Peninsula (Fig. 4, B115 and E062), over Marshall Peak and Cape Bryant (Fig. 4, D108 and B031), to the north-west of Odom Inlet (Fig. 4, B109) and to the east of Cape Knowles and Cadle Monolith (Fig. 4, B110 and E062). Three of these large anomalies were investigated by the ground magnetic survey.

Eielson Peninsula anomalies

Difficult terrain restricted access over much of the Eielson Peninsula and whilst several anomalies were identified only those over the Houston Glacier warranted interpretation. Here a north–south profile (Fig. 3b) was recovered, exhibiting a positive maximum of 4800 nT to the north flanked by a 2000 nT minimum to the south. Although the full extent of the anomaly remains undetermined due to inaccessibility it would appear to be at least 7 km in length.

Cape Bryant anomaly

A magnetic anomaly over the Larsen Ice Shelf near Cape Bryant (Fig. 3c) shows a peak-to-trough amplitude in excess of 6800 nT. The positive northern limb is elongated in an east–west direction, being broader and sweeping north at the western end. It has a maximum width of 7 km. The anomaly lies over the ice shelf with a contrastingly smooth magnetic field to the north, south and east.

This anomaly lies within the closely spaced aeromagnetic grid (Fig. 2a) and so detailed contouring of the data was attempted (Fig. 5). This reveals that there are two components to the anomaly. A 1200 nT peak over Marshall Peak and Cape Bryant is flanked to the east by a 700 nT anomaly (Fig. 4, D108). The two features merge to the south of Cape Bryant (Fig. 4, B031) in the area of the ground survey (Fig. 3c).

Cape Knowles anomaly

To the east of Cape Knowles lies a series of circular positive anomalies (Fig. 3d) with a north–south alignment. At the southern end lies an elliptical anomaly measuring 3 km by 4 km and of 3000 nT amplitude. This is succeeded to the north by an intense 5000 nT anomaly and two smaller 3000 nT peaks. The strong anomalous field appears to be superimposed on a smooth background field, although the area directly to the west was inaccessible.

Interpretation of Magnetic Anomalies

Rock magnetic properties

The volume susceptibilities of 138 samples of rocks from eastern Palmer Land (Table I) were determined using a Geofyzica Brna KT-5 kappameter and induced magnetizations calculated assuming an ambient field of 49000 nT. Metagabbro, gabbro and amygdaloidal basalts are all expected to show induced magnetizations greater than 2 A m^{-1} but granodiorite, granite, metavolcanic and metasedimentary rock, gneiss, mylonite and schist have average magnetizations of less than 0.5 A m^{-1} (Table I). The intensities of remanent magnetization of 26 samples of granite and granodiorite from the area were measured by Longshaw (1981). Values range between 0.01 and 0.35 A m^{-1} with an average of 0.1 A m^{-1} and so granodiorite probably has on average a total magnetization of less than 0.5 A m^{-1}. The intensity of remanent magnetization of gabbro from Elder Bluff, Eielson Peninsula was measured by J.

Table I. Volume susceptibilities of rocks from eastern Palmer Land. The induced intensity of magnetization is calculated assuming an ambient field of 49000 nT and relates to the average susceptibility for each rock unit.

Rock type	*Number of samples*	*Volume susceptibility $SI \times 10^{-3}$ Max*	*Min*	*Av*	*Induced magnetization $A\ m^{-1}$*
Gabbro (Eielson Peninsula)	1	—	—	148.0	5.60
Diorite (Marshall Peak)	1	—	—	44.0	1.67
Gabbro (Cape Bryant)	4	16.0	0.30	8.9	0.30
Granodiorite and granite	39	50.0	0.05	10.4	0.39
Metagabbro and gabbro	10	150.0	0.41	55.3	2.10
Amygdaloidal basalts	7	160.0	0.40	65.1	2.47
Metavolcanics	4	50.0	0.20	9.5	0.36
Metasediments	11	4.8	0.21	0.8	0.03
Gneiss	33	47.2	0.00	4.3	0.16
Mylonite	9	39.4	0.09	11.7	0.40
Schist	24	2.09	0.07	0.3	0.01

Shaw (University College, Cardiff) and a value of 1.2 A m^{-1} obtained. This specimen therefore has a total magnetization of approximately 7 A m^{-1}.

Palaeomagnetic studies have shown that the stable remanent magnetization vectors of Jurassic and Cretaceous igneous rocks from the Antarctic Peninsula have high inclinations similar to that of the present ambient field (Kellogg and Reynolds, 1978; Longshaw and Griffiths, 1983). The total magnetization direction was therefore assumed to coincide with that of the present field (inclination −64°, declination 20° E) for the purposes of modelling the anomalous bodies.

Depth to magnetic source

The depth below sea level of the upper surface of the source of magnetic anomalies was determined from profile data using standard curve-measuring (Åm, 1972) and automated (Hartman and others, 1971) techniques. For these calculations it was assumed that the source body is a dyke of infinite length which strikes perpendicular to the profile. Assumptions of this kind are rarely valid and so calculated values are likely to be overestimates of the true depths. This is especially so where the source bodies are of variable composition and the aeromagnetic profile data cannot distinguish between adjacent anomalies visible on ground traverses (Figs 3 and 4). The majority of the calculated depths are in the range 0–3 km. More reliable estimates were derived by analysis of the oversnow data which suggests source depths for the Eielson Peninsula and Marshall Peak–Cape Bryant anomaly of 1.2 km and for the Cape Knowles anomaly of 0.3 km. A single vertical field measurement over the anomaly north-east of Cape Knowles indicated that the depth to the centre of the source body should be around 0.75 km. The anomaly to the south of Hearst Island has a longer wavelength and a source at approximately 4 km. This exception apart, the small calculated depths indicate that the sources are probably exposed in places beneath the main positive peaks of the anomalies (Fig. 2b).

Three-dimensional interpretation of the magnetic anomalies

The residual oversnow anomalies were modelled using a three-dimensional interpretation program (Coles, 1974) based on the method of Bhattacharyya (1964)

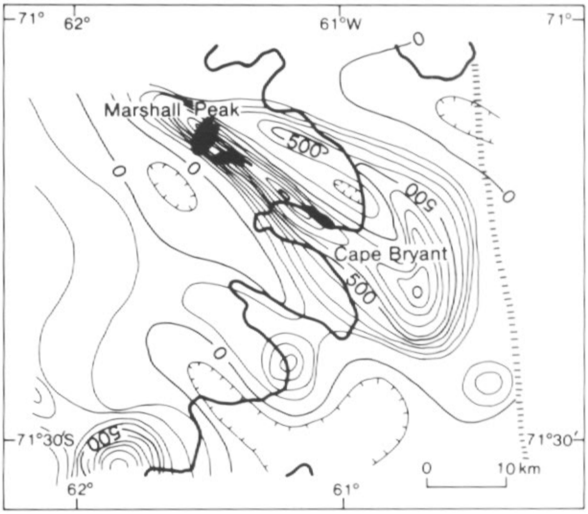

Fig. 5. Detailed aeromagnetic contour map for the area covered by the flight network at 4 km line spacing (Fig. 2a). Contour interval is 100 nT. Rock outcrops at Marshall Peak and Cape Bryant are shaded.

which assumes the source to be due to prism-shaped bodies of arbitrary polarization. Only limited constraints were available for the initial body parameters. BAS airborne radio-echo ice thickness measurements show the nearby ice shelf to be approximately 200 m thick (R. D. Crabtree, pers. comm. 1985) and limited bathymetric data for the Weddell Sea (Renner, 1980) indicates that the bedrock is less than 500 m below sea level. The datum level chosen was the surface of the floating ice shelf, which varied from 1 to 20 m above sea level.

An acceptable correlation between the observed and calculated anomaly at Cape Bryant is given in Fig. 6a. The source body is shown as L-shaped in plan, with upper and lower surfaces at 285 m to 2850 m below datum level respectively. At Cape Knowles the interpreted model (Fig. 6b) comprises two bodies in an approximate north–south alignment. The depth to the upper surface is 190 m and the depth to base is 1900 m. The high intensity of magnetization (16 A m^{-1}) used during the modelling suggests that the dimensions quoted above are minimum values for the depth and horizontal extent of the source bodies. Inaccuracies in the interpretation may also result from demagnetization effects. The models are possibly imaging only the magnetite-rich portions of the source bodies which may extend over a greater area and have a lower magnetization. For example the oversnow survey only covers the south-east limit of the Cape Bryant–Marshall Peak anomaly complex where the two aeromagnetic peaks merge (Fig. 5). Aeromagnetic profiles were therefore modelled to indicate the overall gross shape of the bodies.

Two-dimensional interpretation

The computer program of Lee (1979) was used to model the selected aeromagnetic profiles. The program assumes that the bodies are of infinite strike length and so the models are necessarily approximate. The depth to the base of the bodies depends strongly on the assumed magnetization and magnetic field background level, but it is likely that the models accurately show the horizontal extent of the source bodies and their relationship to rock exposures.

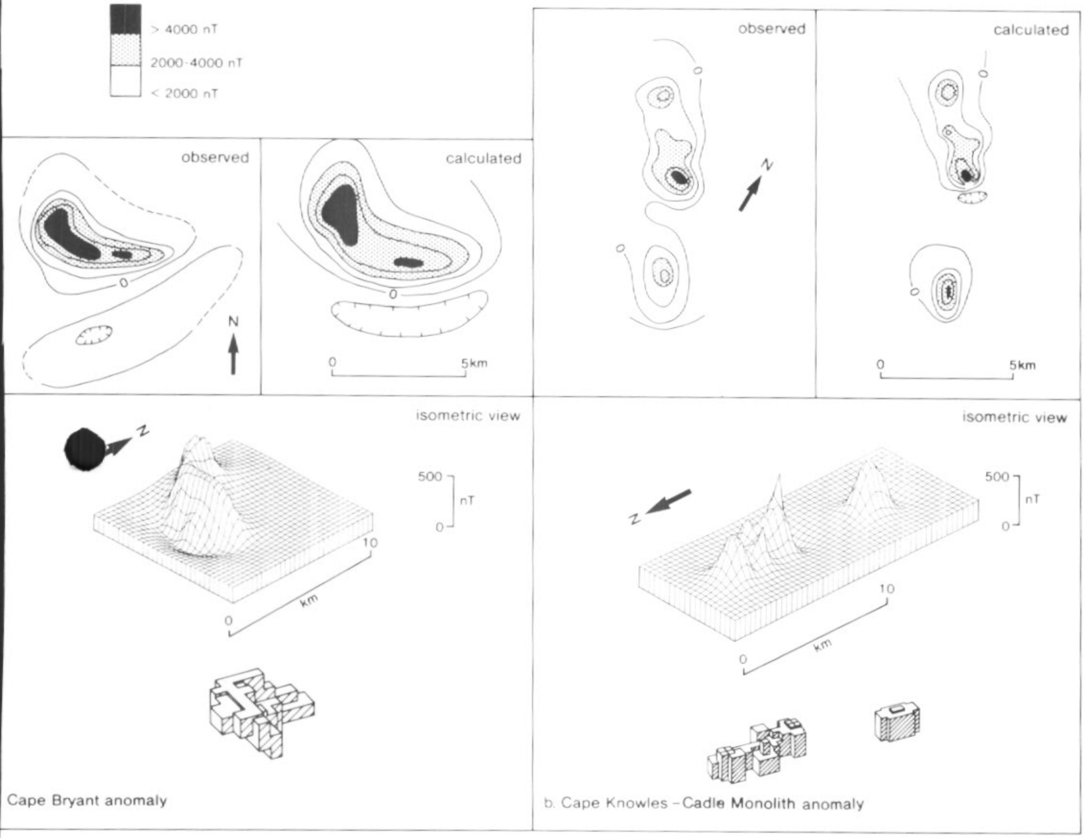

Fig. 6. Three-dimensional models of oversnow magnetic data. Calculated anomalies are compared with observed anomalies. Contour interval 1000 nT. Large positive anomalies are shaded. Isometric views of the models and calculated fields are shown. (a) SE of Cape Bryant. (b) E of Cape Knowles and Cadle Monolith.

The anomalies over Mount Sullivan and Mount Bailey are probably caused by a composite body 30 km wide (Fig. 7, B089) which has a magnetization of approximately 3 A m^{-1}. A similar source is envisaged for the anomalies in the vicinity of Murrish Glacier and Neshyba Peak (Fig. 7, B114). These magnetizations used in modelling anomalies are consistent with those of the metagabbroic rocks exposed at these localities (Table I).

The much larger-amplitude anomaly over Eielson Peninsula may be caused by a 10-km wide body (Fig. 7, E062) as proposed by Renner (1980). The complex anomaly pattern over Marshall Peak and Cape Bryant (Fig. 5) suggests a composite source body which is exposed at Marshall Peak (Fig. 7, D108). The anomaly over Rowley Massif suggests a similar source body (Fig. 7, B109) to that for the anomaly over Cape Knowles–Cadle Monolith (Fig. 7, B110). All of the large-amplitude Black Coast anomalies imply source magnetizations in excess of 5 A m^{-1} similar to those measured on rocks from Eielson Peninsula but much greater than those measured on gabbro from Cape Bryant (Table I).

Aeromagnetic profiles coincident with oversnow profiles were upward continued to the airborne survey altitude (2.5 km) in order to assess their contribution to the whole body complexes. After this process, the oversnow anomaly situated over Eielson

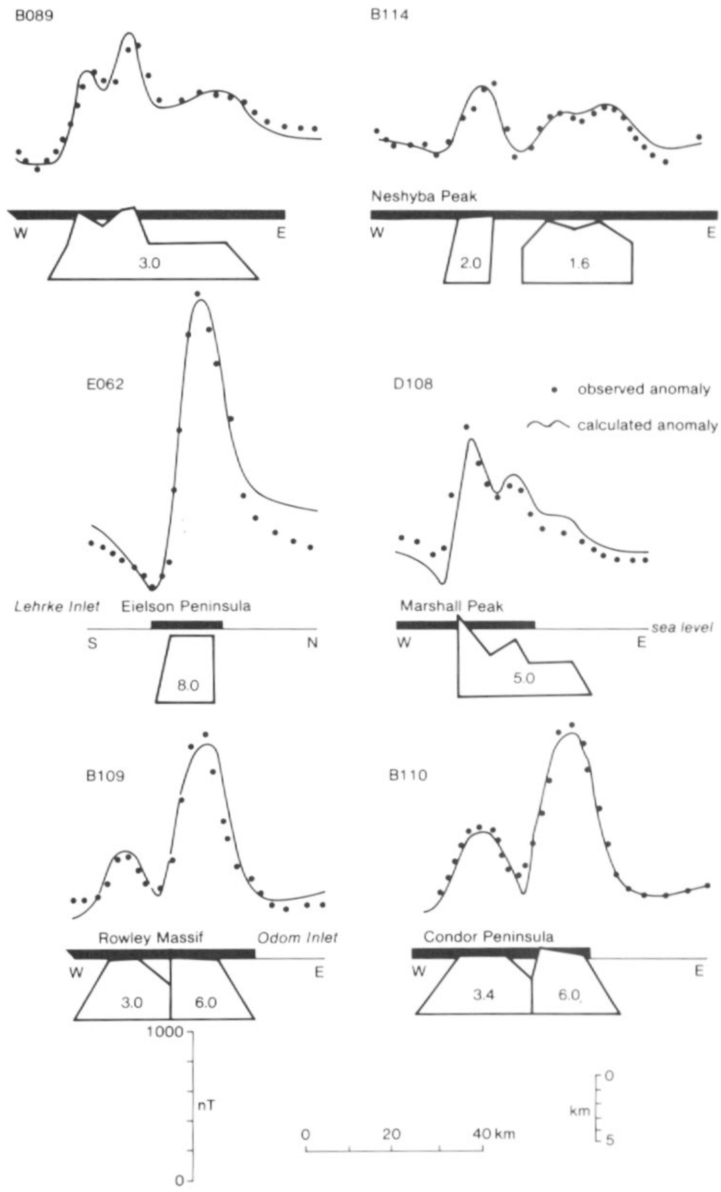

Fig. 7. Two-dimensional models of aeromagnetic profiles (Fig. 4). Thick horizontal line denotes land areas. The assumed intensity of magnetization (A m^{-1}) is shown in the centre of each model.

Peninsula showed good agreement in amplitude with the aeromagnetic profile (Fig. 4, E062). However, profile B115 shows a second component not covered by the ground survey indicating that more than one body exists. Similarly, at Cape Bryant and east of Cape Knowles the aeromagnetic profiles (Fig. 4) and map (Fig. 5) show the source complexes extend over greater area than covered by the ground survey because the upward continued oversnow profiles show a smaller wavelength than the aeromagnetic profiles.

The anomaly to the south of Hearst Island may be related to the large amplitude anomalies over the Black Coast but have a deeper, unexposed source. This is supported by downward continuation of the profile across this body (Fig. 4, B089) by 3 km which produced an anomaly of over 1000 nT and short wavelength comparable to those over areas where the sources are exposed.

Discussion

The main Cretaceous granodioritic body (Singleton, 1980) is considered to represent the main expression of subduction-related magmatic activity in eastern Palmer Land (Vennum and Rowley, 1986). The large magnetic anomalies over the Black Coast are caused by rocks with different compositions and higher magnetizations (Table I). The source bodies are considered gabbroic as a very high magnetization is required to explain the amplitude of the anomalies and because of the correlation with exposed geology, especially the proximity of an anomaly with the Elder Bluff gabbro. Knowles (1945) described this as 'a massive outcrop of hornblendite at least km long and 70 m in height' along the northern shore of Eielson Peninsula. A sample of biotite gabbro (R.3502.1) collected by one of the authors (K.J.M.) from the top of the outcrop was analysed in thin section and found to contain a 50% mafic phase of augite and biotite and a 50% felsic phase of plagioclase and alkali feldspar (B. C. Storey, pers. comm.). To the south, the rock samples collected near the Cape Bryant anomaly include specimens E30.4 and E30.5 which Adie (1955) identified as uralitized gabbros. Singleton (1980) considered that the diorite exposed at Marshall Peak was related to the Cape Bryant gabbros, a conclusion supported by the magnetic data (Fig. 5). The quartz-biotite diorite exposed at Cadle Monolith (Knowles, 1945) may also be related to the source of the anomalies.

Aeromagnetic data gathered over eastern Graham Land (Fig. 8) includes large anomalies such as those on line D600 and A058 which exhibit high amplitude anomalies of 20–30 km wavelength. C020 lies over Adie Inlet, where an alkali-rich gabbro complex (Marsh, 1968) has given a K–Ar age of 83 ± 4 Ma (Rex, 1976). Renner (1980) modelled the subsurface form of this pluton from total-field ground magnetic anomalies of 1500 nT amplitude and produced a laccolith-like body 10 km long and 5 km in width. Unfortunately, no aeromagnetic data are available over the Danger Islands where other rocks of similar back-arc position and petrology are found (Hamer and Hyden, 1984). From Danger Islands, microdiorite and syenite $^{87}Sr/^{86}Sr$ ratios define an isochron indicating a late Cretaceous age of 89 ± 11 Ma, (Hamer and Hyden, 1984). The chemical composition of these rocks shows strong alkaline affinities, again distinct from the calc-alkaline plutonic rocks common along the Antarctic Peninsula (Moyes and Storey, 1986). Alkaline rocks are characteristic of anorogenic, intraplate environments (Sorensen, 1974) and often occur in extensional regimes (Bartholomew and Tarney, 1984; Tarney and others, 1981). Evidence for east–west extension and orogeny in east Palmer Land can be seen in deformed Mesozoic plutons (Meneilly, 1983; Meneilly and others, in press). If extension did occur in east Palmer Land the associated intrusion of volumes of mantle-derived gabbroic plutons is a strong possibility. Preliminary analysis of the Elder Bluff gabbro and the similarities between the Adie Inlet (Fig. 8) and Black Coast (Fig. 4) anomalies may indicate that the intrusive activity was contemporaneous. The magnetic anomalies may therefore represent a suite of bodies associated with an anorogenic, possibly extensional, phase of arc development in the late Cretaceous (Moyes and Storey, 1986).

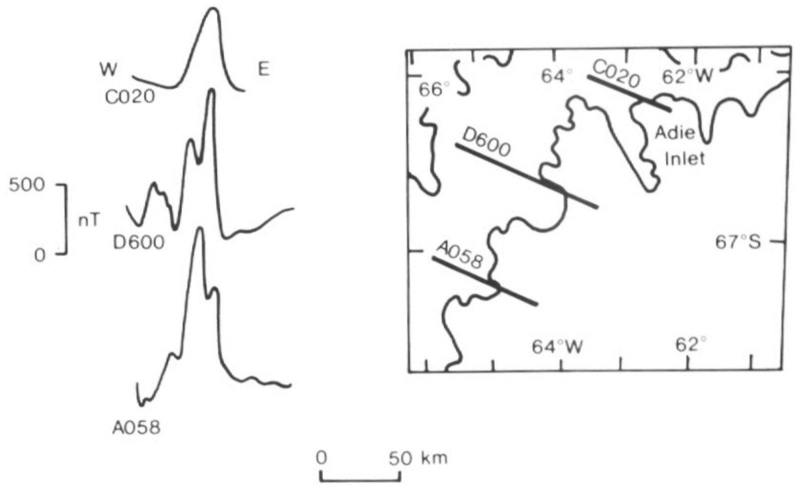

Fig. 8. Aeromagnetic anomaly profiles over eastern Graham Land.

Conclusions

Modelling of the Black Coast magnetic anomalies indicates that they are due to bodies whose upper and lower surfaces extend from around 285 to 2850 m below sea level at Cape Bryant and 190 to 1900 m below sea level at Cape Knowles. The outcrop at Elder Bluff, Eielson Peninsula is of a similar size but rises above sea level, but here the magnetic data were insufficient for detailed modelling. The magnetic susceptibilities required to model the bodies and the available geological evidence indicates that the source rock is gabbroic. The large variation in magnetite content of these rocks is probably responsible for the intense anomalies measured on the ground. The overall complexes are shown by aeromagnetic profiles to be of greater extent and comprising composite bodies of different magnetization. A calculated magnetization (remanent + induced) for the bodies modelled from ground traverse data of 16 A m^{-1} is high and must be regarded as an upper limit.

Thin-section analysis of the most likely source rock at Elder Bluff suggests an affinity to alkaline-gabbros at other east coast locations, one of which exhibits a large aeromagnetic anomaly. A clear north–south alignment of the Black Coast bodies indicates that there was strong tectonic control over their distribution. Of possible origins for the interpreted Black Coast bodies, that which is favoured is that the bodies are part of a suite of alkaline-gabbro plutons associated with an anorogenic phase of arc development in the late Cretaceous.

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