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Inherited crustal features and tectonic blocks of the Transantarctic Mountains: An aeromagnetic perspective (Victoria Land, Antarctica)

F. Ferraccioli and E. Bozzo
Dipartimento per lo Studio del Territorio e delle sue Risorse, Università di Genova, Genoa, Italy

Abstract. Aeromagnetic images covering a sector of the Transantarctic Mountains in Victoria Land as well as the adjacent Ross Sea are used to study possible relationships between tectonic blocks along the Cenozoic and Mesozoic West Antarctic rift shoulder and prerift features inherited mainly from the Paleozoic terranes involved in the Ross Orogen. The segmentation between the Prince Albert Mountains block and the Deep Freeze Range–Terra Nova Bay region is related to an inherited NW to NNW ice-covered boundary, which we name the "central Victoria Land boundary." It is interpreted to be the unexposed, southern continuation of the Ross age back arc Exiles thrust system recognized at the Pacific coast. The regional magnetic high to the west of the central Victoria Land boundary is attributed to Ross age calc-alkaline back arc intrusives forming the in-board Wilson "Terrane," thus shifting the previously interpreted Precambrian "shield" at least 100 km farther to the west. The high-frequency anomalies of the Prince Albert Mountains and beneath the Polar Plateau show that this region was extensively effected by Jurassic tholeiitic magmatism; NE to NNE trending magnetic lineations within this pattern could reflect Cretaceous and/or Cenozoic faulting. The western and eastern edges of the Deep Freeze Range block, which flanks the Mesozoic Rennick Graben, are marked by two NW magnetic lineaments following the Priestley and Campbell Faults. The Campbell Fault is interpreted to be the reactivated Wilson thrust fault zone and is the site of a major isotopic discontinuity in the basement. To the east of the Campbell Fault, much higher amplitude magnetic anomalies reveal mafic-ultramafic intrusives associated with the alkaline Meander Intrusive Group (Eocene-Miocene). These intrusives are likely genetically linked to the highly uplifted Southern Cross Mountains block. The NW-SE trends crossing the previously recognized ENE trending Polar 3 Anomaly offshore of the Southern Cross Mountains are probably linked to Cenozoic reactivation of the Paleozoic Wilson-Bowers suture zone as proposed from recent seismic interpretations. The ENE trend of the anomaly may also be structural, and if so, it could reflect an inherited fault zone of the cratonal margin.

1. Introduction

The Transantarctic Mountains (TAM) are unique since they represent the highest and longest rift-related mountain belt in the world, reaching elevations over 4000 m and extending for over 3500 km across Antarctica from the Ross Sea to the Weddell Sea (Figure 1). The chain marks the long-lived tectonic boundary between cratonic East Antarctica and a complex mosaic of extensional terranes that compose West Antarctica [*Dalziel and Elliot*, 1982]. The TAM form one flank of the Mesozoic and Cenozoic asymmetric West Antarctic rift system [*Behrendt et al.*, 1992]. The Ross Sea rift is part of this system and has been compared to the Basin and Range Province and to the East African rift system [*Tessensohn and Wörner*, 1991]. According to *Wilson* [1995a], the TAM differs from flanks developed along these rifts in its exceptional relief and the more simple and continuous tilt block structure. Though the general structural architecture may appear simple and continuous, ongoing geological and geophysical work is showing that the TAM are segmented into a number of large blocks characterized by different morphology, tectonic structures, magnitude and history of uplift, and possibly crustal thickness [*van der Wateren et al.*, 1994; *Tessensohn*, 1994; *Fitzgerald*, 1992; *Redfield and Behrendt*, 1992]. In Victoria Land some of these blocks are interpreted to be separated by transfer structures [*Mazzarini et al.*, 1997] or by complex accommodation zones [*Wilson*, 1995b] reminiscent of East African accommodation zones [*Rosendahl et al.*, 1992]. Significant variations in volumes of rift-related Cenozoic alkaline volcanism are also interpreted from aeromagnetics to occur in different sectors of the rift [*Behrendt et al.*, 1996].

The present-day TAM are underlain by a dominantly contractional mountain belt referred to as the Ross Orogen that formed in earliest Paleozoic time [*Goodge*, 1995]. The TAM are also superimposed upon part of an inferred Jurassic rift system [*Schmidt and Rowley*, 1986]. The possible relationships between different tectonic blocks of the TAM, tectonomagmatic variations within and along the flank of the Ross Sea rift basins, and the crustal features inherited from the Paleozoic convergent margin and/or the Jurassic rift are, however, poorly known. Recently, *Salvini et al.* [1997] proposed from offshore seismic data and geological field work that the post-Eocene

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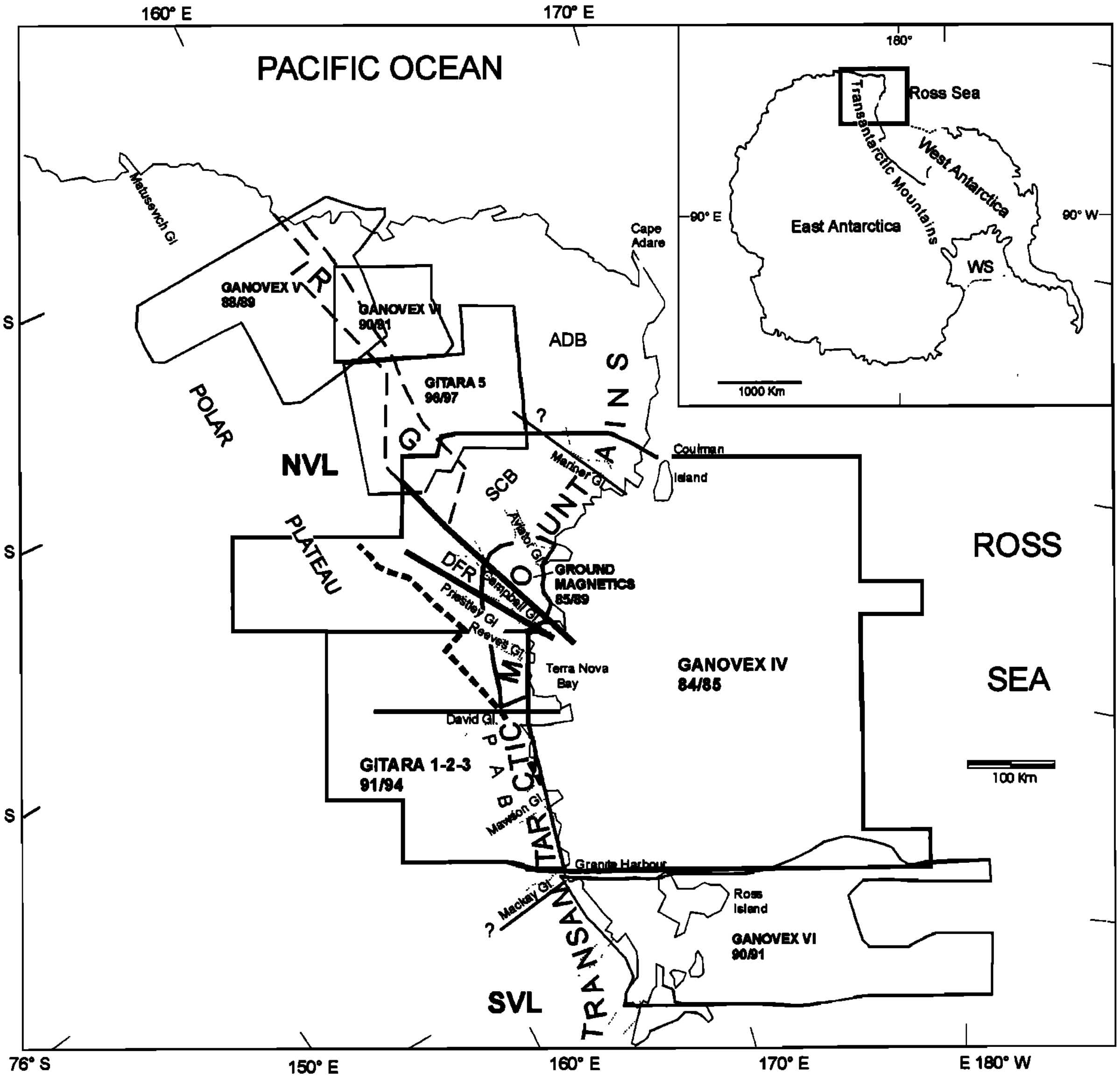

Figure 1. Regional magnetic coverage over the Transantarctic Mountains (TAM), Polar Plateau, and the adjacent western Ross Sea and location of tectonic blocks along the TAM rift shoulder discussed throughout this paper. The thicker dashed line indicates the main magnetic boundary interpreted in our study. Abbreviations are as follows: ADB, Admiralty Block; SCB, Southern Cross Mountains block; RG, Rennick Graben; DFR, Deep Freeze Range block; PAB, Prince Albert Mountains block; NVL, northern Victoria Land; SVL, southern Victoria Land; WS, Weddell Sea.

tectonic framework of the Ross Sea region is intimately linked to reactivation of Paleozoic age terrane boundaries as major right-lateral strike-slip faults. Previously, *Tessensohn* [1994] also suggested that an inherited late stage fault system of the Paleozoic Ross Orogen was used to accommodate the strain linked to Cretaceous continental shear in the Ross Sea region.

We furnish a combined interpretation of newly compiled GITARA (German Italian Aeromagnetic Research in Antarctica) aeromagnetic data over the moderately uplifted Prince Albert Mountains [*Bozzo et al.*, 1997a] and German Antarctic North Victoria Land Expedition (GANOVEX) IV aeromagnetics [*Bosum et al.*, 1989] over the more highly uplifted Deep Freeze Range and Southern Cross Mountains, as well as the adjacent subsided western Ross Sea (Figure 1). The aim of this study is to explore possible relationships between crustal features inherited from Paleozoic terranes (Figure 2) and the later tectonic blocks of the TAM bordering the Ross Sea rift. This is a key issue toward understanding tectonic processes involved in the large-magnitude uplift of the TAM as well as the reason for variations in geophysical and geological character of individual crustal blocks of the TAM.

The GANOVEX IV data were previously interpreted to reveal a major ice-covered inherited boundary between the Wilson Terrane, part of the Cambro-Ordovician Ross Orogen, and the Precambrian "shield," that is, a large area of exposed basement rocks in a craton, commonly with a very gently convex surface [*Bates and Jackson*, 1987]. The origin and later role of this boundary is reinvestigated in this study. To achieve this, we interpret the new and previous aeromagnetic data in conjunction with geologic findings in Oates Land at the Pacific

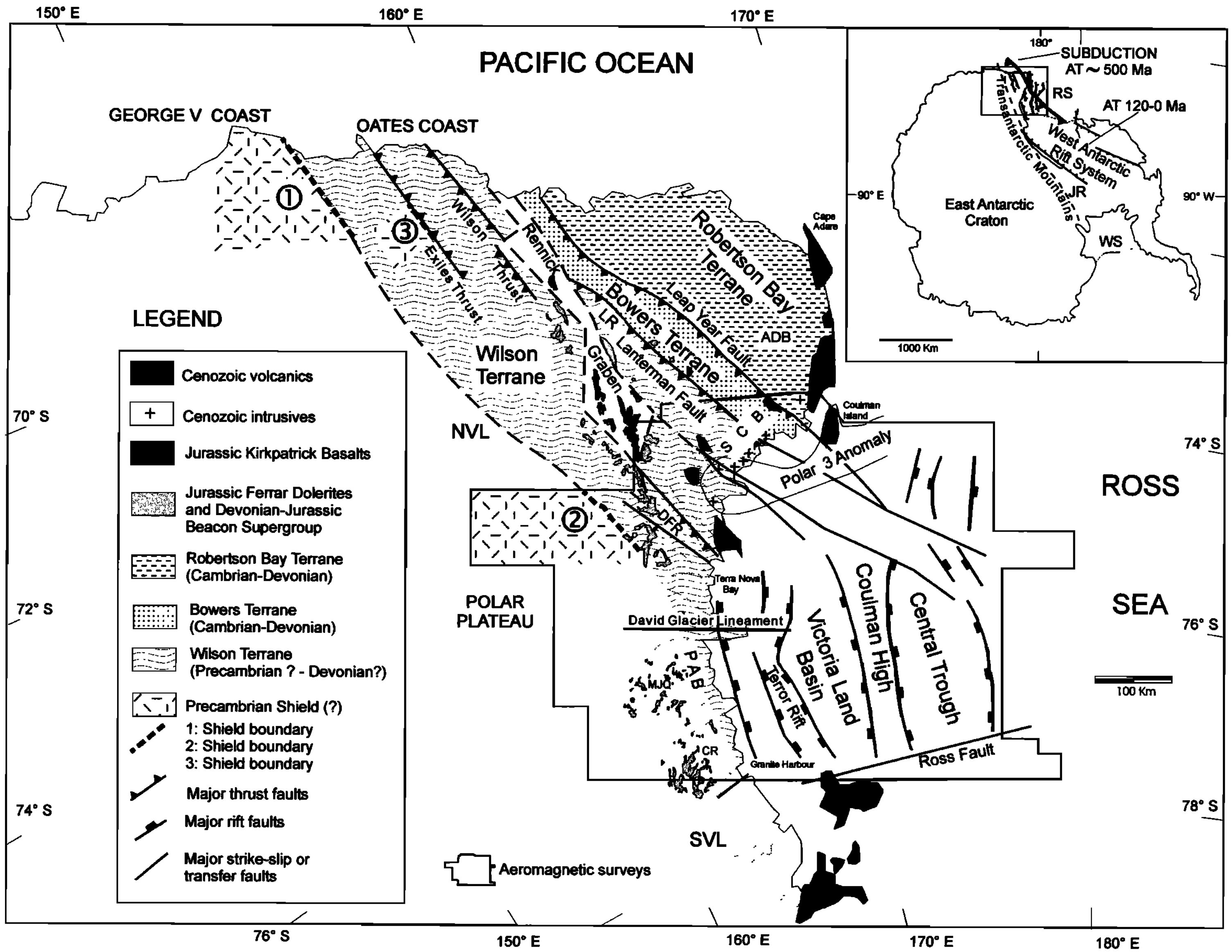

Figure 2. Tectonic sketch map of Victoria Land and adjacent Ross Sea. The inset shows the tectonic evolution of the Ross Sea (RS)–Transantarctic Mountains area: subduction beneath the East Antarctic craton at about 500 Ma; Jurassic tholeiitic magmatism and extension (JR); multistage rifting within the West Antarctic rift system from 120 Ma to the present. Note the unexposed boundary between the Cambro-Ordoviciau Ross Orogen terranes and the Precambrian shield interpreted prior to our study by *Ushakov* [1960] at location 1 and from aeromagnetics [*Bosum et al.*, 1989; *Damaske and Bosum*, 1993] at locations 2 and 3. Offshore rift basins are from *Brancolini et al.* [1995]. Abbreviations are as follows: LR, Lanterman Range; MJQ, Mount Joyce quadrangle area; CR, Convoy Range area; others as in Figure 1.

coast [*Damaske and Bosum*, 1993; *Flöttmann and Kleinschmidt*, 1993].

We first describe the contrasting magnetic anomaly patterns over the western Ross Sea, the Southern Cross Mountains block, the Deep Freeze Range–Terra Nova Bay region, and the Prince Albert Mountains block (Figure 1). We then propose a more detailed interpretation over the Deep Freeze Range and Prince Albert Mountains blocks by also furnishing magnetic models along the GANOVEX V and Antarctic Crustal Profile Experiment (ACRUP) seismic lines [*O'Connell and Stepp*, 1993; *ACRUP Working Group*, 1995; *Della Vedova et al.*, 1997]. Finally, we discuss the role played by inherited crustal features on tectonic blocks along the TAM rift flank.

Relationships between characteristic magnetic anomaly patterns and trends and outcropping geological units and faults, spanning in age from the Paleozoic to the Cenozoic, are used to provide support for our interpretations over ice-covered areas.

2. Geological Setting of Victoria Land

2.1. Basement of the Transantarctic Mountains

The present-day Transantarctic Mountains coincide with the edge of the East Antarctic craton (EAC). The EAC margin has a protracted Neoproterozoic and Paleozoic history as a divergent and convergent plate boundary [*Dalziel*, 1992; *Stump*, 1992]. The outcropping basement of Victoria Land is part of the Cambro-Ordovician Ross Orogen and has been subdivided into three tectonometamorphic terranes (Figure 2), which from the northeast to the southwest are the Robertson Bay Terrane (RBT), the Bowers Terrane (BT) and the Wilson Terrane (WT) [*Bradshaw*, 1989]. The RBT and BT are characterized by very low grade to low grade metasedimentary and metavolcanic rocks of Cambrian-Ordovician age [*Kleinschmidt and Tessensohn*, 1987].

The WT represents the closest outcropping geological unit to the Precambrian East Antarctic craton. The Paleo-Proterozoic to Archean basement of the EAC outcrops only much further west at about 146°E along the Pacific coast in small areas of George V Land [*Menot et al.*, 1995].

In the southern Wilson Terrane, along the western flank of the Campbell Glacier bordering the Deep Freeze Range (Figure 1), a polymetamorphic migmatite-granulite complex could represent a reworked fragment of the EAC [*Talarico et al.*, 1995]. However, since geochronological data are still sparse, *Palmeri* [1995] proposed that the complex might instead represent deep levels of the Cambro-Ordovician Ross Orogen. The metamorphic rocks of the WT, which range from low to high grade [*Talarico et al.*, 1992], were extensively intruded by Cambro-Ordovician granitoids, the Granite Harbour Intrusives (GHI). The GHI are considered to represent a calc-alkaline magmatic arc [*Ghezzo et al.*, 1989] related to the southwestward subduction of the paleo-Pacific plate beneath the EAC [*Kleinschmidt et al.*, 1992].

While the WT seems to have developed along the proto-Pacific margin of the EAC, the BT and RBT are considered to be allochthonous terranes amalgamated to the active margin prior to emplacement of the Devonian age Admiralty Intrusives [*Kleinschmidt and Tessensohn*, 1987], or after their emplacement [*Borg and Stump*, 1987].

The structural architecture of the basement terranes involved in the Ross Orogen and, according to some authors, also in the Silurian-Devonian Borchgrevink Orogeny [*Findlay*, 1990] is complex. Two major NW-SE trending faults separate the three terranes. The Leap Year Fault is a major thrust fault with NE sense of transport which divides the RBT from the BT; the Lanterman Fault is a major thrust, also with NE sense of transport, separating the WT from the BT [*Flöttmann and Kleinschmidt*, 1991]. Along the WT-BT suture zone a chain of pods and lenses of mafic and/or ultramafic rocks occurs [*Ricci et al.*, 1996]. Within the WT at the Pacific coast, *Flöttmann and Kleinschmidt* [1993] further recognized two thrust systems with opposing vergence: the Wilson and the Exiles thrusts (Figure 2).

2.2. Mesozoic and Cenozoic Tectonic Features of the TAM

Denudation of the Ross Orogen formed the Kukri Peneplain, the regional erosion surface separating the basement from the cover rocks [*Gunn and Warren*, 1962]. Starting from the Devonian, elongate intracratonic basins parallel to the ancestral margin subsided [*Woolfe and Barrett*, 1995] and were the site of the Devonian to Jurassic deposition of the continental Beacon supergroup (Figure 2). An extensional tectonic setting accompanied the deposition of volcanoclastics forming the uppermost Beacon strata and the lower part of the Ferrar Group [*Elliot*, 1992]. Widespread extrusion and intrusion of tholeiitic rocks (Kirkpatrick basalt and Ferrar dolerite) occurred at the EAC margin, coeval with crustal extension, with possible strike-slip components, inferred to mark a volcano-tectonic rift zone, mainly developed along the present site of TAM [*Schmidt and Rowley*, 1986; *Wilson*, 1993].

The Late Mesozoic and Cenozoic structural setting of the Ross Sea region has recently been reviewed by *Davey and Brancolini* [1995, and references therein], who recognized four main tectonic events over the past 120 Myr (Early Cretaceous, Late Cretaceous, Eocene, and Oligocene). The same authors conclude that estimates of the amount of Cretaceous and Cenozoic extension, as well as the relative timing of the major extension across the West Antarctic rift system, are still inconsistent. Plate tectonic reconstructions of *Lawver and Gahagan* [1994] suggest that the main phase of extension in the Ross Sea occurred between 105 and 85 Ma, with the exception of the axial Terror rift of the Victoria Land basin (Figures 2 and 3), where Cenozoic deformation is clearly recognized from seismic evidence [*Cooper et al.*, 1991]. Recent paleomagnetic data from mid-Cretaceous intrusive rocks in Marie Byrd Land suggest that extension between East and West Antarctica was 1130 ± 690 km [*DiVenere et al.*, 1994], and according to *Luyendyk et al.* [1996] it incorporated a component of clockwise rotation. Cenozoic transtension oblique to the TAM margin proposed by *Wilson* [1995a] is also not compatible with large magnitude crustal stretching within the West Antarctic rift system in the Cenozoic.

A further complication to the tectonic setting of the Ross Sea region is due to reactivation of Paleozoic faults in a right-lateral strike-slip regime interpreted by *Salvini et al.* [1997], from seismic data offshore, to have occurred in post-RSU6 time. RSU6 constitutes the oldest unconformity recognized in the sedimentary rocks of the Ross Sea rift basins and separates two major successions [*Hinz and Block*, 1984]. The age of RSU6 is weakly constrained as older than 26 Ma and spans the time between the Eocene and late Oligocene [*Busetti*, 1994]. Onshore, evidence for post-Paleozoic reactivation of basement faults is less obvious. In the Lanterman Range, close to the Ross age Lanterman Fault zone, the Granite Harbour Intrusives have been thrust onto the Jurassic Ferrar Supergroup [*Roland and Tessensohn*, 1987] and a strongly folded belt of

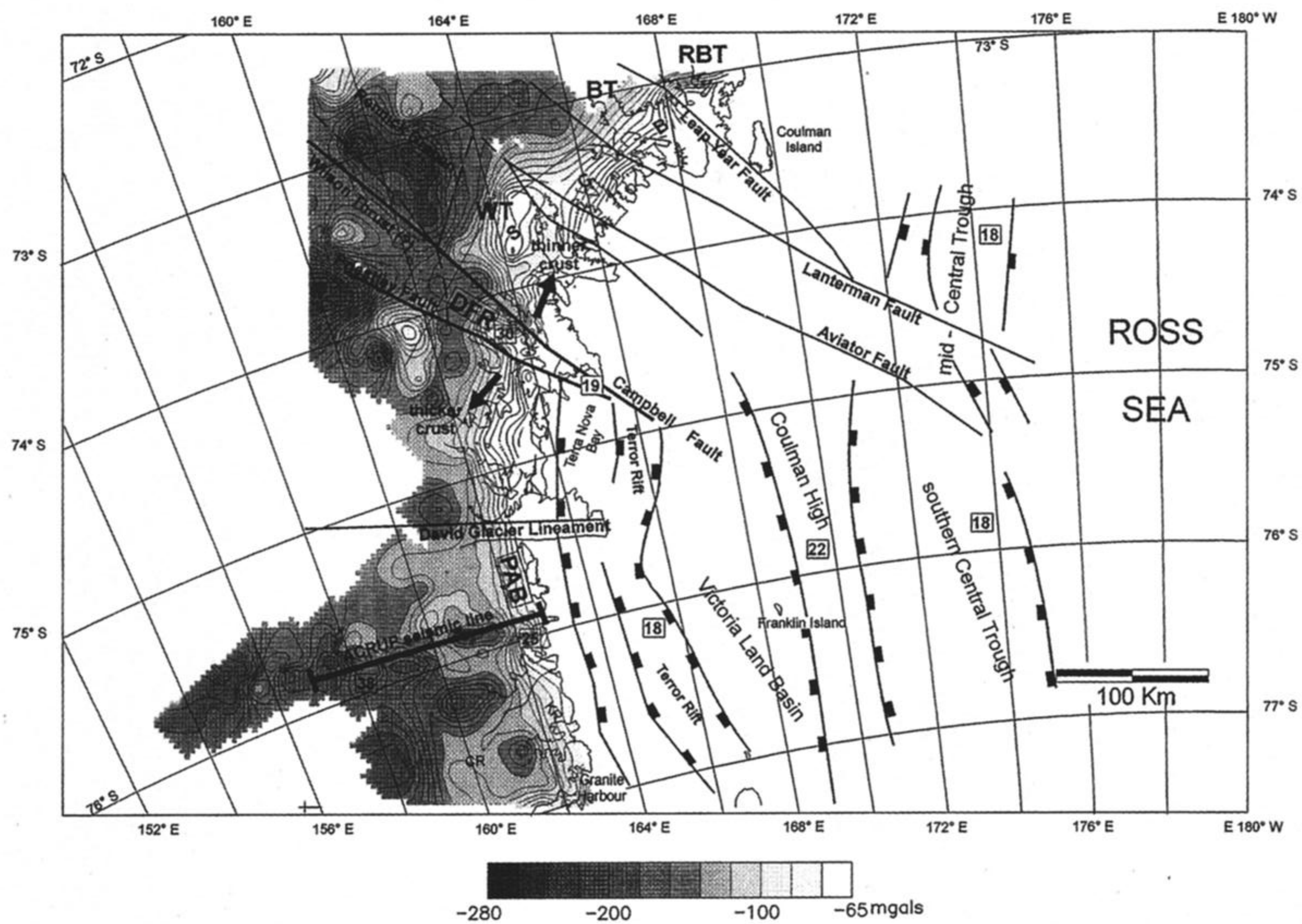

Figure 3. Geophysical framework of the TAM tectonic blocks and adjacent Ross Sea rift basins: onshore Bouger gravity values [*Reitmayr*, 1997] are shown by shading; seismic crustal thickness estimates, given in boxes, along the DFR and the PAB [*O'Connell and Stepp*, 1993; *Della Vedova et al.*, 1997] are in kilometers; offshore faults and crustal thickness offshore are simplified from *Salvini et al.* [1997].

Beacon rocks, unique in the TAM, has been recognized [*Grindley and Oliver*, 1983]. Though the deformation patterns support strike-slip movement of Mesozoic or younger age also onshore, there is no direct way of dating the movements along the faults. Indirect evidence for timing of tectonic activity onshore is provided by anomalous 90–120 Ma K/Ar ages on Jurassic volcanics [*Kreuzer et al.*, 1981], paleomagnetic values [*Delisle and Fromm*, 1986; *Schmier and Burmester*, 1986], and anomalous ages from the Mesa ranges [*Fleming et al.*, 1993]. All these lines of evidence are considered by *Tessensohn* [1994] to reveal a Cretaceous thermal event leading to the formation of the Rennick pull-apart basin (Figure 2), possibly coeval with the early stages of Ross Sea rifting [*Cooper et al.*, 1987].

The extensional tectonic setting of the TAM–Ross Sea rift area in the Cenozoic to Quaternary is reflected in its igneous history. Alkali basaltic volcanism of the McMurdo Volcanic Group commenced between 25 and 18 Ma in three elongate, approximately N-S trending provinces along the Ross Sea margin [*LeMasurier and Thomson*, 1990]. Alkaline intrusives of Cenozoic age (30 Ma) have been identified in northern Victoria Land and named the Meander Intrusives [*Müller et al.*, 1991]. *Tonarini et al.* [1997] furnished new geochronological data which reveal that some of these intrusives are older, of middle Eocene age (50 Ma).

Cenozoic uplift of the TAM is generally viewed to be linked to the Cenozoic extension within the Victoria Land basin [*Fitzgerald and Gleadow*, 1988]. The TAM uplift has been modeled by *Stern and ten Brink* [1989] and *Bott and Stern* [1992], taking into account thermal, erosion, and end loading effects. Recently, *Fitzgerald and Baldwin* [1997] have proposed a detachment fault model for the Cretaceous uplift of parts of the TAM [*Balestrieri et al.*, 1997].

The Mesozoic and Cenozoic faults bordering the tectonic blocks of the TAM rift shoulder of Victoria Land are only partially known (Figures 1, 2, and 3). *Tessensohn* [1994] described the Rennick Graben as an important Mesozoic pull-apart basin of northern Victoria Land, extending from the Pacific coast to the Ross Sea area.

The Deep Freeze Range seems to develop at the southwestern margin of the Rennick Graben itself. *Skinner* [1987], however, interpreted the graben itself to continue to the southwest of the Deep Freeze Range (in the Terra Nova Bay region) and to be linked to the Victoria Land basin offshore through a small graben-like structure named the Nansen Graben. The NW trending Deep Freeze Range may be bounded on its eastern and western side by faults: Indeed, *Salvini et al.* [1997] described faults (the Campbell and Priestley faults) at its margins.

The Southern Cross Mountains have a NE trend and separate the Rennick Graben onshore from its original continuation represented, according to *Tessensohn* [1994], by the Victoria Land rift basin. *Tessensohn* [1994] considered the Southern Cross Mountains as part of the Admiralty block, a highly uplifted block likely linked to a later rift/uplift phase which possibly commenced at 50–40 Ma [*Fitzgerald and Gleadow*, 1988]. *Van der Wateren et al.* [1994], however, proposed that the Southern Cross Mountains block (Figures 1 and 2) is distinct from the Admiralty block based on a landscape evolution model for the region, since the outlet glacier valleys appear to be older than those in the Admiralty Mountains. The boundary between the Southern Cross Mountains block and the Admiralty block may lie along the Mariner Glacier in the area of the Leap Year Fault. We use the term Southern Cross Mountains block throughout the text for the TAM block between the Mariner Glacier and the Campbell Glacier.

Proceeding south along the southern Victoria Land rift flank, much more subdued mountains and lower elevations characterize the Prince Albert Mountains block, extending approximately from the David Glacier to Granite Harbour; tilting and uplift here appears to be smaller compared to the northern Victoria Land blocks [*Wörner*, 1992]. No graben-like structure such as the Rennick Graben of northern Victoria Land has been recognized here either. The glacial pattern is also different. While in northern Victoria Land the main glaciers trend NW and NNW, the David Glacier is approximately WNW, and the Mawson Glacier is close to E-W (Figure 1). The David Glacier lineament may represent according to *Mazzarini et al.* [1997] the northern border of the Prince Albert Mountains block.

Mazzarini et al. [1997] described several lines of geological evidence for major crustal segmentation of the TAM along the David Glacier lineament (Figure 2) between the northern Victoria Land and the southern Victoria Land segments of the rift shoulder, including the distribution of Mesozoic and Cenozoic rocks, the elevation and dip of the Kukri peneplain, and differential uplift. The same authors interpreted the David Glacier lineament to be a major transfer fault of unknown age, possibly formed in the Jurassic and reactivated in the Cenozoic. The lineament across the rift shoulder is further interpreted to accommodate the different strain patterns occurring along the EAC margin during rift/uplift phases.

3. Related Geophysical Research

Several geophysical investigations have been carried out in the Ross Sea area to study the crustal structure and tectonics of the West Antarctic rift system [*Behrendt et al.*, 1993].

The crustal blocks of the Cenozoic and Mesozoic TAM are to date much less well known than the offshore rift basins [*Brancolini et al.*, 1995]. In particular, geophysical evidence (Figure 3) for segmentation of the TAM into different crustal blocks is controversial. *Redfield and Behrendt* [1992] interpreted gravity models of the Mount Melbourne region and of the Prince Albert Mountains (PAB) to reveal thicker crust to the south of the David Glacier and possibly Jurassic mafic feeder bodies at depth beneath the PAB. They further suggested that the increase in crustal thickness might be related to a major inherited structure at the David Glacier, possibly dating from the time of Gondwana breakup. However, *Reitmayr* [1997] did not interpret the regional gravity data to reveal systematic differences in crustal thickness or in regional gravity anomaly pattern north and south of the David Glacier (Figure 3). *O'Connell and Stepp* [1993] proposed a seismic model of the Deep Freeze Range (DFR) area showing the crust to thicken from 19 km at the coast to 30 km at 60 km inland. They further interpreted the seismic data in conjunction with the gravity of *Kienle et al.* [1989] to indicate that the DFR itself is located in a transition area between thinner northern Victoria Land crust and more rapidly thickening crust to the southwest. Preliminary results along the ACRUP seismic line across the PAB indicate that the crust thickens from about 18 km within the Victoria Land basin to 25 km at the coast and 38 km at the edge of the Polar Plateau, over 100 km inland [*Della Vedova et al.*, 1997]. According to *Mazzarini et al.* [1997], crustal thickening gradients beneath the Prince Albert Mountains are larger than those beneath the Deep Freeze Range, thus supporting the existence of the David Glacier lineament and its important role in the separation of the northern and southern Victoria Land segments of the TAM rift shoulder.

4. Magnetic Anomaly Images

A total field magnetic anomaly map of central southern Victoria Land at a 1:250,000 scale has been compiled from three regional GITARA helicopter-borne surveys in the area between Granite Harbour and Terra Nova Bay [*Bozzo et al.*, 1997a]. The magnetic data cover an area of approximately 50,000 km^2; line orientation was WNW-ESE (NNE-SSW tie lines); line spacing was 4.4. km for profiles and 22 km for tie lines, flown at an altitude of 2700 m above sea level. Flight line orientation and spacing were the same as the adjacent GANOVEX IV survey [*Damaske*, 1989], an airborne survey covering an area of 300,000 km^2 between Coulman Island and Ross Island and extending over the TAM and adjacent Polar Plateau [*Bachem et al.*, 1989]. The survey was flown at three different altitudes: 610 m over the Ross Sea, 3660 m over the TAM, and 2700 m over the Polar Plateau.

The reduced version (1:4,500,000 scale) of the combined GITARA-GANOVEX map is shown in Plate 1. Microleveling in frequency domain [*Ferraccioli et al.*, 1998] was applied to improve the signal-to-noise ratio of the GANOVEX IV survey. Integration procedures of individual surveys are described by *Chiappini et al.* [1999]. Digital enhancement of linear trends was achieved with shading.

The magnetic anomaly image was superimposed upon a simplified version of the Cenozoic tectonic map of *Salvini et al.* [1997], a tectonic sketch map of northern Victoria Land [*Pertusati and Tessensohn*, 1995], the geological map of the Terra Nova Bay area–McMurdo Sound area of *Warren* [1969], and the geological map of the region between Mawson and Priestley glaciers of *Skinner and Ricker* [1968]. This allowed correlation of magnetic anomalies with outcrops and faults, extrapolation of similar features under ice cover, and definition of anomalies with no obvious geological correlation. Owing to the reduced size of the image, anomalies have been labeled according to the geology, but the outcropping units are not displayed in Plate 1.

4.1. Western Ross Sea Magnetic Anomalies

The southwestern Ross Sea is characterized by high-frequency anomalies of moderate amplitude, mostly in the 50–100 nT range, with a N-S to NNW trend. The anomalies were interpreted by *Bosum et al.* [1989] as volcanic rocks of possible Cenozoic age and as rift fabric anomalies linked to Cenozoic volcanic rock and submarine Cenozoic volcanoes penetrating the sedimentary section by *Behrendt et al.* [1996]. There is, indeed, a remarkably good fit between seismically constrained volcanics displayed in the Cenozoic tectonic map of *Salvini et al.* [1997] and aeromagnetic anomalies.

To the south of the Terra Nova Bay region, the most evident structural feature visible in the magnetics is the Terror rift, which appears as a distinct N-S to NNW magnetic low. Rift fabric in the southern Central Trough is less evident, as pointed out by *Bosum et al.* [1989]. Along the flanks of the Coulman High, which separates the Victoria Land basin from the Central basin, high-frequency anomalies might reveal Cenozoic volcanics also. Several magnetic models of the Central basin have been proposed by *Behrendt et al.* [1996] to explain the approximately 80 nT N-S trending broad positive anomaly within the southern Central basin and the much higher amplitude anomalies to the south of the Ross fault, which seem to require the presence of Cenozoic volcanics to the south. To the north, close to Coulman Island and just offshore of the Southern Cross Mountains block, a remarkable ENE magnetic anomaly chain, reaching amplitudes well over 1000 nT, has been named the "Polar 3 anomaly" [*Bosum et al.*, 1989]. According to *Behrendt et al.* [1991], the probable source of this anomaly is late Cenozoic volcanic rock, which indeed outcrops extensively nearby on Coulman Island. The Polar 3 area has been interpreted independently by *Behrendt et al.* [1991] and *Wörner et al.* [1989] as a major Cenozoic transfer fault linking offset segments of the rift basins. Plate 1 shows that the high-amplitude circular anomalies belonging to the Polar 3 anomaly are markedly different from the shorter-wavelength (10 km) and lower-amplitude (100 nT) anomalies flanking the Terror rift. Also, our map shows how the individual circular Polar 3 anomalies are bounded by very prominent NW-SE lineations, which almost perfectly coincide with the major strike-slip faults of the area mapped by *Salvini et al.* [1997]. However, major right-lateral offsets along the NW trends crossing the Polar 3 are not evident. A right-lateral offset is clearly recognized along the N-S trend separating the Polar 3 from anomaly S to the east (Plate 1). A NW trend that we name the Central Trough lineament lines up well with the Campbell Fault.

4.2. Southern Cross Mountains Magnetic Anomalies

The Southern Cross Mountains block is characterized by very prominent magnetic anomalies, at least in part comparable to the Polar 3 anomaly offshore and clearly distinct both from the Ross Sea anomalies and the adjacent parts of the Transantarctic Mountains. The anomaly with the largest amplitude (1700 nT) is the Greene Point (GP) anomaly. *Lucchitta et al.* [1989] interpreted the body to reflect a mafic differentiate at depth, beneath alkaline intrusives of likely Cenozoic age. *Müller et al.* [1991] described Cenozoic alkaline intrusives in the area. Recent findings by *Tonarini et al.* [1997] of a gabbroic portion of the Greene Point Igneous Complex (48 Ma) strongly support this previous interpretation.

A 2200 nT ground magnetic anomaly between the Campbell and Tinker glaciers at Mount McGee (MMG) was interpreted by *Bozzo et al.* [1992] as a major mafic intrusive, also of Cenozoic age. The aeromagnetic image also shows a prominent positive anomaly to the north at Mount Jiracek (MJ). The MMG and MJ anomalies are separated by a major NW-SE trending lineation from the Polar 3 anomaly. This magnetic lineation corresponds to the Aviator Fault splay [*Salvini et al.*, 1997].

To the southwest a high-amplitude positive anomaly corresponds to the Cenozoic Mount Melbourne (MM) volcano, while further to the north an anomaly marks the Mount Overlord (MO) central volcano.

A prominent 800 nT magnetic anomaly can be recognized in the Spatulate Ridge (SR) area close to the Tiger Gabbro. A whole rock Sm-Nd isochron yields an age of 535 ± 22 Ma for the Tiger Gabbro [*Rocchi et al.*, 1999]. The geological map of *Pertusati and Tessensohn* [1995] indicates that Meander Intrusives outcrop in the adjacent No Ridge (NR) area. It is therefore possible that the observed magnetic anomaly is related to a Cenozoic intrusive instead of the previously interpreted Tiger Gabbro [*Bosum et al.*, 1989].

Further to the north, much smaller amplitude anomalies correspond to the outcrops of the Devonian Admiralty Intrusives, as recognized also by *Lucchitta et al.* [1989]. Notably, the Mount Supernal (MS) anomaly shows that the Admiralty Intrusives extend to the west of the Lanterman Fault zone and thus seem to occur in the easternmost Wilson Terrane as reported in the *Pertusati and Tessensohn* [1995] map.

The high-frequency anomalies of the Mesa Range (MR) anomalies can confidently be correlated with the Jurassic Kirkpatrick basalts within the Rennick Graben, in contrast with the lower-amplitude anomalies over the Ferrar dolerite sills at the southernmost edge of the graben. Prominent magnetic lineations correspond to the Campbell and Priestley faults bounding the Deep Freeze Range block at the southwestern margin of the Rennick Graben. These lineations were also previously recognized from ground magnetics [*Bozzo et al.*, 1992].

4.3. Prince Albert Mountains Magnetic Anomalies

The Prince Albert Mountains block is dominated by high-frequency anomalies with wavelengths of about 10 km and amplitudes of around 100 nT. *Bozzo et al.* [1997b] proposed that both the Mount Joyce Quadrangle (MJQ) and the Convoy Range (CR) could be defined as "basalt-dominated areas," partially masking deeper "basement anomalies." The anomalies are correlated to the Jurassic Ferrar dolerite sills and Kirkpatrick basalt lavas; the latter are marked by higher-amplitude anomalies (up to 500 nT). The "basalt anomaly pattern" can also be recognized under ice cover. The Convoy Range has clear high-frequency NE and NNE trends, while in the Mount Joyce quadrangle trends vary, having more northerly or even northwesterly trends. Along the western flank of the Kirkwood Range (KR) there is a very clear lineation parallel to the N-S trending Ross Sea rift basins. The Kirkwood Range lineation also coincides with a major fault inferred by *Warren* [1969]. The NE trends of the Convoy Range area do not propagate across the N-S western boundary of the Victoria Land basin.

Just to the east of the high-frequency anomalies of the Mount Joyce quadrangle a remarkable NNW to NW trending regional high with peaks of over 250 nT and wavelength of individual anomalies of over 30 km has also been recognized and named the GITARA anomaly complex (GAC) [*Bozzo et al.*, 1997b]. The GAC corresponds roughly to the outcropping Paleozoic Granite Harbour Intrusives in the Mount George Murray (MGM) area and extends to the north in the Burrage Dome (BD) area. This regional magnetic high continues to the north beneath the Polar Plateau, where it was interpreted by *Bosum et al.* [1989] to reflect the presence of the magnetic Precambrian shield. Plate 1 shows that the high-frequency anomalies beneath the Polar Plateau are virtually identical to those of the Prince Albert Mountains region and thus reveal the presence of Jurassic igneous rocks beneath the ice there also.

Another prominent magnetic anomaly occurs in the area of the most remote outcrops of the Prince Albert Mountains, corresponding to the Martin Nunataks (MNK) at the edge of the Polar Plateau. The anomaly is a double-peak positive feature with an amplitude of over 650 nT. The geological map of the area between David and Mariner Glaciers of *Carmignani et al.* [1989] indicates that Jurassic basalts may be present in the region. The Martin Nunatak anomaly likely reveals a major downthrown block, which we name here the "Martin Nunatak block," in which the Kirkpatrick basalts were preserved from erosion, possibly in a similar fashion to the basalts of the Rennick Graben. This downfaulted block interpreted from the magnetics is likely linked to the recently proposed David Glacier lineament [*Mazzarini et al.*, 1997].

4.4. Upward Continued Magnetic Anomaly Map

An enhanced magnetic map was produced by differential upward continuation from the original level to 10 km above sea level (Plate 2). This map emphasizes deeper sources by enhancing variations in magnetic properties within the basement, while it is less sensitive to near-surface details such as volcanics and shallow brittle fabric. The magnetic anomalies related to the Jurassic tholeiites and to the Cenozoic volcanics are thus significantly smoothed out in this image.

Within the Ross Sea, the Terror rift appears as a prominent magnetic low in contrast to the approximately N-S trending magnetic high over the Coulman High (CH). A NW trending magnetic high can also be recognized beneath the southern Central Trough.

The Polar 3 anomaly is still the most outstanding anomaly of the Southern Cross Block (SCB), with peaks reaching 400 nT. It is a much more intense magnetic feature than the anomalies over outcropping volcanic edifices such as Mount Melbourne and Mount Overlord, thus supporting thick highly magnetic intrusions, such as the Greene Point gabbro, as the sources, rather than volcanics. Though the anomaly itself exhibits an overall coast-parallel ENE trend, NW-SE crosscutting trends still correlate with the major faults of the region.

The GITARA anomaly complex (GAC) now appears as a distinct feature of the Prince Albert Mountains block (PAB). It is bounded on its eastern flank by a NW to NNW regional lineament, referred to as B1, readily evident also in Plate 1. Across B1 there is a 100 nT level shift between the regional negative anomaly field to the east and the positive GAC to the west. Such a break is similar to the regional break across the previously recognized lineament separating the Polar Plateau high to the northwest from the TAM low to the northeast [*Bosum et al.*, 1989]. We name this lineament the eastern Polar Plateau lineament (E). Apparently, however, this lineament is shifted some 40 km to northeast with respect to B1 across a lineament at right angles to the two, as best seen in Plate 1. The upward continued map shows that the previously recognized eastern Polar Plateau lineament might also continue to the south and reach the Terra Nova Bay region, but in that area the anomaly break is not as remarkable compared to the break across B1.

In the 73°–74°S sector the western Polar Plateau is characterized by an extensive 200 nT high, while to the south, only the Martin Nunatak anomaly has similar amplitude. The eastern and western sections of the Polar Plateau seem to be separated by a major lineament lying on strike with B1. We name this feature the western Polar Plateau lineament (W).

An approximately N-S trend flanking the westernmost part of the Prince Albert Mountains block is indicated with B2. To the south in the Convoy Range area the basement seems weakly magnetic in a similar fashion to the DFR and SCB. Notably the M1 magnetic minima trend shows that NNW basement fabric is present in the south. The M2 minimum links quite well to the B2 lineation to the north.

5. Interpretation

Two-dimensional interpretation and modeling of magnetic anomalies of the Southern Cross Block have been presented by *Bosum et al.* [1989]. Magnetic models across the Wilson-

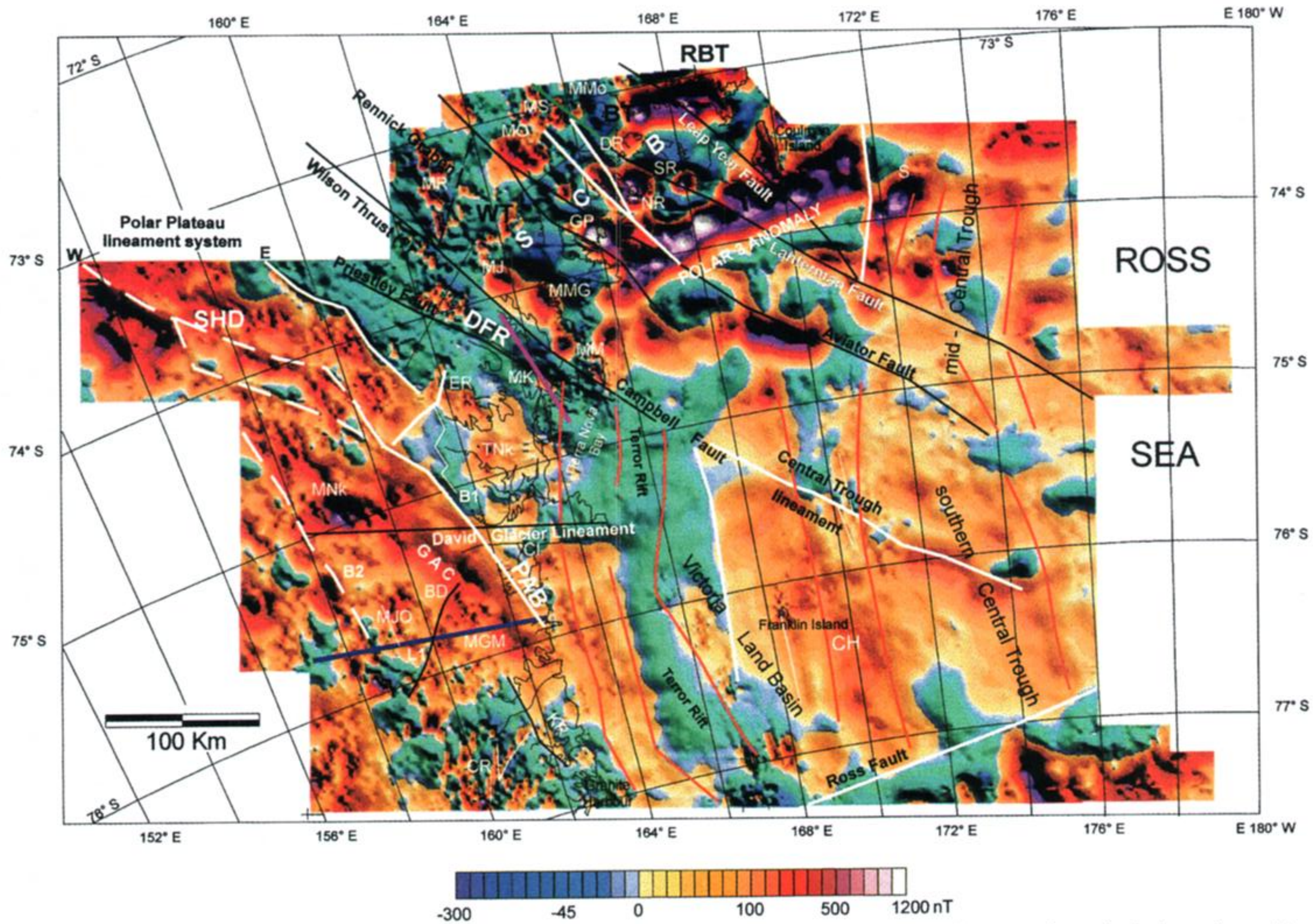

Plate 1. Interpreted total field magnetic anomaly map. Red lines are the main rift faults known from seismics, black lines are the main faults and roughly coincident regional magnetic lineaments (e.g., L1), white lines are regional magnetic lineaments, and thin white lines are high-frequency trends. Note the prominent eastern (E) and western (W) lineaments forming the Polar Plateau lineament system, B1 flanking the GITARA Anomaly Complex (GAC) and the subparallel B2 lineament (see text for explanation). Green line marks the Lanterman Fault with limited magnetic signature onshore. The magnetic anomalies are labeled according to outcropping and interpreted buried geology: (1) MM, Mount Melbourne; MO, Mount Overlord (Cenozoic McMurdo Volcanic Group); (2) GP, Greene Point; NR, No Ridge, Polar 3 anomaly; MMG, Mount McGee; MJ, Mount Jiracek (Cenozoic Meander intrusive complex); (3) MR, Mesa Range; DFR, Deep Freeze Range; ER, Eisenhower Range; MJQ, Mount Joyce quadrangle; CR, Convoy Range; KR, Kirkwood Range, MNk; Martin Nunatak (Jurassic Ferrar dolerites, Kirkpatrick basalt); (4) MMO, Mount Montreuil; MS, Mount Supernal (Devonian Admiralty Intrusives); (5) MK, Mount Keinath; TNk, Teall Nunatak; CI, Cape Irizar; MGM, Mount George Murray; and BD, Burrage Dome (Cambro-Ordovician Granite Harbour Intrusives); (6) SR, Spatulate Ridge, DR area (Cambrian Tiger Gabbros and Dessent Metamorphics); and (7) SHD, previously interpreted Precambrian shield. Dark blue line shows the location of the onshore ACRUP seismic experiment, violet line is the GANOVEX V seismic line. RBT denotes Robertson Bay Terrane; BT denotes Bowers Terrane; SCB denotes Southern Cross Mountains block; PAB denotes the Prince Albert Mountains block; CH denotes the Central High.

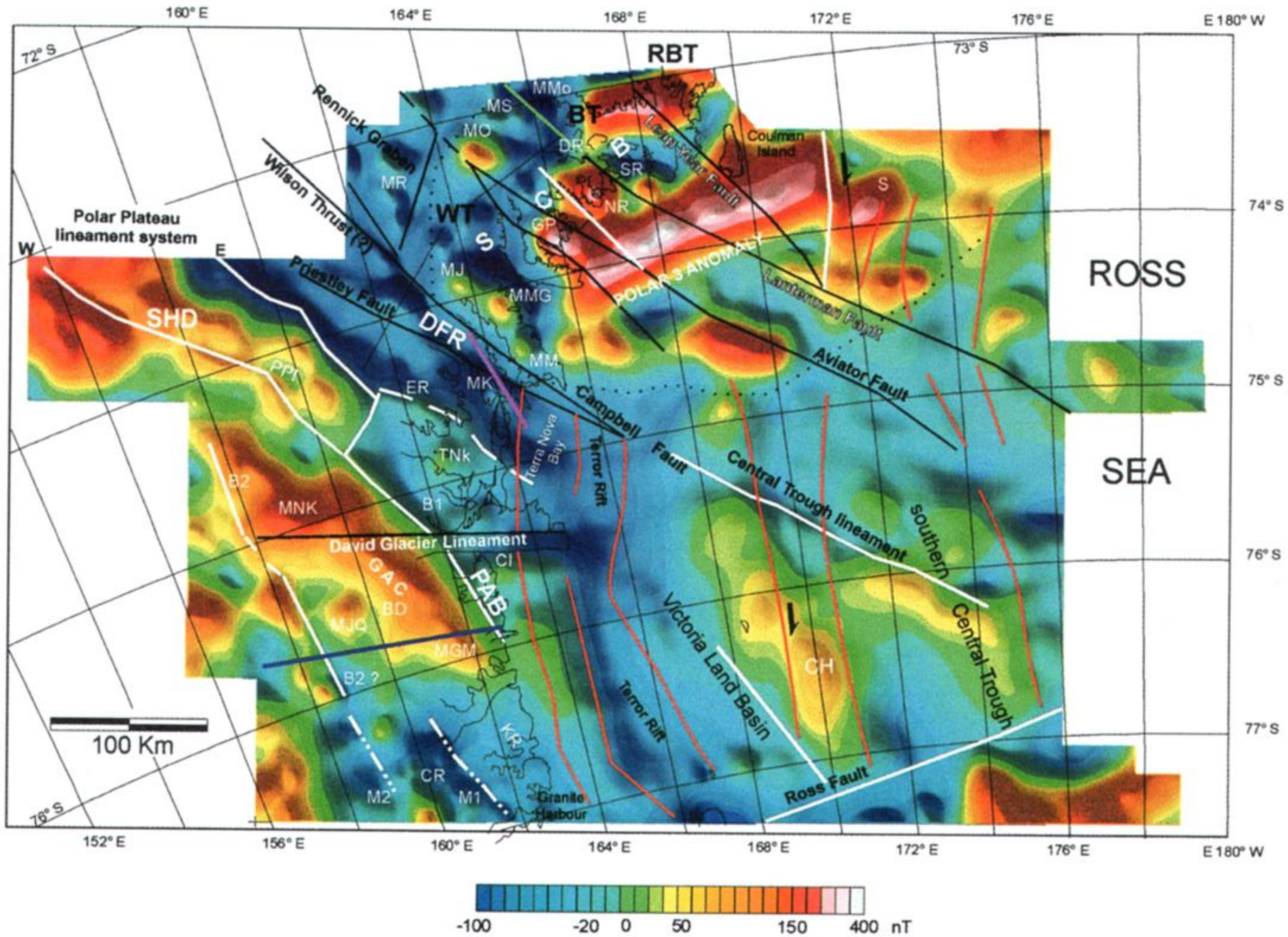

Plate 2. Upward continued magnetic anomaly map (10 km above sea level). Note the positive regional field beneath the Polar Plateau and PAB in sharp contrast to the low of the DFR and SCB. The dot-dashed line indicates the magnetic boundary of SCB with respect to the surrounding western Ross Sea and TAM blocks. Note also the positive anomaly field beneath the eastern Victoria Land Basin, Coulman High, and southern Central Trough. Abbreviations as in Plate 1.

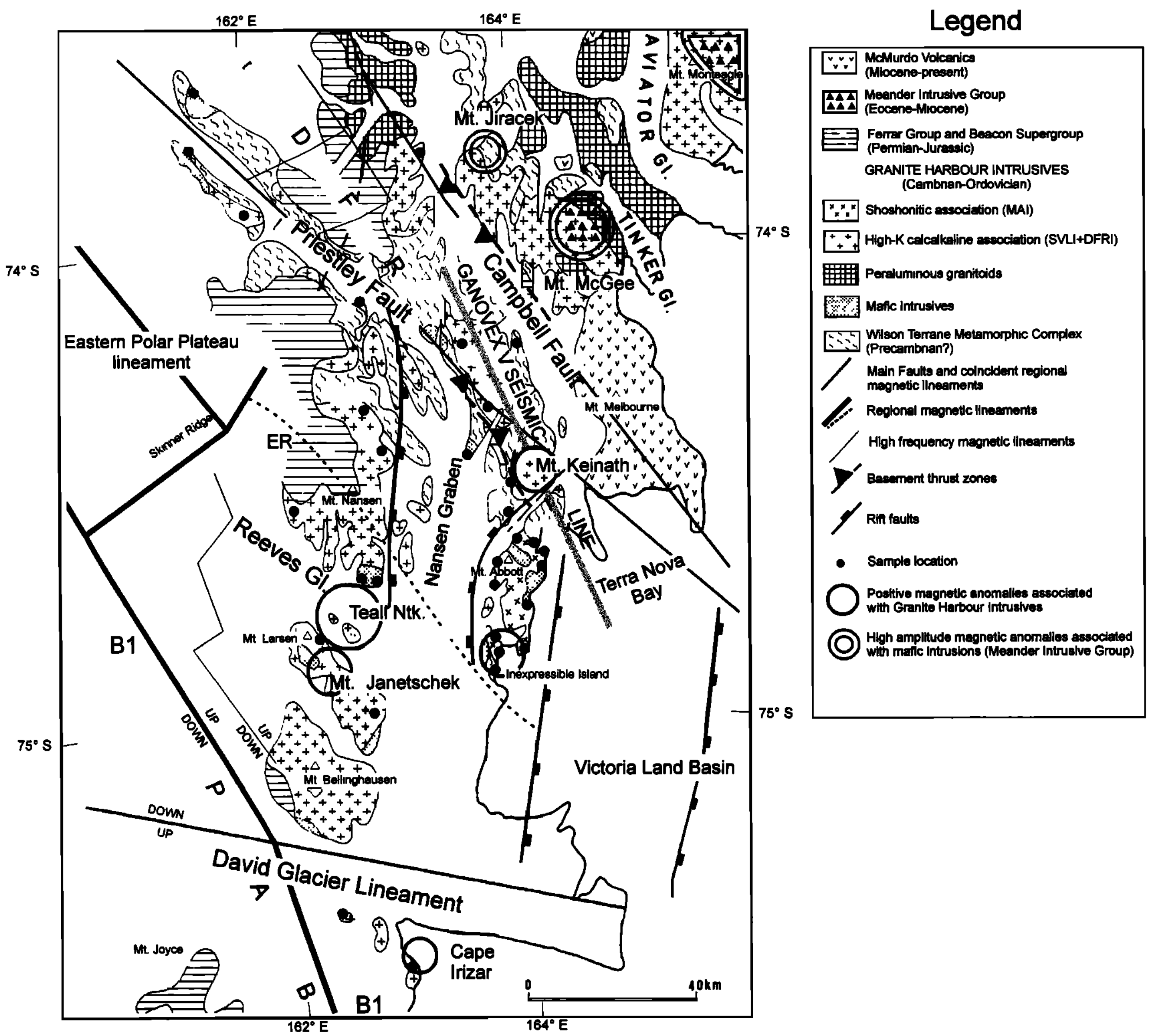

Figure 4. Magnetic interpretation superimposed upon geological map of the Terra Nova Bay region modified from *Biagini et al.* [1991a, b]. Faults along the B1 magnetic lineament and along the David Glacier lineament from *Pertusati et al.* [1999]. Nansen Graben is from *Skinner* [1987].

Bowers suture zone have more recently been discussed by *Bozzo et al.* [1995]. We start by interpreting the anomalies in the Terra Nova Bay region between the David Glacier and the Aviator Glacier, where ground magnetic constraints have been furnished by *Bozzo and Meloni* [1992] and geological investigations are relatively well established. In particular, we model the anomalies along the GANOVEX V seismic line across the Deep Freeze Range flanking the Rennick Graben. We then move to the south of the David Glacier, where ground magnetic measurements have not been undertaken, geological work is less detailed, and ice cover is more extensive. Finally, we discuss magnetic models for the Prince Albert Mountains region along the ACRUP seismic line to complete the new interpretation efforts.

5.1. Terra Nova Bay Region

The Terra Nova Bay region is a key area for the reconstruction of possible relationships between basement features and tectonic blocks of the TAM in northern Victoria Land (Figure 4). A magnetic lineament was recognized from ground magnetics along the Campbell Glacier [*Bozzo et al.*, 1992]. The Campbell Fault is marked by a sharp aeromagnetic gradient to the south and a NW trend in the magnetic minima to the north. The fault divides the Southern Cross Block (SCB), where high-amplitude anomalies are caused by McMurdo volcanics and the Meander Intrusive Group [*Tonarini et al.*, 1997], from the Deep Freeze Range (DFR) block, where the anomalies are related to the Jurassic Ferrar sills.

We interpret the Deep Freeze Range as the uplifted western shoulder of the Rennick Graben. To the south of the Campbell Fault, ground magnetic anomalies have been mapped [*Bozzo et al.*, 1989] over some Cambro-Ordovician Granite Harbour Intrusives (GHI), namely, over Mount Keinath (peak to peak amplitude of 1200 nT), Teall Nunatak (300 nT), Mount Janetschek (300 nT), and Inexpressible Island (100 nT); dis-

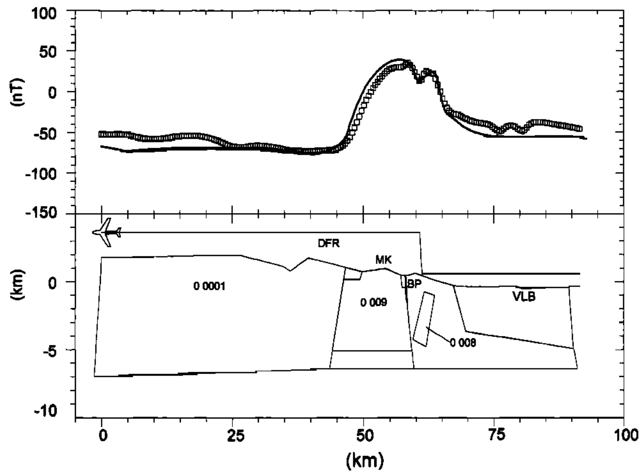

Figure 5. Magnetic model along the GANOVEX V seismic line across the Deep Freeze Range (DFR) and adjacent western Victoria Land Basin. Susceptibilities are in SI for all models. The main magnetic anomaly is over Mount Keinath (high-K Granite Harbour intrusive). Abbreviations are as follows: VLB, Victoria Land Basin; BP, Browning Pass; MK, Mount Keinath.

tinct high-frequency anomalies have also been mapped over Jurassic Ferrar dolerite sills of the Eisenhower Range. On the aeromagnetic anomaly map (Plate 1) the Mount Keinath anomaly is a 40 nT positive feature, while the Teall Nunatak and Mount Janetschek anomalies are higher-amplitude anomalies (150 nT).

In Figure 4 we superimposed the main magnetic anomalies detected over the Ross Age Granite Harbour Intrusives and the Cenozoic Meander Intrusive Group on a modified version of the geological map of *Biagini et al.* [1991a, b] for a detailed interpretation.

In the Terra Nova Bay area the Granite Harbour Intrusives show a bimodal distribution of magnetic susceptibility values, with quite a strong prevalence of the low-susceptibility fraction [*Bozzo et al.*, 1992]. No magnetic anomalies are observed over the peraluminous Granite Harbour Intrusives, occurring mainly to the east of the Deep Freeze Range [*Biagini et al.*, 1991a]. To the west of the Deep Freeze Range, magnetic anomalies over the Granite Harbour Intrusives correspond in part to the high-K calc-alkaline associations of *Biagini et al.* [1991b]. The magnetic anomalies over the Granite Harbour Intrusives are related to a suite of "magnetite type" intrusions [*Biagini et al.*, 1991b] close to the "magnetite series" [*Ishihara*, 1977]. The alkali-rich Irizar Granite [*Gunn and Warren*, 1962] also belongs to the magnetite series [*Biagini et al.*, 1991b]: Indeed, an over 100 nT aeromagnetic anomaly corresponds to the type locality of the Irizar Granite to the south of the David Glacier. No anomalies are instead present over mafic intrusives, which *Biagini et al.* [1991b] reported to belong to the "ilmenite series."

In Figure 5 we furnish a magnetic model along the GANOVEX V seismic line [*O'Connell and Stepp*, 1993]. This line crosses the Mount Keinath (MK) anomaly, which is the most outstanding feature of the profile. The anomaly can easily be modeled with a small magnetic pluton (0.009 SI), which actually crops out. Very low amplitude anomalies (not modeled) may correspond to variations within the basement of the Deep Freeze Range (DFR). A small dike-like body to the south of Browning Pass (BP) has been introduced to explain the lower-amplitude peak of the Mount Keinath anomaly. Significantly, no seismic velocity contrast was detected across the Mount Keinath pluton, and the gravity signature of the intrusive is not evident in *Reitmayr*'s [1997] regional data.

5.2. Prince Albert Mountains Region

In Figure 6 we display a two-dimensional magnetic interpretation map modified from *Bozzo et al.* [1997c] as a base for a more detailed interpretation of the Prince Albert Mountains region.

As previously noted, this sector of the TAM is anomalous compared to other adjacent regions since it is characterized by much lower elevations (less than 2000 m) and smoother topography. The Kukri Peneplain is found at lower elevations (1200 m versus over 2000 m) compared to northern Victoria Land [*Wörner*, 1992].

The Ross age basement crops out along an approximately 30 km wide strip subparallel to the coast. Field observations in the area suggest the presence of rafts of metamorphic rocks of the Wilson Terrane resembling the Priestley schists of the Terra Nova Bay region [*Kleinschmidt and Matzer*, 1992] intruded by syntectonic and posttectonic granitoids belonging to the Granite Harbour Intrusives, which in turn are cut by abundant acidic and basic dikes [*Fenn and Henjes-Kunst*, 1992]. A pre-Granite Harbour subvolcanic andesitic unit the Johnnie Walker formation [*Tessensohn et al.*, 1992; *Molzahn et al.*, 1996] is marked with an asterisk in Figure 6.

The long-wavelength NNW trending GITARA anomaly complex (GAC) of the Prince Albert Mountains does not seem to correspond to the outcropping Johnnie Walker formation in the Mawson Glacier area. It seems to be associated with the Granite Harbour Intrusives to the north of the Mawson Glacier. A 50 nT N-S trending magnetic high flanking the Kirkwood Range to the south of the Mawson Glacier (Plate 1) is composed of much higher frequency anomalies, which disappear in the upward continued map shown in Plate 2. These high-frequency anomalies could be related to basic volcanics of any age, including the Johnnie Walker formation, but the simplest explanation is that the sources are Jurassic Ferrar rocks which are extensive in this area [*Warren*, 1969].

From the structural point of view no evidence for either major NW to NNW trending fault zones of Ross age or more recent fault zones has been found along the coast. The most dominant structural features are small brittle faults which have a N-S to NE-SW trend [*Kleinschmidt and Matzer*, 1992]. There is thus no obvious geological explanation for the remarkable NNW trending B1 magnetic lineation bordering the GAC and representing the southern continuation of the Polar Plateau lineament system (Plates 1 and 2). To the north of the David Glacier, however, B1 correlates well with a major fault inferred from geological field work [*Pertusati et al.*, 1999], which relatively lowers the southwestern sector, as shown in Figure 4. The magnetics reveals that this fault continues to the south of the David Glacier. The B1 lineament then trends offshore, where it appears to be cut by N-S faults of the western Victoria Land basin. Further south a separate lineament, which we refer to as the Kirkwood Range lineament (KR in Plate 1), is related to a major N-S fault dipping east along the TAM front [*Warren*, 1969].

Delisle [1994] interpreted radio echo sounding data further inland, combined with the dip of the Kukri Peneplain and

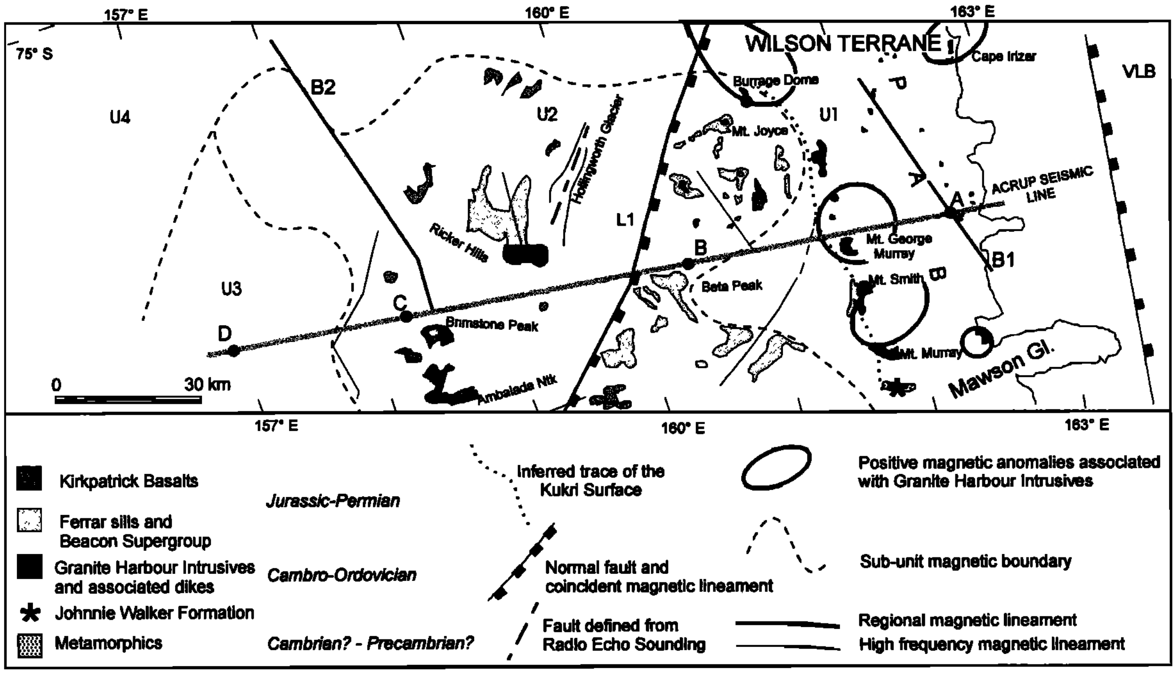

Figure 6. Magnetic interpretation superimposed upon geological map of a sector of the Prince Albert Mountains [from *Skinner and Ricker*, 1968]. Fault along the L1 magnetic lineament from *Pertusati et al.* [1999]. U1, U2, U3, U4 are the magnetic subunits in the ACRUP area *Bozzo et al.* [1997c]. U1 is part of the regional GITARA anomaly complex; U2 is part of the Mount Joyce quadrangle high-frequency anomaly pattern; U3 is a broad magnetic low; and U4 is again a high.

thickness of the Ferrar and Kirkpatrick rocks, to reveal major post-Jurassic faulting separating the Prince Albert Mountains region into discrete crustal blocks: the Mount Smith coastal block, the Mount Joyce–Beta Peak block, and the Brimstone Peak–Ricker Hills block at the edge of the Polar Plateau. The major fault dividing the Mount Joyce–Beta Peak block from the Brimstone Peak–Ricker Hills block was inferred by *Delisle* [1994] to run along the NE-SW trending Hollingworth Glacier. The major NE trending magnetic lineation (L1) is, however, interpreted to run not along the Hollingworth Glacier, but rather to the east of the glacier itself. This interpretation is also supported by new field work of the geological team of the PNRA (Programma Nazionale di Ricerche in Antartide). The major normal fault mapped by *Pertusati et al.* [1999] based on this new field work almost perfectly coincides with the L1 magnetic lineament (Figure 6).

Plate 1 shows that NE trends are present not only in the Mount Joyce quadrangle but also in the Convoy Range to the south. The lineations could be interpreted as faults due to NW-SE extension [*Ferraccioli et al.*, 1997] as independently interpreted from onshore structural data from southern Victoria Land [*Wilson*, 1995b].

5.3. Magnetic Models Along the ACRUP Seismic Line

In Figures 7a and 7b we present magnetic models along the ACRUP seismic line (Figure 6) across the Prince Albert Mountains [*ACRUP Working Group*, 1995]. The subice morphology used in the models was derived from radio echo sounding (RES) measurements collected in the Prince Albert Mountains area and along the ACRUP line itself. These measurements are described by *Reitmayr et al.* [1997].

The upper crustal structure model is shown in Figure 7a. The high-frequency anomalies are related to the presence of Jurassic Ferrar sills and Kirkpatrick lava flows, as seen from the geologic interpretation of the magnetic anomaly maps. The ACRUP seismic data also indicate an upper TAM unit, interpreted as sedimentary or volcanic rocks with a p wave velocity of 5.3–5.4 km/s thickening from about 1 km at the coast to about 3–4 km beyond shot point C at the edge of the Polar Plateau [*Della Vedova et al.*, 1997].

The magnetic model, in agreement with the geologic sections of *Wörner* [1992], shows that the tholeiitic cover rocks, if present at all, are not as thick at the coast, having likely been eroded because of the uplift of the TAM. The reported upper TAM seismic velocities at the coast probably indicate that the Ferrar sills intruded the granitoid basement, as was recognized further to the south [*Wörner*, 1992]. However, as shown in Figure 7a, unless these sills were much thicker than the 100–150 m recognized just north of Mount Murray, the high-amplitude (250 nT) Mount George Murray high cannot be related to sills intruding the basement. Thus other explanations for this anomaly are favored and are discussed later.

Proceeding inland across the Prince Albert Mountains toward the polar plateau, it was not possible to obtain a satisfactory fit between the observed and calculated anomalies by simply using the seismically derived thickness and geometry of the cover rocks [see *Della Vedova et al.*, 1997, Figure 5]. We further verified that the subice morphology on its own cannot account for the magnetic anomalies. A simple westward to southwestward tilt of the Kukri Peneplain (2°–3° [*Gunn and Warren*, 1962] or 1°–2° [*Wörner*, 1992]) would result in the base of Ferrar rocks at depth between −5000 to −1500 m beneath shot point C in the Brimstone Peak (BrPk) area. Our model

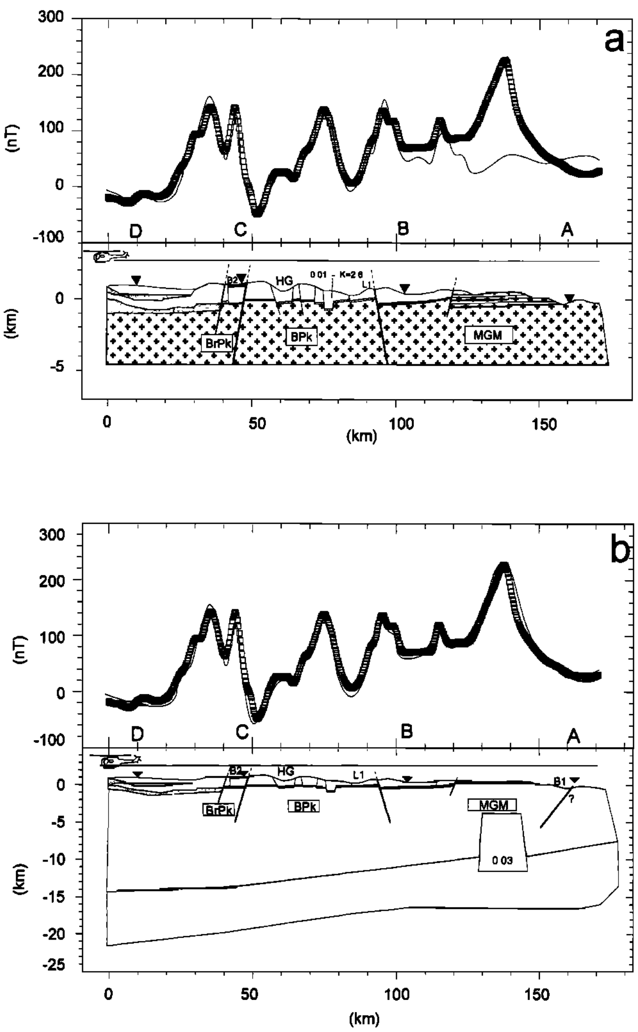

Figure 7. (a) Magnetic model of upper crustal structure along the ACRUP seismic line showing interpreted faults separating the Prince Albert Mountains tectonic blocks. K is the average remanence value used for the Jurassic Ferrar dolerite layer displayed as the unshaded region; shading indicates nonmagnetic Beacon sedimentary rocks. (b) Complete magnetic model. Note the intrusion-like body of probable Paleozoic age beneath Mount George Murray (MGM). Abbreviations are as follows: BPk, Beta Peak; BrPK, Brimstone Peak; HG, Hollingworth Glacier; others as in previous figures.

leads to a much shallower depth estimate (0 to −500 m range), though slightly deeper than the RES estimates (above +500 m) of *Delisle* [1994]. As noted by *Delisle* [1994], it is necessary to introduce a series of structural discontinuities, very likely representing faults, to reduce the discrepancy between the elevation of the Ferrar base and the Kukri Peneplain dip. The best solution we managed to achieve from magnetic models, though obviously not unambiguous, is shown in Figure 7a. For example, the Hollingworth Glacier (HG), which is a subice topographic low, is marked by a short-wavelength magnetic high, thus requiring a local thicker section of magnetic Jurassic rocks, possibly within a small graben. However, as already pointed out, this feature is unlikely to be one of the major fault zones of the region. At the edge of the Polar Plateau, positive correlation between magnetics and subice topography is seen in the area of seismic shot point D: A magnetic low, in fact, corresponds to a subice low. One possibility is that the broad magnetic low referred to as magnetic unit U3 by *Bozzo et al.* [1997c] is simply due to the weakly magnetic basement at depth, combined with ice cover. The other possibility, which we tend to favor from the magnetic models, is that the magnetic low also reveals a thicker, mainly sedimentary layer (most likely Beacon sediments) overlying weakly magnetic basement. The sedimentary layer is likely thinner to the northwest (unit U4 in Figure 6) where the magnetic field is again positive. We obtained a good fit by introducing a rather abrupt change in thickness of the cover rocks (Beacon rocks plus Jurassic tholeiites) between shot point C and D, likely revealing a major fault zone just to the east and possibly dipping west (B2?). A preliminary ACRUP seismic tomography image is qualitatively consistent with this interpretation, since it shows an uppermost crustal layer with a 4.5 km/s velocity mainly to the west of shot point C, compared to a higher-velocity uppermost crustal layer (5.2 km/s) to the east of C, as well as an abrupt change in basement relief in the same area [*Della Vedova et al.*, 1997, Figure 6].

In Figure 7b we propose a complete magnetic model of the Prince Albert Mountains along the ACRUP line. In particular, we focused on the Mount George Murray (MGM) anomaly (250 nT), which is part of the GITARA anomaly complex. Though this regional feature seems to mainly overlie outcrops of the Granite Harbour Intrusives, systematic magnetic measurements of these rocks has not been undertaken in this region yet. Thus rather than simply assuming that the sources of the GAC are the Paleozoic granitoids, *Ferraccioli et al.* [1997] presented a series of possible alternative hypotheses for the origin of the Mount George Murray anomaly. These hypotheses are briefly reviewed here:

1. The first hypothesis posits buried alkaline Cenozoic intrusive(s): Magnetic anomalies over the partially exposed alkaline mafic intrusives are typically much more intense (1000 nT range). From the geological point of view we would expect to find some evidence for Cenozoic intrusive magmatism (e.g., dike swarms) in outcrop if a major pluton were present at depth, which does not seem to be the case in the Prince Albert region.

2. The second hypothesis posits buried Jurassic tholeiitic intrusive(s): The large volumes of Ferrar and Kirkpatrick rocks exposed in the Prince Albert region might well indicate the presence of major mafic feeder bodies at depth [*Redfield and Behrendt*, 1992]. However, our calculations showed that a thick, layered gabbroic feeder body such as the Dufek intrusion near the Weddell Sea [*Behrendt et al.*, 1994; *Ferris et al.*, 1998] would cause a much more intense magnetic anomaly, especially if remanence similar to the one used for the Ferrar sills (K = 2.6 on average) is introduced in the model. No high-amplitude positive gravity anomaly such as the one detected over the Dufek intrusion [*Behrendt et al.*, 1974] was reported by *Reitmayr et al.* [1997] along the ACRUP line. There is no seismic evidence for a high-velocity layered complex at shallow depths in the new seismic results [*Della Vedova et al.*, 1997].

Our preferred model is thus that an Early Paleozoic intrusion is indeed the source of the Mount George Murray anomaly. Similar reasoning holds for the whole GITARA anomaly complex (Plates 1 and 2). Are these buried intrusives genetically linked to the volcanics of the Johnnie Walker formation?

6. Discussion

6.1. Boundary Between the Wilson "Terrane" and the Precambrian Shield

One of the fundamental issues with respect to the tectonic development of the Transantarctic Mountains–Ross Sea area concerns the existence, the position, the nature, and later role of the boundary between the Precambrian "shield" and the terranes involved in the Cambro-Ordovician Ross Orogen.

The magnetic model over the Polar Plateau of *Bosum et al.* [1989] shows that the crust at depth is more magnetic than over the adjacent Wilson Terrane (WT). The increased magnetization is interpreted by *Bosum et al.* [1989] to be old Precambrian basement compared to the weakly magnetic basement involved in the Ross Orogen. *Roland* [1991] also believed that the magnetic anomaly pattern beneath the Polar Plateau reveals the presence of the "shield," that is, a large area of exposed rocks in a craton [*Bates and Jackson*, 1987]. The boundary between the WT and the Precambrian shield has been interpreted by *Bosum et al.* [1989] to be marked by the eastern Polar Plateau lineament (Plates 1 and 2). *Roland* [1991] interpreted the lineament to be the southern continuation of the boundary between the shield and the Ross Orogen inferred from previous gravity and magnetics to lie between the Oates Coast and George V Coast [*Ushakov*, 1960] as shown in Figure 2.

Significantly, no Precambrian "shield rocks" are exposed along the Prince Albert Mountains, where the NW to NNW GITARA anomaly complex (GAC) lies on strike with the previously recognized Polar Plateau magnetic high. Our magnetic study indicates that the regional magnetic high over the Prince Albert Mountains could be related to Ross age intrusives rather than to a high-grade Precambrian shield. This is in part supported by ground magnetic measurements in the Terra Nova Bay region showing that to the west of the Campbell Glacier, magnetic anomalies can be correlated with a magnetite-rich suite of Ross age high-K calc-alkaline intrusives.

The magnetic maps we produced also reveal that there is not a single lineament concealed beneath the Polar Plateau, but at least two major lineaments forming a complicated lineament system (Polar Plateau lineament system). To the south the B1 lineament of the Prince Albert Mountains lies on strike with the western Polar Plateau lineament (Plate 1). However, as best seen in the upward continued map (Plate 2), the anomaly break across B1 is more similar to the break across the eastern Polar Plateau lineament. A right angle segment is inferred to link the two lineaments.

Hereafter we use the name "central Victoria Land boundary" (CVLB) for the remarkable eastern aeromagnetic lineament separating the Polar Plateau magnetic high from the TAM magnetic low and for B1 flanking to the east the GITARA anomaly complex of the Prince Albert Mountains (Figure 8).

According to *Kleinschmidt and Matzer* [1992], there is no major exposed fault along the coastal part of the Prince Albert Mountains. This makes interpretation of the CVLB difficult. We consider three possibilities:

1. Is the CVLB related to a major fault system of the Ross Orogen, as the NW trend of the boundary might suggest?
2. Does the CVLB area mark a transition zone between the Precambrian shield and the Wilson Terrane, and, if so, what tectonic setting could this transition zone correspond to?
3. Does the CVLB represent a major Jurassic or post-Jurassic normal and/or strike-slip fault zone?

To address question 1, we examined the structural architecture of Oates Land at the Pacific coast described by *Flöttmann and Kleinschmidt* [1993]. There two major NNW trending Ross age (470–490 Ma) thrust systems have been recognized: the Wilson and the Exiles thrust. The high-grade metamorphic basement of the central Wilson Terrane is detached and thrusts east and west over lower-grade forearc and back arc sedimentary rocks along the Wilson and Exiles thrust respectively, as shown also in the schematic cross section of Figure 8.

A remarkable aeromagnetic lineation detected from GANOVEX V data in Oates Land was named by *Damaske and Bosum* [1993] the "Matusevich line": It coincides with the location of the Exiles thrust [*Flöttmann et al.*, 1993]. A narrow, 10 km wide linear anomaly enhances the magnetic signature of the Exiles thrust to the north; it is indicated with D2 in Figure 8. This feature is strikingly similar to the linear anomaly D1 at the CVLB (Plate 1) beneath the Polar Plateau. We interpret the D2 magnetic feature in Oates Land to likely reflect syntectonic intrusives emplaced along a shear zone associated with the eastern Exiles thrust [*Flöttmann and Kleinschmidt*, 1993; *Schüssler*, 1995] and the D1 feature of the CVLB to reflect a similar shear zone associated with the southern continuation of the eastern Exiles thrust. The western Polar Plateau lineament might instead represent the southern continuation of the western Exiles thrust [*Schüssler*, 1995] as shown in Figure 8.

With regard to question 2, *Ferraccioli et al.* [1997] interpreted the anomalies of the GITARA anomaly complex within the Prince Albert Mountains region to reflect a "shield border zone." The term is used to indicate a transition zone between the Precambrian "shield" and the Wilson Terrane involved in the Ross Orogen.

According to *Tessensohn* [1997] the designation "terrane" is not appropriate for the Wilson Terrane. There in fact is no exposed terrane boundary between the East Antarctic craton and the in-board Wilson Terrane. The latter tectonic unit is interpreted to represent a magmatic arc developed at about 500 Ma at the edge of the East Antarctic craton in response to westward directed subduction beneath the craton. The Wilson "terrane" is not interpreted to be an allochtonous terrane docked against the craton, as the Bowers and Robertson Bay terranes are considered to be [*Tessensohn*, 1997; *Ricci et al.*, 1997].

According to *Flöttmann et al.* [1993], the Exiles thrust system of Oates Land is a foreland fold-thrust belt defining the boundary between the Ross Orogen and the East Antarctic craton. Our study indicates that the interpreted southern prosecution of this boundary zone has a prominent magnetic signature and that the anomalies in the boundary area may be related to a suite of Ross age intrusives. This is quite striking since no positive magnetic anomaly is detected over the main part of the Wilson "terrane" magmatic arc, contrary, for example, to the well-known Pacific Margin Anomaly over the more recent Antarctic Peninsula magmatic arc [*Garrett*, 1990]. Our magnetic models indicate that to fit the magnetic anomalies of the GITARA anomaly complex we have to introduce intrusive bodies with susceptibility values and dimensions similar to the intrusives marking the transition between the Antarctic Peninsula magmatic arc and the back arc region [*Johnson*, 1996]. We speculate that an arc–back arc tectonic setting at some stage of the Ross Orogen may be appropriate also for the magnetic "suite" of intrusives in the area of the central Victoria Land boundary. We speculate that an arc–back arc tectonic setting at some stage of the Ross Orogen may be appropriate also for the magnetic "suite" of intrusives in the area of the

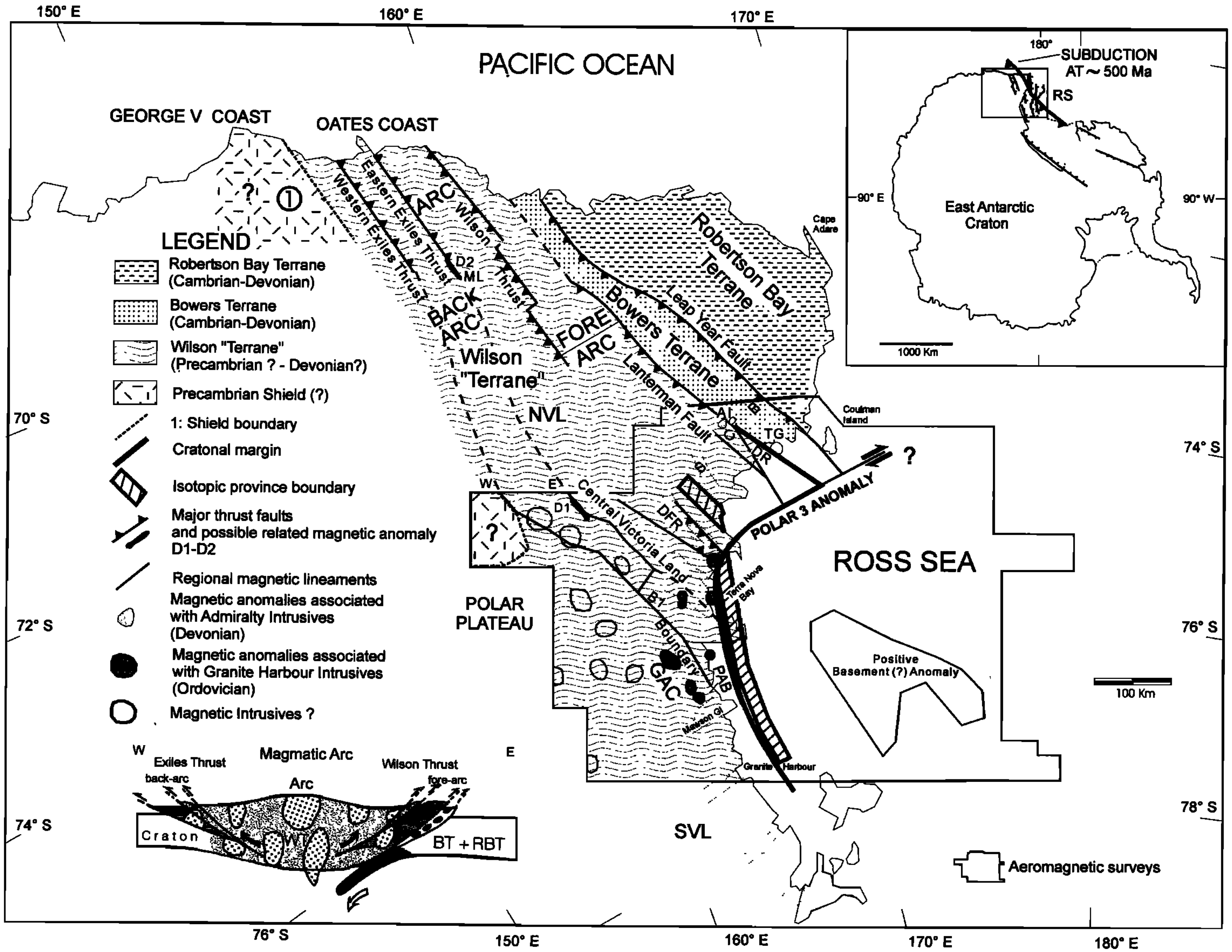

Figure 8. Crustal features of the Paleozoic terranes at the transition to the presumed Precambrian shield. The schematic cross section from *Flöttmann and Kleinschmidt* [1993] shows major tectonic components recognized along the paleo-Pacific convergent margin. The magnetic central Victoria Land boundary is interpreted to represent the unexposed southern continuation of the Ross age back arc eastern Exiles thrust marked to the north by the magnetic ML (Matusevich line). Magnetic basement similar to the area west of the CVLB may underlie the later Ross Sea rift. Also note the isotopic discontinuity in the area of the Campbell Glacier and its possible prosecution along the margin of the later Ross Sea rift [*Borg and DePaolo*, 1994]; as well as the possible inherited geometry of the cratonal margin [*Goodge and Dallmeyer*, 1996]. Abbreviations are as follows: AI, Admiralty Intrusives; TG, Tiger Gabbro; others as in previous figures.

central Victoria Land boundary. The higher amplitude magnetic anomaly farther to the west (Plates 1 and 2) may mark the true beginnings of the Precambrian Shield (Figure 8). In analogy to anomalies over Gawler craton rocks in Australia, *Finn et al.* [1999] indeed suggest the sources to be mafic middle to late Proterozoic igneous rocks.

A long-wavelength positive anomaly zone can be recognized at the easternmost Victoria Land basin, over the Coulman High and southern Central Trough (Plate 2). This feature may reveal that the Ross Sea rift is underlain by a Paleozoic(?) magnetic basement terrane, as inferred also by *Behrendt et al.* [1996]. Considering the amplitude of the anomaly, this magnetic basement could be of the same nature as the Early Paleozoic basement to the west of the central Victoria Land boundary (Figure 8).

With respect to question 3, the possible role of this boundary and other inferred or known inherited tectonic features in the later evolution of Victoria Land is discussed in section 6.2.

6.2. Inheritance and Tectonic Blocks of the TAM

6.2.1. Central Victoria Land boundary and the Prince Albert Mountains block. If we compare the high-frequency magnetic anomalies to the west and to the east of the central Victoria Land boundary, it is clear that the high-frequency pattern is much more developed to the west (Plate 1). We correlate these high-frequency anomalies to the Jurassic tholeiites outcropping the Mount Joyce–Convoy Range areas and buried under ice cover of the Polar Plateau (Figure 9).

The large difference in the volume of Jurassic tholeiites to the west and to the east of the central Victoria Land boundary could be due to (1) substantial post-Jurassic differential uplift between the Prince Albert Mountains block and the more highly uplifted northern Victoria Land blocks due to reactivation of the CVLB; (2) original differences in the Jurassic magmatic patterns in the two areas, influenced by reactivation in Jurassic times of a preexisting fault zone; or (3) a combination of the two factors.

Mazzarini et al. [1997, and references therein] interpreted differential uplift between the Prince Albert Mountains block (maximum 5–6 km) and the northern Victoria Land blocks (up to 10 km) to be linked to the presence of the David Glacier lineament as shown schematically also in Figure 9. Indeed a WNW, high-amplitude magnetic anomaly at Martin Nunatak (Plates 1 and 2) may be related to a thick layer of Kirkpatrick basalts within a downthrown block, associated with the David Glacier lineament. New apatite fission track data have been collected over the Prince Albert Mountains [*Balestrieri and Fioretti*, 1998] to verify the aeromagnetic interpretation of post-Jurassic faulting along the CVLB and David Glacier lineament. Tectonic relationships between the CVLB and the David Glacier lineament have not been studied here. However, it appears probable that the Mesozoic to Cenozoic(?) WNW trending transfer fault marked by the David Glacier lineament is strongly influenced, both in terms of location and kinematics, by the preexisting NW fault zone (F. Mazzarini, personal communication, 1997).

Recently, *Lisker et al.* [1997] presented apatite fission track evidence from Oates Land, combined with structural observations indicating that the Ross age Exiles thrust system was likely reactivated in the Cretaceous, but no clear indication for Cenozoic reactivation was found. We have presented magnetic arguments indicating that the central Victoria Land boundary could represent the unexposed southern continuation of the Exiles thrust system. This segment of the inherited fault system might also have played a fundamental role in the Cretaceous. Considering the abrupt change in the high-frequency "Jurassic pattern" across the CVLB, reactivation of this southern segment of the Exiles thrust in post-Jurassic times seems in fact likely. Strong support for this hypothesis is furnished by recent geologic mapping [*Pertusati et al.*, 1999] which shows a major post-Jurassic fault downthrown to the west at exactly the same location of the NW trending central Victoria Land boundary, just north of the David Glacier (Figure 4).

From the magnetic point of view there is no unambiguous indication for Cenozoic reactivation of the CVLB onshore. To the south of the David Glacier, the NNW central Victoria Land boundary appears to be cut by the westernmost N-S trending faults of the Victoria Land basin. The latter faults have experienced significant Cenozoic activity according to seismic results [*Del Ben et al.*, 1993]. However, offshore Granite Harbour (Plate 1), it is possible to recognize a NNW magnetic trend lying on strike with the CVLB. The magnetic trend matches a fault zone flanking the Terror rift which was active in post-Oligocene time [*Salvini et al.*, 1997].

Northeast to north-northeast trending magnetic lineations of the Prince Albert Mountains block could reflect Cretaceous and/or Cenozoic faulting oblique to the Ross Sea rift basins. The interpretative magnetic model we propose for the Prince Albert Mountains block is in general agreement with the interpretations of *Delisle* [1994], who described NE trending faults dividing the Prince Albert Mountains into discrete crustal blocks and with new geological field work in the area. The magnetic lineations could be interpreted as faults due to NW-SE extension [*Ferraccioli et al.*, 1997] as has been interpreted from onshore structural data from southern Victoria Land [*Wilson*, 1995a].

6.2.2. Wilson thrust and the Deep Freeze Range block. Two prominent NW magnetic lineaments follow the Priestley and Campbell Faults described by *Salvini et al.* [1997] as Cenozoic features. The faults represent the western and eastern edges of the Deep Freeze Range block flanking the Rennick Graben.

Kleinschmidt [1992] interpreted the ductile shear zones along the margin of the Campbell Glacier to reveal a probable continuation into the Terra Nova Bay region of the Ross age Wilson thrust recognized at the Oates Coast (Figures 2, 4, and 9). Close to the Priestley glacier, *Skinner* [1991] also described a Ross age thrust, the Boomerang thrust, with opposite sense of transport (SW directed) compared to the NE directed Wilson thrust (Figure 4). *Kleinschmidt* [1992] interpreted the Boomerang thrust to be a small conjugate thrust linked to the main Wilson thrust, rather than the southern continuation of the major Exiles thrust system.

A major geochemical and isotopic discontinuity within the Granite Harbour Intrusives occurs at the Tinker glacier, just west of the Campbell Glacier [*Rocchi et al.*, 1998]. The discontinuity may also divide arc-related magmatism to the north from island arc or back arc magmatism to the south [*Rocchi et al.*, 1994]. This fundamental break in the basement is significant, since only to the west of the nearby Campbell Fault are magnetic anomalies associated with the Ross age Granite Harbour Intrusives. Furthermore, a back arc tectonic setting to the south appears to be consistent with our magnetic interpretation.

A major tectonic lineament named the Rennick fault crosses northern Victoria Land and reaches the Deep Freeze Range [*Balestrieri et al.*, 1994]. This lineament is interpreted as a

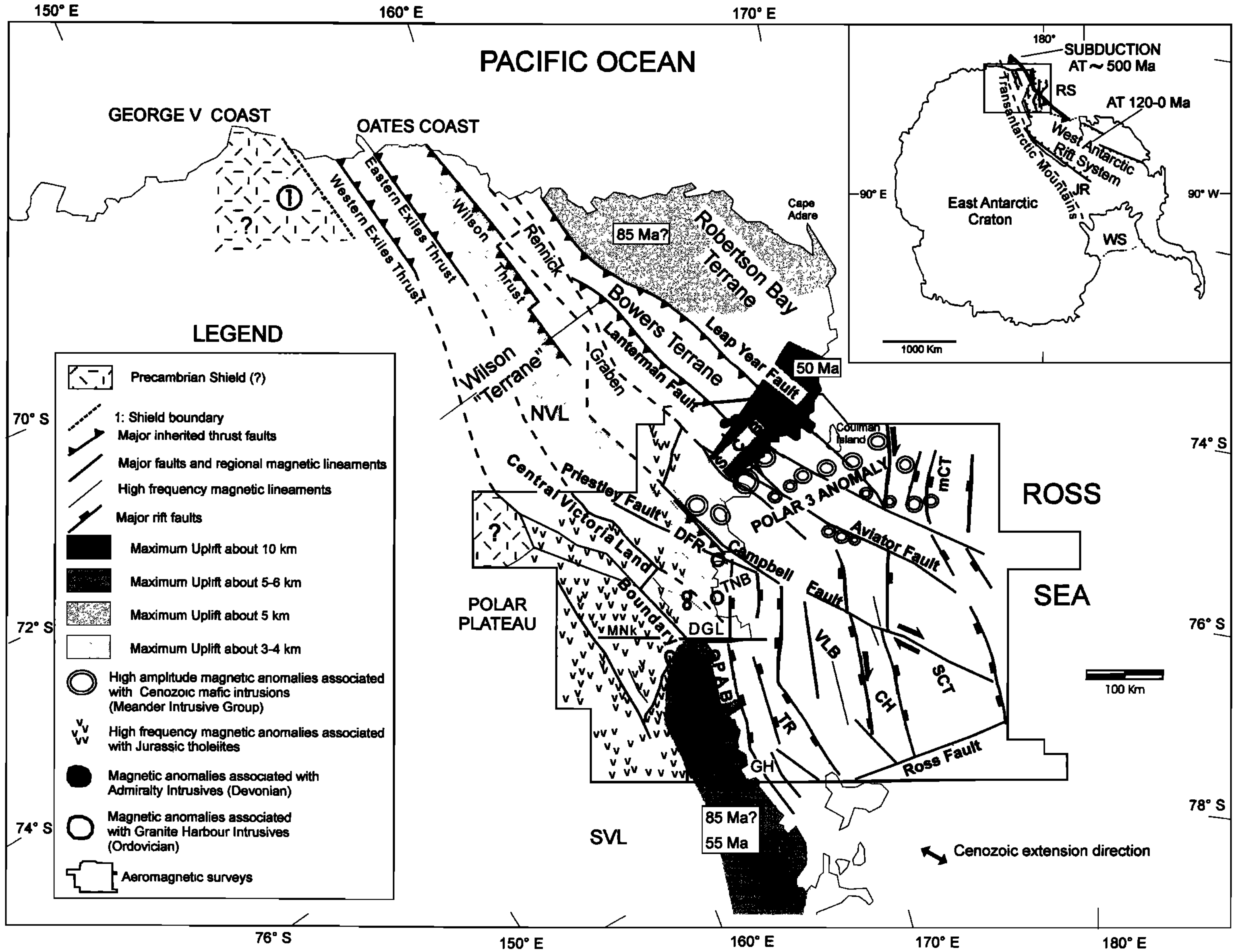

Figure 9. Interpretation of tectonic blocks forming the West Antarctic rift shoulder. Superimposed upon the inherited Paleozoic structural architecture of the region we display differential uplift of the Victoria Land TAM blocks derived from regional apatite fission track work summarized by *Mazzarini et al.* [1997] and variations in Jurassic and Cenozoic magmatic patterns revealed from our magnetic study. Abbreviations are as follows: GH, Granite Harbour; TR, Terror rift; VLB, Victoria Land basin; SCT, southern Central Trough; mCT, mid Central Trough; TNB, Terra Nova Bay; others as in previous figures.

fundamental boundary between two crustal blocks with different uplift histories. We speculate that this fault could well be associated with the major aeromagnetic lineament within the basement marking the Campbell Fault and the inferred southern continuation of the Wilson thrust system.

All these lines of evidence (structural, isotopic, apatite fission track studies, and magnetics) strongly suggest that the Deep Freeze block flanking the Rennick Graben developed in an area of important preexisting discontinuities within the basement.

6.2.3. Wilson-Bowers suture zone and the Southern Cross Mountains block. To the east of the Campbell Fault within the Southern Cross Mountains block (SCB), high-amplitude magnetic anomalies reveal large volumes of mafic-ultramafic intrusives associated with the alkaline Meander Intrusive Group (Eocene-Miocene) [*Tonarini et al.*, 1997]. The large extent of the inferred Cenozoic mafic and ultramafic intrusions revealed by magnetics, beneath the highly uplifted Southern Cross Mountains block, indicates that the vast thermal anomaly induced by the plutons might be an important factor in the uplift of this block.

To the west of Campbell Fault, such intrusive magmatism does not appear to be present; also volcanoes (namely, Mount Melbourne and Mount Overlord) are restricted to the SCB. Can this significant difference in volume of Cenozoic magmatism along the TAM rift shoulder be related to the inherited structural framework?

The SCB is characterized by the Lanterman Fault and Leap Year Fault which form a major Ross age NW trending fault zone marking the boundary between the Wilson "terrane" and the Bowers and Robertson Bay Terranes to the east [*Flöttmann and Kleinschmidt*, 1991]. According to previous studies the magnetic signature of the Wilson-Bowers suture zone onshore is modest [*Bozzo et al.*, 1995]. Indeed, our images also show that there is little magnetic contrast at the Ross Sea coast between the easternmost Wilson "terrane" and the Bowers Terrane. However, a magnetic trend can be detected over the Dessent Ridge (DR in Plate 1) bordering the Lanterman Fault, and an anomaly is close to the Tiger Gabbro in the Spatulate Ridge area. The NW magnetic trends are evident across the Polar 3 anomaly (Plate 1), where they match the offshore prosecution of the Leap Year and Lanterman Faults, as well as the Aviator Fault splay. The faults are interpreted from seismic data to be major faults reactivated in a right-lateral strike-slip regime in post-Oligocene time [*Salvini et al.*, 1997]. The Cenozoic intrusive centers revealed by the magnetics may have been preferentially emplaced in the Southern Cross Mountains–Polar 3 region where the crust was weaker because of the presence of a series of preexisting NW fault zones which favored magma ascent.

The ENE trend of the Polar 3 anomaly remains intriguing. *Behrendt et al.* [1991] interpreted the ENE trend of the Polar 3 anomaly as a major Cenozoic transfer fault zone linking offset segments of the Ross Sea rift basins. *Salvini et al.* [1997] argued that the ENE anomaly trend is not a Cenozoic transfer fault, but rather it is related to compressional deformation induced by the right-lateral strike-slip component along the NW faults. One possibility that we put forward is that the ENE trend may reflect an inherited feature further weakening the SCB region and thus also favoring the emplacement of the Cenozoic intrusives. A speculative ENE trending strike-slip fault has been inferred to exist at the same location by *Borg and DePaolo* [1994] at about 500 Ma based on isotopic mapping (Figure 8). *Goodge and Dallmeyer* [1996] further speculated that the cratonal margin inherited from Neoproterozoic rifting may have had a step-like geometry and that the ENE trend may have acted as a transform fault separating the northern and southern Victoria Land segments involved in the early stages of the Ross Orogen.

7. Conclusions

We interpret the magnetic data set over part of Victoria Land to show that segmentation of the TAM rift flank has very likely occurred and is probably related to the preexisting basement infrastructure. Comparison between magnetic anomaly patterns over the Prince Albert Mountains, Terra Nova Bay, the Deep Freeze Range at the southwestern flank of the Rennick Graben, the Southern Cross Mountains, and the western Ross Sea rift basins shows this segmentation. The main results of our study are as follows:

1. A NW to NNW trending regional magnetic lineament, which we name the central Victoria Land boundary, separates the Prince Albert Mountains to the south from the Terra Nova–Bay Deep Freeze Range regions to the north. It is interpreted to be the unexposed southern continuation of the Exiles thrust system recognized from geological field work and magnetics to the north at the Pacific coast. Magnetic anomalies in the central Victoria Land boundary zone are attributed to a suite of Ross age intrusives emplaced in a back arc tectonic setting at the transition between the Wilson "terrane" and the Precambrian East Antarctic shield.

2. The Prince Albert Mountains region was extensively effected by Jurassic tholeiitic magmatism as revealed by widespread high-frequency anomalies. Jurassic magmatism may have focussed along the preexisting central Victoria Land boundary zone. The abrupt difference in this magnetic anomaly pattern across the central Victoria Land boundary could also reveal that the boundary acted as a major fault in post-Jurassic times. Together with the David Glacier lineament it may well have influenced the tectonic patterns of the moderately uplifted Prince Albert Mountains block during rift/uplift phases occurring along the margin of the East Antarctic craton in the Mesozoic and maybe Cenozoic.

3. Magnetic lineaments can be recognized along the Cenozoic Priestley and Campbell Faults, flanking the Deep Freeze Range block at the southwestern edge of the Rennick Graben. These faults likely followed basement thrusts and discontinuities inherited from the Ross Orogen.

4. Only to the east of the Campbell Fault, within the Southern Cross Mountains Block (SCB), do high-amplitude magnetic anomalies reveal extensive rift-related alkaline mafic plutonism correlated with the Cenozoic Meander Intrusive Group. These intrusives are genetically related to the uplift of the SCB block. The intrusives were likely emplaced within weaker crust, compared to the adjacent TAM blocks, along the Ross age NW trending fault zones at the margin between the Wilson-Bowers and Robertson Bay Terranes. The prominent NW trends across the Polar 3 anomaly are linked to Cenozoic reactivation of these faults as interpreted from seismic data offshore. Major right-lateral offset along the NW trends is not, however, evident. The overall ENE trend of the Polar 3 anomaly may also be linked to an ancient inherited feature along the craton margin.

Overall, we show how the growing regional magnetic data set over Victoria Land and the adjacent Ross Sea is a valuable tool for studying the preexisting basement infrastructure of the

Transantarctic Mountains and its possible influence on the later tectonic blocks developed along the West Antarctic rift flank.

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E. Bozzo and F. Ferraccioli, Dipartimento per lo Studio del Territorio e delle sue Risorse, Università di Genova, Via le Benedetto XV, 5, 16132 Genova, Italy. (magne@dipteris.unige.it)

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