NEW AEROMAGNETIC MAP OF WEST ANTARCTICA (WEDDELL SEA SECTOR): INTRODUCTION TO IMPORTANT FEATURES

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Abstract: A new aeromagnetic anomaly map of the Weddell Sea sector of West Antarctica is presented. Between 1973 and 1987 the British Antarctic Survey (BAS) conducted 8 reconnaissance aeromagnetic surveys covering an area which includes the Antarctic Peninsula, Ronne Ice Shelf, Ellsworth Land and the area between the Ellsworth, Whitmore and Thiel mountains. Over 114,000 line-km of data have been acquired. The profile data were filtered heavily to produce the new map, which is thus restricted to showing only the major regional anomalies which reflect gross crustal structure rather than local shallow sources. The dominant feature of the map is the Pacific Margin Anomaly (PMA) which extends without a break along the Pacific margin of the Antarctic Peninsula and Ellsworth Land. The PMA is restricted to the oceanward half of the exposed Mesozoic-Cenozoic magmatic arc and is related to a linear mafic-intermediate batholith complex. A distinctive region of high amplitude anomalies surrounds Haag Nunataks and suggests that the Precambrian rocks exposed there extend beneath parts of the Ellsworth Mountains and Ronne Ice Shelf. The remainder of Ronne Ice Shelf is characterised by long wavelength anomalies representing sources beneath a deep sedimentary basin. In contrast, Berkner Island has a large positive anomaly interpreted as shallower magnetic basement. Quiet magnetic conditions characterise the Ellsworth-Whitmore-Thiel mountains area in the southern part of the map with local anomalies caused by plutons associated with continental fragmentation.

Key words: aeromagnetic, West Antarctica, Pacific Margin Anomaly, regional tectonics, crustal blocks

Introduction

Between 1973 and 1987 the British Antarctic Survey (BAS) conducted eight reconnaissance aeromagnetic surveys in West Antarctica (Fig. 1), including two which were completed with United States logistical support during a joint BAS-United States Antarctic Research Program (USARP) project (Dalziel and Pankhurst, 1987). The first four seasons up to 1980, were concentrated on the Antarctic Peninsula (Renner et al., 1985). Since 1980, activity has been concentrated farther south. Data were collected over the Ronne Ice Shelf in 1983 (Herrod and Garrett, 1986) and around the Ellsworth and Thiel mountains during 1984 (Garrett et al., 1987; Garrett et al., 1988). The survey of the Antarctic Peninsula was extended southwards over southern Palmer Land and Ellsworth Land during 1986 (Jones and Maslanjy, 1991). During the final survey in 1987 Ellsworth Land, the Ellsworth Mountains and Bryan Coast were covered (Maslanjy and Storey, 1990). To mark completion of the two-decade reconnaissance phase of the programme, 114,000 line-km of data covering an area of 1,980,000 km² have been compiled and published as part of the BAS GEOMAP series (Maslanjy et al., 1991). This paper introduces the more important points arising from the map and its accompanying text (Maslanjy et al., 1991).

The new aeromagnetic map (Fig. 2; Maslanjy et al., 1991) represents a substantial advance in the geophysical database that will improve our understanding of the crustal structure of West Antarctica. We recognize the limited resolution of the surveys and identify four geological objectives in compiling the map.

a) To provide a picture of major structures of the Pacific margin plutonic complex of the magmatic arc.

b) To map the structure and extent of metamorphic rocks exposed at Haag Nunataks.

c) To map the distribution of igneous centres related to fragmentation of Gondwana.

d) To reveal aspects of the basin beneath the Ronne Ice Shelf.

Fig. 1. Location map of Weddell Sea sector of West Antarctica.

Fig. 2. Aeromagnetic anomaly map. Contour interval 100 nT, positive anomalies are shaded. Major anomalous areas: 1) Pacific Margin Anomaly (PMA); 2) east coast anomalies; 3) Haag Nunataks anomalies; 4) Berkner Island. Quiet areas: 5) Larsen Ice Shelf; 6) Alexander Island; 7) Ronne Ice Shelf; 8) Ellsworth Mountains and environs. Bold lines indicate positions of profiles modelled in Fig. 3 (Modified from Maslany et al., 1991).
Tectonic Setting

West Antarctica consists of several elevated areas separated by deep sub-ice troughs and basins. There are five broad areas within which bedrock is higher and where rock exposures fall into distinct tectonostratigraphic groupings. It has been suggested that these elevated areas may be independent crustal blocks (Jankowski and Drewry, 1981; Dalziel and Elliot, 1982; Storey et al., 1988) namely: Antarctic Peninsula (AP), Thurston Island (TI), Haag Nunataks (HN), Ellsworth-Whitmore mountains (EWM) and Marie Byrd Land (MBL) (see Fig. 1 of Storey et al., 1988). The intervening areas, where bedrock is often deeper than 1000 m bsl, probably represent basins or rifts which accommodated movement between the crustal blocks.

The Antarctic Peninsula is an Andean-type orogenic belt of Mesozoic and Cenozoic age reflecting subduction of Pacific Ocean floor beneath the western continental margin. Sedimentary and meta-sedimentary rocks flank the magmatic arc massif. To the west, Alexander Island is a Mesozoic fore-arc province. Back-arc sequences are found on the eastern sides of Graham Land, Palmer Land and Ellsworth Land. The area around Thurston Island represents the westward continuation of the magmatic arc of the Antarctic Peninsula. The metamorphic rocks exposed at Haag Nunataks are the only ones of definite Precambrian age in West Antarctica. The Ellsworth Mountains contain a thick folded sequence of Palaeozoic sedimentary rocks. Isolated outcrops farther south contain similar rocks and also Middle Jurassic granites associated with early break-up of Gondwana. Ronne Ice Shelf is believed to cover a deep basin containing a thick sedimentary sequence (Masolov, 1980).

The Aeromagnetic Survey

The objective of the aeromagnetic survey programme was to achieve a coverage at 15–20 km line spacing in areas of short-wavelength anomalies such as the Antarctic Peninsula, and a broader spacing of 30 km in areas of longer-wavelength anomalies such as Ronne Ice Shelf. Tie lines, spaced at up to 150 km, were flown to control individual surveys, and long tie lines were flown to link the surveys together. This broad lattice covered the area with a network which was sufficiently dense to map regional anomalies; the profiles gave detail of individual anomalous zones. Flight elevation varied with the surface topography. In mountainous areas a constant barometric altitude of 2500 m was maintained, and reduced to 760 m over Ronne Ice Shelf. Over the ice sheet in the south, drape flying with a minimum clearance of 150 m was possible. A large part of the network over the Antarctic Peninsula was completed from BAS stations on Adelaide Island and Alexander Island. Facilities were also provided by Chile and Argentina for flights over the northern Antarctic Peninsula. Farther south, fuel was provided at American and Russian stations. More remote surveys were done from temporary camps at ship- or aircraft-deployed field depots.

Diurnal magnetic variations and magnetic storms were monitored throughout the survey periods both by BAS observatories in West Antarctica, and by base station magnetometers in the immediate survey areas. Serious problems can occur when flying within the auroral zone, south of 73°S (Maslanyj and Damaske, 1986) but flying was generally restricted to magnetically quiet periods. Lines flown during magnetically active periods were re-flown whenever possible. Total-field magnetic measurements were made using a Geometrics G-803 proton-precession magnetometer, with a sensor mounted on the wingtip of a BAS Twin Otter aircraft. The magnetic field was sampled once a second which at the survey speed of 240 km/h, is equivalent to 62 m over the ground. Passive compensation methods were used to minimize the magnetic effect of the survey aircraft and reduce heading errors to less than 10 nT. The navigation system varied during the survey programme but mostly included self-contained Doppler systems. After correction of flight paths, we believe that positions over land and ice shelves are accurate to 1 km. This navigation error is acceptable for a regional survey of this magnitude.

Data Processing

The magnetic profiles were filtered to remove aircraft-generated noise and short-wavelength anomalies. The 1985 International Geomagnetic Reference Field (IGRF) (Barralough, 1985) was subtracted. To simplify the processing an elevation datum of zero was used when calculating the IGRF correction. This could lead to the correction being too great by between 40 nT in the north of the map and 70 nT in the south. For each individual survey, magnetic mis-ties at the intersections of lines with tie lines were minimized then the data from all the surveys were merged into one dataset. At this stage we included 5000 line-km of profile data from National Science Foundation (NSF)- Scott Polar Research Institute (SPRI)- Technical University of Denmark (TUD) surveys (Jankowski, 1983a) covering a gap at the southern end of the Ronne Ice Shelf. On examining the remaining mis-tie values at the intersection points there was no significant magnetic datum offset between any of the individual survey areas. A 6 km-grid was superimposed on the data and the magnetic field at each point was calculated using an octant search technique. The grid was then filtered and contoured at 50 nT intervals on a scale of 1:2,500,000 (Maslanyj et al., 1991). This map is reproduced at a smaller scale with 100 nT contour interval in Fig. 2.

Interpretation and Discussion

Introduction

Computer modelling (Busby, 1987) of selected flight line profiles (Figs. 3a–f) has been used to explain the major anomalies. Magnetic properties of outcropping rocks have been measured by a number of authors (see Maslanyj et al., 1991 for summary and sources), and were used to guide magnetisation vectors during modelling. Bedrock topography was used to constrain upper limits to the tops of the modelled bodies. Depth to magnetic source calculations using Werner-based deconvolution of profile data (as discussed by Jankowski, 1983b) were used to constrain lower limits to the tops of bodies.

Pacific Margin Anomaly (PMA): The magmatic arc

This major curvilinear anomaly (Fig. 2) is the dominant feature of the map, extending for 2000 km along the Pacific
Fig. 3. 2.5-dimensional modelling of selected profiles to illustrate interpretation of the major anomalies. A uniform magnetisation in the direction of the Earth's field is assumed for each profile. Body magnetisations are in A/m. Locations of profiles are shown in Fig. 2 (Modified from Maslanyj et al., 1991).
margin of the Antarctic Peninsula and Ellsworth Land. The anomaly is broadly sigmoidal in shape and up to 120 km wide. Local maxima occur with wavelength 20 km and amplitudes of 200–600 nT. When examined in detail, the PMA shows several changes in amplitude and pattern. The source of the PMA is believed to be a complex linear batholith (Fig. 4; Renner et al., 1985; Garrett, 1990). The correlation of mafic outcrops with magnetic and isotopic residual gravity anomalies suggests that the PMA is caused by concentrations of mafic material (Garrett, 1990). It is important to note that the PMA is generally restricted to the western half of the exposed Mesozoic–Cenozoic arc and does not reflect all the arc rocks.

The PMA has been modelled using large, simple magnetic bodies with homogenous magnetisations of around 2–2.5 A/m (Figs. 3a–c; see also for example Garrett and Storey, 1987; Garrett, 1990). Although consistent with the aeromagnetic and gravity datasets, these models are an oversimplification of a complex body of varying age, composition and magnetisation. Radiometric age determinations from the Antarctic Peninsula indicate that at least two phases of extension-related mafic intrusions contribute to the PMA (Meneilly et al., 1987). The first phase generated Upper Jurassic gabbros in northern Palmer Land during the early stages of Gondwanaland break-up. The second, during the slowing of subduction, correlates with Cenozoic plutons off the western coast of Graham Land. The western limit of the PMA is not revealed by the aeromagnetic anomaly map, but isolated flight lines farther west over Thurston Island show a similar large anomaly (Fig. 4; Maslanjy et al., 1991), which correlates with lower Cretaceous gabbro (Storey et al., 1991). The PMA is therefore continuous between the Antarctic Peninsula and Thurston Island, supporting paleomagnetic evidence for little post-Early Cretaceous fragmentation of the Pacific Margin (Grunow et al., 1987). Fault zones which segment the PMA (Fig. 4) often correspond to major bedrock features such as the Palmer Land–Graham Land transition (Garrett, 1990). Some fault zones lie close to the extrapolated trends of oceanic fracture zones to the west (Hawkes, 1981; Barker, 1982). The cause of this segmentation is unclear but the faults are probably Cenozoic in age (Garrett, 1990).

**Palmer Land, Graham Land and eastern Ellsworth Land:**

The mainland spine of the Antarctic Peninsula shows several isolated positive anomalies between the PMA and the eastern coast. The high amplitude (up to 2000 nT) short-wavelength (15–25 km) anomalies on the eastern coasts of Palmer Land and Graham Land correlate with exposed Cretaceous gabbro plutons (McGibbon and Garrett, 1987). These anomalies can be modelled by 10 km-wide bodies at shallow depth with total magnetisations between 5 and 7 A/m (Fig. 3c). Similar plutons may also be the source of the anomalies in eastern Ellsworth Land, although the causative bodies are not exposed.

**Alexander Island and George VI Sound:**

Alexander Island is characterised by low magnetic gradients (<5 nT/km; Fig. 2) which reveal little of the geologi-}

cal structure of the fore-arc complex. Discrete moderate amplitude anomalies (100 nT) correspond to Cenozoic alkali-alkaline volcanic rocks, and to calc-alkaline igneous rocks related to the magmatic arc (Fig. 3b). The long wavelength anomaly over George VI Sound suggests that it is underlain by fore-arc sedimentary material. The eastern edge of this quiet field correlates with the major physiographical boundary at the west coast of Palmer Land, marking the edge of both the magmatic arc and the PMA (Figs. 3b and 4). The cause of the large (400 nT) positive anomaly over Charcot Island is unknown.

**Haag Nunataks Area: Precambrian basement**

The Haag Nunataks area is characterised by high amplitude (up to 1000 nT) short wavelength anomalies and also by linear anomalies of up to 600 nT which parallel the trends of the Evans, Carlson and Rutford ice streams (Figs. 1 and 2). The isolated exposure of Precambrian rocks at Haag Nunataks correlates with a 1000 nT anomaly and the surrounding anomalies indicate an extensive area (100,000 km²) of shallow Precambrian basement beneath the ice (Figs. 3c and d). Changes in anomaly amplitude across the area reflect variations in basement depth. The correlation of topographic scarps with linear magnetic anomalies suggests the importance of fault control in the block (Figs. 3c and d). The most important of these topographic features is the northeastern edge of the Sentinel Range where bedrock elevation falls 7 km in a distance of less than 50 km (Drewry and Jordan, 1983).

Interpretation of the Haag Nunataks anomalies relies critically on the few exposures of Precambrian rocks at the nunataks themselves. The exact nature of the basement over the area is therefore still open to question. The anomalies clearly define the boundaries of the HN block (Fig. 4). Faulting throughout the HN block may be the result of NE-SW extension possibly during the Cenozoic (Garrett et al., 1987).

**Larsen Ice Shelf, Orville Coast and Ronne Ice Shelf:**

Low magnetic gradients over James Ross Island, the Larsen Ice Shelf and the Orville Coast (Fig. 2) may be related to back-arc sedimentary basins of late Mesozoic and Cenozoic age (Farquharson et al., 1984; Rowley et al., 1983). Depth to magnetic source calculations over Larsen Ice Shelf suggest 4–5 km of sedimentary rocks (Macdonald et al., 1988).

Low magnetic gradients (<5 nT/km) characterise the Ronne Ice Shelf (Fig. 2), covering an area 600 by 600 km. Modelling (Fig. 3e) and calculated depths to magnetic basement (Maslanjy et al., 1991) suggest 15 km or more of non-magnetic material overlying an undulating basement of high total magnetisation (3.5 A/m). These estimates agree with estimates from seismic and gravity data (Kamenev and Ivanov, 1983) and with calculated depths from previous aeromagnetic surveys (Masolov, 1980). The nature of the basement is uncertain. Our modelling (Fig. 3e) and upward continuation of characteristic profiles implies continuous Precambrian basement between exposures at Haag Nunataks and in Coats Land (Maslanjy et al., 1991). However there
may also be a substantial Middle Jurassic igneous contribution to the basement, such as the possible extension of the layered Jurassic gabbro outcrop at the Dufek Massif at depth to beneath Berkner Island (Johnson et al., 1992; Behrendt et al., 1974; Behrendt et al., 1981). This may be associated with early stages of Gondwana breakup. Berkner Island has the most extensive long wavelength (100 km) positive anomaly on the map (Fig. 2). Despite calculated basement depths of 10–15 km, we have modelled a shallower basement surface there (Fig. 3e) to avoid very high body magnetisations. This shallowing occurs along a major fault coinciding with the western grounding line of the island (Figs. 3e and 4).

Similar, though less clear, trends across the Ronne Ice Shelf also suggest basement faults. These faults may have their origins in crustal extension, possibly contemporaneous with the development of a Middle Jurassic failed rift system (Kristoffersen and Hinz, 1991), and associated with movement between AP, EWM, HN and East Antarctica. Subsequent thermal subsidence of the lithosphere may account for the thick overlying sediments.

Ellsworth - Whitmore mountains block:
Palaeozoic sediments

The subdued magnetic field (gradients <5 nT/km; Fig. 2)

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Fig. 4. Sketch map showing the interpretation of the major anomaly zones. AP, Antarctic Peninsula crustal block; HN, Haag Nunataks crustal block; EWM, Ellsworth - Whitmore mountains crustal block. (From Maslanyj et al., 1991).
over much of this area is attributed to thick Palaeozoic sedimentary and metasedimentary rocks (Behrendt et al., 1974; Jankowski and Drewry, 1981; Fig. 4). Excluding the Sentinel Range, there is no magnetic evidence to indicate the nature of the basement of the EWM. Local anomalies of 40 km wavelength and up to 400 nT amplitude punctuate the field and are associated with Middle Jurassic granites related to the breakup of Gondwana (Garrett et al., 1988). These anomalies are modelled (Fig. 3f) by moderate depth (5–10 km) magnetic bodies with magnetisations of 1–2.2 A/m beneath the granites (Fig. 3f). The magnetic data are of little help in identifying the transition zone between East and West Antarctica (Jankowski et al., 1983) in this area.

Summary

The aeromagnetic data have improved our understanding of the crustal blocks and intervening basins of this part of West Antarctica. The key points arising from the data are:

(a) The Pacific Margin Anomaly is continuous between the Antarctic Peninsula and Thurston Island. The physiographical boundary between these blocks may not be as significant as was thought previously.

(b) Crystalline basement of the Haag Nunatak block may also lie beneath parts of the Sentinel Range of the Ellsworth Mountains and the Ronne Ice Shelf.

(c) Areas with few magnetic anomalies indicate that the Ellsworth Whitemore Mountains block may extend farther north than indicated by the sparse bedrock topography data.

(d) The Ronne Ice Shelf may be underlain by up to 15 km of sedimentary and metasedimentary rock which thins to around 2 km on Berkner Island.

The new map and accompanying models give a new overall picture of crustal structure. This has important implications for the tectonic history of this part of West Antarctica.

Acknowledgements

This paper is based on work by the authors and by Myron Maslanyj, Steve Garrett and Geoff Renner. We would like to thank all those involved in the survey operations and fieldwork and also numerous colleagues who have discussed and reviewed the work. Logistical support for the aeromagnetic surveys was provided by BAS and by the United States Antarctic Research Programme (under grant DPP 82-13798 to I.W.D. Dalziel). The British Geological Survey gave access to computing facilities and Scott Polar Research Institute provided published data from earlier surveys.

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