ANNALI DI GEOFISICA, VOL. 42, N. 2, April 1999

Interpretation of ground and aeromagnetic surveys of Palmer Land, Antarctic Peninsula

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Abstract
Aeromagnetic data for Palmer Land provide new information on crustal structures of the Antarctic Peninsula. Features shown on the compilation of the Lassiter Coast and Orville Coast are characterized by systems of subparallel regional anomaly zones and lineaments. The magnetic data reveal the widespread presence of an orthogonal pattern of crosscutting linear discontinuities that can be interpreted as a Late Cretaceous/Early Tertiary fracture pattern. The main displacements in the anomaly pattern between the two units are recognized in Wetmore-Irvine glaciers area where the structure of the Antarctic Peninsula changes orientation from SW-NE to S-N. The NW-SE trending transitional zone is probably a transfer zone associated with north-westerly movement of the Lassiter Coast crustal segment relative to the Orville Coast segment. Within the Lassiter Coast a fragment of Pacific Margin Anomaly (PMA), Central Plateau Magnetic Anomaly and East Coast Magnetic Anomaly (ECMA) are mapped. Two-dimensional modelling suggests that PMA is caused by a limited depth body (8 km) consisting of numerous plutons, probably, of different ages, composition and magnetization. The Central Plateau Magnetic Anomaly and the Merrick-Sweeney-Latady zone of the Orville Coast are represented by strong positive anomaly bands that are associated with gabbro-diorite rocks and accompanying plutons intruded near by the border of Mount Poster Formation and Latady Formation. The ECMA are alignments of high-amplitude magnetic anomalies caused by gabbro-diorite bodies, which are located within the framework of the Cretaceous granite-granodiorite plutons. Granite-granodiorite plutons of Lassiter Coast Intrusive Suite are mostly reflected by positive anomalies (100-500 nT). Modelling studies and the character of distribution of the magnetic anomalies suggest that the plutons of Lassiter Coast Intrusive Suite are prominently reflected in magnetic anomalies of regional extent. The plutonic activities during the geological evolution of Palmer Land have been a more important process than what is apparent from rock outcrops. Magmatic activity abruptly diminished westward from the Behrendt Mountains apparently due to a modification of the crustal structure of the Antarctic Peninsula. The area between the Evans Ice Stream and the Behrendt Mountains is possibly underlain by the non-magnetic equivalent of the Haag Nunataks basement, similar to that which has been inferred for the Ellsworth Mountains.

Key words *aeromagnetic survey – batholith – magnetic anomalies – modelling – Palmer Land – susceptibility*

1. Background geology

The Antarctic Peninsula (fig. 1) is considered as a Mesozoic-Cenozoic Andean-type magmatic arc and one of the discrete crustal blocks that comprise West Antarctica. Mid-Paleozoic basement rocks (Milne and Millar, 1989) are believed to underlie much of the Antarctic Peninsula. The oldest known rocks which crop out

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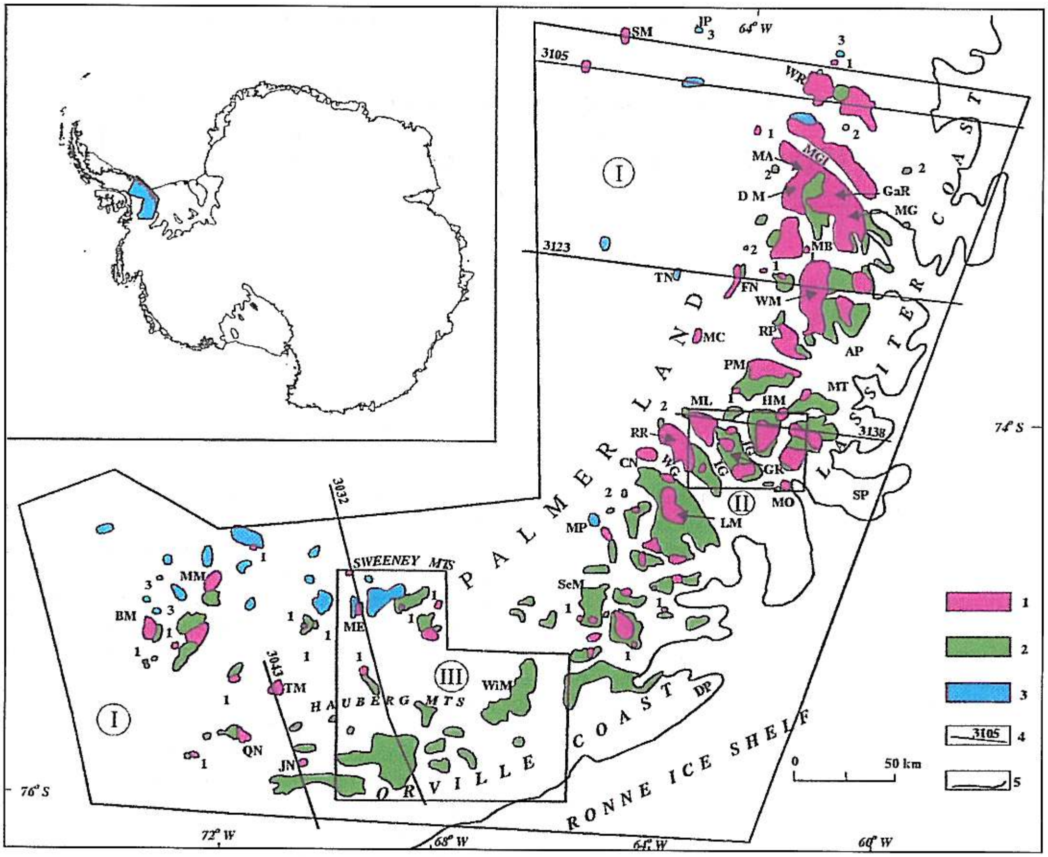

Fig. 1. Sketch map of Orville and Lassiter Coasts showing the major outcrops of Lassiter Coast Intrusive Suite, Mount Poster Formation and Latady Formation (modified from Rowley *et al.*, 1992). Upper inset box shows study area in Antarctica. I = Location of the aeromagnetic survey. II = Location of ground magnetic survey for fig. 4. III = Location of ground magnetic survey for fig. 6. 1 = Intrusions; 2 = Latady Formation; 3 = Poster Formation; 4 = Location of profiles used for 2.5D modelling; 5 = Coast line. Location of place names referred to in the text: AP: Arctowski Peak; BM: Behrendt Mountains; CN: Cooper Nunataks; DN: Dana Mountains; DP: Dodson Peninsula; FN: Ferguson Nunataks; GaR: Galan Ridge; GR: Guettard Range; HM: Hutton Mountains; IG: Irvine Glacier; JG: Johnston Glacier; JN: Janke Nunataks; JP: Journal Peaks; LM: Mountains; MA: Mount Axworthy; MB: Mount Barkow; MC: Mount Coman; ME: Mount Edward; MGl: Mosby Glacier; MG: Mount Grimminger; ML: Mount Laudon; MM: Merrick Mountains; MO: Mount Owen; MP: Mount Poster; MT: Mount Tricorn; PM: Playfair Mountains; QN: Quilty Nunataks; RP: Rivera Peaks; RR: Rare Range; ScM: Scaife Mountains, SM: Seward Mountains; SP: Smith Peninsula; TM: Thomas Mountains; TN: Toth Nunataks; WiM: Wilkins Mountains; WG: Wetmore Glacier; WM: Werner Mountains; WR: Wegener Range.

in Palmer Land close to the study area are Mid-Paleozoic (?) FitzGerald Quartzite Beds (FQB) and Permian sedimentary rocks of the Erehwon Beds (EB) (Laudon, 1991). FQB and EB were correlated with Devonian Crashsite quartzite and Polarstar Formation of the Ellsworth Mountains respectively (Laudon and Craddock, 1992).

The majority of rock exposure occurs in the south and east of the region along and inland of the Orville and Lassiter Coasts. These outcrops consist of folded Middle-Late Jurassic volcanogenic shale, siltstone, sandstone and sparse conglomerate of the Latady Formation (LF), which interfingers with silicic-intermediate calc-alkaline volcanic rocks of the Mount Poster Formation (Rowley *et al.*, 1992). During the Palmer Land deformational event the Latady Formation was folded before the onset of Early Cretaceous plutonism (Kellogg and Rowley, 1991). Laudon and Ford (1997) reported that some rocks of the Latady Formation are indistinguishable from the Erehwon Beds on either chemical or petrologic bases, therefore it is possible that some unfossiliferous outcrops mapped as LF may instead be EB. The plutonic rocks belonging to the Lassiter Coast Intrusive Suite, found throughout the area (fig. 1) and dated 95-130 Ma, vary in composition from gabbro to granite, although granite and granodiorite predominate (Vennum and Rowley, 1986).

2. Aeromagnetic surveys

Aeromagnetic surveys (fig. 2) of Palmer Land were flown by the Polar Marine Research Expe-

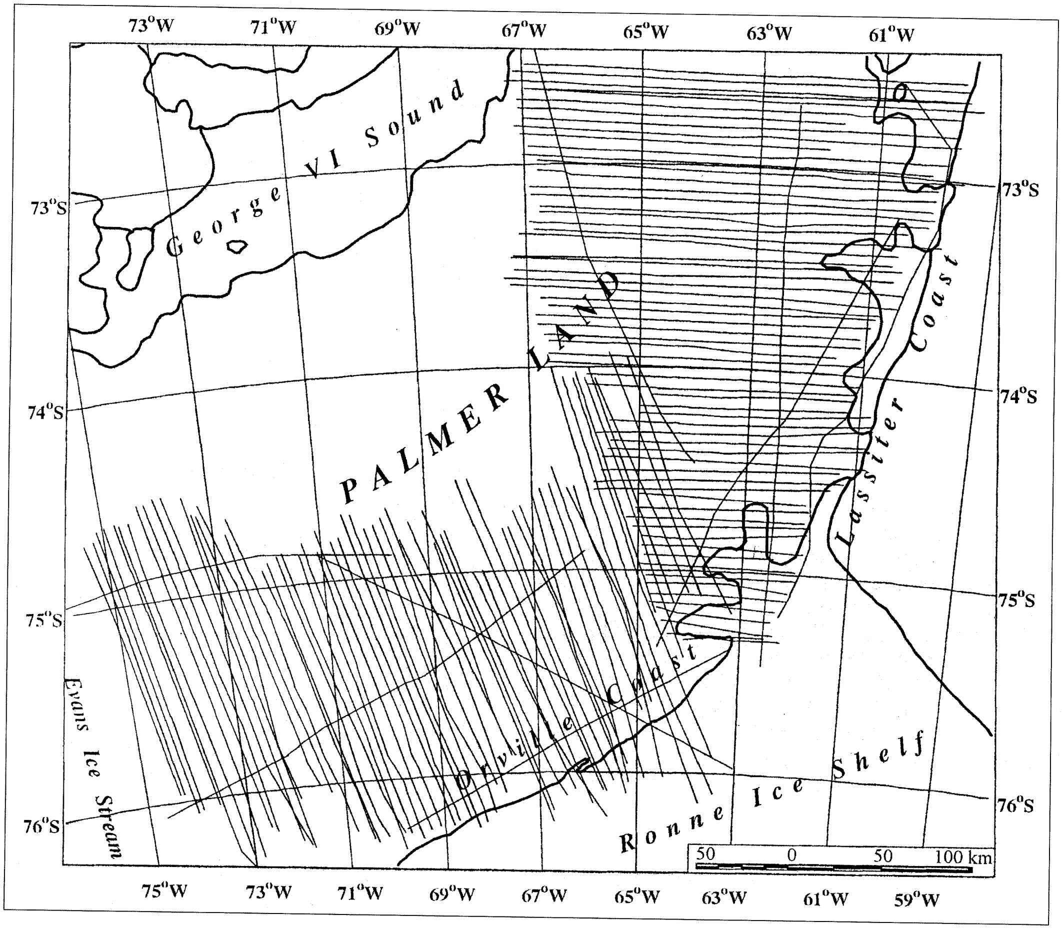

Fig. 2. Aeromagnetic flight-line network collected by the PMGRE over Southern Palmer Land, Antarctic Peninsula.

dition (PMGRE) in 1985-1986. These surveys were performed along lines with 5 km spacing perpendicular to the spine of the mainland at a fixed barometric elevation of 2500 m on the Orville Coast and of 2700 m above sea level on the Lassiter Coast. The data were collected from an Ilyushin IL-14 sky-equipped aircraft using a proton precession magnetometer with a sensor mounted in a 5 m tail stinger.

Navigation relied on DISS Doppler units supplemented by a photographic record provided by a camera electronically triggered by the magnetometer. During flights, diurnal magnetic variations were monitored at the Druzhnaja-2 filed-base station. Corrected profile positions are considered accurate to 0.5-1 km. Profile data were processed to remove diurnal variations and high-frequency noise caused by aircraft systems. The 1985 International Geomagnetic Reference Field (IGRF, Barraclough, 1981) was used to remove the global component of the magnetic field.

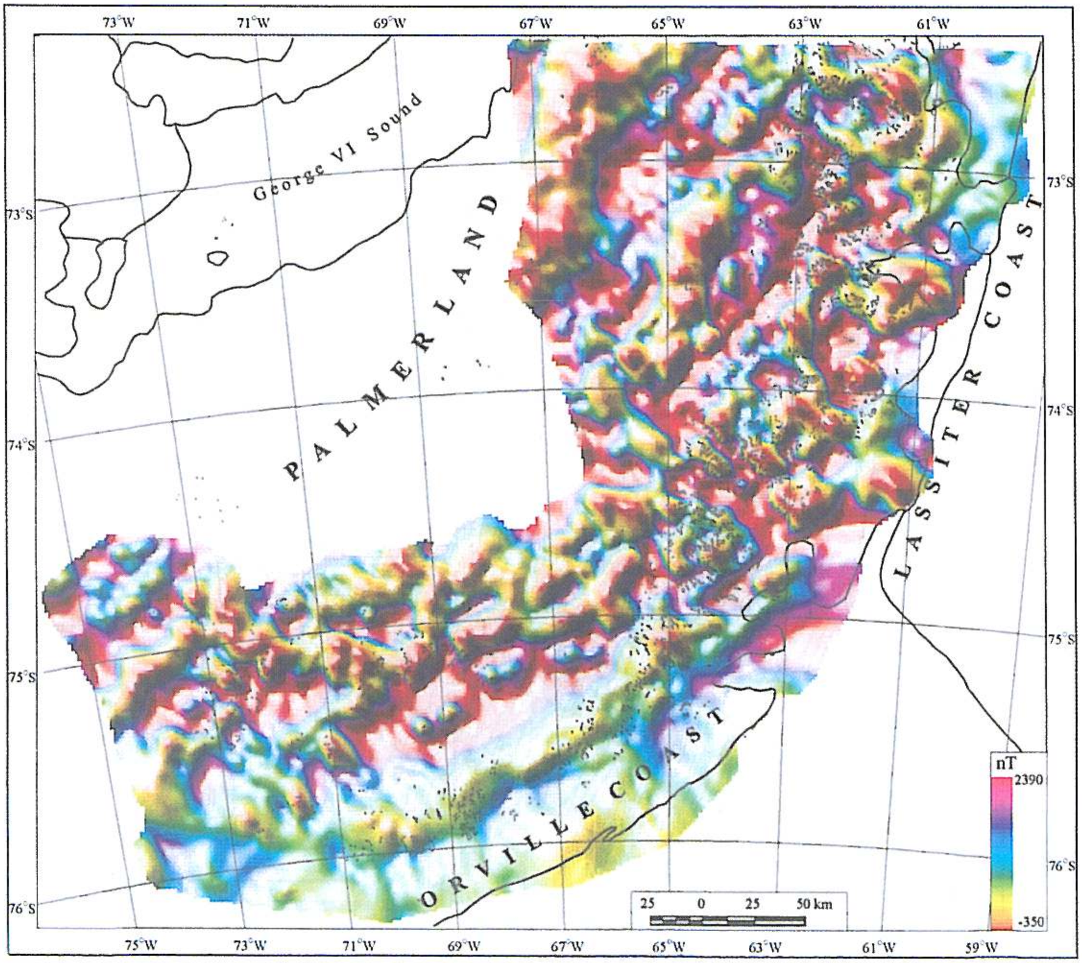

Fig. 3. Shaded-relief aeromagnetic map of Southern Palmer Land (illumination is from northwest (315°) at an inclination of 45°.

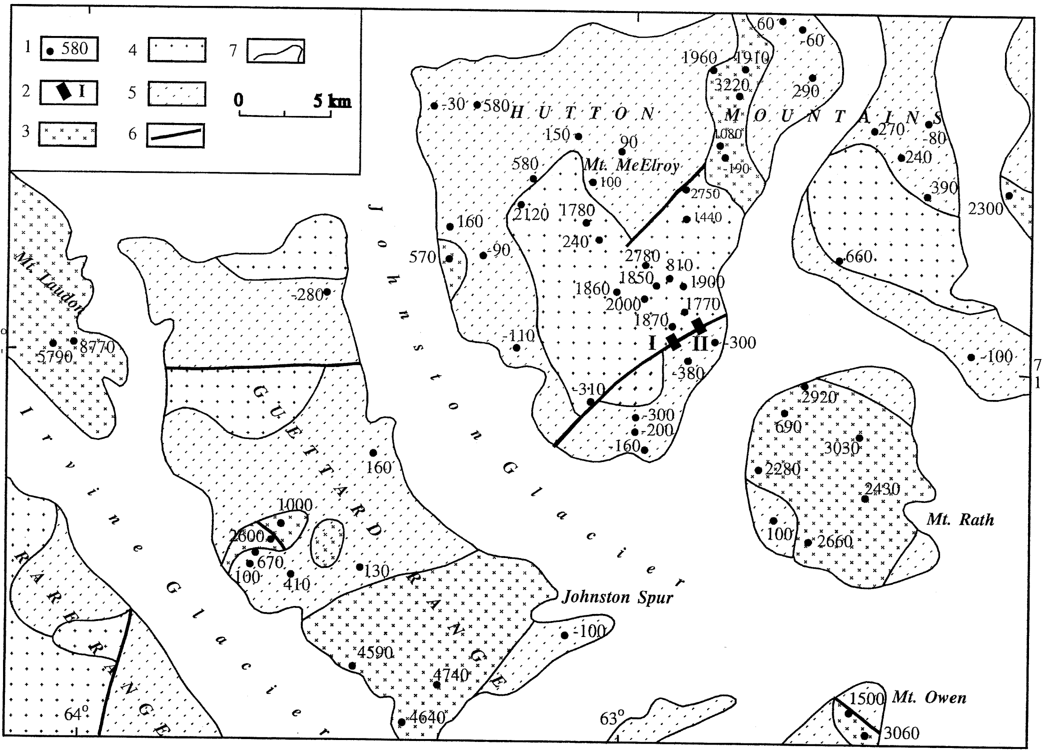

Fig. 4. Ground magnetic data in the Hutton Mountains and Guettard Range. 1 = Measured values of magnetic anomalies; 2 = Locations of the ground magnetic profiles shown in fig. 5; 3 = Granodiorite plutons; 4 = Monzodiorite plutons; 5 = Latady Formation; 6 = Faults; 7 = Geological boundary.

The data were originally recorded onto paper records and were converted to machine-readable form by digitizing diurnally-corrected values from the original graph maps.

3. Ground magnetic survey

In addition to the aeromagnetic surveying in this region, ground magnetic observations were completed in the 1984-1985 field season by a two-man party simultaneously with geologic work. The ground survey was carried out in the Hutton Mountains (HM) and the Guettard Range (GR) (fig. 1). The magnetic anomalies were measured by a Z-28 quartz-magnetometer with variable observation spacing on various types of rocks. Diurnal variations were monitored by a Z-28 base-station magnetometer which was located in the centre of the ground survey. The average variation during the survey was less than 50 nT and the maximum recorded change 170 nT. Corrections for global component of the magnetic field were defined by an arbitrary level.

The irregular distribution of data points meant that manual contouring was not preferred for the production of the ground magnetic anomaly map (fig. 4). Two ground magnetic profiles shown on fig. 5 illustrate the character of magnetic anomalies over the contact of granodiorite pluton with the Latady Formation.

Ground data (about 200 points) in the Sweeney, Hauberg and Wilkins Mountains were

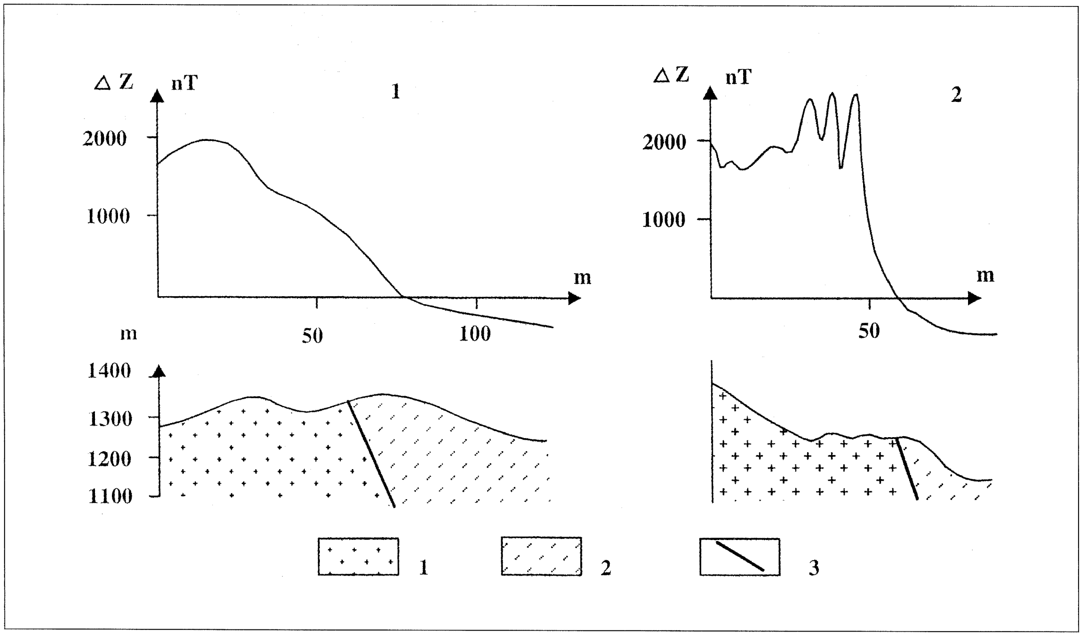

Fig. 5. Ground magnetic profiles in the Hutton Mountains across the contact of granodiorite pluton with Latady Formation. 1 = Granodiorite; 2 = Latady rocks.

collected by using MMP-203 proton-precession magnetometer. The average value of the observed anomalies and the volume susceptibility of the rocks is shown in fig. 6. The International Geomagnetic Reference Field was calculated and subtracted at each survey point using the IGRF 1985 coefficients (Barraclough, 1981). Diurnal variations were monitored in the survey area using an M-33 portable base station magnetometer.

Ground magnetic surveys were performed in advance of and during the aeromagnetic surveys were concentrated in two regions (fig. 1). At some locations in the Wilkins and the Hauberg Mountains the magnetic anomalies with amplitude up to 500 nT are observed over area where the non-magnetic sedimentary rocks of Latady Formation are found (fig. 6). It seems plausible that ground magnetic anomalies are associated with intrusions intruded during the Cretaceous.

All magmatic rocks cause high-amplitude magnetic anomalies but there are differences over different types of rocks in their intensity. The highest amplitudes (4000-10000 nT) are over quartz-monzodiorite with gabbro-ultrabasic nodules from the GR near Mount Laudon (fig. 4). The granodiorite plutons are reflected by positive anomalies of about 1400-2400 nT. As distinct from granodiorites, monzodiorites are characterized by higher intensities. The most prominent anomalies for monzodiorite plutons occurred near Mount Johnston Spur (4600-4700 nT) and Mount Rath (2200-3000 nT). The anomalies over North Hutton Massive have values from 1080 up to 3220 nT and are associated with granodiorites.

In the Orville Coast ground observations were concentrated mainly on the sedimentary rocks of the LF, but a few measurements on granodiorite showed, that in this part of Palmer Land the magnetic anomalies produced over this rock type can be considerable. Unlike granodiorite, calc-alkaline volcanic rocks belonging to the Mount Poster Formation show no measurable values at all.

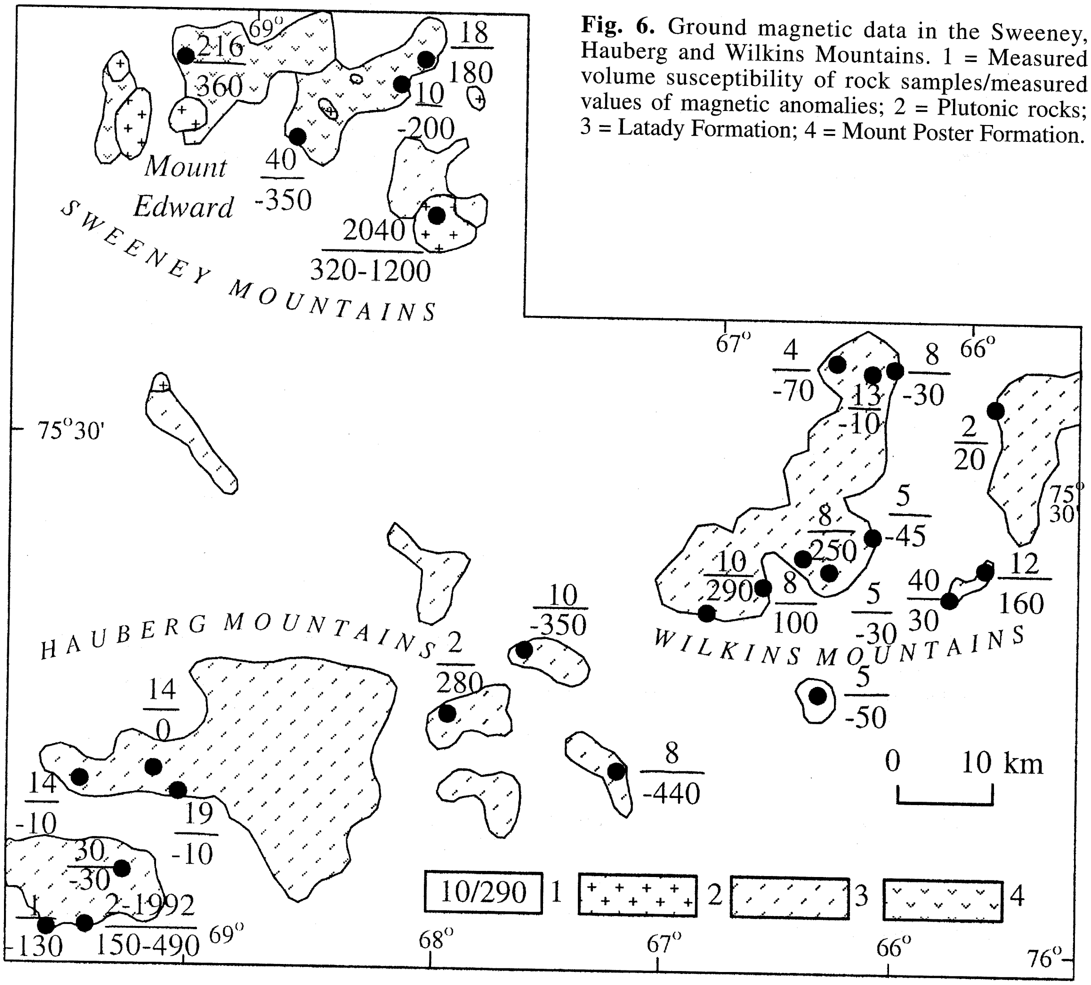

Fig. 6. Ground magnetic data in the Sweeney, Hauberg and Wilkins Mountains. 1 = Measured volume susceptibility of rock samples/measured values of magnetic anomalies; 2 = Plutonic rocks; 3 = Latady Formation; 4 = Mount Poster Formation.

4. Magnetic properties of rocks

Magnetic properties of rocks were measured on samples collected in the Palmer Land area during several geologic expeditions of PMGRE in this region and by E.N. Kamenev (VNIIOkeangeologia) during US Geological Survey expedition to the Lassiter Coast in 1972-1973. Volume susceptibility of rocks from the Orville Coast has been measured by using a hand-held Geofyzica Brno KT-5 kappameter. The results are given in fig. 7.

The volume susceptibilities were determined for a total of 713 rock samples. The sample locations are widely distributed throughout the survey area. Most samples (277) are from the area of Guettard and Rare Ranges, Hutton and Latady Mountains and Copper Nunataks which are dominated by the plutonic rocks of the Lassiter Coast Intrusive Suite (LCIS) (Rowley *et al.*, 1992). Values range from less than (1-5) × 10^{-3} SI units to 110 × 10^{-3} SI units.

Granodiorite, monzodiorite and diorite are all expected to show volume susceptibilities of approximately (10-30) × 10^{-3} SI units, thus clearly distinguishable from quartz-monzodiorite containing abundant large gabbro-ultrabasic nodules (70-120 × 10^{-3} SI units) from locations on

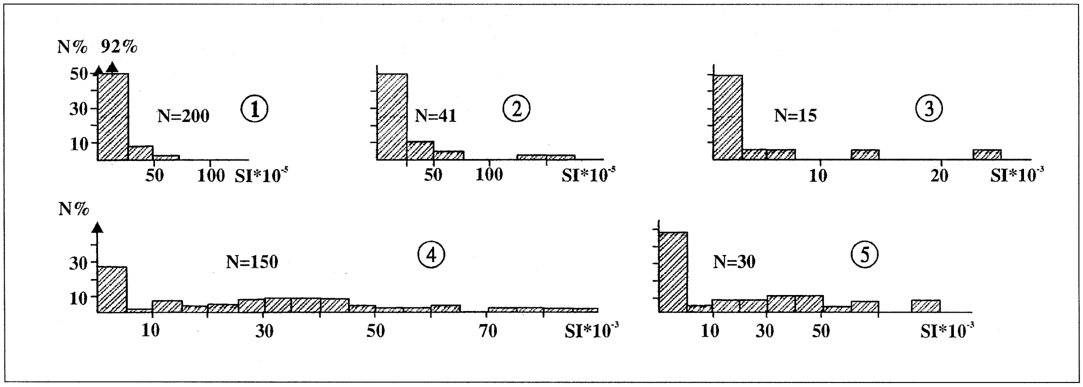

Fig. 7. Histogram of measured susceptibility of rock samples from the Southern Lassiter Coast and the Orville Coast: 1 = Latady Formation; 2 = Contact-altered metasediments; 3 = Basic volcanic rocks; 4 = Intermediate to acidic plutonic rocks; 5 = Felsic-intermediate to acidic volcanics and dykes.

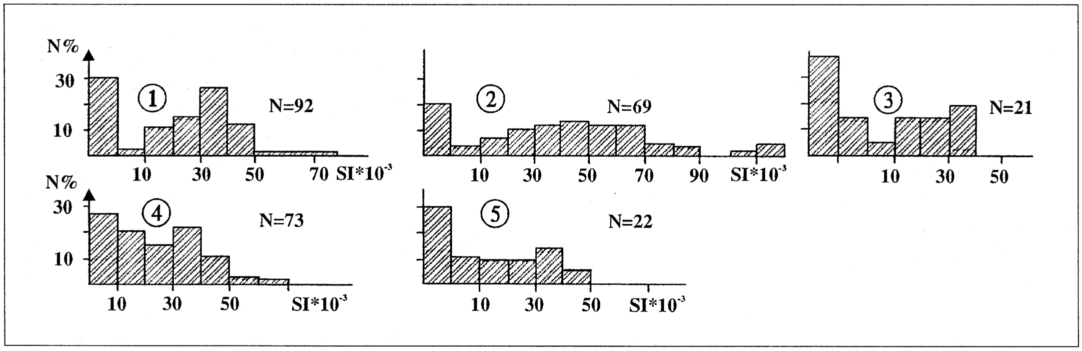

Fig. 8. Histogram of measured susceptibility (SI*10^{-3} units) plutonic rock samples from: 1 = Hutton Mountains; 2 = Guettard Range; 3 = Cooper Nunataks; 5 = Latady Mountains.

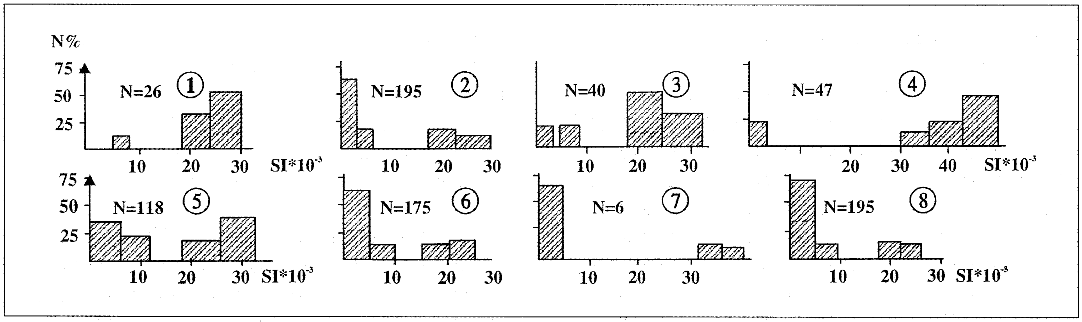

Fig. 9. Histogram of measured susceptibility (SI*10^{-3} units) of rock samples from the Northern Lassiter Coast: 1 = Granites; 2 = Quartz-monzodiorites; 3 = Granodiorites; 4 = Plagiogranites; 5 = Quartz-diorites; 6 = Gabbros; 7 = Contact-altered metasediments; 8 = Latady Formation.

Table I. Volume susceptibility of rock samples from Northern Lassiter Coast.

Lithology	Number of samples	Volume susceptibility (SI × 10^{-3})		
		Max	Min	Mean
Granite	26	70	4.5	16-29
Plagiogranite	6	17	0.1	0.15
Granodiorite	118	47	0.02	0.25, 17-31
Quartz-diorite	195	35	0.08	0.3
Quartz-monzodiorite	40	50	0.15	18-33
Gabbro	47	150	0.15	0.3, 30-56
Sedimentary rocks	195	40	0.02	0.2

the GR near by Mt. Laudon. It should be noted that 35-45% of intrusive rocks (fig. 8) show no measurable values at all. The same is true for metavolcanic, sedimentary, metasedimentary and contact-altered rocks which all give very low values of less than 0.25 10^{-3} SI units (fig. 9). The dyke rocks and veins yield values of the order of (10-40) × 10^{-3} SI units, however, 45% of them show no measurable susceptibility values at all.

Apart from the measurements on samples mainly collected on the Orville Coast and within the HM and GR of the Lassiter Coast, the magnetic susceptibility was measured using rock samples collected by E.N. Kamenev from the area of Lassiter Coast between 72°00S and 74°00S. The results are summarized in table I, grouped according to rock type. As can be readily seen, granite, quartz-monzodiorite and granodiorite yield similar values of the order of (16-33) × 10^{-3} SI units. However, granodiorite has bi-modal distribution of volume susceptibility that define two type of plutons, one with low (17-33) × 10^{-5} SI units and the other with high (17-31) × 10^{-3} SI units values. Higher susceptibilities are shown by gabbros (30-55) × 10^{-3} SI up to 150 × 10^{-3} SI units with mean values (22-42) × 10^{-5} SI units and (30-50) × 10^{-3} SI units for contact and central parts of plutons respectively. Measurements of the density of gabbro give 2.9 Mg/m^3 for the central part of plutons and 2.69 Mg/m^3 for contact parts.

Apart from a small outcrop near by Mount Laudon on the Antarctic Peninsula Geologic Map for the Lassiter Coast there is no record of gabbroic intrusions (Rowley *et al.*, 1992). Kamenev's samples were collected from several places from the Dana and Werner Mountains where diorite rocks are shown. According to E.N. Kamenev (personal communication, 1994), gabbroic rocks form two isometric intrusions in the Dana Mountains with areas of approximately 130 km^2 and 60 km^2 and one in the Werner Mountains (25 km^2). The central parts of the plutons expose biotite-amphibolite quartz gabbro. The contact zones are represented by biotite-hornblende gabbro-diorite or biotite-amphibolite gabbro-norite. The contact rocks form the greater part of the massive.

The outcrop of Mount Coman shows layering alteration amphibolite gabbro and chloritiezed and epidotiezed diorite. The thickness of the layers is 2-5 m, which are broken by many of cracks. The metamorphism of the gabbroic rocks of Mount Coman is different from the 'fresh' rocks of the LCIS, possibly suggesting that intrusion may be situated in another structural zone.

5. Modelling

Five aeromagnetic profiles, 3105, 3123, 3138, 3038 and 3043 have been modelled employing information from sub-ice topography, outcrop geology, volume susceptibility of rocks. The aeromagnetic data have been also analysed using the Euler and Werner deconvolution techniques (Nabighian, 1972; Hartman *et al.*, 1971).

The 2.5D modelling was done on the profile aeromagnetic data by using gravity and modelling program GRAVMAG, the theory for the magnetic calculations is taken from Shuey and Pasquale (1973). This is an interactive graphics-based program in which sub-surface bodies are defined as a set of polygonal bodies in the plane of the profile. In the perpendicular plane the polygons are assigned a finite strike length (modelled strike lengths for all bodies are 30 km). Body shape and properties are edited interactively until a satisfactory fit between observed and calculated fields is archieved. It was assumed, that the total magnetization of the bodies was parallel to the Earth's present field.

5.1 . *Section along profile 3105*

The profile 3105 extends (see fig. 1) east from George VI Sound on the Lassiter Coast. It crosses the Pacific Margin Anomaly (PMA after Maslanyj *et al.*, 1991) close to the Seward Mountains composed by intermediate-basic rocks (Rowley *et al.*, 1992), the area around the Journal Peaks with high-frequency anomalies and the Wegener Range with very strong anomaly reaching in amplitude of 1900 nT of unknown geology.

The magnetic model (fig. 10) shows that the PMA can be matched by assuming highly magnetic material in the upper crust. The magnetic body for the PMA was divided into vertical sections and an acceptable fit between observed and calculated magnetic anomalies obtained with volume susceptibilities between 25×10^{-3} and 90×10^{-3} SI units. Susceptibilities of $(50\text{-}100) \times 10^{-3}$ SI units are sufficient to match the amplitude of the observed anomaly; these values are typical of mafic igneous rocks (*e.g.*, gabbro and basalt, 75×10^{-3} SI units; diabase, 88×10^{-3} SI units; Telford *et al.*, 1976). The rather high value for central polygon is not consistent with average measured rock properties, which have been used by previous interpretations of the PMA (Garret, 1990). However, mafic rocks with similar susceptibility widely distributed over the Palmer Land (Maslanyj *et al.*, 1991).

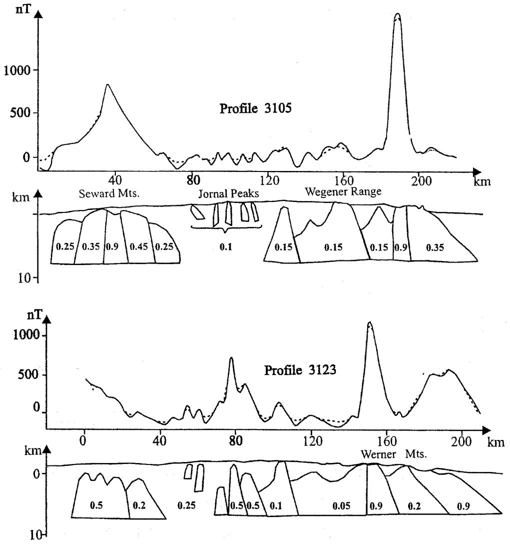

Fig. 10. 2.5D modelling of two selected profiles (3105 and 3123) to illustrate interpretation of the major aeromagnetic anomalies over the Lassiter Coast, Antarctic Peninsula. Location of these profiles is shown in fig. 1. A uniform magnetization of the Earth's field is assumed for each profile. Body susceptibilities marked in 10^{-3} SI units. Modelled strike lengths for all bodies are 30 km.

On other hand, our modelling shows that the PMA-batholith can be interpreted as limited on the depth (8 km) body consisted of numerous plutons, probably, of different ages, compositions and magnetizations. Furthermore, our model for this segment of the PMA with 8 km thick causative bodies is not in agreement with previous models (Garret, 1990; Maslanyj *et al.*, 1991; Johnson, 1996) in which it is necessary to introduce batholith type bodies of 20 km tick to explain the PMA. Admittedly, their overestimated thickness of the batholith is due to using for modelling gridded data selected at 5-km intervals (Garret, 1990), when magnetic anomalies with wavelengths of up to 10 km were aliased.

Short-wavelength anomalies of 50 nT amplitude near the Journal Peaks correlate with exposed Mesozoic calc-alkaline volcanic rocks and are modelled by shallow unrooted bodies

(1-2 km) with volume susceptibility 10 × 10^{-3} SI units. Another assumption is that these anomalies could be caused by bedrock topography (Garret, 1990). Magnetic anomalies over the Wegener Range caused by Cretaceous calc-alkaline plutonic rocks are modelled as a composite body with low magnetization.

The most conspicuous anomaly on profile 3105 with an amplitude 1900 nT is probably caused by a 8 km wide body (fig. 10) with volume susceptibility of 90 × 10^{-3} SI units. Similar sources of the anomalies are envisaged in the vicinity of Eielson Peninsula, Cape Bryant and Cape Knowles with exposed metagabbroic rocks (Renner *et al.*, 1985; McGibbon and Garret, 1987). Geological investigations confirm the presence of large gabbroic plutons along the Black Coast (Singleton, 1980; Renner *et al.*, 1985; Storey and Garret, 1985). These alkaline gabbros of Cretaceous age are associated with high-amplitude magnetic anomalies and emplaced probably in an extensional back arc or Weddell Sea marginal setting (Moyes and Storey, 1986).

5.2. *Section along profile 3123*

Profile 3123 crosses the mainland of the Antarctic Peninsula close to Mount Vang and Toth Nunataks with exposed upper Jurassic to Lower Cretaceous volcanic rocks and extends east over the Werner Mountains towards New Bedford Inlet. The PMA modelled as a composite body extending down to 8 km (fig. 10) with volume susceptibility of 50 × 10^{-3} SI units. The Central Plateau Anomaly (anomaly N2 after Jones and Maslanyj, 1991) is continuous along strike for more than 150 km. The source of the CPMA is believed to be a linear plutonic complex, which is associated with diorite-gabbro rocks exposed over Mount Coman and close to the Galan Ridge (Rowley *et al.*, 1992). Correlation of these outcrops with magnetic anomalies suggests that the CPMA is apparently caused by concentrations of mafic material. The magnetic sources were modelled by three component bodies with a volume susceptibility of 55 × 10^{-3} SI units.

The part of profile 3123 crossing the Werner Mountains was modelled with the upper surface of the magnetic bodies near bedrock surface, which corresponds to exposed geology (Rowley *et al.*, 1992). The most prominent magnetic anomaly with an amplitude up to 1250 nT is observed over a diorite outcrop in the eastern part of the Werner batholith (Rowley *et al.*, 1992). It shows a well-defined circular shape and is modelled by a 10 km wide source body reaching to a depth of around 7 km.

5.3. *Section along profile 3138*

Profile 3138 is situated over the Guettard Range and the Hutton Mountains, where there are rocks of the Lassiter Coast Intrusive Suite varying in composition from gabbro to granite (Pankhurst and Rowley, 1991). Magnetic anomalies reach 900 nT over the quartz-monzodiorite rocks of Mount Laudon and around 300 nT over the granodiorite massive in the Hutton Mountains. The magnetic sources are modelled by a composite body (fig. 11), which includes numerous plutons with volume susceptibility consistent with measured rock properties. This model would not fit the observed field data at the north-western end of the profile.

It was mentioned above that quartz-monzodiorite rocks containing abundant large gabbro-ultrabasic modules from locations on the Guettard Range are characterized by high level of volume susceptibilities of the order of (70-120) × 10^{-3} SI units. The anomaly over this

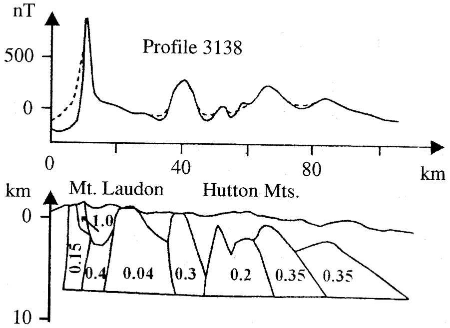

Fig. 11. 2.5D modelling along profile 3138 (location marked in fig. 1).

region is reproduced by narrow body extending down to 2 km with volume susceptibilities of 100×10^{-3} SI units.

5.4. *Sections along profiles 3032 and 3043*

The modelling of magnetic-source bodies at the Orville Coast was accomplished by using two profiles. Profile 3032 extends from northern part of the Sweeney Mountains to the Hauberg Mountains, which are characterized by exposed by silicic-intermediate calc-alkaline volcanic rocks of the Mount Poster Formation and sedimentary rocks of the Latady Formation respectively.

The circular high amplitude anomaly (1900 nT) observed over the Sweeney Mountains corresponds to the Edward pluton, which consists mostly of gabbro-quartz monzodiorite rocks (Pankhurst and Rowley, 1991). The anomaly was modelled using a simple source body and a satellite (fig. 12) with volume susceptibilities of 100×10^{-3} SI units. The top of the main body is at the surface and the bottom is around 8 km. The satellite body is used for compensation of a strong low produced by the main body. It is not possible to model the relative maximum on the negative background to the east from the Mount Edward anomaly. This is probably due to an off-profile body.

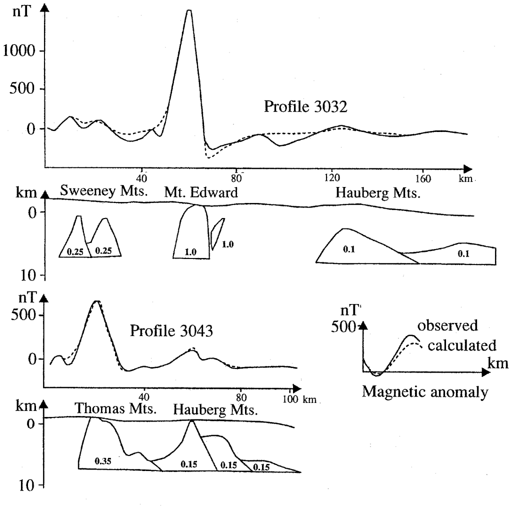

Fig. 12. 2.5D modelling of two selected profiles (3032 and 3043) to illustrate interpretation of the major aeromagnetic anomalies over the Orville Coast, Antarctic Peninsula.

The magnetic anomaly pattern of the Hauberg Mountains is characterized by low-amplitude anomalies and is not associated with exposed geology, which consists mainly of the non-magnetic rocks of the Latady Formation (Rowley *et al.*, 1992). There is only one small nunatak (Janke Nunatak) which is a granodiorite intrusive. The model for this part of the profile 3032, as well as for profile 3043 consist of a bodies with low homogeneous magnetization of 10×10^{-3} SI units dipping east towards the Ronne Ice Shelf.

6. Magnetic anomalies of Palmer Land

For the purpose of the present study the aeromagnetic data were interpolated onto 1.5 km grid by using the GSC (Atlantic, Geological Survey of Canada) geophysical image processing and visualization tool package on a SUN SPARC station 20 at VNIIOkeangeologia, St. Petersburg, Russia. No attempt was made to continue analytically the anomaly data to a common altitude.

The obtained final grid set was transferred into the ER Mapper software system (Earth Resource Mapping Pty. Ltd., 1995) where all image processing was carried out. The color shaded-relief map (fig. 3) was produced by using a sun-angle routine with artificial illumination from northwest (315°) and an inclination of 45°. The grid values were scaled to a range of 256 using histogram-equalization and the values were converted into a 3-band pseudo-colored image by using the RGB (Red, Green, Blue) combination.

Although Palmer Land is relatively well exposed, most of the area is covered by ice and snow and inaccessible for geologic exploration. Geological information will always be patchy and confined to the limited number of outcrops. The aeromagnetic survey with flight-line spacing 5 km between profiles is the most effective tool for obtaining information not only beneath the ice, but even from beneath the sedimentary rocks that crop out at the surface.

In general, magnetic features trend roughly parallel to the curvature of the Southern Antarctic Peninsula. The three major positive anomalies are recognized within the study area. These are the Pacific Margin Anomaly, Central Plateau Magnetic Anomaly and East Coast Magnetic Anomaly. The mapped fragment of the PMA, the dominant magnetic feature of the West Antarctica extending for 2000 km along the Pacific margin (Johnson and Smith, 1992) of the Antarctic Peninsula and Ellsworth Land, is characterized by local maxima with wavelengths of 30-50 km and amplitudes of 300-1000 nT.

Existent exposures of the Antarctic Peninsula Volcanic group (see Rowley *et al.*, 1992) with low values of magnetic properties cannot cause the observed anomalies. It is broadly assumed that a complex linear batholith is the source of the PMA (Renner *et al.*, 1985; Garret, 1990; Maslanyj *et al.*, 1991). There are few determinations of the radiometric age of plutons which cause the PMA. Garret (1990) reported that in the North-Western Palmer Land, gabbro and amphibolite were intruded during Late Jurassic times and caused the metamorphism of rocks at the Goettel Escarpment, but this is poorly constrained as only a basalt dyke was K-Ar dated at 156 ± 7 Ma (Leat *et al.*, 1995).

The discrete gabbro intrusions from the same region give a minimum age of 140 Ma (Piercy and Harrison, 1991). Similar Early Cretaceous intrusions corresponding to the PMA are widespread along the west coast of the Northern Palmer Land and Southern Graham Land representing one of the possible sources of the PMA. This was supported by recent investigations of Vaughan *et al.* (1998). They reported that the spatial relationship of Early Cretaceous plutons to positive magnetic anomalies suggest that the major part of the Palmer Land segment of the PMA formed in the Early Cretaceous, rather than the Jurassic (Garret, 1990) or Tertiary (Storey and Garret, 1985).

As mentioned above, the Central Plateau Magnetic Anomaly (CPMA) represents a continuous linear belt of high-intensity magnetic anomalies associated with highly magnetically susceptible gabbroic to tonalitic-granodioritic extension-related rocks. The gabbro intrusion exposed at Mount Coman is associated with a magnetic anomaly of 1300 nT amplitude, whereas the diorite intrusion lies close to the Galan Ridge corresponds to a 500 nT magnetic anomaly. The CPMA is highly transected by orthogonal faults, nevertheless we suggest that the Merrick-Sweeney-Latady lineament of the Orville unit (discussed subsequently) is the southern-southwestern continuation of the CPMA.

The East Coast Magnetic Anomaly is a group of discrete high-amplitude anomalies (600-5000 nT) that form a broadly linear belt trending parallel to and inland of the Lassiter and Black Coasts. The width of the ECMA is about 75-100 km. Comparison of the aeromagnetic anomaly map with the outcrop geology shows that bulk of the positive anomalies occurs over areas of development of the Lassiter Coast Intrusive Suite. Broad, irregular anomalies (100-500 nT amplitude) are related to the Cretaceous plutons of granite-granodiorite composition, whereas small (10-20 km) circular anomalies of 800-1900 nT amplitude are corresponded to dioritic or gabbroic intrusions of similar age (Pankhurst and Rowley, 1991). However, in some parts, such as the Playfair Mountains and over intrusion to the west from the Werner Mountains dioritic rocks are associated with the negative anomalies. As a rule they are located to the S-SW of the intrusions characterized by intensive magnetic anomalies. Magnetic properties of plutonic rocks vary considerably and central parts of gabbroic plutons mostly yield higher susceptibilities than contacts. It is highly likely that, in some cases, negative anomalies are associated with such outer parts of plutons (*e.g.*, Playfair Mountains) or alternatively due to the less mafic composition and dominance of ilmenite over magnetite (Moyes and Storey, 1986) or may be explained by reversed remanent magnetization (Vaughan *et al.*, 1998).

The magnetic anomaly pattern allows us to subdivide the survey area into two units named in accordance with their geographical position as the Lassiter Coast unit and the Orville Coast unit. The magnetic data reveal the widespread presence of an orthogonal pattern of crosscutting linear discontinuities that can be interpret-

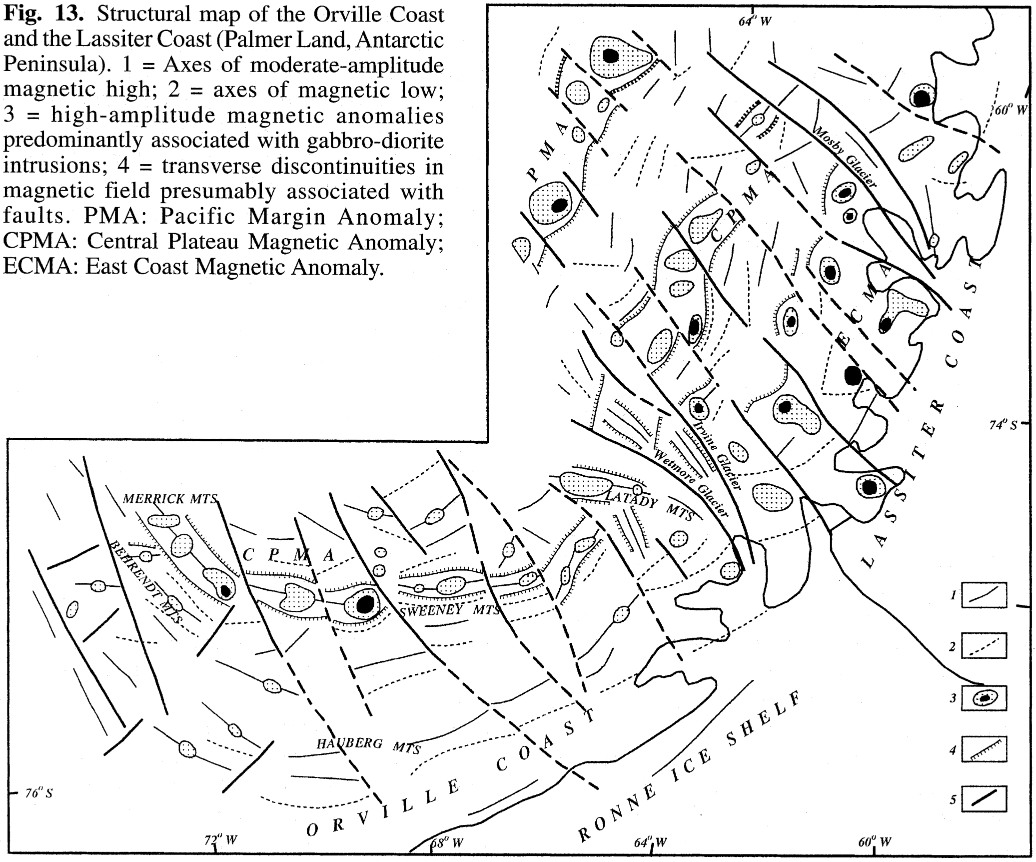

Fig. 13. Structural map of the Orville Coast and the Lassiter Coast (Palmer Land, Antarctic Peninsula). 1 = Axes of moderate-amplitude magnetic high; 2 = axes of magnetic low; 3 = high-amplitude magnetic anomalies predominantly associated with gabbro-diorite intrusions; 4 = transverse discontinuities in magnetic field presumably associated with faults. PMA: Pacific Margin Anomaly; CPMA: Central Plateau Magnetic Anomaly; ECMA: East Coast Magnetic Anomaly.

ed as Late Cretaceous/Early Tertiary fracture pattern (fig. 13). As a whole, they are outlined along mountain glaciers. The most outstanding of such discontinuities corresponds to the boundary or transitional zone between the two units. It is lies along the Wetmore-Irvine glaciers and corresponds to NW-SE trending negative anomalies (fig. 3). The remarkable linearity of this feature is presumably associated with substantial strike-slip displacements of the Lassiter Coast crustal segment relatively to the Orville Coast segment. However, an absolute value of strike-slip motion is difficult to estimate; it may be around 10-20 km. Another example of a sharply defined crosscutting lineament is associated with the negative anomalies observed in vicinity of the Mosby Glacier.

6.1. *Lassiter Coast Unit*

The most prominent magnetic highs within the ECMA are associated with known intrusions such as are found near by Mt. Laudon, Mt. Grimminger, Rivera Peaks, Dana, Werner and Wegener Mountains. In some places they occur over outcrops with unknown geology (Peak Arctowski and Mount Tricorn).

Two major lineaments of high-amplitude anomalies are recognized. The westernmost part of the ECMA is considered as the Mount Grimminger-Mount Laudon (MG-ML) lineament that is characterized by an alignement of semicircular steep-gradient anomalies with 10-20 km in diameter and inferred alignement of the causative bodies (mainly gabbroic plutons). There are no doubts that the MG-ML lineament can be continued northward from the Mosby Glacier where a similar magnetic high with an amplitude of 1900 nT is recognized, though its source is unknown. We interpret this high to be a gabbroic intrusion similar to that observed along the Black Coast in the vicinity of Eielson Peninsula, Cape Bryant and Cape Knowles (McGibbon and Garret, 1987; Jones and Maslanyj, 1991). These alkaline gabbro plutons were intruded during an extensional phase of arc development in the Late Cretaceous (Moyes and Storey, 1986).

The amplitudes within the lineament range from 800 to 1900 nT, very high considering that aircraft was about 1-1.5 km above the possible sources. Most of the positive anomalies have associated negative lobes on their south-western sides as would be expected for anomalies caused by induced magnetization in the present Earth field direction.

The other lineament outlined within the ECMA, the Johnston Spur-Peak Arctowski lineament is characterized by a linear set of high- to moderate-intensity magnetic anomalies. It includes the highest value (5000 nT) measured within the whole study area. This extremely high-amplitude anomaly which arises from an unknown source was observed in the vicinity of Mount Tricorn. We interpret this anomaly to be caused by a gabbroic intrusion.

The magnetic anomalies observed over the Guettard Range (GR) are related to composite plutons intruded into metasedimentary rocks of the Latady Formation. The highest value (750 nT) corresponds to diorite rocks, whereas quartz-monzodiorite rocks found in the southern-eastern part of the GR correspond to anomalies only 200-300 nT in amplitude. The areal extent of the GR magnetic anomaly is much bigger than the exposed part of the intrusion emplaced near by Johnston Spur Mount suggesting that rest of intrusion does not reach the surface. The same is true for the Hutton Mountains, as well as for the Werner Mountains where an irregular broad magnetic anomaly corresponds to a larger area than that of the outcropping granodioritic intrusions.

Two broad semicircular magnetic anomalies observed near by Mount Oven and over the Smith Peninsula give us additional examples of where the areal extent of magnetic anomalies exceeds the horizontal dimensions of outcropping intrusions. This is evidence that plutonic activity during the geologic evolution of Palmer Land has been a more important process than is apparent at outcrops. The horizontal dimension of the exposure of plutonic rocks outcropping at Mount Oven is limited in comparison to the area of the mapped magnetic anomaly (550 nT in amplitude) exactly corresponding to a crustal block outlined by a fault system associated mostly with sedimentary rocks of the Latady Formation. The similarities in the form and amplitude between the Mount Oven and Smith Peninsula anomalies allow us to interpret the latter as being due to a pluton which does not reach the surface.

6.2. *Orville Coast Unit*

The magnetic grain of the Orville Coast Unit allows us to distinguish two major linear belts or lineaments. One of them stretches continuously from the Merrick Mountains through the Sweeney Mountains towards the Latady Mountains and is associated with gabbro-diorite rocks and accompanying plutons intruded near by border of the Mount Poster Formation and the Latady Formation (Kellogg and Rowley, 1991). The lineup of the highs and the inferred lineup of the causative bodies may reflect fundamental structures that controlled the Mesozoic evolution of the Antarctic Peninsula. The Merrick-Sweeney-Latady lineament may be considered as paired feature that is outlined by two subparallel chains of positive anomalies with amplitudes up to 1900 nT and divided by coherently stretched negative anomalies. In some places these chains are connected by N-S oriented anomalies. Major exposures of plutonic rocks within the lineament correlate well with positive anomalies although in different ways.

The most intensive magnetic anomaly with amplitude 1900 nT is associated with the complex Cretaceous gabbro-diorite intrusion of Mount Edward (Rowley *et al.*, 1992). Another small exposure of gabbroic rocks located to the east from Mount Edward only corresponds to the magnetic gradient of the lineament. The amplitude of the magnetic anomalies over the granite-granodiorite plutons which outcrop along the axis of the lineament varies from 100-200 nT in the Latady Mountains to 950 nT in the Merrick Mountains. Metavolcanic rocks belonging to the Mount Poster Formation have no obvious correlation with the magnetic anomaly pattern.

The area located between the Sweeney Mountains in the north and the Hauberg Mountains in the south has few exposures and is characterized by a broad low overprinted by short-wavelength anomalies. These anomalies with amplitudes up to 600 nT partly correspond to known plutons of different composition outcropping in the Thomas Mountains, Witte Nunataks as well as being located over areas with no exposures.

The second magnetic lineament extends for at least 400 km from the Southern Behrendt Mountains across the Hauberg Mountains and Peterson Hills, across the Wilkins and Scaife Mountains to the Southern Latady Mountains is named as the Behrendt-Hauberg-Scaife lineament. It is arcuate in form and associated with subdued low-amplitude anomalies, indicating deeper causative bodies. To the south-east the lineament is flanked by a narrow belt (15-25 km) of negative anomalies of about 50-100 nT amplitude. Isolated magnetic anomalies with amplitude up to 500 nT are located in opposite parts of this linear magnetic belt (close to Mount Hassage, Quilty Nunataks and over Janke Nunatak in the west; over Mount Terwileger, Mount Brundage and other localities in Latady Mountains in the north-east) correspond to known intrusions of different composition. This observation allows us to suggest that a linear plutonic complex may be found under sediments of the Latady Formation along whole length of the lineament.

Broad, subdued magnetic anomalies with amplitude which do not exceed 100 nT run in a similar manner parallel to the other anomaly-belts within the Orville Coast Unit from the northern tip of the Dodson Peninsula towards the Evans Ice Stream. They are located close to the grounding-line of the Ronne Ice Shelf and may be considered as a transition zone between the Palmer Land magnetic unit and the Weddell Sea Embayment magnetic zone or a transition zone between structures of the Antarctic Peninsula and Weddell Sea Embayment crustal blocks. The causative sources of the magnetic anomalies are buried at 4-8 km (fig. 7) under sediments and may be interpreted as plutonic bodies of Antarctic Peninsula batholith intruded into nonmagnetic sedimentary rocks of the Latady Formation.

Of particular interest is the conspicuous long-wavelength magnetic anomaly (see fig. 1, Golynsky and Aleshkova, 1999) with of 700 nT amplitude observed in the Southernmost Antarctic Peninsula (close to Cape Zumberge composed by sedimentary rocks of Latady Formation) and the complex long-wavelength low amplitude magnetic anomaly (150 nT) located southward from the Korff Ice Rise. Magnetic images presented by Golynsky and Aleshkova (1999) strongly suggest that despite their trends which are not consistent with those within the Haag Nunataks (HN) unit, causative sources might be related with the basement of the HN crustal block. This suggests that the basement of HN may extend beneath the Ronne Ice Shelf as was inferred previously by many authors (Kadmina *et al.*, 1983; Garret *et al.*, 1987; Maslanyj and Storey, 1990) and the Antarctic Peninsula. It should be noted that in the interpretation of British aeromagnetic data given by Maslanyj and Storey (1990, see fig. 9) the area covered by the Cape Zumberge magnetic anomaly was also included within a possible extension of the HN crustal block.

7. Discussion and conclusions

Analysis of the aeromagnetic surveys flown at 5 km intervals over Palmer Land clearly suggests that the Cretaceous plutons of the Lassiter Coast Intrusive Suit are mainly reflected in the magnetic anomalies of regional extent. A dense network of profiles allows us to observe positive magnetic anomalies over outcrops of Cretaceous plutons of different composition in many areas which were not seen during previous investigations by the British Antarctic Survey where the profile spacing of 20 km was too large. A similar situation can be seen in the area around Sweeney and Behrendt Mountains.

The gravity data collected between Ellsworth Mountains and Antarctic Peninsula (McGibbon and Smith, 1991), as well in southwestern corner of the Weddell Sea Embayment (Aleshkova *et al.*, 1999) is of particular interest. These data clearly show the distinction between relatively high Bouguer anomalies up to 80 mGal over the HN crustal block and its possible continuation towards the Ronne Ice Shelf and the negative Bouguer anomalies over the rest of the Antarctic Peninsula. It is obvious that the observed Bouguer anomaly cannot be explained by simple variations in crustal thickness and probably has a deep-seated source.

The boundary between the two areas can be traced as a linear Bouguer anomaly gradient along a bedrock scarp southwestward from the Behrendt Mountains. This is inconsistent with the aeromagnetic data that define the boundary between the two crustal units as being along the Evans Ice Stream. It should be noted, that although the magnetic anomaly pattern of the area between the Behrendt Mountains and the Evans Ice Stream is similar of that in Palmer Land, the magnetic anomalies are much subdued and their amplitudes do not exceed 200 nT. Additionally, the spatial distribution of magnetic anomalies and their causative sources within this 'transitional zone' between two crustal units is very limited. Major lineaments of the Orville unit asymptotically turn out to the north-west or are terminated close to boundary outlined by gravity data. This probably indicates that magmatic activity associated with Cretaceous plutonism abruptly diminished in this area due to modification of the crustal structure of the Antarctic Peninsula.

The magnetic images (Golynsky and Aleshkova, 1999) in particular give the impression that the magmatic front associated with mafic-intermediate plutons intruded along the spine of the Antarctic Peninsula stops in vicinity or turns away from the northern flank of the Haag Nunataks crustal block. We further speculate that the Haag block might have acted as a rigid indenter during the Mesozoic evolution of the Antarctic Peninsula.

We suggest that the area between the Evans Ice Stream and the Behrendt Mountains is underlain by non-magnetic equivalent of the Haag Nunataks basement, similar to that inferred for the Ellsworth Mountains. The existence in this part of Antarctic Peninsula of the Mid-Paleozoic Fitzgerald quartzite beds and Permian sedimentary rocks of the Erehwon beds, which were correlated with Devonian Crashsite quartzite and Polarstar Formation of the Ellsworth Mountains respectively (Laudon and Craddock, 1992), apparently supports this interpretation.

We concur with Garret (1990) and Johnson (1997) that the crust of the Antarctic Peninsula is segmented in a way that bears a possible relationship to oceanic fracture zones. Three major sinistral zones which displace the curvilinear magnetic, physiographic and gravity patterns were previously distinguished in Northern Palmer Land and Graham Land (Garret, 1990). Our data also confirm the presence of numerous fault zones (fig. 13) within the Lassiter and Orville Coasts of Palmer Land. However, without compilation and integrated analysis of our aeromagnetic data and of the British Antarctic Survey any suggestions regarding to their possible relationship with oceanic fracture zones would be groundless and speculative.

The main results of the model calculations of the magnetic sources of the Antarctic Peninsula suggest that they can be modelled by composite bodies that appear in the upper crust within a layer with thickness of 8-10 km. This is not in agreement with previous models published by Garret (1990), Maslanyj *et al.* (1991) and Johnson (1996). According to their models the PMA batholith is a simple bodies extending to 20 km below sea level with a uniform magnetization 2 A/m. Other components of the Antarctic Peninsula batholith were modeled by introducing high-magnetic bodies (3 A/m) in the lower crust and/or by near-surface bodies with magnetization within the range of 0.6-7.0 A/m. The new data presented here confirm that causative sources of magnetic anomalies may be associated with different plutonic rocks, and the more mafic varieties are correlated with the high-intensity magnetic anomalies of about 800-1900 nT. Granite-granodiorite plutons of Lassiter Coast Intrusive Suite are mostly reflected by positive anomalies (100-500 nT).

The models across the Lassiter Coast clearly suggest that this part of the Antarctic Peninsula experienced widespread plutonism, magmatic rocks might be found through the whole width of the magmatic arc. The plutonic rocks form one of the major batholiths of the circum-Pacific rim. It was emplaced as a linear epicontinental structure over the period *c.* 240 to 10 Ma, with a Cretaceous peak of activity (extensional phase) that started at 142 Ma and waned during the Late Cretaceous (Leat *et al.*, 1995). There is no consensus as to the origin of Early Cretaceous extension, but it post-dated a peninsula-wide episode of Late Jurassic to Early Cretaceous compression, and appears to represent the termination of a Late Jurassic hiatus in arc magmatism (Storey *et al.*, 1996; Vaughan *et al.*, 1998).

The estimated width of the batholith across the Lassiter coast is about 230 km. Magnetic data, geological observations and our models provide evidence that magmatic activity along the Orville Coast essentially diminishes from east to west.

Acknowledgements

The data used in this study were gathered by PMGRE geophysicists under the guidance of Valery Masolov. We are pleased to acknowledge our colleagues of the VNIIOkeangeologia and PMGRE, in particular Garrik Grikurov and Eugene Kamenev, for helpful discussion regarding this work. We thank P. Morris, F. Ferraccioli and an anonymous reviewer for their constructive reviews.

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