GROUND MAGNETICS IN NORTH VICTORIA LAND (EAST ANTARCTICA)

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Abstract: Ground magnetic surveys across North Victoria Land (NVL), East Antarctica, were carried out during the Antarctic summers 1986–1990. These surveys cover an area of about 15,000 km² located between latitudes 73°55’S and 75°15’S and longitudes 161°30’E and 165°30’E. The corrected values of the field data were interpolated to produce the residual map. Shaded relief plots have been effective in defining structural trends and characteristic anomaly patterns. Magnetic susceptibility measurements accompanied the entire ground survey. Frequency distribution histograms with mean values, standard deviations and relative dispersions of susceptibility values for the main rock types are presented. The data were used to obtain a “Magnetic Susceptibility Domains Map”. The results indicate that intense positive anomalies occur along two corridors, one between Priestley and Reeves glaciers and the other between Aviator and Campbell glaciers; all the more intense of them are of surficial nature; all rock types characterized by high susceptibility produce geomagnetic anomalies, even if their outcrop is not extensive. These rocks belong to the Mt. Melbourne volcanics, Jurassic dolerites and Granite Harbour plutons. None of the formations of the metamorphic complex are responsible for intense magnetic signals. In order to find the average depth of the crustal magnetic sources, the spectral analysis of the anomaly data was performed. The two-dimensional power spectrum in this area shows magnetic anomaly sources at two different depths. Finally a structural model along a transect from the Polar Plateau to Mariner Glacier, approximately 210 km long, has been worked out.

Key words: ground magnetics, magnetic maps, susceptibility, magnetic modeling

Introduction

The ground magnetic surveys were performed in the central part of the North Victoria Land, surrounded by the Antarctic Plateau at west (W), the Transantarctic Mountains at north-northwest (NNW), and the Ross Sea at east (E). This area lies between latitudes 73°55’S and 75°15’S and longitudes 161°30’E and 165°30’E.

Coupled with geological work, the ground magnetic surveys represent the first approach to the geophysical exploration on land during the Italian expedition 1986–87. In the following years until 1990, they have been continued with the following goals: 1) to produce a total field magnetic map which would form the basis for further magnetic studies (e.g. aeromagnetics, now in progress), 2) to determine the magnetic properties of the rocks in the area to reduce the ambiguity in the magnetic anomalies interpretation, and 3) to investigate the geological significance of the residual magnetic field, especially of areas where the rocks are largely hidden by ice-cover.

Geological Setting

The generalized geological setting of North Victoria Land, as proposed by Tessensohn et al. (1981) and Lucchitta et al. (1989), shows three major subdivisions: 1) basement composed of crystalline rocks (Wilson Group and Granite

Fig. 1. Geological sketch map of Central Victoria Land. 1 - basement (Wilson Group, Granite Harbour Intrusives, Bowers Group, Robertson Bay Group, Admiralty Intrusives); 2 - cover (Beacon SuperGroup); 3 - Cenozoic volcanics (Mt. Melbourne and Mt. Overlord volcanics); 4 - group boundaries; (modified from Carmignani et al., 1987).

Fig. 1.

Harbour Intrusives), sedimentary and volcanic rocks (Bowers and Robertson Bay groups), and granites (Admiralty Intrusives), 2) cover (Beacon Supergroup) intruded by dolerite (Ferrar Dolerite) and overlain by basalts (Kirkpatrick Basalt), and 3) Cenozoic volcanic rocks (McMurdo Volcanics) (Fig. 1).

The Wilson Group is a pre-Ordovician metamorphic complex formed by metasedimentary sequences and metaigneous bodies. The Bowers Group is formed by low-grade metasediments and metavolcanics of Cambro-Ordovician age. The Robertson Bay Group consists only of low-grade metasediments.

The Granite Harbour and the Admiralty intrusives represent two generations of intrusive bodies of Cambro-Ordovician and Devonian-Carboniferous age respectively.

The Cenozoic volcanics are related to the rifting phase of the Ross Sea. Mt. Melbourne and Mt. Overlord are the main volcanic structures of the region concerned.

**Magnetic Maps**

The magnetic measurements (403 station points) were performed with Geometrics G856 and Scintrex MP3 proton precession magnetometers. The magnetic field data were corrected for the daily variation, the secular variation, and the elevation. The correction for the daily variation of the magnetic field was performed with reference to the “Terra Nova Bay” Italian Geomagnetic Observatory data. The geomagnetic secular variation of −57 nT/y was determined for the same Observatory. This value, centered at the epoch 1987.0, slightly differs from the IGRF theoretical model. The elevation correction of −33 nT/km, corresponding to the vertical IGRF gradient, was used to reduce all data to the sea level, by considering geomagnetic dipole field terms only (Bozzo and Meloni, 1992).

The IGRF 1987 (Barraclough, 1987) was further removed to obtain the residual magnetic field data. By gridding, contouring and plotting by micro-computer programs (Geosoft Inc., 1989), the residual magnetic maps were elaborated (Bozzo et al., 1989) in Figs. 2a–c. The “lines” in Figs. 2a–c indicate the central axis of glacier valleys.

The residual magnetic field map, shown in Fig. 2a, emphasizes the intensity and the wavelengths of local anomalies (Bozzo et al., 1988). The individual anomalies could be broadly classified into groups, which reveal the different magnetic character exhibited by the rocks of the Paleozoic basement and those of the more magnetically active Jurassic basalts, dolerites, and Cenozoic volcanics. Similar trend of magnetic anomalies in the northern part of this map is also detected by aeromagnetics (Bosum et al., 1991).

The shaded-relief presentations, treating the potential field as a topographic surface, are more effective in the evaluation of magnetic and gravimetric anomaly maps, because the vertical anomaly gradients are controlled by the depth of the causative structures. The 3D images enhance features which trend roughly perpendicular to the direction of illumination and highlight geological trends related to magnetization contrasts of the upper crust and to the depth of magnetic basement. This effect can be used to locate structurally significant lineaments, which are often not

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Fig. 2. Magnetic anomaly maps. a) Total field residual map, contour interval 100 nT, b) Shaded-relief residual map, c) Shaded-relief low-pass (20 km) filtered residual map.
apparent on standard contour maps. Filtered maps have been used to locate the deeper extent of the structural surface lineations (e.g. Lee and Green, 1990).

Shaded-relief images of the study area were produced to represent the residual magnetic data (Fig. 2b) and the low-pass filtered anomaly map with a cut-off wavelength of 20 km (Fig. 2c). In Fig. 2c, the magnetic anomalies having sources shallower than 5 km have been removed (e.g. Behrendt and Grimm, 1985) and those having deeper extent of the surface lineations are enhanced. The filtered shaded-relief map was compared with the contour and shaded-relief map by the aeromagnetic survey over the western Ross Sea continental shelf and part of North Victoria Land which has been presented by Behrendt et al. (1991) and discussed in Bozzo and Meloni (1992).

**Magnetic Susceptibility of the Rocks**

Measurements of magnetic susceptibility $k$ were carried out with a KT5 field susceptibility meter. The 2355 rock samples were firstly grouped into the following seven lithological types on the basis of the geological map by Carmignani et al. (1987): 1) McMurdo Volcanics, 2) Ferrar Dolerite, 3) granitoids belonging to the Granite Harbour Intrusives, including granites, granodiorites and tonalites, 4) mafic rocks, belonging to the Granite Harbour Intrusives, including diorites, quartzdiorites and gabbros, 5) Priestley formation, consisting of low grade metamorphic metasediments, 6) Priestley schists, migmatites and granulites, considered together, 7) Bowers Group, only in the northern area, formed by metasediments and metavolcanites.

In order to recognize the main magnetic markers responsible for the geomagnetic field spatial variation, the average value of the susceptibility $k$, and the dispersion coefficient $s$ (i.e. the ratio between the standard deviation and the corresponding mean value), were determined for all lithological types (Fig. 3a). The granites, the Priestley formation and the highest grade metamorphites show lower average $k$ values than those of the McMurdo Volcanics, as well as the mafic rocks belonging to the Granite Harbour Intrusives and of the Ferrar Dolerites. The dispersion coefficient is rather low for all the lithologies, when compared with similar measurements (Puranen et al., 1968).

Histograms of $k$ values distribution were performed (Fig. 3a), by considering both the measured samples all together and the different lithologies separately. For three lithological types it was impossible to draw an histogram, because of the limited number of data.

The granitoids belonging to the Granite Harbour Intrusives show a bimodal distribution of the $k$ values, with a strong prevalence of the fraction with the minimum susceptibility. The bimodality of the histograms is likely due to the presence in the area, of two populations of granitoids with different susceptibility. The measurements show anomalously high $k$ values for this type of rock. High susceptibility granitoids were sampled in the whole investigated area; but there is a predominance of high $k$ values in the plutons of the area south of Mt. Nansen, as well as south of the Reeves Glacier.

Similar difference in magnetic susceptibility of granitoids was found by Ishihara (1979). This author described two types of granites; titanomagnetite type which has low susceptibility and the magnetite type with high susceptibility.

Other lithological types do not show such bimodality, although in the Priestley formation and in the high grade metamorphites a fraction with enhanced magnetic susceptibility appears.

To obtain a comprehensive spatial distribution of $k$ in the sampled area, the susceptibility domain map has been drawn (Fig. 3b). In this map, the lithologies with similar distribution of the mean susceptibility values are grouped into a single domain. The borders among different domains were drawn along the geological boundaries, as indicated by Carmignani et al. (1987). In some cases, different lithological outcrops were included in a single susceptibility domain according to the tectonic sketch map by Carmignani et al. (1987). Finally, four domains were identified in the area: 1) low susceptibility domain, which includes the Wilson Group formations with average susceptibility not greater than 500·10^-6 S.I.; 2) medium-high susceptibility domain, including the more femic intrusive formations belonging to Granite Harbour Intrusives, whose mean susceptibility is 1638·10^-6 S.I.; 3) high susceptibility domain, which includes the Kirkpatrick Basalts, the Ferrar Dolerites and the McMurdo Volcanics, with a mean susceptibility greater than 8000·10^-6 S.I.; 4) domain of granitoids, corresponding to the acid member of the Granite Harbour Intrusives. The domain of granitoids was not characterized on the basis of the mean susceptibility values, but on the basis of its distribution, because as already pointed out, this lithology shows bimodal distribution of the magnetic susceptibility and the mean value of $k$ is not meaningful.

**Structural Modeling of the Residual Magnetic Field**

The spectral analysis of marine aeromagnetic anomalies to evaluate the magnetic relief of the Ross Sea area surveyed during the GANOXEX IV expedition, was carried out by Bosum et al. (1989). Similarly the Fourier analysis of the whole anomaly data set of the ground surveys was performed, in order to find the mean depth of the magnetic anomaly sources, with the method of Spector and Grant (1970).

The two-dimensional power spectrum in this area (Fig. 4a) shows two depth levels for the main geological magnetic markers. The first level is responsible for the high frequency components of the anomalies, and it lies at a depth of 1.05 km. The sources of this shallow magnetic marker are probably related to the Cenozoic and Jurassic volcanic outcrops, which produce the most intense anomalies. Such depth range includes the outcropping formations, since our sampling interval do not allow to find anomaly sources at a depth less than 1 km (see e.g. Behrendt and Grimm, 1985). The second level of magnetic sources responsible for the low frequency components, was found at a depth of 10.6 km. This latter could be diagnostic of variations in magnetic properties of the basement, possibly affected by a higher degree of metamorphism (Bosum et al., 1989).

On the basis of the magnetic maps and the spectral
Fig. 3. a) Distribution histograms of rock-susceptibility data. A logarithmic scale was selected for the abscissas, whereas for the ordinates the frequency percentage is taken. At the top of each chart, the number $n$ of samples, the average susceptibility $k$ and the dispersion coefficient $s$ of the main lithological type, are reported. b) Map of rock-susceptibility domains. The profile BZ is analyzed for structural modeling (see Fig. 4b).
Fig. 4. a) Two-dimensional power spectrum of the magnetic anomaly data in the surveyed area. b) Structural model along the magnetic anomaly profile BZ, from Eisenhower Range to Mariner Glacier (see Fig. 3b).

analysis of anomaly data, as well as of the rock susceptibility values, a model of crustal structure along the profile was obtained. The automatic forward and inverse 2.5-D modeling techniques adopted here, were proposed by Shuey and Pasquale (1973) and Rasmussen and Petersen (1979). The 2.5-D approach provides convenience and calculation speed comparable to the 2-D modeling without loss of generality to the 3-D technique (Cady, 1980). The magnetic profile BZ (Figs. 2a and 3b), extending from Eisenhower Range to the Mariner Glacier (Fig. 1), has a total length of 210 km. The profile shows a strong positive anomaly, greater than 2400 nT, near the Tinker Glacier. This anomaly can be ascribed, according to Tessensohn (1987), to a mafic to ultramafic intrusion, though it did not reach the surface. The magnetic susceptibility of the intrusive body, determined from the model, is $6500 \times 10^{-6}$ S.I.; the value is close to the mean measured susceptibility of the McMurdo Volcanics.

The two smaller anomalies, at the NE side of the profile, were interpreted as due to two dykes of different dip, with a modeled susceptibility of $1800 \times 10^{-6}$ S.I. and $1300 \times 10^{-6}$ S.I. for the northern and the southern body respectively. The rocks outcropping in this area suggest that the Meander-Intrusives and tiger-gabbros could be responsible for the anomalies, as suggested by Bosum et al. (1989).
The profile shows a regional decrease from W to E, which may be ascribed to a progressive lowering of the magnetic basement, having a susceptibility of 1000·10⁻⁶ S.I.

Discussion

A geodynamical pattern of this area was already hypothesized by Behrendt (1968) on the basis of aeromagnetic lines surveyed over the Transantarctic Mountains. The investigation pointed out that this belt, unlike other ones in the world, is not characterized by any magnetic signature. The aeromagnetic data of the German-U.S. campaign GANOEXIV 1984/85 (Bosum et al., 1991; Behrendt et al., 1991) showed that the Transantarctic chain could be the effect of a recent fault block tectonics, in which it constitutes the upheaval of the Ross Sea depression (Tessensohn, 1987). Moreover, the Rennick Graben may be extending to the Ross Sea, crossing our survey area, where the aeromagnetic anomalies show an elongated pattern with NW-SE strike, in the direction of the Priestley to Campbell glaciers, which is consistent with our study.

The ground magnetic surveys carried out from 1986 to 1990 by us in the central part of North Victoria Land have been investigated from structural standpoint (see also Bozzo et al., 1987, 1988), on the basis of the following considerations:

i) The residual magnetic pattern (Fig. 2a) shows that intense positive anomalies occur between the Priestley and Reeves glaciers, as well as between Campbell and Aviator glaciers. These areas roughly correspond to outcrops of Jurassic dolerites and Cenozoic volcanics respectively. All the most intense anomalies are due to shallow sources.

ii) The shaded-relief representations of original and filtered anomaly maps, indicate NW-SE trending lineations in the magnetic anomaly pattern. These lineations, present at a deeper level (see Fig. 2c) can be ascribed to the major structural evidence in the area, that is, the tectonic control of the glacial valleys. Furthermore, the location of these lineaments should be related to the southwards prosecution of the graben-like structure of Rennick Glacier down to the Ross Sea depression, according to Bosum et al. (1989).

iii) The magnetic susceptibility values of the main outcrops supplied two main suggestions: (a) all rock types with high susceptibility produce geomagnetic anomalies, even if their outcrop is not extensive, and (b) none of the formations of the metamorphic complex are responsible for intense magnetic signals.

Our susceptibility data are not enough to describe the total magnetization of rocks, especially for the Mt. Melbourne volcanics, for which the remanent magnetization largely prevails over the induced magnetization (Manzoni and Miletto, 1988). Conversely, for the other lithological types prevalent in this area, our susceptibility data can locate the main source of the observed magnetic anomalies. Consequently, they were statistically described (Fig. 3a) and utilized to draw a magnetic domain map (Fig. 3b) which can be a support for further magnetic studies.

iv) The two-dimensional spectral analysis of the residual field data (Fig. 4a) confirms the presence of shallow magnetic sources responsible for high frequency components of the spectrum. They have been identified in the Mt. Melbourne volcanics, Ferrar Dolerite and Granite Harbour plutons, which mostly overlie a deeper magnetic basement related to the long wavelength anomalies. These suggestions together with the previous considerations, have been utilized to elaborate, along a profile, an interpretative cross-section of the area (Fig. 4b).

v) The most notable magnetic feature of the profile which starts from Eisenhower Range and reaches to the Mariner Glacier, is the strong positive anomaly in the Tinker Glacier area. Its tectonic significance may be due to an ultrafemric intrusion related to Cenozoic volcanics. The best fit of this anomaly (Fig. 4b) has supplied a dyke-like model with a deeper extent in disagreement with an unrooted outcrop proposed by the surface geology (Carmignani et al., 1987). This assumption is supported by susceptibility measurements performed on volcanics rock samples which were used as constraint in quantitative modeling and in agreement with aeromagnetic interpretation (Bosum et al., 1989).

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