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Magnetic investigations of the junction between Wilson and Bowers terranes (northern Victoria Land, Antarctica)

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Abstract: A magnetic survey was carried out in the area between Lady Newnes Bay and Evans Névé (northern Victoria Land), to ascertain whether the contact between the Wilson and the Bowers terranes could be identified remotely. The survey consisted of three ground and 12 helicopter-borne profiles. The method was calibrated on the southernmost profiles, which cover a well-exposed section of the contact between the Wilson and Bowers terranes. The northern profiles were located in an area where the contact is poorly constrained by outcrops, so that it could be tested whether the junction displays a magnetic signature. The magnetic data and the 2.5-D modeling of three selected profiles indicate that no easily recognizable magnetic signature defines this contact. The main features of the area are magnetic anomalies probably controlled by the "Meander Intrusives" and the McMurdo volcanic rocks, both characterized by high susceptibility values. If an anomaly related to the contact exists, then it is probably masked by these stronger anomalies.

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Introduction

During the southern summer of 1989/90 (ItaliAntartide V expedition), we carried out a magnetic survey along the contact between the Wilson and the Bowers terranes (northern Victoria Land, Antarctica).Magnetic data were collected along three profiles on the ground and along 12 other profiles, using a helicopter-borne magnetometer (Fig. 1).

The aim of the project was to check whether the major suture zone of northern Victoria Land had a magnetic signature. In the Evans Névé, located in the north-western part of the area under investigation, rock outcrops are very rare and this important geological contact is covered by ice. If it could be proven that it has a clear magnetic signature, a magnetic survey could then be used to identify its position under the ice cover.

Geological framework

The area under investigation (Fig. 1) is bounded by Mariner Glacier to north-east and by Icebreaker Glacier to the south-west; by the Evans Névé to the north-west and by the coast of Lady Newnes Bay (Ross Sea) to the south-east. In this area, the south-west sector of the junction between the high grade crystalline rocks of the Wilson Terrane and the low grade volcanic and sedimentary rocks of the Bowers and the Robertson Bay terranes is the most prominent geological feature. In the southernmost segment of this junction, another tectonic unit, the Dessent Ridge Unit, occurs between the Wilson and the Bowers terranes.

Wilson Terrane (WT)

From the coastline to the Gair Glacier area, the WT consists of high grade gneisses intruded by the Granite Harbour Intrusives (Gair 1964, Tessensohn *et al.* 1981). North of Gair Glacier and Mount Supernal the metamorphic grade decreases, and the WT is represented by medium grade gneisses with minor metavolcanic rocks; thus a clear metamorphic gradient from SE–NW can be recognized. From a structural point of view, the WT is characterized by a regional foliation, with a moderate dip toward south-west. Further details on both the metamorphic evolution and the structural features can be found in Kleinschmidt *et al.* (1984) and in Castelli *et al.* (in press).

The easternmost part of the WT is characterized by a continuous zone of intrusive rocks ("tonalite belt", GANOVEX and ItaliAntartide 1991), which can be followed from the Ross Sea to the Mount Supernal area. These intrusive rocks consist mainly of tonalites with subordinate gabbros, diorites and more acid rocks. Commonly they show a well-developed foliation, nearly parallel to the regional one.

In the area north of Mount Supernal (Niagara Icefalls area) some small mafic and ultramafic bodies were discovered during mapping (1988/89 and 1989/90 ItaliAntartide expeditions). Although the actual contacts of these bodies could not be observed, mapping suggests that the host to the ultramafic rocks are the medium grade schists of the WT. From a magnetic point of view, the ultramafic rocks are interesting, as they show considerably higher values of susceptibility (K) compared to the surrounding rocks; K is about 20000 10^{-6} SI on average.

Dessent Ridge Unit (DRU)

The DRU consists of amphibolites and metasedimentary rocks. It shows both primary and metamorphic features (Kleinschmidt *et al.* 1984, Capponi *et al.* 1988) and is considered to be an independent tectonic unit (Capponi *et al.* in press b).

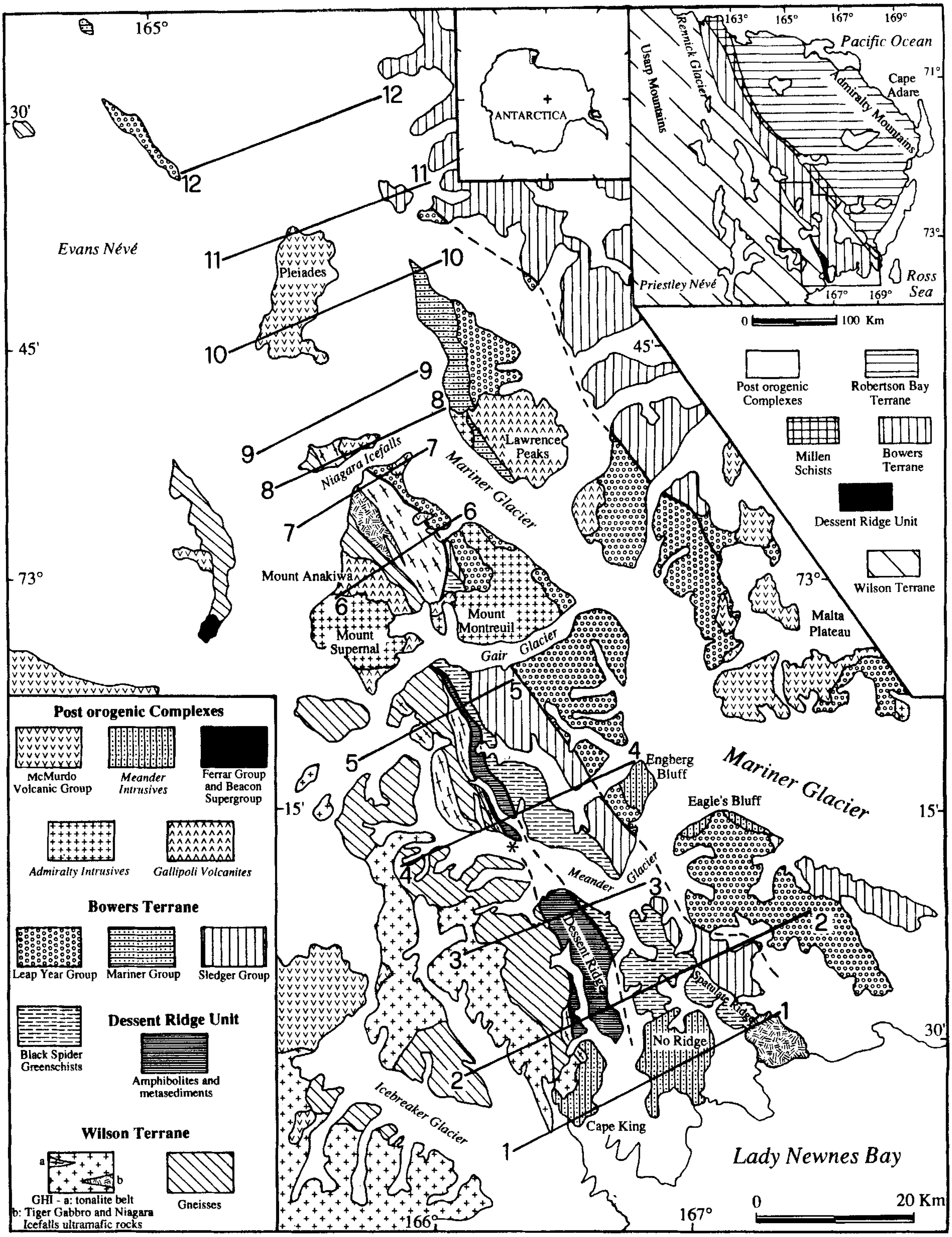

Fig. 1. Geological Map (from GANOVEX & ItaliAntartide, 1991, with modifications). GHI stands for Granite Harbour Intrusives. Heavy lines are the main tectonic contacts. The star indicates the outcrop at 73°16'S, 166°17'E (MMGO). Numbers indicate "helimagnetic" profiles. Ground profiles 1, 2 and 3 correspond to "helimagnetic" profiles 1, 2 and 3.

Both the contact with the WT and the regional foliation strike NW–SE and dip moderately south-west. Stretching lineations are widespread and plunge south-west, at 10–30°.

Within the DRU, the rocks from the outcrop at 73°16'S, 166°17'E (hereafter MMGO, standing for Medium Meander Glacier outcrop) show slightly different features. Petrographical and geochemical data by Scambelluri *et al.* (in press) suggest that the rocks from MMGO (basically amphibolites) differ in some way from the other amphibolites of the DRU because of differences in the PT conditions and original bulk chemistry.

Bowers Terrane (BT)

The BT comprises the Sledger, Mariner and Leap Year groups. The Sledger Group of volcanic (Glasgow Formation, Laird & Bradshaw 1983) and sedimentary rocks (Molar Formation, Laird *et al.* 1982), with very low to low-grade metamorphism, is overlain first by the Mariner Group, forming a regressive cycle, and then by the Leap Year Group of continental quartzitic sediments (Laird *et al.* 1982).

Some outcrops of a layered gabbro (Tiger Gabbro, GANOVEX Team 1987) characterize the area of Spatulate Ridge. The radiometric age of this gabbroic body suggests that it belongs to the Granite Harbour Intrusives, but, its spatial association to the BT is probably tectonic in origin.

From a structural point of view, the BT rocks are affected by a single folding event, expressed by broad to open anticlines and synclines, with SE–NW axes which are horizontal or plunge gently SE. Axial planes commonly dip SW and a cleavage parallel to the axial plane is widespread.

The contact with the DRU is characterized by rocks (Black Spider Greenschists) with a more complicated structural evolution and a higher metamorphic grade (Gibson *et al.* 1984). Although the plane of contact with the DRU dips SW, Gibson *et al.* (1984) noted that it does not coincide with the regional foliation.

Robertson Bay Terrane (RBT)

The RBT is composed of metasedimentary rocks, strongly resembling the Molar Formation of the BT; the metamorphic grade ranges from very low to low. The contact with the BT is marked by the Millen Schist, a belt of more deformed rocks. Away from the Millen Schist area, the structural features are similar to those of the Molar Formation of the BT (Capponi *et al.* in press a).

Other units

Other geological units are present in the area. However, because their emplacement post-dates the juxtaposition of the terranes, they cannot be considered as strictly belonging to the WT, the BT, or the RBT.

The *"Gallipoli Volcanites"* are andesitic and basaltic in composition and crop out at Mount Anakiwa and Lawrence Peaks.

The *"Admiralty Intrusives"* include granitic bodies, represented by the massif of Mount Supernal and Mount Montreuil of Devonian age (364–354 Ma, Nathan 1971; Stump unpublished data quoted in Borg *et al.* 1986). As the granite at Mount Supernal cuts the contact between the WT and the BT, its emplacement post-dates the junction of the two terranes.

The *"Meander Intrusives"* are alkali granites and alkali syenites of Miocene age, (GANOVEX Team 1987), and intruded both the WT and the BT. The most important outcrops in this area occur at Cape King, No Ridge and Eagle's Bluff.

Rocks belonging to the McMurdo Volcanic Group (Miocene to Quaternary mafic volcanic rocks) characterize the area of the Pleiades, in the north-western part of the zone under investigation (Nathan & Schulte 1968). *The McMurdo Volcanic Group* also comprises the Miocene volcanic sequence of Malta Plateau (GANOVEX Team, 1987).

Previous magnetic data

One of the main contributions to the geophysical reconnaissance of Victoria Land was the aeromagnetic survey carried out by the German expedition GANOVEX IV (Bosum *et al.* 1989). The main target of that survey was the Ross Sea embayment and its relationship with the Transantarctic Mountains. This survey was, therefore, designed to cover the different tectonic structures, identified through geological studies, at the edge of the Antarctic craton. The survey partly covered the BT.

Another contribution is represented by the ground magnetic survey, carried out as part of the Italian Earth Sciences Programme (PNRA) in Antarctica. This survey was carried out during four Italian expeditions (1985–89) across northern Victoria Land. The investigated area is surrounded by Aviator Glacier, Drygalski Ice Tongue, the Ross Sea and the Polar Plateau. A magnetic map at the scale of 1:250 000 summarized the results (Bozzo *et al.* 1989, Bozzo & Meloni 1991) and was discussed by Bozzo *et al.*(1992).

Susceptibility measurements were made in conjunction with the geomagnetic survey, to correlate the rock types with their magnetic signatures. They were collected from outcrops near the survey points, or on samples collected during mapping. 2355 measurements of K were carried out during the first three expeditions. Other susceptibility data were available from GANOVEX IV (Bosum *et al.* 1989).

New magnetic data

The ground magnetic survey discussed here represents the northward extension from previous surveys up to Mariner Glacier. It was carried out during the 1989/90 ItaliAntartide Expedition, with measurements taken along profiles parallel to the coastline. K measurements on rock samples were also extended northward. The magnetic profiles measured on the ground as well as from the air, were planned in a direction perpendicular to the strike of the geological contacts. As all the major contacts dip south-west, the profiles were aligned in this direction to provide the best chance of detecting the deeper extension of the geological units.

To optimize the number of profiles within the available time, we concentrated our measurements on the Wilson-Dessent-Bowers contacts, neglecting the BT-RBT contact. Nevertheless, as the rocks of BT and RBT are similar, no particular differences in magnetic signature were expected. The susceptibility data are summarized in the distribution histograms (Fig. 2), and raise the following points:

a) Very high K values characterize the McMurdo and the Gallipoli volcanic rocks, as well as the Meander intrusive rocks; they are moderately clustered. Results from the Niagara Icefalls ultrabasites are more scattered, but most samples have very high susceptibility.

b) K values are closely similar for the WT and the BT and are moderately clustered.

c) The mean K values for the DRU and the tonalite belt are very high, but this is due to only few high K samples, which are volumetrically negligible. Most samples of the DRU have only slightly higher K than the WT and BT.

Ground profiles

Three profiles from Icebreaker to Mariner Glacier are discussed in this section (Fig. 1). They are based on a total of 275 stations, with an average sample spacing of 2 km. Transport between observation sites was by helicopter. Proton precession magnetometers (PPM), with a resolution 0.1 nT, were used for the survey. Field measurements were corrected for the daily variation of the magnetic field, as recorded at the "Terra Nova Bay" Italian Geomagnetic Observatory. The survey area was 120–160 km away from Terra Nova Bay.

Helicopter-borne profiles

A PPM magnetometer was also used for the airborne profiles. The sensor was installed in a "bird" at the end of a 30 m-long cable. The sampling rate along these profiles was every 2–3 sec, corresponding to a ground resolution of 40–80 m, depending on the speed of the helicopter. The flight altitude ranged between 2750 and 3000 m.

As no telemetric system was available, positioning was performed by visual control on a topographic map (the U.S. Geological Survey 1:250 000 maps were used). The chance of controlling the quality of such positioning was provided by the northernmost profiles in the area of the Pleiades, where the presence of volcanites provided very sharp magnetic anomalies, with characteristic shapes. It was possible to compare the anomalies recorded by the helicopter-borne magnetometer with the same anomalies along profiles 1 to 7 on the aeromagnetic map. In this way we were able to assess the error by visual positioning: it is estimated to be less than 250 m, thus sufficient for the purpose of the survey.

Magnetic anomaly profiles

The profiles of the residual magnetic field are shown in Fig. 3. In profiles 1 to 3, the "helimagnetic" anomaly is plotted together with the ground magnetic anomaly and the aeromagnetic profile, extracted from sheet 2 of the GANOVEX IV aeromagnetic map (BGR-USGS 1987). Note that the aeromagnetic profiles of GANOVEX IV were flown at 3660 m a.s.l., whereas the altitude of helicopter-borne profiles was lower (2750 to 3000 m).

For profiles 4 to 7 there are no corresponding ground magnetic anomalies and the "helimagnetic" anomaly is plotted against the aeromagnetic anomaly; profiles 8 to 12 are outside the aeromagnetic survey coverage and the "helimagnetic" profiles are the only magnetic data available in the area. From a qualitative point of view, the 12 profiles can be arranged in three groups.

Profiles 1 to 3 show anomalies of medium wavelength (tens of km) with an amplitude of 300–700 nT (up to 1500 nT in ground profile 1). These anomalies might be related to the presence of the Meander intrusive rocks. Profile 1 shows a reasonably good correlation with GANOVEX IV and ground magnetic data. Two large ground anomalies merge into one in the airborne data, probably due to near-surface sources. Unfortunately, in profile 2 ground data do not show the marked anomaly shown in the aeromagnetic and helicopter-borne profiles. This is probably because the station spacing was not sufficient to define the magnetic field in the area; there is a gap of about 6 km along the ground profile over the anomaly area. Furthermore, the aeromagnetic and "helimagnetic" anomalies do not match very well, especially for the pronounced anomaly in the south-eastern part of the profile. Such a discrepancy could be caused by the shallow bodies not detected by the GANOVEX IV survey, with its 4.4 km line spacing. In profile 3 the helicopter-borne and the GANOVEX data compare well. The apparently poor correlation with the ground data is actually due to a single measurement, probably influenced by a near surface source.

Profiles 4 and 5 do not intersect any important outcrop of Meander intrusive rocks: therefore, the magnetic field appears flat over the contacts between the WT, DRU and BT. This suggests that the DRU and the BT do not show any significant anomaly.

In profiles 6 to 12, anomalies of large amplitude (up to 1500 nT) and very short wavelength (2–3 km) are due to the presence of the volcanic rocks of the Pleiades area. Profiles 11 and 12 were flown over a complete ice cover. In this area the geological information is very limited and the magnetic profiles can help to locate volcanic bodies. Profiles 6 and 7 show significant discrepancies between the helicopter-borne and the GANOVEX IV surveys. The line spacing of 4.4 km, used by GANOVEX IV, in an area with anomalies of high amplitude and very short wavelength, is not suitable to ensure a complete definition of the geomagnetic field. Hence, the magnetic profile derived from the GANOVEX map may not be truly representative

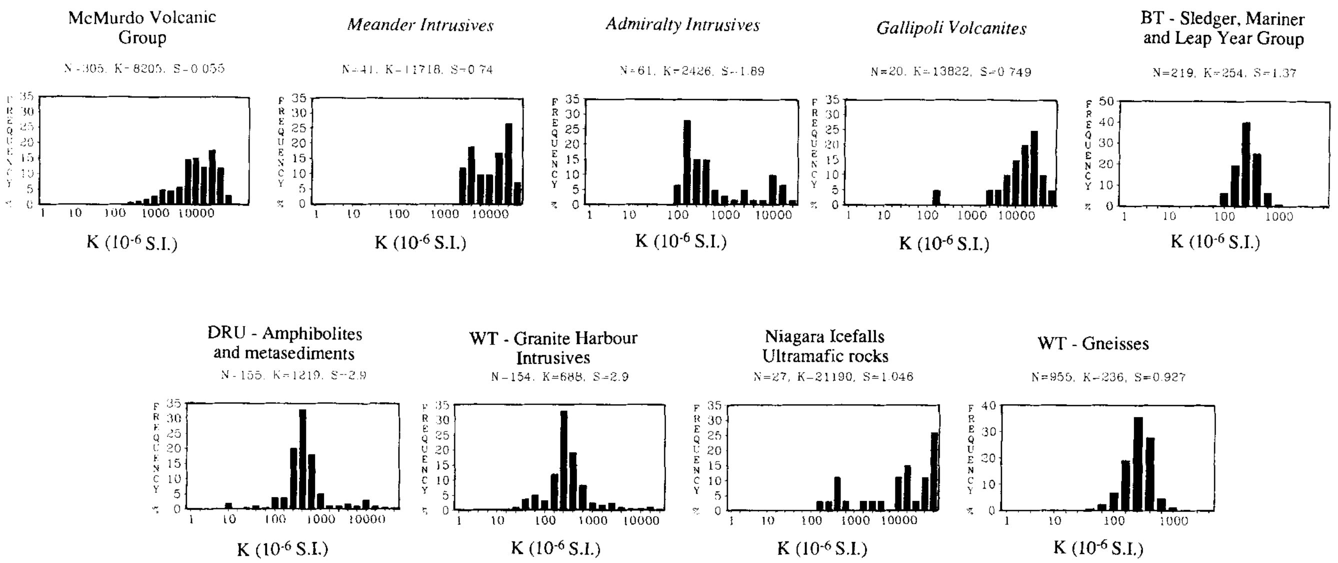

Fig. 2. Distribution histograms of magnetic susceptibility. N = total number of measured samples; K = mean susceptibility; S = dispersion coefficient (mean K/standard deviation ratio).

of the anomaly field in the area. Also the higher flight altitude adopted for the GANOVEX IV survey (3660 m) and the different orientation of the survey lines do not allow the comparison of the two airborne data sets in this area.

Magnetic modelling and geological interpretation

On the basis of the magnetic profiles, the geological information available in the area, and the rock susceptibility values, we propose models for the crustal structure along the profiles. Three profiles were selected for a quantitative interpretation using a 2.5-D technique. We adopted automatic forward and inverse 2.5-D modeling techniques, proposed by Shuey & Pasquale (1973) and Rasmussen & Petersen (1979). The 2.5-D approach has the advantages and speed of the 2-D one with much of the generality of the 3-D technique (Cady 1980). The

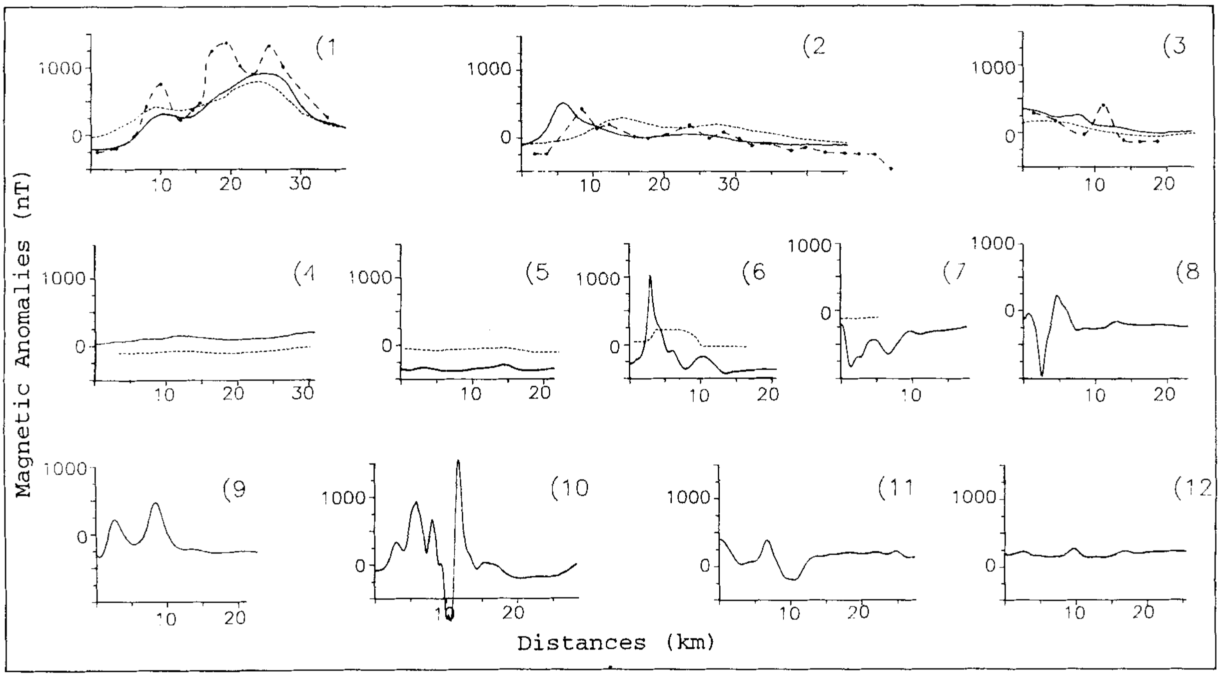

Fig. 3. Magnetic anomaly profiles. Solid line = helicopter-borne profiles; short dashes = GANOVEX IV Aeromagnetic survey data; long dashes = Ground profiles. All profiles are oriented SW (left)–NE (right).

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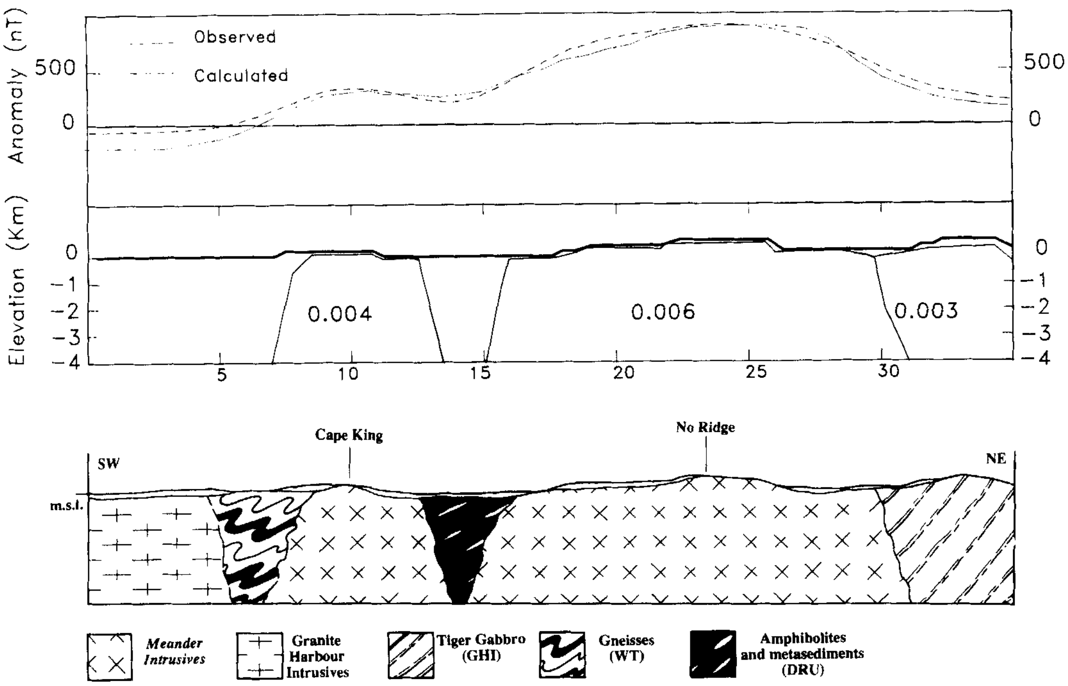

Fig. 4. Magnetic model and geological cross section for the profile 1 (the scale of the geological cross-section is the same of the magnetic model). Susceptibility values are in SI units.

susceptibility values used for the models were chosen after taking into account the measurements on rock samples shown in Fig. 2.

Profile 1

In this profile and in the southernmost ones, the main magnetic features are influenced by the bodies of Meander intrusive rocks. The magnetic anomaly is easily explained by a model taking into account the intrusive bodies cropping out in the Cape King and No Ridge areas (Fig. 4). No special magnetic signature appears to be linked with the WT–BT contact, nor to the DRU.

Profile 4

The anomaly at the north-eastern end of this profile (Fig. 5) is easily explained as a result of the Meander intrusive rocks cropping out at Engberg Bluff, close to the north-eastern end of the profile. A minor anomaly near the WT–DRU contact, corresponding to MMGO is more difficult to explain. Three hypotheses are proposed:

a) The anomaly is due to a body of the McMurdo or the Gallipoli volcanic rocks, covered by ice. Although this hypothesis is feasible, anomalies known to be caused by the McMurdo volcanic rocks (as the anomalies in the northern profiles), show a sharper spectral pattern and higher amplitudes.

b) The anomaly is due to the tonalite belt, whose K is higher compared to that of the other WT rocks (Fig. 6). If this hypothesis is correct, it would be a useful tool to locate the suture, as the tonalite intrusion is present continuously along the junction between the WT and the DRU (Capponi *et al.* in press b). Unfortunately an anomaly with such features is not regularly present in the adjacent profiles (profiles 3, 5 and 6): for this reason this hypothesis does not completely explain the anomaly.

c) The anomaly is caused by the amphibolites cropping out at MMGO. For these rocks Scambelluri *et al.* (in press) found different petrographical and geochemical features compared to the other amphibolites of the DRU. K values of the samples from MMGO are compared with the K values of the other Dessent amphibolites in Fig. 6. Although we have fewer samples from MMGO, some differences do exist: whereas the DRU amphibolites have K values around $200\ 10^{-6}$ with only few samples having a very high K, the MMGO amphibolites have regularly higher K, although the highest values are lower than those of the DRU. Unfortunately MMGO type rocks are not present everywhere along the WT–DRU junction and, even if this hypothesis is the most feasible one, this does not provide us with an effective method to locate the contact.

A very good fitting of the anomaly is obtained with a model taking into account the combined influence of a sliver of MMGO amphibolites and two slivers of tonalite (Fig. 5). We conclude that the anomaly is due to the occurrence of both the MMGO rocks and the tonalite belt in the same area.

Profile 9

In this and other profiles of the Niagara Icefalls area, the magnetic features are influenced by the anomalies produced by the mafic volcanic rocks of the Pleiades (Fig. 7). The magnetic

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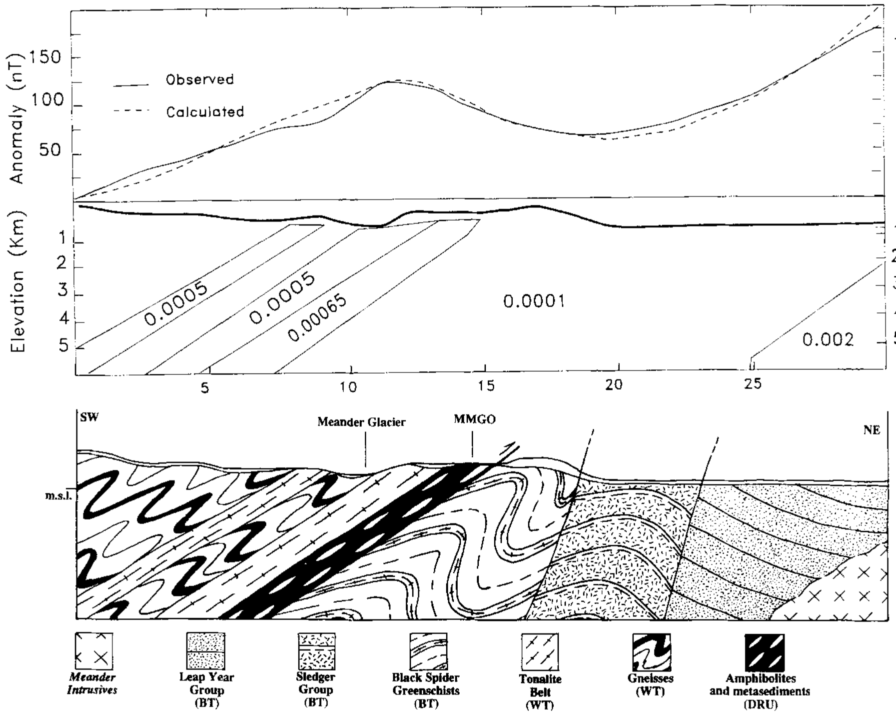

Fig. 5. Magnetic model and geological cross section for the profile 4 (the scale of the geological cross-section is the same of the magnetic model). Susceptibility values are in SI units.

anomaly is easily fitted by a model with very thin sheets of volcanic rocks. There are no indications of magnetic anomalies due to the WT–BT contact, which lacks the intercalation of the DRU.

In spite of their high susceptibility values, no anomaly linked to the ultramafic bodies of the Niagara Icefalls area is evident: this suggests that their volumetric importance is negligible.

Conclusions

In general, geological contacts at regional scales are marked by clear magnetic signatures. This can be due to several reasons, such as the juxtaposition of rocks with very different susceptibility, uplift of the crystalline basement, or the presence of slivers of mafic and ultramafic rocks trapped along ophiolitic sutures. The presence of a magnetic signature can be a tool to locate major contacts where poor outcrop conditions prevail (Camfield & Gough 1977, Gibb *et al.* 1983, Jackson 1985). De Beer *et al.*

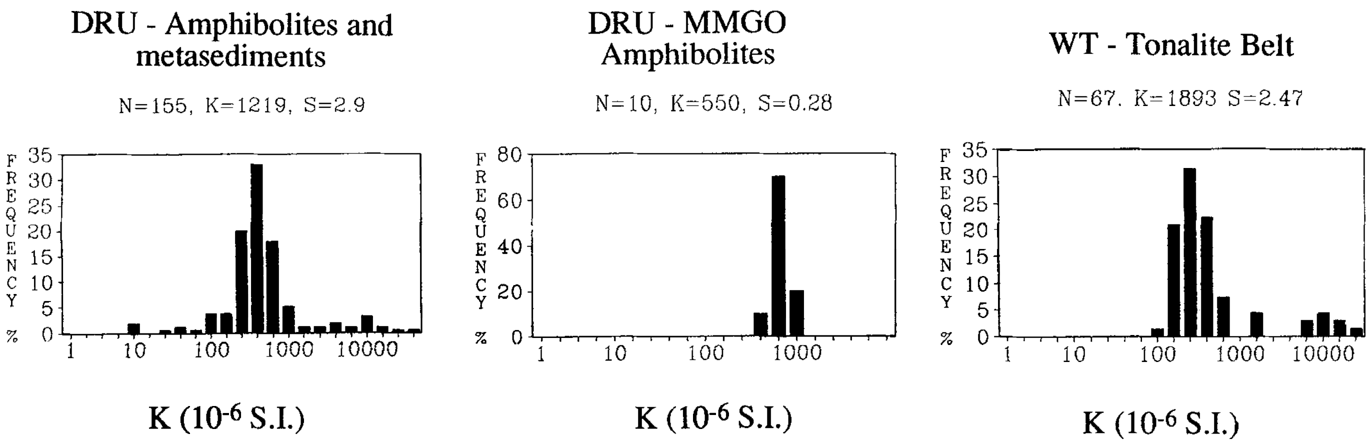

Fig. 6. Distribution histograms for the susceptibility of DRU amphibolites, MMGO amphibolites and tonalite belt.

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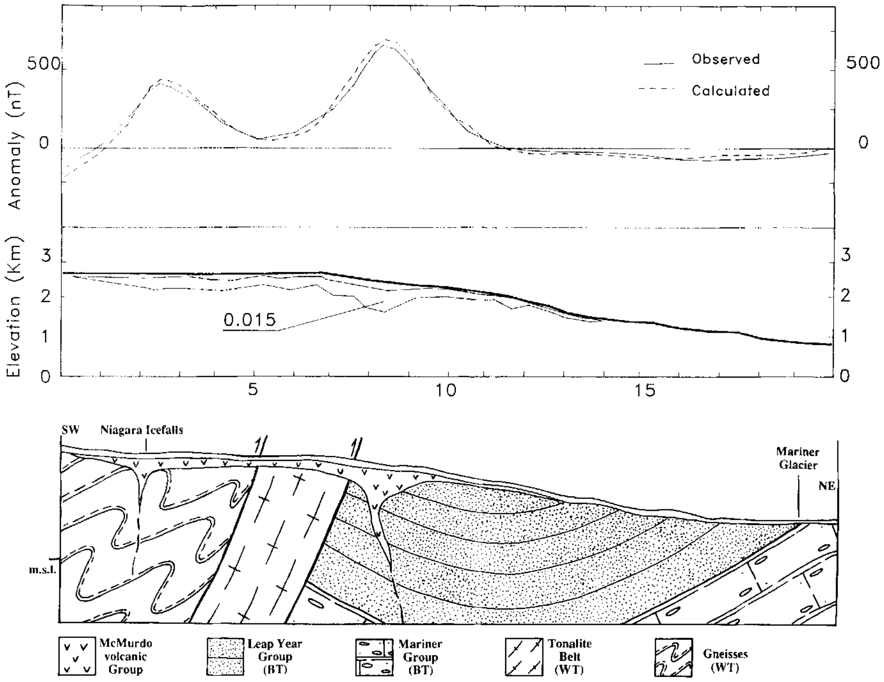

Fig. 7. Magnetic model and geological cross section for profile 9 (the scale of the geological cross-section is the same of the magnetic model). Susceptibility is in SI units.

(1982) reported the discovery and mapping of a conductive belt by magnetometer array surveys in South Africa, while Reeves (1985) showed the detection of a suture zone at the regional scale under the sands of the Kalahari Desert using gravimetric and magnetic methods.

A preliminary geological analysis suggested that the area of northern Victoria Land under investigation looked promising for this kind of study. It shows most of the necessary features: the contact between WT and BT, mostly covered by ice, puts rocks from very different structural levels in contact with each other, and the mafic rocks of the DRU are trapped along the suture zone. Although the ultramafic bodies of the Niagara Icefalls do not exactly follow the WT–BT contact, nevertheless, their very high susceptibility could represent a magnetic marker, close enough to the contact.

In spite of these characteristics, magnetic data and their modelling show that in this area, the main features of the magnetic field are controlled by the high susceptibility bodies of Meander intrusive and McMurdo volcanic rocks. They also indicate that there is no specific magnetic signature linked to the WT–BT contact, regardless whether the DRU is present or absent. If any anomaly systematically linked to the WT–BT contact exists, it is completely masked by the stronger anomalies caused by the Meander Intrusive and the McMurdo volcanic rocks.

Our investigation supports and completes the findings by Lucchitta *et al.* (1987) and Bosum *et al.* (1989), which suggested the lack of a magnetic signature for this junction on the basis of the aeromagnetic survey of the GANOVEX IV.

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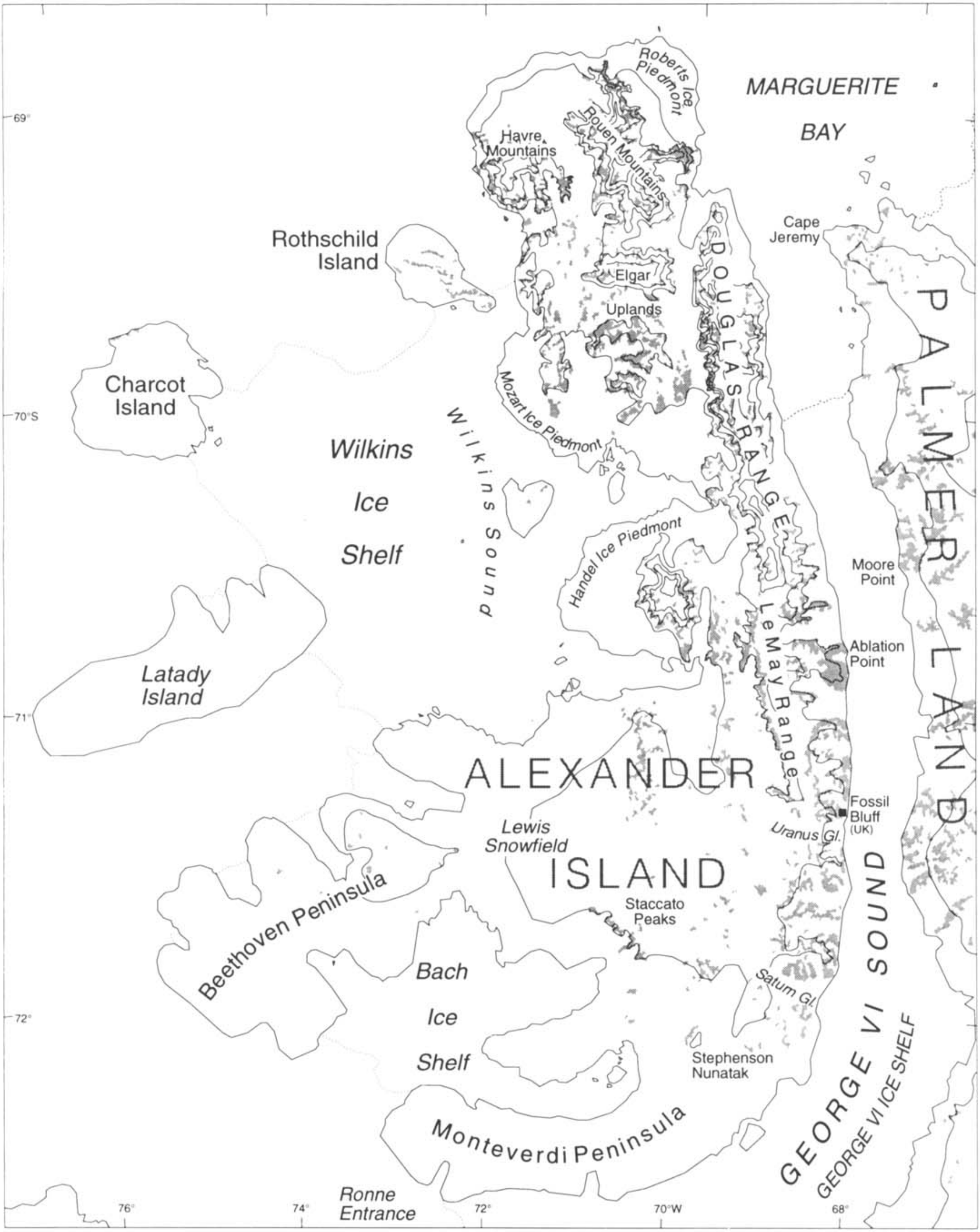
Antarctic Science **Handy Atlas Map No. 11.**
IMW Sheets SR 17–18, SR 19–20, SS 16–18, SS 19–21, Alexander Island, 1:2 000 000 scale, contour interval at 500 m. Dotted lines represent the positions of ice fronts, and the shaded areas rock outcrops.



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