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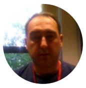

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Magmatic and tectonic patterns over the Northern Victoria Land sector of the Transantarctic Mountains from new aeromagnetic imaging

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ABSTRACT

New aeromagnetic data image the extent and spatial distribution of Cenozoic magmatism and older basement features over the Admiralty Block of the Transantarctic Mountains. Digital enhancement techniques image magmatic and tectonic features spanning in age from the Cambrian to the Neogene. Magnetic lineaments trace major fault zones, including NNW to NNE trending transtensional fault systems that appear to control the emplacement of Neogene age McMurdo volcanics. These faults represent splays from a major NW–SE oriented Cenozoic strike-slip fault belt, which reactivated the inherited early Paleozoic structural architecture. NE–SW oriented magnetic lineaments are also typical of the Admiralty Block and reflect post-Miocene age extensional faults. To re-investigate controversial relationships between strike-slip faulting, rifting, and Cenozoic magmatism, we combined the new aeromagnetic data with previous datasets over the Transantarctic Mountains and Ross Sea Rift. Two key observations can be made from our aeromagnetic compilation: 1) Cenozoic alkaline intrusions along the margin of the Ross Sea Rift lie oblique to the NW–SE strike-slip faults and are not significantly displaced by them; 2) the Southern Cross and the Admiralty Blocks are much more significantly affected by Cenozoic magmatism compared to the adjacent tectonic blocks, thereby indicating major tectono-magmatic segmentation of the Transantarctic Mountains rift flank. We put forward three alternative tectonic models to explain the puzzling observation that major Cenozoic alkaline intrusions emplaced along the Ross Sea Rift margin show no evidence for major strike-slip displacement. Our first model predicts that the alkaline intrusions were emplaced along left-lateral cross-faults, which accommodated distributed right-lateral shearing. In contrast, our second model does not require major distributed strike-slip shearing, and relates the emplacement of Cenozoic alkaline intrusions to sea-floor spreading in the Adare Basin, coupled with intracontinental transfer faulting. The third model is an attempt to reconcile the two opposing hypothesis and relies on a recent inference, which postulates that opening of the Adare Basin relates to fault splaying from the Balleny strike-slip fault zone. A low seismic velocity anomaly in the upper mantle appears to extend from the Ross Sea Rift under the Admiralty and Southern Cross Blocks of the Transantarctic Mountains. Lateral flow of hot upper mantle from the rifted region to the rift flank may explain the observed tectono-magmatic segmentation of the Transantarctic Mountains. We infer that this process caused a regional upwarp of the Curie isotherm under the Admiralty and Southern Cross Blocks of the Transantarctic Mountains, and facilitated extensional faulting, renewed uplift, and volcanism in the Neogene.

1. Introduction

The West Antarctic Rift System (WARS) is inferred to extend for over 3200 km (inset in Fig. 1) from the Ross Sea to the Bellingshausen Sea (Behrendt, 1999) and is characterized by widespread Cenozoic alkaline magmatism (LeMasurier and Thomson, 1990), which is largely buried beneath the West Antarctic Ice Sheet (Behrendt et al., 2004). The products of this long-lasting Cenozoic magmatic province are however relatively well-exposed in the Transantarctic Mountains (TAM), forming the uplifted flank of the WARS (ten Brink et al., 1997; Bialas et al., 2007). The driving mechanism for Cenozoic magmatism within the WARS (Behrendt, 1999) and along the TAM (Stern and ten Brink, 1989; Bialas et al., 2007) is still a matter of considerable debate and has been explained by contrasting models (Behrendt, 1999; Rocchi et al., 2002a).

Cenozoic alkaline plutons, dyke swarms and volcanoes outcrop in Northern Victoria Land (NVL), as shown in Fig. 1. These rocks provide key insights into the Cenozoic tectono-magmatic processes of the WARS (Rocchi et al., 2002a) and into coeval palaeo-environments

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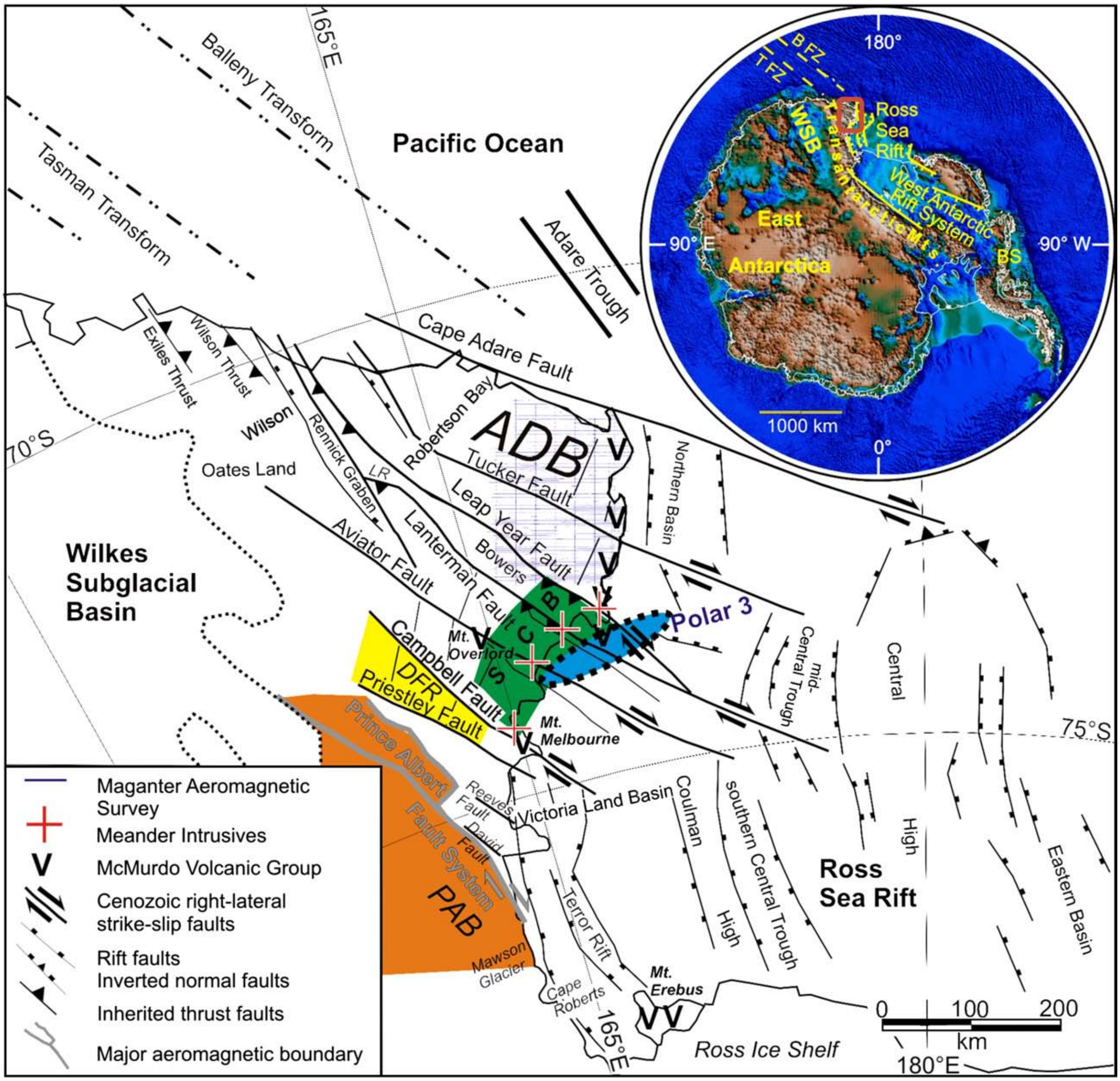

Fig. 1. Tectonic sketch map for Victoria Land (modified from Ferraccioli and Bozzo, 2003) showing major crustal blocks of the TAM (SCB: Southern Cross Block; DFR: Deep Freeze Range Block; PAB: Prince Albert Block; ADB; Admiralty Block). These TAM blocks are bounded by major early Paleozoic fault zones that were reactivated as right-lateral strike-slip faults in the Cenozoic (Salvini et al., 1997). These fault belts are also co-linear with major transforms and fracture zones in the Southern Ocean and may have accommodated differential shear along them (Storti et al., 2007). Mount Melbourne and Mt. Overlord volcanoes are located along the Campbell and Aviator faults respectively, two major strike-slip faults. Mt. Erebus is an active volcano at the southern end of the Terror Rift. Also note the location of the new MAGANTER aeromagnetic survey targeting the northern extent of the Cenozoic magmatic province of the TAM, and older basement features over the Admiralty Block. The position of the prominent Polar 3 aeromagnetic anomaly detected from a previous survey (Bosum et al., 1989) is also shown. The geological source and tectonic significance of this anomaly is re-discussed in the text. The colored map in the inset shows subglacial topography for the Antarctic continent and ocean floor bathymetry for the adjacent Southern Ocean (Lythe et al., 2001). The red box shows our aeromagnetic study area. Abbreviations: BFZ: Balleny Fracture Zone; TFZ: Tasman Fracture Zone; WSB: Wilkes Subglacial Basin; BS: Bellingshausen Sea.

(Armienti and Baroni, 1999; Smellie et al., 2007). The intrusive–subvolcanic rocks are known as the Meander Intrusives, while the volcanics are part of the McMurdo Volcanic Group (LeMasurier and Thomson, 1990). High-amplitude aeromagnetic anomalies have provided a useful geophysical tool to image the subglacial extent of Meander Intrusives and the McMurdo Volcanic Group over the Southern Cross Block of the TAM (Bosum et al., 1989; Ferraccioli and Bozzo, 1999). However, their sub-ice distribution further north, over the highly elevated Admiralty Block of the TAM (Van der Wateren and Cloetingh, 1999; Baroni et al., 2005), has remained elusive due to the lack of aeromagnetic coverage.

Geological investigations over NVL and seismic observations within the Ross Sea Rift have suggested that inherited Early Paleozoic structural features (e.g. Federico et al., 2006) may have been reactivated as major strike-slip faults in the Cenozoic and may act as a driver for Cenozoic magmatism (Salvini et al., 1997; Rocchi et al., 2005; Storti et al., 2007). The increasing availability of regional aeromagnetic coverage has assisted in delineating some inherited crustal features over NVL, and helped in assessing their possible Cenozoic reactivation (Ferraccioli and Bozzo, 2003). Inherited crustal features and later Cenozoic fault arrays are however less well-known over the Admiralty Mountains region, compared to other tectonic blocks further south.

To re-address this knowledge gap, we present and discuss the results of the new MAGANTER aeromagnetic survey over the Admiralty Block and merge this dataset with previous aeromagnetic

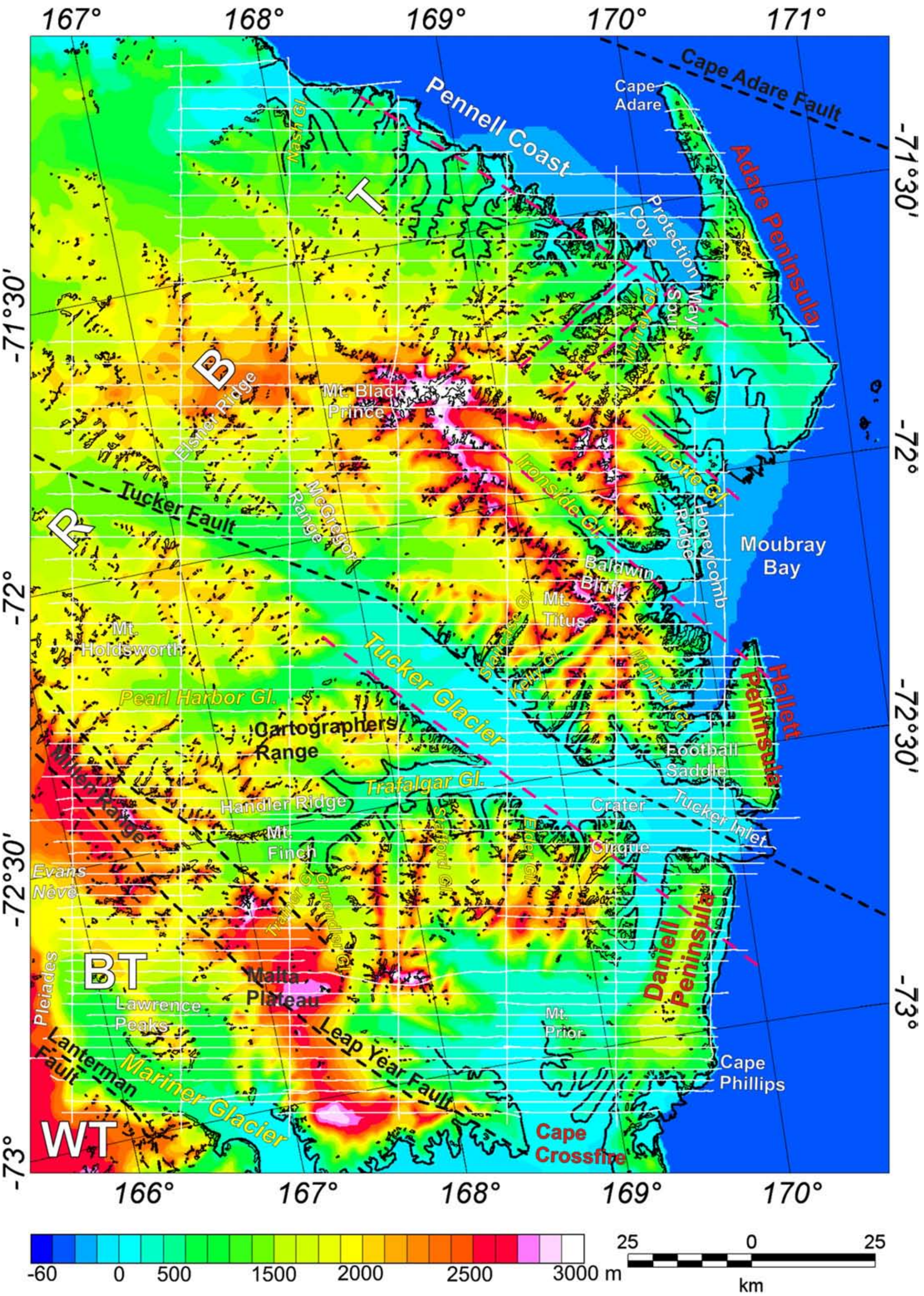

Fig. 2. Flight lines for the MAGANTER aeromagnetic survey (white) over the Admiralty Block superimposed upon a surface elevation digital model (Liu et al., 1999). Black dashed lines show major faults from Salvini et al. (1997) and dashed red lines show faults from Läufer et al. (2006b). Note that the aeromagnetic survey crosses the tectonic boundaries between the Wilson (WT), Bowers (BT) and Robertson Bay Terranes (RBT).

anomaly grids over NVL and the Ross Sea Rift region. With the aid of digital enhancement techniques we delineate magmatic features and tectonic structures ranging from Cambrian to Neogene Age. Our aeromagnetic interpretation raises intriguing new questions about the origin of Cenozoic magmatism and its relation with Cenozoic strike-slip faults over NVL, oceanic and continental rifts offshore, and possible thermal anomalies in the upper mantle.

2. Regional geological framework

NVL features a major NW–SE to NNW–SSE oriented fault belt formed during the early Paleozoic Ross Orogen (Fig. 1) (Ricci et al., 1997; Finn et al., 1999; Ferraccioli et al., 2002a; Federico et al., 2006). The Lanterman Fault marks the boundary between the Wilson and the Bowers terranes, while the Leap Year Fault separates the Bowers and the Robertson Bay Terranes (Capponi et al., 1999). Within the Wilson Terrane, the Wilson Thrust and the Exiles Thrust have been inferred to extend from Oates Land to the Ross Sea coast (Flöttmann and Kleinschmidt, 1991; Läufer et al., 2006a). Following the Ross Orogen, Devonian to Early Carboniferous Admiralty Intrusives and coeval Gallipoli Volcanics were emplaced (Fioretti et al., 1997a,b).

Several authors have proposed that reactivation of the early Paleozoic fault zones of NVL occurred and may have induced intraplate deformation within this part of Antarctica. Steinberger et al. (2004) suggested that this was accomplished mainly before 65 Ma. In contrast, Salvini et al. (1997) interpreted seismic evidence offshore and geological data onshore to suggest that reactivation began in Eocene times (Rossetti et al., 2006). Aeromagnetic evidence (Ferraccioli and Bozzo, 1999; Ferraccioli et al., 2003) suggests that these reactivated fault zones segment the TAM rift flank into several discrete tectonic blocks (Fig. 1). Deformation of Triassic Beacon and Jurassic Ferrar rocks and thrusting in the Lanterman Range (LR in Fig. 1) portrays post-Jurassic reactivation of the Lanterman Fault (Roland and Tessensohn, 1987). This deformation has been interpreted as caused by Cenozoic right-lateral strike-slip displacement along the Lanterman Fault (Rossetti et al., 2002), which also induced transtensional opening of the Rennick Graben (Rossetti et al., 2003; Armadillo et al., 2004). Dating of pseudotachylytes along the Priestley Fault (Storti et al., 2001) suggests reactivation at ~34 Ma (Di Vincenzo et al., 2004). Within the Ross Sea Rift right-lateral strike-slip faulting is seismically constrained to be post-RSU6. Negative and positive flower structures and fault inversions are imaged from seismic profiles and are kinematically consistent with post RSU6 right-lateral strike-slip faulting (Salvini et al., 1997). However, the age of this seismic unit is poorly known: it has been interpreted as post 34 Ma by Busetti (1994), or more recently about 17 Ma by Fielding et al. (2007).

The Ross Sea Rift basins are generally envisaged as having formed earlier in response to broad Basin and Range type extension, which ceased at about 85 Ma (Lawver and Gahagan 1994; Trey et al., 1999). Reactivation of the inherited Mesozoic rift basin faults may relate to later Cenozoic strike-slip faulting (Salvini et al., 1997), which affected mainly the western part of the Ross Sea Rift (Davey and Brancolini, 1995). The narrow Terror Rift within the Victoria Land Basin may have opened in response to Cenozoic strike-slip faulting within the western Ross Sea Rift (Salvini et al., 1997; Storti et al., 2001). Cenozoic transtension along the TAM–West Antarctic Rift System boundary has been documented from structural evidence over southern Victoria Land and from high resolution aeromagnetics (Wilson, 1995; Bozzo et al., 1997c). The amount of Cenozoic extension in the Ross Sea Rift is still hotly debated (Decesari et al., 2007). Marine geophysical data in the Adare Trough, suggests approximately 170 km of Cenozoic extension between East and West Antarctica between 43 and 26 Ma (Cande et al., 2000; Cande and Stock, 2006), which may have linked to continental extension within the Ross Sea Rift (Davey et al., 2006; Decesari et al., 2007).

Lithospheric-scale strike-slip deformation has been inferred to link to excess shear along major oceanic transform faults such as the Tasman Transform and the Balleny Transform (Storti et al., 2007) (Fig. 1). Such strike-slip deformation may have promoted transtension-related decompression melting of the mantle, thereby also triggering Cenozoic alkaline magmatism of NVL (Rocchi et al., 2002a, 2003, 2005).

Geochemical and geochronological investigations have been performed over the Cenozoic alkaline magmatic rocks of NVL, including the Meander Intrusives and McMurdo Volcanic Group (Rocchi et al., 2003). The Meander Intrusives are made up of gabbroic and syenitic rocks, either interlayered or mingled (Rocchi et al., 2002b). These plutons crop out between the Campbell Fault and the Leap Year Fault (Fig. 1) and are marked by high-amplitude positive aeromagnetic anomalies (Bosum et al., 1989; Müller et al., 1991). The gabbro-syenite plutons have ages between 23 and 48 Ma (Tonarini et al., 1997). Widespread Cenozoic dike swarms (47–35 Ma) crosscut Paleozoic basement rocks and the Cenozoic igneous complexes (Rocchi et al., 2003). The volcanic outcrops have been subdivided in Mt. Melbourne and Hallett volcanic provinces (Hamilton, 1972; Wörner and Veireck, 1989; LeMasurier and Thomson, 1990; McIntosh and Gamble, 1991; Nardini et al., 2003). NVL volcanics are sodic-alkaline and comprise a bimodal association of basalts and trachytes/rhyolites (Rocchi et al., 2002a). The ages of the volcanic rocks range between 13.8 and 2.2 Ma in the Hallett Coast area and <8.1 Ma in the Mt. Melbourne Volcanic Province. The overall geochemical composition of the Meander Intrusive Group overlaps that of the Melbourne Volcanic Province. High ratios of Nb and Ta relative to LILE and Y-HREE have been reported, which is characteristic of ocean-island basalts (Rocchi et al., 2002a). Intrusive rocks, dikes and younger volcanic rocks share similar trace element patterns (Rocchi et al., 2003).

3. Aeromagnetic survey

The aim of the MAGANTER aeromagnetic survey (Armadillo et al., 2006) was to trace the extent of Cenozoic magmatism north of Mariner Glacier over the highly uplifted Admiralty Mountains Block of the TAM (Van der Wateren and Cloetingh, 1999) and address its possible relationship with major fault zones. Approximately 11,000 line-km of data were collected over an area of 32,000 km^2 (Fig. 2). Line spacing was set to 4.4 km with tie lines 22 km apart, which is typical for reconnaissance aeromagnetic surveys over NVL (Damaske, 1994; Bozzo et al., 1999, 2002a,b; Chiappini et al., 2002). Over selected sectors a detailed, 2.2 km line-interval was adopted. Nominal survey flight altitude was 2700 m with areas flown at higher altitude (3000 and 3500 m), owing to the high elevations of the Admiralty Mountains. Aeromagnetic processing included post-processing of GPS data, magnetic base station correction, IGRF removal, levelling and microlevelling (Ferraccioli et al., 1998).

4. Total field aeromagnetic anomaly map

The new total field aeromagnetic anomaly map for the Admiralty Mountains region is shown in Fig. 3. By comparing the amplitudes, wavelengths, and trends of aeromagnetic anomalies with published geological maps (GANOVEX Team, 1987; Capponi et al., 1993) we identify and discuss the main geological and tectonic features of the region. High-amplitude (up to 600 nT), short-wavelength (<5 km), and mostly positive anomalies overlie Daniell Peninsula, Hallett Peninsula and Adare Peninsula. A prominent −350 nT anomaly lies west of Hallett Peninsula over the Football Saddle area. Another high-amplitude negative anomaly (−500 nT) overlies Cape Adare. Magnetic trends over Daniell Peninsula, Hallett Peninsula and Adare Peninsula are N–S to NNW–SSE oriented. These anomalies trace 13.8–2.2 Ma volcanic rocks assigned to the Hallett Volcanic Province (Smellie et al., 2007), part of the McMurdo Volcanic Group (LeMasurier and Thomson, 1990). A N–S oriented anomaly chain extends from Protection Cove and along Mayr Spur east of Murray Glacier and is interpreted to image largely ice-covered Cenozoic volcanics (Mortimer et al., 2007). A similar, but less prominent anomaly chain can be recognized in the Elder Glacier region to the south. A remarkable N–S oriented alignment of high-frequency aeromagnetic anomalies extend over the Malta Plateau as far north as Trafalgar Glacier, and is interpreted as delineating largely unexposed Cenozoic volcanics. Outcrops of these volcanic rocks have been recognized over Handler Ridge, Mt. Finch and in the Trainer and Gruendler glacier areas (Fig. 3 in Smellie et al., 2007). In the southwestern corner of the survey area high-amplitude aeromagnetic anomalies delineate another region of Cenozoic volcanics at the margin of the almost entirely ice-covered Evans Névé, and likely relate to exposures of these rocks over the Pleiades (Capponi et al., 1993).

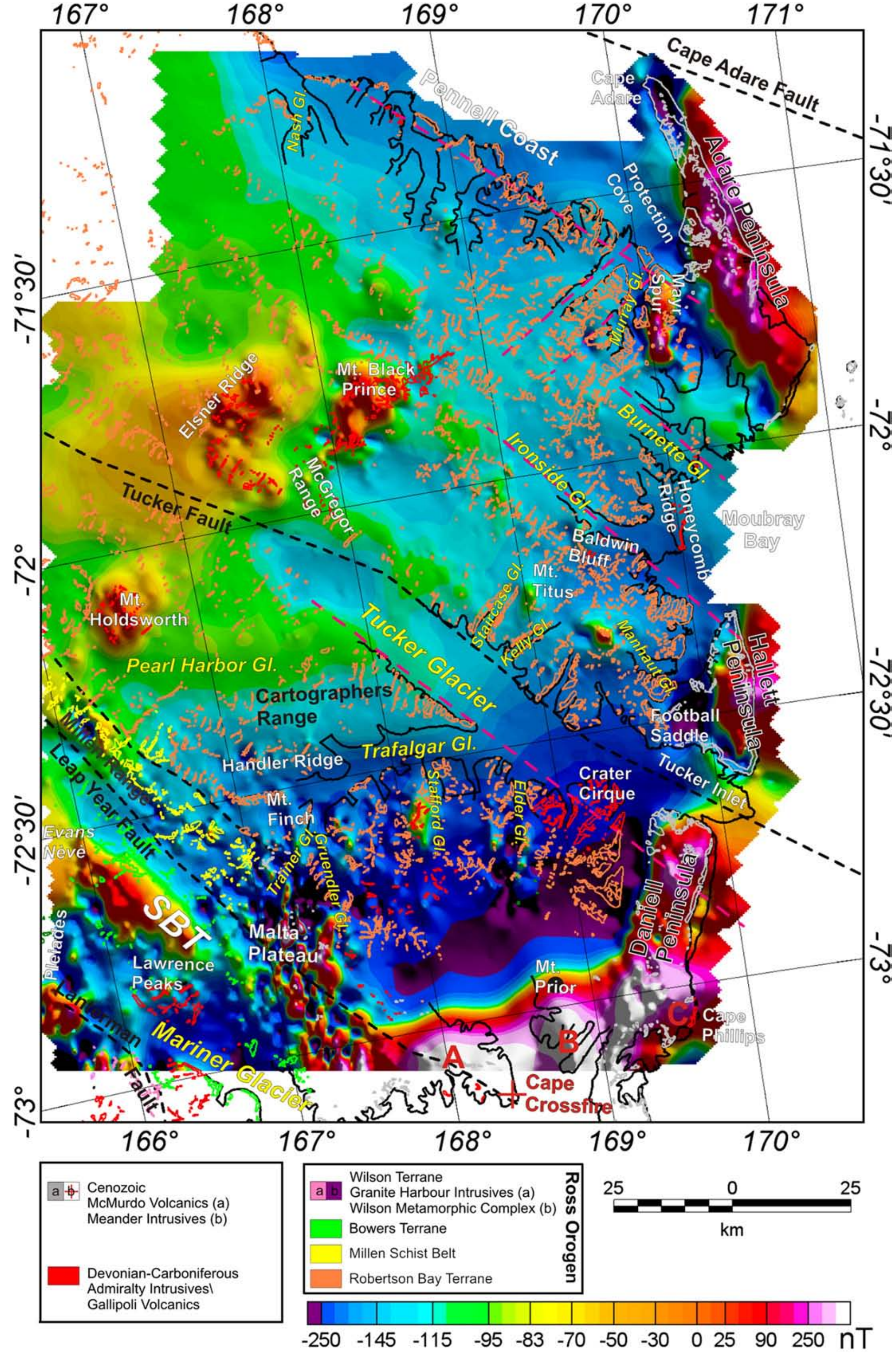

Fig. 3. Total field aeromagnetic anomaly map over the Admiralty Block superimposed upon a geological sketch map (modified from GANOVEX Team, 1987 ; Capponi et al., 1993). Aeromagnetic anomalies reveal rock types of Cambrian to Neogene Age (see text for explanation). High-amplitude, short-wavelength anomalies image Cenozoic volcanics of the McMurdo Volcanic Group, while discrete highs between the Malta Plateau and Daniell Peninsula (A–B–C), reveal three major Cenozoic intrusions, assigned to the Meander Intrusives. Black dot shows the position of Cenozoic dikes in the Mount Prior area (Rocchi et al., 2003).

A high-amplitude (>800 nT) anomaly (A) is interpreted as imaging the buried part of the Cape Crossfire Igneous Complex, the northernmost Meander Intrusive recognized so far from geological fieldwork (Rocchi et al., 2002b). Another two comparable aeromagnetic anomalies trace two inferred Meander Intrusives further to the east. The one south of Mt. Prior (B) is located near outcrops of Cenozoic

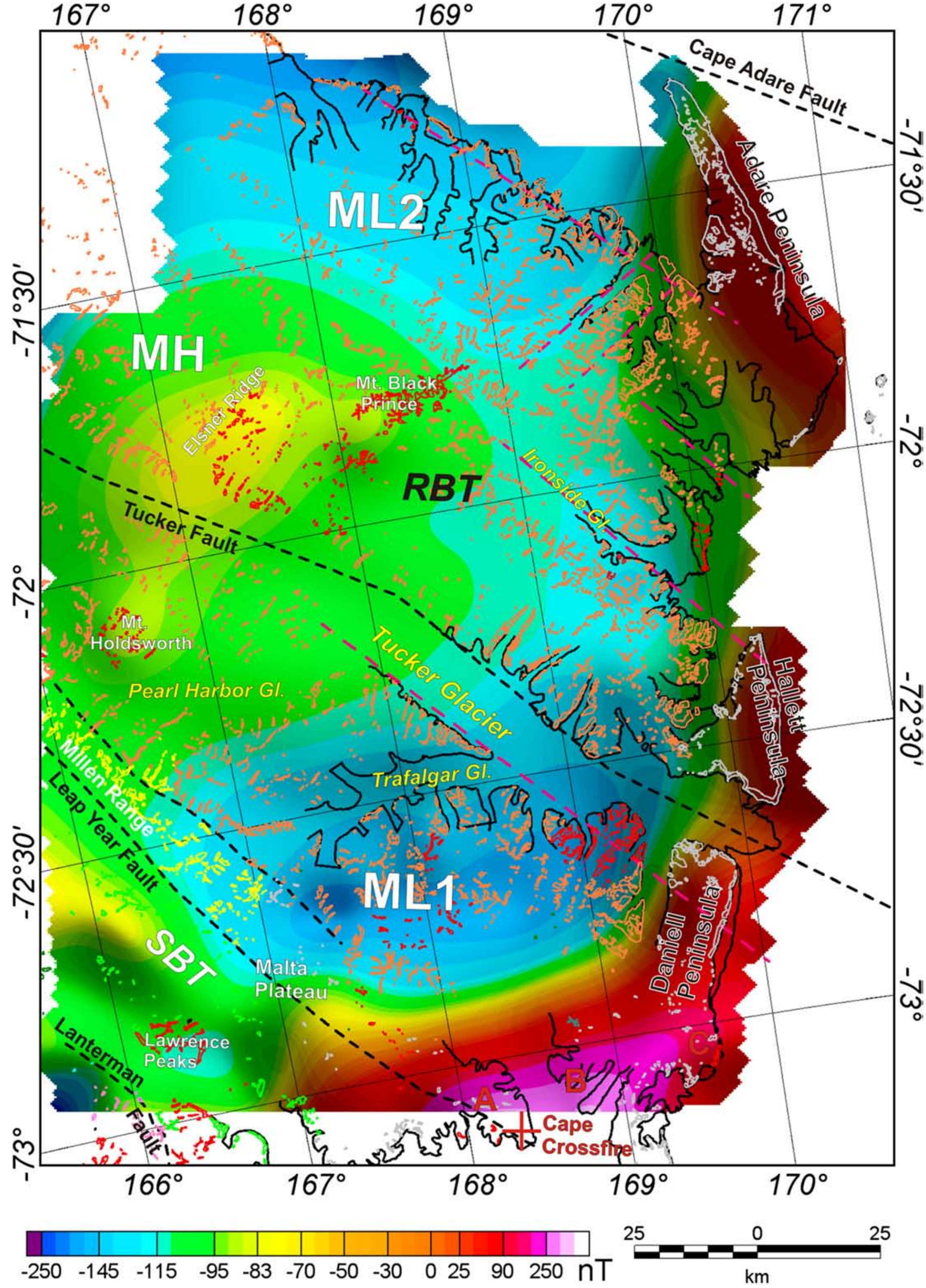

Fig. 4. Upward continued aeromagnetic anomaly map (10 km level) enhancing magnetic signatures from deeper geological sources over the Admiralty Block. Geological sketch map as in Fig. 3. The discrete high over the Elsner Range area, images an Admiralty Intrusive. A remarkable difference in the long-wavelength magnetic patterns characterizes the Robertson Bay Terrane, with two coastal lows (ML1 and ML2) surrounding a broad high (MH). The map enhances the E–W trend of buried Cenozoic intrusions between Malta Plateau and the base of the Daniell Peninsula.

dike swarms (Rocchi et al., 2003). The other possible intrusion (C) is more difficult to detect, but may underlie the Cenozoic volcanic rocks exposed at Cape Phillips.

The aeromagnetic patterns are also useful to image the older Paleozoic basement rocks (Fioretti et al., 1997a,b; Federico et al., 2006). In the Robertson Bay Terrane aeromagnetic anomalies with amplitudes up to 250 nT delineate approximately 360 Ma Admiralty Intrusives and associated Gallipoli Volcanics in the Mt. Black Prince area (Fioretti et al., 1997a). Gallipoli volcanic rocks at Lawrence Peaks (Mariner Glacier area) exhibit a prominent aeromagnetic signature in the Bowers Terrane (Fioretti et al., 1997a). Lower amplitude (up to 100 nT) anomalies map Admiralty Intrusives over the Elsner Range, north of the inferred Tucker Fault (Salvini et al., 1997) and over Mt. Holdsworth, north of Pearl Harbor Glacier. Three other Admiralty

Intrusives are interpreted from aeromagnetic data west of the Hallett Peninsula. One crops out along the western flank of Ironside Glacier at Baldwin Bluff (GANOVEX Team, 1987). A second intrusion lies at the head of Manhaut Glacier; it was not mapped previously, but was visited during the MAGANTER aeromagnetic survey (Rocchi pers. comm. 2002). A third intrusion is inferred to lie in the area of Mt. Titus, between Staircase and Kelley glaciers, but is currently unvisited. South of Trafalgar Glacier a discrete magnetic anomaly images an Admiralty Intrusive, emplaced on the western flank of the Stafford Glacier. However, many exposed Admiralty Intrusives of the Admiralty Block (e.g. Crater Cirque and Honeycomb Ridge) show no aeromagnetic signature. This is consistent with a bimodal distribution of magnetic susceptibilities, which identifies both low and highly magnetic suites of Admiralty Intrusives (Bozzo et al., 1995).

A NW–SE trending aeromagnetic high is imaged over the Bowers Terrane, where Cambrian Glasgow Volcanics crop out. We interpret this long-wavelength anomaly as reflecting buried mafic intrusions underlying the Cambrian volcanics. A remarkable contrast in the long-wavelength aeromagnetic anomaly pattern is detected over the Robertson Bay Terrane. An over 125 km-wide sector of the Robertson Bay Terrane between the Trafalgar Glacier to the south and the Nash Glacier in the northwest of the survey area features a broad and subdued magnetic high. In contrast, a regional magnetic low runs parallel to the coast over the rest of the Robertson Bay Terrane. The magnetic low is particularly prominent between Malta Plateau and Tucker Glacier.

Hereafter, we compare aeromagnetic lineaments and the gradients with inferred faults over the survey region. Just to the south of the aeromagnetic survey area, the Mariner Plateau contains a well-exposed section of the contact between the Wilson Terrane and the Bowers Terrane, which is marked by the inferred southern extension of the Lanterman Fault and associated fault strands (Capponi et al., 1993; Capponi et al., 1999). However, the inferred northern continuation of the Lanterman Fault (in the southwestern corner of the aeromagnetic image) displays only a weak signature related to gradients flanking magnetic anomalies associated with Cenozoic volcanic rocks (Fig. 3).

The tectonic boundary between the Bowers Terrane and the Robertson Bay Terrane is marked by the Leap Year Fault, which is bounded by a low-grade metamorphic belt with deformation ages of 480–490 Ma and known as the Millen Schist Belt (Capponi et al., 2004). Short-wavelength (10 km) aeromagnetic anomalies with amplitudes of 50 nT overlie outcrops of sheared greenschist facies metamorphic rocks assigned to the Millen Schist Belt.

The inferred Cenozoic Tucker Fault (Salvini et al., 1997) exhibits subtle magnetic gradients, for example along the southern flank of the McGregor Range, where it separates a magnetic high to the north-east from a corresponding low to the south-west. The long-wavelength character of the low-high couple suggests deep intra-basement sources. Further south over the Tucker Inlet a NW–SE gradient truncates the magnetic low between Malta Plateau and Tucker Glacier and may speculatively delineate the ice-covered Tucker Fault. However, Läufer et al. (2006b) suggested that the Tucker Fault lies further to the south, closer to the western flank of the Tucker Glacier, eventually cross-cutting the Daniell Peninsula. Notably subtle magnetic gradients can be recognized in the middle of the Tucker Glacier, east of the Cartographers Range, and may image a segment of the Tucker Fault.

Two NW–SE oriented Cenozoic strike-slip faults have been inferred by Läufer et al. (2006b) beneath the Ironside and Burnette glaciers in the Moubray Bay area between Hallett and Adare peninsula. A subtle NW–SE oriented magnetic grain can be recognized over the same general region. The remarkably linear NW–SE trend of the Pennell Coast may be related to a major Cenozoic strike-slip fault extending to the southern edge of the Adare Peninsula (Läufer et al., 2006b). Notably a weak NW–SE oriented magnetic gradient lies parallel to the coast in this area, although it appears to lie further inland.

5. Enhanced aeromagnetic images

5.1. Upward-continued aeromagnetic map

A set of enhanced images was compiled for advanced aeromagnetic anomaly interpretation over the Admiralty Mountains Block. Fig. 4 displays an upward continued aeromagnetic anomaly map at a 10 km observation level, which enhances signatures arising from deeper sources at the expense of shallower ones (Blakely, 1995). Our map significantly enhances the remarkable segmentation of the Robertson Bay Terrane into three distinct areas characterized by regional highs (MH) and lows respectively (ML1 and ML2). Within the Robertson Bay Terrane discrete aeromagnetic highs overlie the Devonian–Carboniferous Admiralty Intrusives over Mt Black Prince, Elsner Range and Mt Holdsworth, suggestive of thick intrusions. In contrast, the magnetic signatures over other occurrences of Admiralty Intrusives (e.g. in the Ironside and Trafalgar Glacier areas) are almost entirely smoothed out, indicating that these intrusions are not deeply rooted. Similarly magnetic signatures over shallow level Gallipoli Volcanics in the Lawrence Peaks area are entirely smoothed out. The NW–SE oriented magnetic high over the southern Bowers Terrane (SBT) images deep-seated mafic rocks beneath the Cambrian Glasgow Volcanics. High-frequency aeromagnetic anomalies over Cenozoic volcanics of the Malta Plateau have disappeared, while the anomalies over the Daniell, Hallett and Adare peninsulas are reduced to a broad regional high. This suggests that the thickness of the latter Cenozoic volcanics is significant. Finally, the upward continued aeromagnetic map enhances the ENE–WSW trend of the Meander Intrusives, between the Malta Plateau and the Daniell Peninsula.

5.2. Maximum horizontal gradient of pseudo-gravity and tilt derivative map

To detect the edges of magnetic source-bodies and lineaments we utilized the peaks of the maximum horizontal gradient of pseudo-gravity (Cordell and Grauch, 1985; Blakely and Simpson, 1986) and a modified tilt derivative filter (Verduzco et al., 2004) following Cooper and Cowan (2006). These enhanced magnetic maps were superimposed upon a Radarsat image and upon the regional geological sketch map (Fig. 5). Three sets of magnetic trends can be recognized with NW–SE, N–S, and NE–SW orientations respectively. These magnetic trends lie parallel to the main morphological alignments including glacier valleys and mountain crests, suggesting that the Cenozoic landscape of the Admiralty Mountains Block (Van der Wateren and Cloetingh, 1999; Baroni et al., 2005) is strongly controlled by tectonic structures.

The most evident magnetic trends to the north-east of the Tucker Fault (Salvini et al., 1997) are NE–SW oriented. For example, a prominent magnetic lineament and topographic scarp is defined along the western flank of the Murray Glacier and overlies a major normal fault, which dips steeply to the west (Läufer et al., 2006b). Another NE–SW oriented fault is inferred by Läufer et al. (2006b) to flank the Dugdale Glacier, but does not exhibit a comparable magnetic signature. A prominent NE–SW magnetic trend flanks the Mount Black Prince area. We interpret it as delineating a major fault flanking Admiralty Intrusives and Gallipoli Volcanics (Fioretti et al., 1997a). A set of NE–SW magnetic lineaments can be recognized between Tucker and Ironside Glaciers. These magnetic trends are inferred to mark faults controlling the location of several NE–SW oriented tributary glaciers (e.g. Staircase Glacier and Kelly Glacier) feeding into Tucker Glacier. The NE–SW trending fault sets we interpret appear to be truncated against the trace of the Tucker Fault (Salvini et al., 1997). However, the Tucker Fault itself does not show up in the maximum horizontal gradient of the pseudogravity map. South of the Tucker Fault a prominent NE–SW magnetic lineament is detected along the Lensen Glacier, a tributary of the Pearl Harbor Glacier. These NE–SW

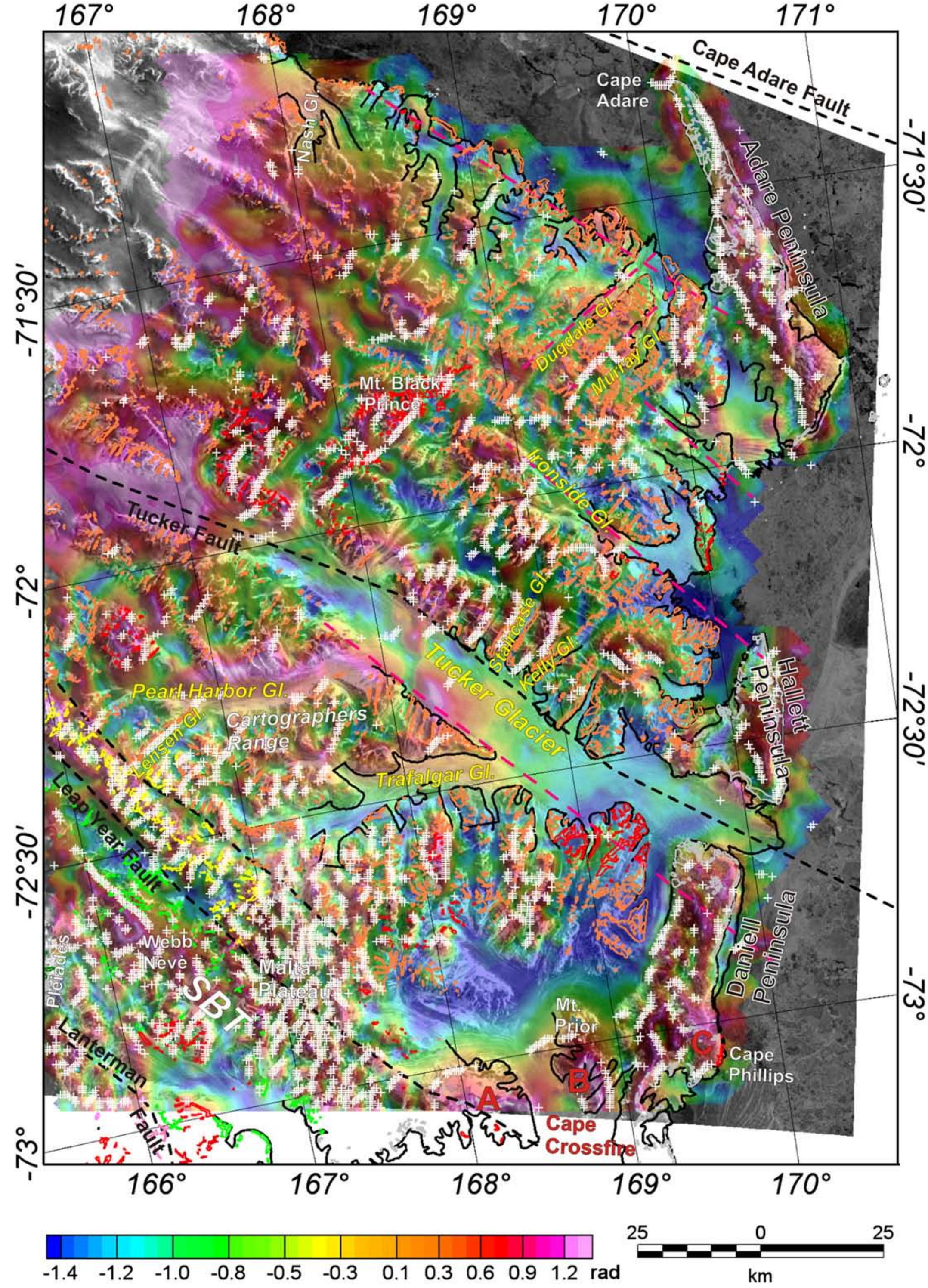

Fig. 5. Maximum horizontal gradient of pseudo-gravity and modified tilt derivative map superimposed upon a Radarsat image and the geological sketch map. The color scale refers to the modified tilt derivative values (Cooper and Cowan, 2006), while the white plus symbols show the peaks of the maximum horizontal gradient of pseudo-gravity (Blakely and Simpson, 1986). NE–SW, NNW–SSE and N–S oriented arrays of magnetic lineaments are imaged. These lineaments reflect major faults controlling the Cenozoic landscape of the Admiralty Block (Baroni et al., 2005; Faccenna et al., 2008).

oriented magnetic lineaments are interpreted to reflect major normal faults recognized from structural observations and interpretation of satellite images (Faccenna et al., 2008).

The most remarkable NW–SE magnetic lineament lies in the Webb Nèvè and is interpreted to reveal a fault zone flanking inferred mafic intrusions underlying Cambrian Glasgow Volcanics of the Southern Bowers Terrane (SBT). N–S to NNW–SSE oriented magnetic lineaments are detected along the Adare Peninsula and interpreted to mark hitherto unrecognized fault zones controlling the emplacement of Cenozoic volcanic rocks assigned to the Hallett Volcanic Province (Läufer et al., 2006b; Mortimer et al., 2007). Other less prominent N–S magnetic lineaments can be recognized in both the Hallett and Daniell

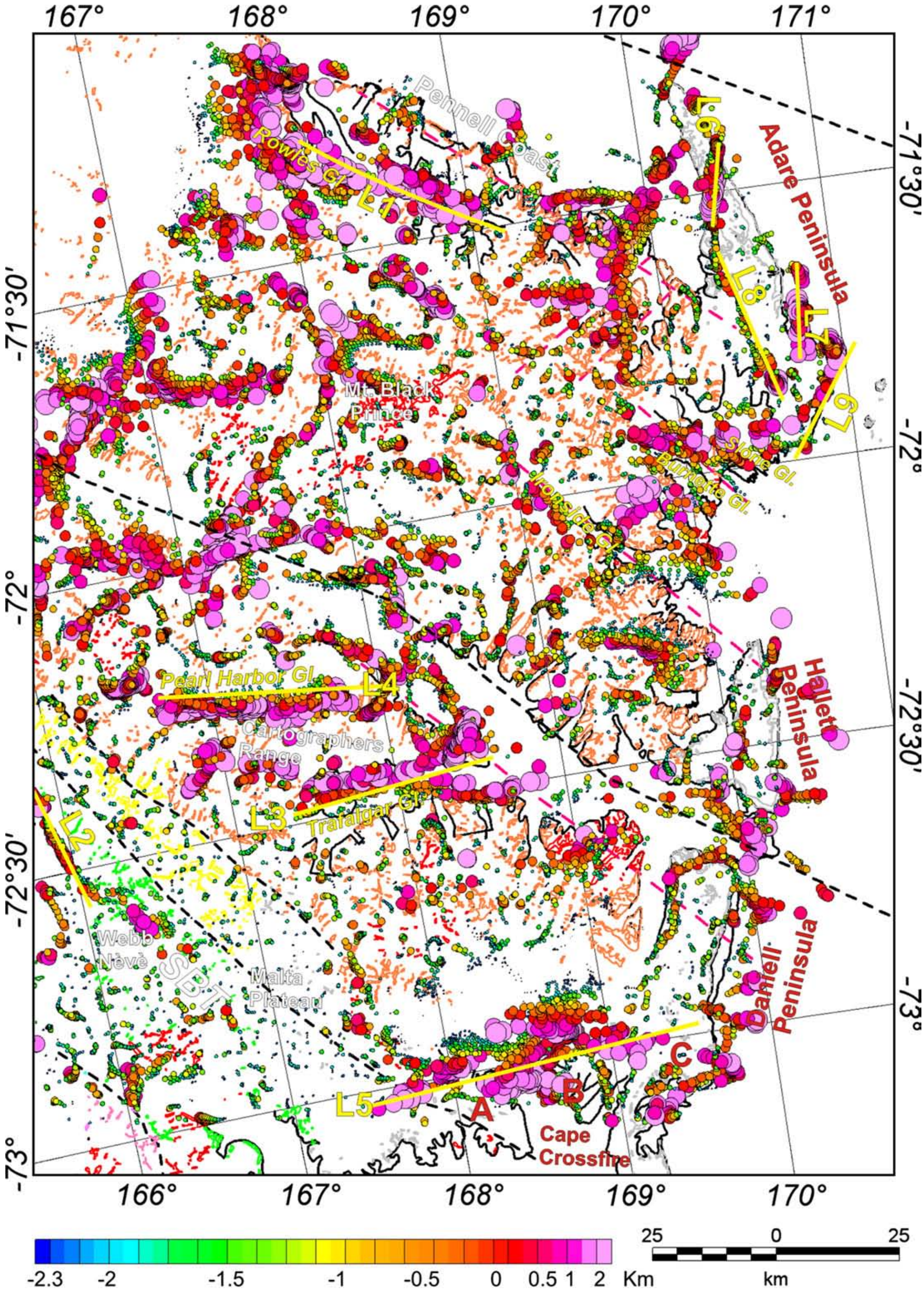

Fig. 6. Three-dimensional Euler Deconvolution map (structural index SI = 0) superimposed upon the geological sketch map. The color scale shows estimated depths of magnetic sources from sea-level (positive numbers are below sea-level). The diameter of the solution circles is proportional to the depth. Note in particular: i) a major NW–SE oriented lineament parallel to the Pennell Coast (L1); ii) NNE–SSW (L6, L7 and L9) and NNW–SSE (L8) trending lineaments in the Adare Peninsula region, iii) E–W oriented lineaments flanking the Cartographers Range (L3 and L4) and a sub-parallel lineament between Malta Plateau and Daniell Peninsula (L5). The latter lineament flanks Cenozoic Meander Intrusives (A, B and C). These lineaments reveal major fault systems of the Admiralty Block.

peninsulas and are interpreted as reflecting similar faults affecting Cenozoic volcanics. N–S trending magnetic lineaments are also detected in the Malta Plateau region and are interpreted as reflecting subglacial faults and associated Cenozoic volcanics rocks. NW–SE structural trends are imaged over the Millen Schist Belt, which decorates the tectonic boundary between the Bowers and the Robertson Bay Terranes (Capponi et al., 2004). East–West trends are detected over the Trafalgar and Pearl Harbor glaciers and are interpreted to image major faults flanking the Cartographers Range. At the base of the Daniell Peninsula the tilt derivatives locate the edge of an inferred Cenozoic Meander Intrusive (B), which lies to the south of Cenozoic dyke swarms mapped at Mt. Prior (Rocchi et al., 2003).

5.3. 3D Euler Deconvolution map

To estimate the depth and location of magnetic sources we applied 3D Euler Deconvolution (Reid et al., 1990) to the total field aeromagnetic grid. Fig. 6 shows the results for structural index SI = 0 and for a window size 3×3 grid cells (1320×1320 m). The map reveals a prominent NW–SE trending lineament (L1) over the Rowles Glacier region which lies parallel to a NW–SE trending fault located along the Pennell Coast and to other NW–SE oriented faults inferred to underlie the Burnette and Ironside glaciers further to the south (Läufer et al., 2006b). A NW–SE oriented magnetic lineament (L2) can be recognized over the Webb Nèvè, and is interpreted as imaging a fault flanking mafic intrusions within the southern Bowers Terrane (SBT). E–W trending magnetic lineaments (L3 and L4) are detected over Trafalgar and Pearl Harbor glaciers and may image fault zones flanking the Cartographers Range. An E–W trending lineament (L5) is also recognized between the Malta Plateau and the Daniell Peninsula and is inferred to delineate a fault zone flanking buried Cenozoic Meander Intrusive rocks. Relatively shallower source and NNE–SSW (L6–L7) to NNW–SSE (L8) trending magnetic lineaments are apparent over the Adare Peninsula. These lineaments are interpreted to delineate fault zones responsible for the emplacement of Cenozoic rocks of the Hallett Volcanic Province (Mortimer et al., 2007). A NE–SW trending lineament (L9) at the base of the Adare Peninsula may mark a normal fault zone recognized from geological data onshore (Läufer et al., 2006b) and an adjacent aeromagnetic survey (Damaske et al., 2007).

6. Aeromagnetic interpretation and regional compilation

A new geological sketch map was compiled by superimposing regional geological maps with our aeromagnetic interpretation over the Admiralty Mountains Block of the Transantarctic Mountains based upon total magnetic field and enhanced aeromagnetic images (Fig. 7). The contrasting long-wavelength aeromagnetic pattern over the Robertson Bay Terrane is interpreted as revealing different magnetic properties of basement rocks underlying the metasediments of the Robertson Bay Group. Petrological, geochemical and geochronological studies of crustal xenoliths suggests compositional heterogeneity of the intermediate to lower crust of the Robertson Bay Terrane (Gemelli et al., 2007). Contrasting crustal segments include juvenile Ross-age(?) mafic crust and granitic-like crust, which are interpreted to form the deep roots of the Robertson Bay Terrane (Gemelli et al., 2007). Speculatively the contrasting aeromagnetic signatures over the Robertson Bay Terrane could stem from this heterogeneity within the basement. Alternatively and/or additionally the broad magnetic low over the coastal parts of the Robertson Bay Terrane may be related to upwarp of the Curie isotherm as addressed further in the discussion.

By analogy with previous aeromagnetic interpretations over the northern part of the Bowers Terrane (Finn et al., 1999; Ferraccioli et al., 2002a) we propose that the long-wavelength aeromagnetic high detected over the southern part of the Bowers Terrane is caused by mafic basement of inferred fore-arc affinity underlying Cambrian-age Glasgow Volcanics. The Bowers and Robertson Bay Terranes are separated by the strongly sheared Millen Schist Belt, a complex tectonic amalgam of both terranes (Capponi et al., 2004). Similar high-frequency aeromagnetic patterns to those we detected over the Millen Schist Belt have also been interpreted further north, and may be imaging strongly sheared scraps of oceanic basement rocks (Finn et al., 1999; Ferraccioli et al., 2002a).

Our new interpretation map also shows the spatial distribution of magnetite-rich Admiralty Intrusives and associated Gallipoli Volcanics of Devonian–Carboniferous age (Fioretti et al., 1997a,b). Notably not all Admiralty Intrusives of the Admiralty Mountains Block exhibit a magnetic signature, consistent with previous aeromagnetic findings and magnetic susceptibility measurements over adjacent parts of NVL (Bozzo et al., 1995; Bozzo et al., 1999; Damaske et al., 2003).

The extent of Cenozoic magmatic rocks is also mapped. Meander Intrusives have been interpreted between Mariner Glacier and the Daniell Peninsula. At least two, possibly three intrusions are imaged from aeromagnetics. The E–W trend of these intrusions is oblique to the NW–SE oriented terrane boundaries and intra-terrane faults and to NE–SW trending normal faults of the Admiralty Mountains (Läufer et al., 2006b; Faccenna et al., 2008). It is also at high angle to the NNE–SSW, N–S and NNW–SSE oriented Cenozoic volcanics.

Cenozoic volcanic rocks of the Adare, Hallett and Daniell peninsulas fringe the western flank of the Northern Basin, which is part of the Ross Sea Rift (Davey and Brancolini, 1995; Decesari et al., 2007). The aeromagnetic data suggest strong tectonic control on the location of Neogene volcanic rocks in particular for the Adare Peninsula, where NNE–SSW to NNW–SSE oriented faults are most clearly imaged. Jordan (1981) and Läufer et al. (2006b) suggested that Neogene volcanism is synkinematic with transtensional faulting, and that faulting continued to be active after the volcanic activity had finished. The overall lozenge shape of aeromagnetic lineaments over the Adare Peninsula is interpreted to reflect a possible transtensional fault pattern, which facilitated Neogene magma emplacement. The prominent NE–SW aeromagnetic lineaments are interpreted to reflect normal faults of post-Late Miocene age (Faccenna et al., 2008).

Our magnetic interpretation indicates that N–S to NNW–SSE trending Cenozoic magmatism also extends further inland between Mariner Glacier and Trafalgar Glacier beneath the ice covered Malta Plateau. We suggest that this area forms a distinct Neogene volcano-tectonic rift zone, we name the Malta Plateau rift, which is located ~80 km to the west of the rift flank of the Northern Basin. This inferred volcano-tectonic rift zone is likely a brittle upper crustal feature that affected the TAM rift flank itself. We suggest that it represents a transtensional feature linked to complex fault splaying along NW–SE Cenozoic strike-slip faults, such as the Leap Year Fault (Salvini et al., 1997), and the aeromagnetically imaged Trafalgar Fault. Aeromagnetic patterns suggest that inheritance played an important role for Neogene volcanic rock emplacement in the inferred Malta Plateau rift. The linear magnetic fabric observed over fault zones assigned to the Ross-age Millen Schist Belt (Capponi et al., 2004) continues into the Malta Plateau region, providing clear evidence for structural inheritance affecting the emplacement of Neogene volcanics. The Cartographers Range is instead interpreted as a transpressional push-up structure related to a sharp E–W bend in the major NW–SE oriented Cenozoic strike-slip fault systems.

To place the new aeromagnetic results over the Admiralty Mountains Block in a broader regional context we compiled a new aeromagnetic map for the Transantarctic Mountains and the adjacent Ross Sea Rift (Fig. 8). The map was derived by combining the new Maganter aeromagnetic grid with previous aeromagnetic grids (Bosum et al., 1989; Bozzo et al., 1997a,b, 1999 and 2002a,b; Chiappini et al., 2002; Damaske et al., 2003), using the grid stitching technique described by Johnson et al. (1999). Additionally, we utilized the ANTOSTRAT (1995) database to trace the extent of the Northern Basin and also incorporated some recently published aeromagnetic interpretations over the Adare Trough and Northern Basin (Damaske et al., 2007).

7. Discussion

7.1. Contrasting models for Cenozoic magmatism of the West Antarctic Rift System and TAM rift flank

Cenozoic rocks over NVL share several geochemical patterns typical of the alkaline magmatic rocks within the WARS as a whole. These rocks resemble ocean island basalts (OIB) with HIMU (High $\mu = {}^{238}U/{}^{204}Pb$) affinity (Hart et al., 1997), a characteristic that may be

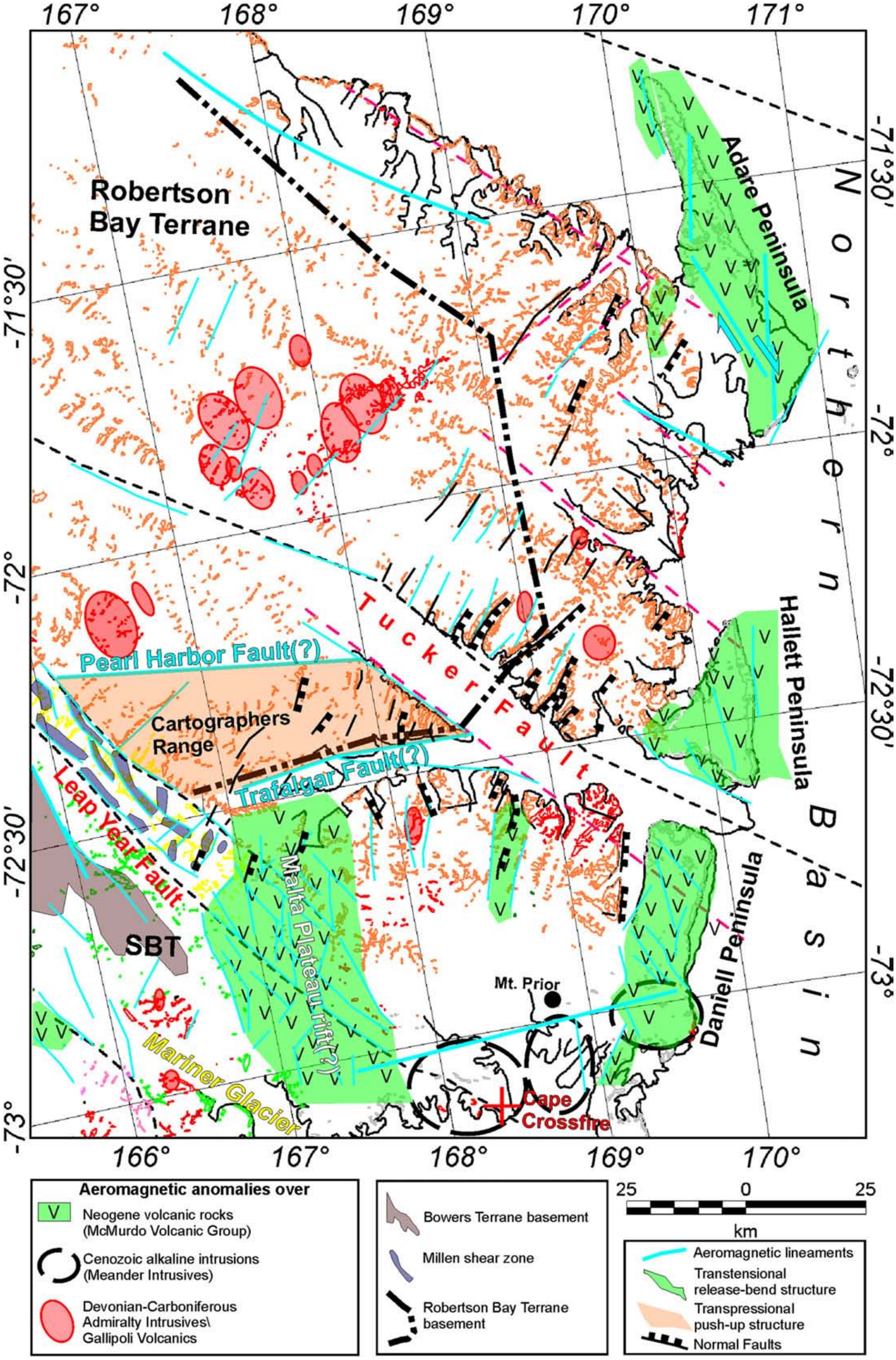

Fig. 7. Aeromagnetic interpretation map for the Admiralty Block of the TAM superimposed upon the geological sketch map. Aeromagnetic anomaly patterns trace the subglacial extent of Neogene volcanic rocks, Cenozoic alkaline intrusions, and Devonian–Carboniferous Admiralty Intrusives and associated Gallipoli Volcanics. Note the location of anomalies related to basement rocks underlying the Bowers and Robertson Bay Terranes. Aeromagnetic lineaments are displayed in blue and are interpreted as revealing major faults. Several NE–SW oriented magnetic lineaments correlate well with NE–SW trending normal faults of late Cenozoic age (Faccenna et al., 2008). A transtensional release-bend structure, associated to Cenozoic right-lateral strike-slip faulting is identified and flanks volcanic rocks of the Adare Peninsula. The newly inferred Malta Plateau rift may be a comparable transtensional structure. A transpressional push-up structure flanks the Cartographers Range and is associated with a sharp E–W bend in the trace of major NW–SE oriented strike-slip faults.

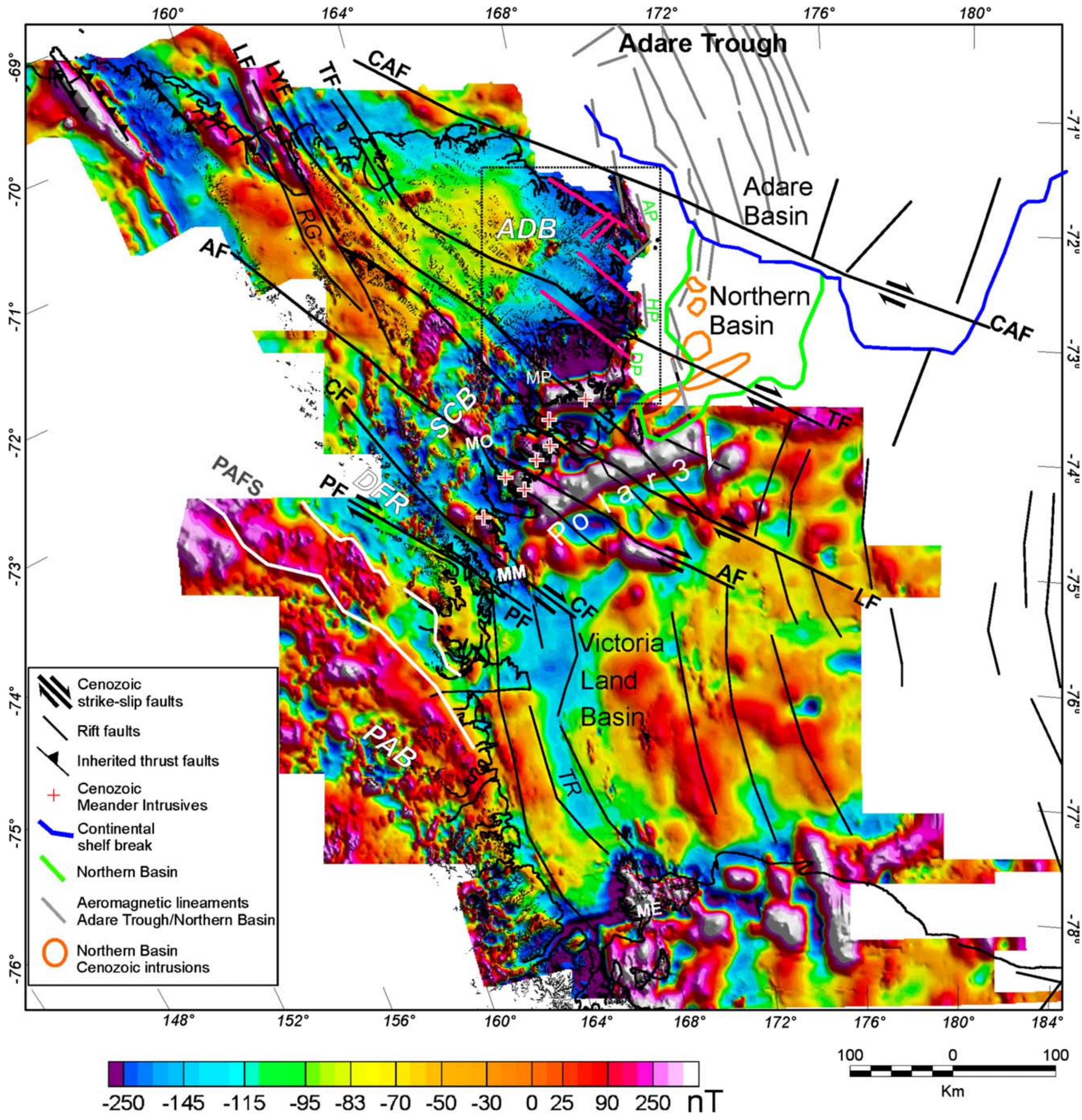

Fig. 8. New aeromagnetic anomaly compilation for the TAM and adjacent Ross Sea Rift. Black outlines denote outcrops areas of the TAM. Dotted line shows the new MAGANTER survey. Note the contrasting magnetic anomaly patterns over the Admiralty Block (ADB), the Southern Cross Block (SCB), the Deep Freeze Range (DFR) and the Prince Albert Block (PAB). Recent aeromagnetic interpretations over the Adare Trough and Northern Basin region (Damaske et al., 2007) are also shown. The Polar 3 aeromagnetic anomaly and the newly detected anomalies between Malta Plateau (MP) and the Daniell Peninsula (DP) are related to Cenozoic intrusions emplaced along approximately E–W oriented trends, which are highly oblique to the NW–SE oriented Cenozoic strike-slip faults. Other abbreviations as follows: CAF—Cape Adare Fault; TF—Tucker Fault; LYF—Leap Year Fault; LF—Lanterman Fault; RG: Rennick Graben; AF: Aviator Fault; CF: Campbell Fault; PF—Priestley Fault; PAFS—Prince Albert Fault System; TR—Terror Rift; DP, HP and AP—Daniell, Hallett and Adare peninsulas. Also note the location of major volcanoes: Mt Erebus (ME), Mount Melbourne (MM) and Mount Overlord (MO). The latter two appear to be spatially associated with major strike-slip faults.

attributed to subducted oceanic lithosphere transported back to the surface via mantle plumes (Hofmann, 2003). Indeed several models for the source and origin of Cenozoic magmatism have postulated the existence of a single large mantle plume or of several smaller plumes under the WARS (e.g. Behrendt, 1999; Storey et al., 1999), perhaps also impinging beneath the TAM and inducing thermal uplift (Stern and ten Brink, 1989). The lines of evidence for a possible mantle plume beneath the WARS have been summarised by Behrendt (1999) and include: (i) geochemical similarity between the basalts of the WARS and basalts typically associated with long-lived hot-spot tracks; (ii) the presence in Marie Byrd Land of large Cenozoic domal uplift patterns, coupled with horst and graben subglacial faulting (Ferraccioli et al., 2002b; Luyendyk et al., 2003); (iii) the inferred small magnitude of Cenozoic crustal extension in the WARS, which would appear to be insufficient to generate the huge volumes of Cenozoic magmatism inferred from aeromagnetics to lie within the Ross Sea Rift basins and beneath the West Antarctic Ice Sheet; (iv) high heat flow in the Ross Sea Rift area and beneath parts of the West Antarctic Ice Sheet (Della Vedova et al., 1992; Della Vedova and Pellis, 1994; Engelhardt, 2004; Maule et al., 2005); v) Additionally, Cenozoic alkaline magmatic provinces of the WARS appear to be underlain by slow velocity seismic anomalies, which could be due to elevated temperatures in the asthenosphere (e.g. Bannister et al., 2000; Danesi and Morelli, 2001; Shapiro and Ritzwoller, 2004; Lawrence et al., 2006a,b) induced by a mantle plume. Finn et al. (2005) argued, however, that most of the regions of slow seismic velocities beneath West Antarctica are restricted to the upper 250 km of the mantle, i.e. shallower compared to the >400 km detected for example beneath East African Rift System, which is typically envisaged to be underlain by a mantle plume.

The other end-member category of models accounts for Cenozoic alkaline magmatism without invoking a mantle plume origin. Early models by Fitzgerald et al. (1986) linked magmatism within the WARS with "passive" Cenozoic rifting, while Tessensohn and Wörner (1991) attributed it to "active" Cenozoic rifting. More recent models by Rocchi et al. (2002a, 2003, 2005) postulate that the middle Eocene increase in differential velocity along the Southern Ocean fracture zones (Fig. 1) induced dextral strike-slip motion along inherited Paleozoic faults of NVL (Salvini et al., 1997; Ferraccioli and Bozzo, 1999; Storti et al., 2007). Lithospheric-scale intraplate strike-slip deformation is envisaged as having promoted local decompression melting of the upper mantle source of Cenozoic alkaline magmas, which was metasomatically enriched during a previous amagmatic phase of late Cretaceous extension (Rocchi et al., 2005). Their model predicts that alkaline Cenozoic magma rose and was emplaced along NW–SE Cenozoic fault systems and along related N–S transtensional fault arrays (Salvini et al., 1997). An alternative model by Finn et al. (2005) envisages the Cenozoic magmatic province of the TAM as a small component of a huge long-lived, low-volume, diffuse alkaline magmatic province encompassing the easternmost part of the Indo-Australian Plate, West-Antarctica, and the southwest segment of the Pacific Plate. This model predicts that Cenozoic magmatism was caused by sudden detachment and sinking of subducted slabs, which triggered melting of previously metasomatised mantle lithosphere.

7.2. Alternative models for Cenozoic magmatism of the TAM based upon aeromagnetic interpretation

Of the several contrasting models that have been previously put forward to explain the origin of Cenozoic magmatism of the TAM, those that are arguably more readily testable from an aeromagnetic perspective include the strike-slip fault model (e.g. Salvini et al., 1997; Rocchi et al., 2002a) and the Cenozoic rifting model (e.g. Tessensohn and Wörner, 1991).

Our regional aeromagnetic map (Fig. 8) clearly shows the inherited NW–SE trending early Paleozoic structural grain over the TAM, particularly within the Wilson Terrane, the Bowers Terrane and along the boundary between the Bowers and Robertson Bay Terranes. Prominent magnetic gradients correspond to major NW–SE oriented fault zones such as the Prince Albert Fault System (Ferraccioli and Bozzo, 2003), the Priestley Fault (Storti et al., 2001), and the Campbell and Aviator faults (Salvini et al., 1997). There is an evident change in magnetic pattern north and south of the Campbell and Priestley faults (Ferraccioli and Bozzo, 1999). The magnetic break across the Campbell Fault also matches an isotopic discontinuity in the Ross-age basement rocks (Rocchi et al., 1998). In contrast, more subtle gradients mark the trace of the Lanterman Fault (Capponi et al., 1999; Rossetti et al., 2002) near the Ross Sea coast, as previously noted also by Bozzo et al. (1995). The addition of the new MAGANTER aeromagnetic grid now reveals segments of the Leap Year Fault and of the Tucker Fault. The geodynamic model of Salvini et al. (1997) predicts that all these inherited fault system were reactivated in the Cenozoic as major right-lateral strike-slip faults and Rocchi et al. (2002a) proposed that these intraplate strike-slip faults may have facilitated the emplacement of Cenozoic plutons, dyke swarms and the volcanic rocks. The reconnaissance character of the current aeromagnetic coverage does not allow for imaging of Cenozoic dyke swarms. However, it does enable recognition of major volcanic and intrusive complexes and allows us to re-investigate their spatial relation with regional strike-slip fault zones.

Several aeromagnetic observations remain puzzling in the context of the possible association between Cenozoic magmatism and NW–SE oriented strike-slip faulting. First, high-amplitude aeromagnetic anomalies between Malta Plateau and Daniell Peninsula suggest that Cenozoic Meander Intrusives lie at high-angle with respect to the NW–SE oriented strike-slip faults, but subparallel to the prominent Polar 3 aeromagnetic anomaly offshore. The ENE–SSW trend of the Polar 3 anomaly has been previously explained in two contrasting ways. Behrendt et al. (1996) interpreted the ENE–SSW magnetic trend as reflecting a leaky Cenozoic transfer fault linking extensional continental rifts, i.e. the Northern Basin and the Victoria Land Basin (Figs. 8 and 9a). Salvini et al. (1997) argued instead that the trend of the Polar 3 anomaly relates to a push-up basement structure, induced by right-lateral strike-slip faulting along NW–SE oriented faults (Fig. 9b). Similarity in magnetic anomaly patterns over the Polar 3 anomaly and the anomalies between the Malta Plateau and the Daniell Peninsula indicates that the sources for the Polar 3 anomaly are not basement rocks, but are Cenozoic intrusions assigned to the Meander Intrusives. In addition, several magnetic anomalies over the Southern Cross Block (Ferraccioli and Bozzo, 1999) clearly correspond to known outcrops of Meander Intrusives (Tonarini et al., 1997). New aeromagnetic data (Damaske et al., 2007) reveal the presence of similar Cenozoic intrusions also along the southwestern margin of the Northern Basin, and that are aligned with the Polar 3 and Malta Plateau anomalies (Figs. 8 and 9b–c). These observations on the location and trends of anomalies related to Cenozoic intrusions must also be coupled with the lack of any aeromagnetic evidence for major strike-slip displacement along NW–SE trends cutting across the Polar 3 anomaly.

The lack of aeromagnetic evidence for major strike-slip displacements of the alkaline intrusions is both intriguing and hard to reconcile with recent geodynamic models and structural observations over several fault zones of northern Victoria Land. One might infer that the strike-slip faults were active syn-magmatism, but then they became largely inactive, or that complex fault splaying has occurred, effectively dissipating motion along the NW–SE principal displacement zones of the faults along "secondary" fault arrays. The possibility that NW–SE strike-slip faults and magmatism were synchronously active, and that both faulting and intrusive magmatism may be diachronous over adjacent blocks of the TAM (Fig. 9c) has been presented by Rocchi et al. (2005). However, seismic interpretations indicate that strike-slip faulting is likely to have continued in Neogene times, at least along the offshore trace of the Campbell and Priestley faults (Rossetti et al., 2006). Structural data (Läufer et al., 2006b; Faccenna et al., 2008) and our aeromagnetic evidence onshore also suggest the occurrence of Neogene strike-slip faulting further north over the Admiralty Block. Hence we would expect to see some aeromagnetic indication for strike-slip motion across the Polar 3 anomaly, unless these displacements are of relatively small-magnitude. Equally intriguing is the high-angle of aeromagnetic anomaly trends related to these Cenozoic intrusions with respect to the NW–SE strike of the major strike-slip fault systems.

We suggest three alternative hypotheses to explain these aeromagnetic observations. Hypothesis one postulates that differential post-Eocene right-lateral strike-slip movement along NW–SE faults was accommodated not only by N–S to NNW–SSE oriented fault splays, but also by ENE–WSW trending cross-faults (Fig. 9c). Analogue modelling experiments using both brittle and viscous materials have been performed to investigate the development and interaction of strike-slip faults in zones of distributed shear (Schreurs, 2003). These experiments indicate that cross-faults, lying at a high-angle to the master faults and with an opposite sense of shear may develop in such

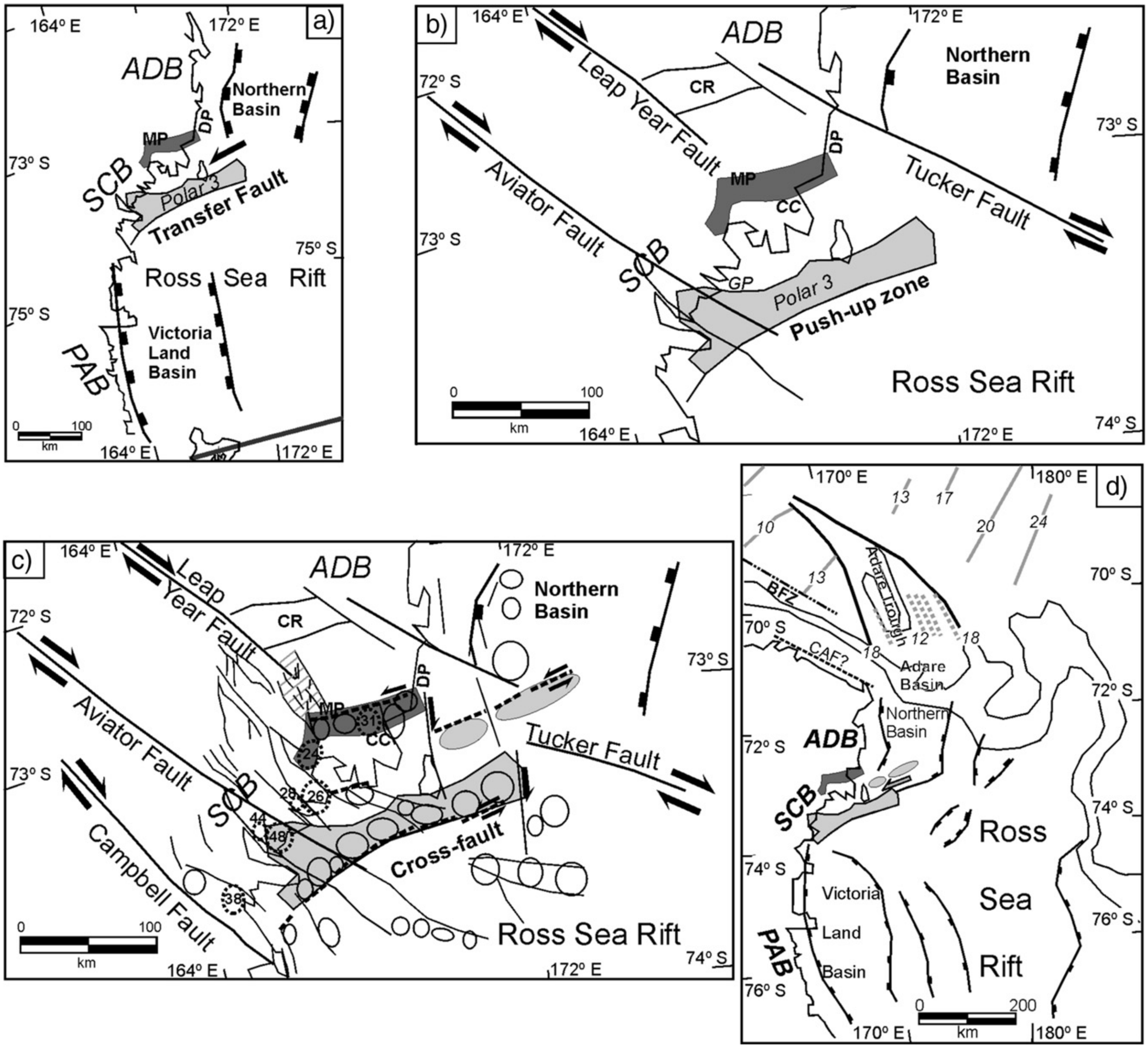

Fig. 9. Contrasting models for the tectonic setting along the Ross Sea Rift margin. Crustal blocks of the TAM: ADB: Admiralty Block; SCB: Southern Cross Block; PAB: Prince Albert Block. Panel a) leaky transfer fault model for the Polar 3 anomaly (light grey shading) modified from Behrendt et al. (1996). Darker grey shading indicates the location of sub-parallel anomalies between the Malta Plateau (MP) and the Daniell Peninsula (DP). The transfer fault would link two continental rift basins, the Northern Basin and the Victoria Land Basin, and the sources of the magnetic anomalies are Cenozoic intrusions; b) push-up strike-slip fault model modified from Salvini et al. (1997). In this model magnetic anomalies relate to uplifted basement sources in a restraining bend of a dextral strike-slip fault system, roughly parallel to the one we have interpreted over the Cartographers Range (CR). However, the occurrence of high amplitude anomalies over outcrops of Cenozoic intrusions at Greene Point (GP) and Cape Crossfire (CC) argues against this model. c) Cross-fault model: Cenozoic intrusions are emplaced along major cross-faults with left-lateral sense of shear that accommodate distributed right-lateral strike-slip deformation. Dotted circles are outcropping Cenozoic intrusions (numbers correspond to ages in Ma), while solid circles are intrusions interpreted from aeromagnetics. Apparent right-lateral displacements of alkaline intrusions at the eastern margin of the Polar 3 anomaly and Daniell Peninsula relate to Neogene transtensional faulting. Hatched grey pattern corresponds to the newly revealed Malta Plateau rift, an inferred transtensional fault splay of the Leap Year Fault. d) This model predicts that intracontinental transfer faulting links sea-floor spreading in the Adare Trough and Adare Basin with continental rifting in the Ross Sea Rift. Marine magnetic anomalies are shown in grey (Davey et al., 2006). Spreading occurred between 43 and 26 Ma, which overlaps with the age range of alkaline intrusions emplaced along the Ross Sea Rift margin (see panel c). This model argues against major coeval intraplate strike-slip deformations, in particular along the Cape Adare Fault (CAF) and along the inferred prosecution of the Balleny Fracture Zone (BFZ).

regions. By analogy, the ENE–WSW trend of the Malta Plateau and Polar 3 anomalies could relate to emplacement of Cenozoic alkaline intrusions along inferred left-lateral cross-faults, oriented at high-angle to a distributed NW–SE trending right-lateral strike-slip shear zone. Cross-faults with an opposite sense of slip to the master faults are known to occur over major strike-slip fault belts such as the San Andreas fault system, in SW Washington, and over the Dead Sea fault system (Wells, 1989; Petersen et al., 1991; Westaway, 1995).

Our second hypothesis (Fig. 9d) would be more incompatible with published strike-slip fault models for the NVL region (Salvini et al., 1997), but would be in better agreement with some previous marine geophysical interpretations (Cande and Stock, 2006; Davey et al., 2006). It suggests that Cenozoic oceanic spreading over the Adare Trough from 43–26 Ma (Cande et al., 2000) was linked to continental rifting over the western Ross Sea Rift via leaky transfer fault zones, which were oblique to the inherited NW–SE structural grain. Notably, the lack of any obvious displacements of magnetic anomalies 16 and 18 along the east side of the Adare Basin and Northern Basin argues against any major strike-slip displacement along at least one of the major faults inferred by Salvini et al. (1997), namely the Cape Adare

Fault (Cande and Stock, 2006; Davey et al., 2006). Recent aeromagnetic data over the western flank of the Adare Basin (Damaske et al., 2007) also suggests continuity in magnetic anomalies into the Northern Basin, supporting the lack of obvious strike-slip displacement along the inferred trace of the Cape Adare Fault (Fig. 8). If the second hypothesis holds true, then it would imply that the minor strike-slip faulting, which may have led to the emplacement of Cenozoic dyke swarms and volcanics (Rocchi et al., 2002a, 2003, 2005), was not responsible for the emplacement of the larger alkaline intrusions, which would instead be linked to sea-floor spreading and rifting in the Adare Trough and Adare Basin, coupled with intracontinental transfer faulting.

The third hypothesis is an attempt to reconcile hypotheses one and two. In this scenario sea-floor spreading in the Adare Basin and subsequent rifting within the Adare Trough itself (Müller et al., 2005) would relate to inferred, but as yet unproven fault splaying off the NW–SE oriented Balleny strike-slip fault belt, as hypothesised by Storti et al. (2007). In this scenario, sea-floor spreading in the Adare Basin sector, faulting along NW–SE oriented strike-slip faults, and ENE trending cross-faults in the continental crust of the TAM and western Ross Sea Rift region could be coeval, and led to emplacement of major alkaline intrusions. Some fault strands (e.g. parts of the Cape Adare Fault) could have remained largely inactive, thereby potentially explaining the lack of obvious displacements of marine magnetic anomalies. Displacements along the master faults inferred to cut across the Polar 3 anomaly would still be accommodated largely by the cross-faults, as predicted in hypothesis 1 (Fig. 9c). Later transtensional N–S to NNW oriented fault splays may have accommodated virtually all the residual shear along the main NW–SE oriented fault zones. Faulting may have continued to be active in Neogene times, allowing for the emplacement of volcanic rocks, e.g. along the rift flank of the Northern Basin, and further inland along the newly identified Malta Plateau rift (Figs. 7 and 9c). Notably, seismic profiles across the postulated right-lateral Balleny strike-slip deformation belt have been interpreted as revealing flower structures affecting sediments of inferred Neogene age in the southern Adare Trough and Adare Basin region (Fig. 3 in Storti et al., 2007).

Hypothesis one could be tested with detailed structural observations in the Malta Plateau region, to see if there is any evidence for left-lateral cross faults onshore, which would link to inferred distributed right-lateral shear. High-resolution aeromagnetic surveying over the Polar 3 region—e.g. similar to the Cape Roberts survey—(Ferraccioli and Bozzo, 2003), could reveal structural patterns in much greater detail and also target possible smaller-scale residual displacements along the NW–SE oriented master faults. Seismic imaging close to coast is challenging due to sea-ice cover, but if acquired, it would assist significantly in the structural interpretation of high-resolution aeromagnetic data. Testing hypothesis two would require integration of new aeromagnetic data with marine magnetic data over the Adare Trough and Adare Basin region, and further re-assessment of seismic data, which is already planned (Damaske, pers. comm., 2008). Verifying hypothesis three would require the acquisition of new aeromagnetic data over a much larger swath of the Southern Ocean, in particular over the inferred extension of the Balleny Fracture zone, which would be achievable by using long-range aircraft.

7.3. Cenozoic magmatism and inferred regional upwarp of the Curie isotherm

Our aeromagnetic compilation (Fig. 8) reveals that tectonic blocks of the TAM located to the northeast of the Campbell Fault, such as the Southern Cross Block and part of the Admiralty Block were significantly affected by Cenozoic magmatism, including both intrusive and volcanic components. Major volcanoes such as Mt. Melbourne and Mt. Overlord (Fig. 8) appear to be spatially associated with major Cenozoic strike-slip faults, such as the Campbell and Aviator faults (Ferraccioli et al., 2000). In contrast, tectonic blocks to the southwest of the Campbell Fault, such as the Deep Freeze Range Block, or the Prince Albert Block (Ferraccioli and Bozzo, 1999; Van der Wateren and Cloetingh, 1999) lack comparable high-amplitude anomalies, typically associated with Cenozoic magmatic rocks. Although major NW–SE oriented Cenozoic strike-slip faults flank the Prince Albert Mountains (Salvini and Storti, 1999; Ferraccioli and Bozzo, 2003) no major Cenozoic alkaline intrusions are present, and volcanics do not occur there either. Cenozoic dykes have been inferred along the Ross Sea Rift margin side of the Prince Albert Block by Rossetti et al. (2000), but subsequent geochemical and geochronological investigations reveal that these are Ross-age (Nardini et al., 2003).

Aeromagnetic and geological evidence reveals significant tectono-magmatic segmentation along the Cenozoic TAM rift flank. The outstanding open question is: what does the observed segmentation relate to? To address this question we analyzed the long-wavelength aeromagnetic anomaly pattern over the Ross Sea Rift and adjacent TAM. The long-wavelength aeromagnetic anomaly pattern provides a tool for evaluating the depth of the Curie isotherm (Blakely, 1995). Broad positive aeromagnetic anomalies are detected over a significant portion of the Ross Sea Rift (Figs. 8 and 10). Assuming that these anomalies are imaging pre-rift basement rocks, as interpreted over the adjacent TAM (Ferraccioli et al., 2002a), then a reasonable inference is that there appears to be no major upwarp of the Curie isotherm associated with postulated Cenozoic rifting affecting the broad Ross Sea Rift (Decesari et al., 2007). However, the impact of Cenozoic rifting is still subject to major debate and several authors (e.g. Karner et al., 2005) have suggested that distributed rifting was largely accomplished in the Cretaceous. A Cretaceous age for the wide-mode stage of continental rifting would likely imply that any major thermal anomaly associated to the rifting process would have decayed significantly (McKenzie, 1978). The narrow Terror Rift region stands in contrast to the regional magnetic high over the rest of the Ross Sea Rift, because it is marked by a prominent linear magnetic low. Bosum et al. (1989) discussed whether the magnetic low may at least in part reflect upwarp of the Curie isotherm, in addition to thick sedimentary infill in the rift basin. Given that enhanced heat flow has been measured over the Cenozoic-age Terror Rift (Della Vedova and Pellis, 1994), this hypothesis appears plausible to us. Perhaps more intriguing though is the long-wavelength aeromagnetic pattern over the TAM. The Southern Cross Block and the coastal regions of the Admiralty Block both share a broad low, in sharp contrast to the surrounding regions, which feature several long-wavelength magnetic highs attributed to Ross-age arc and fore-arc basement rocks (Finn et al., 1999; Ferraccioli et al., 2002a). The broad magnetic low encompasses areas of the Wilson Terrane, the Bowers Terrane and the Robertson Bay Terrane alike, which are all affected by widespread Cenozoic magmatism (Figs. 8 and 10). Although it is possible that this is due to original contrasts in magnetic properties of deep Ross-age basement rocks we attribute this to a regional upwarp of the Curie isotherm overprinting the magnetic signature of deep basement rocks. If the latter hypothesis holds true, then it could indicate that enhanced heat flux linked to Cenozoic rifting is not restricted to the Terror Rift, but could extend under the Admiralty and Southern Cross Blocks of the TAM (Fig. 10). Two independent geophysical observations support our inference: 1) regionally enhanced heat flux may characterize NVL, according to the inversion of satellite magnetic anomaly data and thermal modelling (Maule et al., 2005) and; 2) low seismic velocities in the upper mantle (Danesi and Morelli, 2001) are not confined to the Ross Sea Rift, but appear to extend beneath NVL (Fig. 10). Faccenna et al. (2008) suggested that this seismic velocity pattern reflects upwelling of hot mantle beneath the WARS and lateral mantle flow under the NVL segment of the TAM.

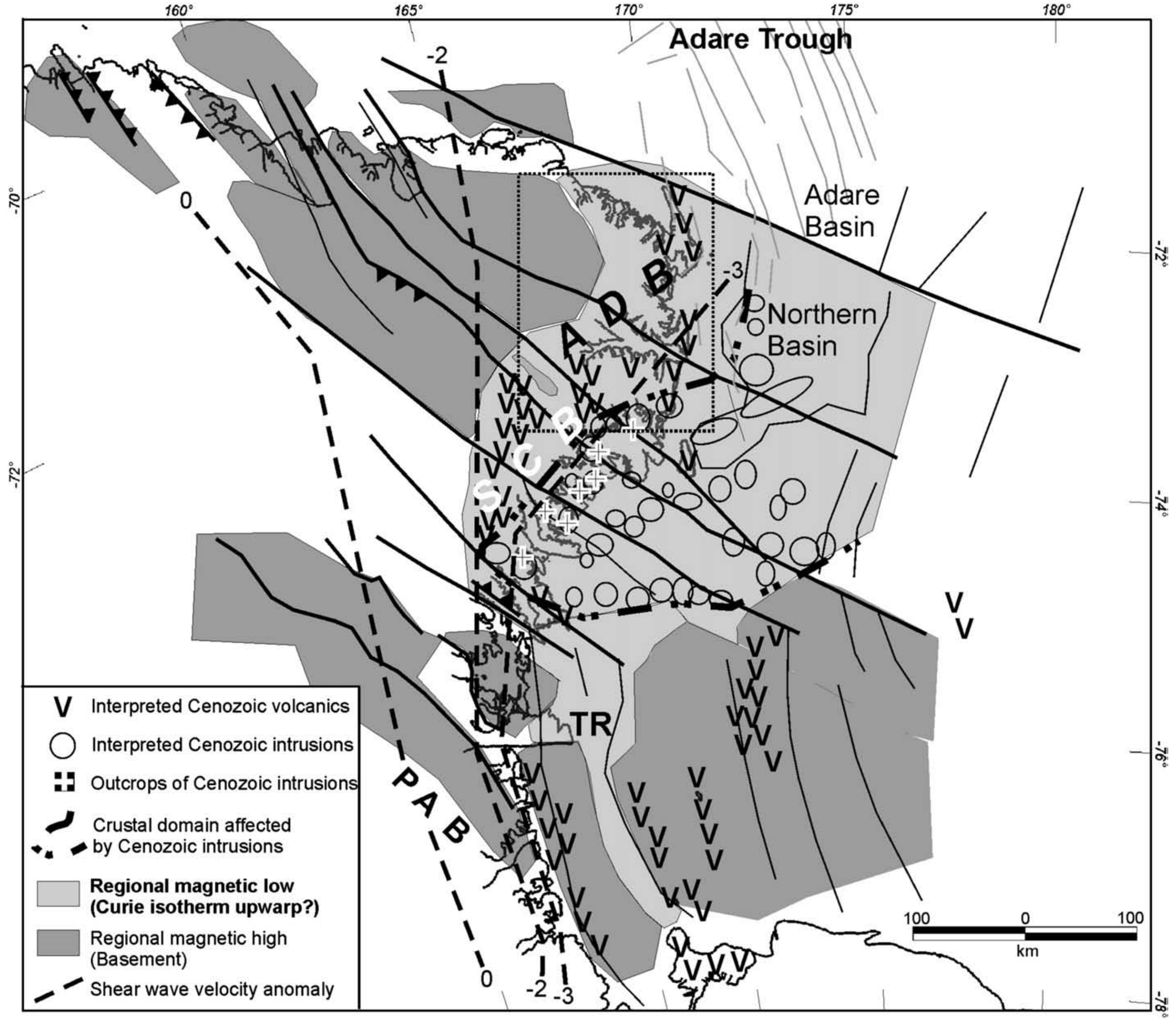

Fig. 10. Aeromagnetic interpretation map for the TAM and adjacent Ross Sea Rift. Dotted line denotes the new MAGANTER survey. The Admiralty Block (ADB) and Southern Cross Block (SCB) in NVL are much more extensively affected by Cenozoic magmatism compared to the Prince Albert Block (PAB) in southern Victoria Land. We suggest that the magnetic lows over the Terror Rift (TR), the Southern Cross and the Admiralty Blocks of the TAM reflect regional upwarp of the Curie isotherm in response to high heat flow. Slow seismic velocities in the upper mantle underlying the Ross Sea Rift region extend under the TAM rift flank in NVL (Danesi and Morelli, 2001). Lateral flow of hot upper mantle has been inferred under the Admiralty Block (Faccenna et al., 2008) and may explain the inferred upwarp of the Curie isotherm, the anomalously high elevations of the Admiralty Block, extensional faulting, and the occurrence of Neogene magmatism further away from the rift flank.

This process may explain the aeromagnetic evidence for a significant extent of Neogene to Recent magmatism far away from the Ross Sea Rift flank, the anomalously high elevations of the Admiralty Block, and also the occurrence of major NE–SW oriented extensional faults over the Admiralty Block. The normal faults that appear to dominate the structural architecture of the Admiralty Block are interpreted as reflecting crustal bulging and extensional collapse processes (see also Fig. 6 in Faccenna et al., 2008). The lower elevation Prince Albert Block in southern Victoria Land does not appear to be underlain by slow upper mantle seismic velocities, suggesting that that this largely amagmatic block may not have been affected by a comparable thermal anomaly. However, the spatial resolution of current seismological datasets warrants caution in addressing the possible segmentation in the upper mantle under the TAM rift flank. Joint inversion of recently acquired seismological data and gravity data (DeMartin and Roselli, 2007; Jordan et al., 2007) could assist in testing the inferred extent of the thermal anomaly in the upper mantle that we infer to impinge under NVL.

8. Conclusions

1. New aeromagnetic anomaly data for the high elevation Admiralty Block of the TAM delineate Ross-age basement rocks and post-Ross magmatic rocks, assigned to the Devonian–Carboniferous Admiralty Intrusives and associated Gallipoli Volcanics. Mafic rocks of inferred oceanic affinity have been interpreted to underlie the Cambrian-age Glasgow Volcanics of the Bowers Terrane. Slivers of sheared oceanic rocks have been imaged along the tectonic boundary

between the Bowers and Robertson Bay Terranes. Finally, basement rocks of possible continental affinity have been revealed under part of the Robertson Bay Terrane.

2. The highest amplitude aeromagnetic anomalies map the extent and distribution of Cenozoic magmatic rocks, including Meander Intrusives and McMurdo Volcanics. We interpreted aeromagnetic lineaments with a NNW to NNE orientation as revealing transtensional fault arrays, and suggested that these faults control the location of Neogene volcanics. The Neogene volcanic rocks were emplaced along the margin of the Northern Basin and also further inland, along a separate volcano-tectonic rift zone, we named the Malta Plateau rift. NE–SW magnetic lineaments reveal major normal faults of inferred Late Miocene to Recent age (Faccenna et al., 2008). Together with older NW–SE Cenozoic strike-slip faults these extensional faults provide strong tectonic controls on the Cenozoic landscape of the Admiralty Block.

3. The new aeromagnetic data over the Admiralty Block were compiled with existing data over the adjacent TAM and the Ross Sea Rift. We utilized this magnetic compilation to re-address possible relationships between strike-slip faulting, rifting, and Cenozoic magmatism. In particular, we noted that the trend of the Cenozoic alkaline intrusions is oblique to the NW–SE strike-slip faults and there is no aeromagnetic evidence for significant strike-slip displacements across them. This observation is quite hard to reconcile with current strike-slip geodynamic models for the NVL region. To address this discrepancy we put forward three alternative tectonic models. Our first model postulates that major ENE oriented left-lateral cross-faults accommodated the majority of distributed strike-slip motion and led to the emplacement of Cenozoic alkaline intrusions. Our second model suggests that major alkaline intrusions were emplaced along leaky transfer faults, linking oceanic spreading in the Adare Trough with continental rifting in the Victoria Land Basin. This model agrees better with independent marine geophysical and aeromagnetic evidence (Cande and Stock, 2006; Davey et al., 2006; Damaske et al., 2007). The third hypothesis is a composite of the two and relies upon a recent inference, predicting that the opening of the Adare Trough relates to fault splaying along the Balleny strike-slip fault belt (Storti et al., 2007).

4. Our magnetic compilation highlights major tectono-magmatic segmentation of the TAM rift flank. Some tectonic blocks, such as part of the Admiralty Block and the Southern Cross Block, were extensively affected by Cenozoic magmatism, in contrast to the surrounding tectonic blocks, despite the occurrence of a Cenozoic strike-fault belt in all these blocks. To further our understanding of the possible causes for such segmentation, we analyzed the long-wavelength magnetic anomaly patterns over the Ross Sea Rift and the adjacent TAM rift flank. The Terror Rift, the Southern Cross Block and the Admiralty Block of the TAM are marked by a regional magnetic low, which we interpreted as reflecting an upwarp of the Curie isotherm, in response to enhanced heat flux. High heat flux at crustal levels may speculatively link to upwelling of hot upper mantle and lateral mantle flow from the Ross Sea Rift to the TAM (Faccenna et al., 2008). The thermal anomaly may have facilitated late Neogene extensional faulting, promoted renewed uplift in the highly elevated Admiralty Block, and triggered coeval volcanism inland of the rift flank.

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