Cenozoic strike-slip faulting from the eastern margin of the Wilkes Subglacial Basin to the western margin of the Ross Sea Rift: an aeromagnetic connection

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Abstract: Tectonic modelling of regional aeromagnetic anomaly patterns suggests Cenozoic right-lateral strike-slip faulting along an inherited fault system of the Transantarctic Mountains and adjacent hinterland. We name it here the Prince Albert Fault System. The Reeves Fault and David Fault are Cenozoic right-lateral strike-slip faults and form part of the NW–SE-striking segment of this complex fault system, extending to the eastern margin of the Wilkes Subglacial Basin. Our aeromagnetic interpretation suggests therefore that the Wilkes Subglacial Basin may be connected to the Cenozoic strike-slip kinematic framework of the Transantarctic Mountains and western Ross Sea Rift. The southernmost segment of the Prince Albert Fault System parallels the N–S-striking McMurdo Sound Fault Zone and, together with it, defines a transtensional western Ross Sea Rift margin. High-resolution aeromagnetic images define the Cape Roberts pull-apart basin and suggest that Cenozoic magmatism may have focused along the transtensional western Ross Sea Rift margin itself.

The Transantarctic Mountains are the highest and longest non-contractional mountain belt in the world (ten Brink *et al.* 1997). The range reaches elevations over 4000 m and extends for over 3500 km across Antarctica (inset in Fig. 1). The rifted nature of the adjacent continental crust of the Ross Sea Rift, part of the West Antarctic Rift System, is well documented from seismic, gravity, and magnetic evidence (Cooper *et al.* 1987; Trehu *et al.* 1993; Brancolini *et al.* 1997; Behrendt 1999; Trey *et al.* 1999). Crustal architecture of the Transantarctic Mountains is less well constrained but has been investigated with gravity (e.g. Reitmayr 1997), aeromagnetic (e.g. Ferraccioli & Bozzo 1999), and large offset seismic data (O'Connell & Stepp 1993; Della Vedova *et al.* 1997). The Wilkes Subglacial Basin (Drewry 1976) lies in the remote and entirely ice covered hinterland of the Transantarctic Mountains (inset in Fig. 1). Hence, its crustal structure and tectonic origin is presently very poorly constrained.

Early structural models envisaged the Transantarctic Mountains as the upper plate of an asymmetric extensional orogen (Fitzgerald *et al.* 1986) or as a flexural uplifted footwall of a half-graben-type extensional basin located in the Ross Sea (Stern & ten Brink 1989). The Wilkes Subglacial Basin has been modelled either as a component of the flexural triad including the Ross Sea Rift, the Transantarctic Mountains, and the basin itself (ten Brink & Stern 1992; ten Brink *et al.* 1997), or previously as a rift basin within East Antarctica (Drewry 1976; Steed 1983). Extensive geophysical investigations are lacking to validate either of these models. New gravity and magnetic models along a single traverse appear to favour broad crustal extension (Ferraccioli *et al.* 2001) rather than lithospheric flexure across the Wilkes Subglacial Basin (Stern & ten Brink 1989; ten Brink & Stern 1992; ten Brink *et al.* 1997).

The Cenozoic tectonic setting of the Ross Sea Rift and Transantarctic Mountains may be more complex that previously modelled. The regional tectonic framework may relate to reactivation of Palaeozoic-age faults as major right-lateral strike-slip faults (Salvini *et al.* 1997*a, b*; Salvini *et al.* 1998; Ferraccioli & Bozzo 1999; Salvini & Storti 1999; Ferraccioli *et al.* 2000). Cenozoic strike-slip faults may cut across both the thicker continental lithosphere of the Transantarctic Mountains and the

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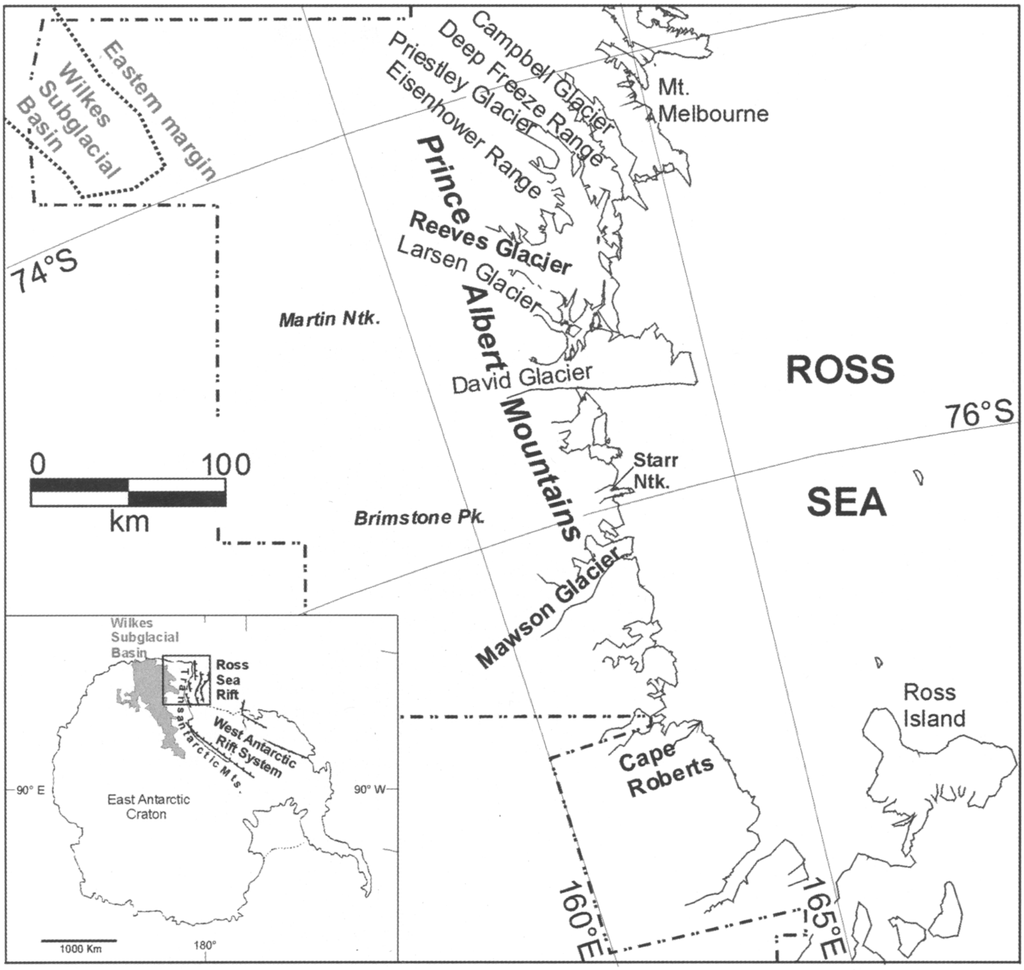


Fig. 1. Aeromagnetic study area over the Transantarctic Mountains, eastern margin of the Wilkes Subglacial Basin and Ross Sea. Bold dashed line indicates the western edge of aeromagnetic survey coverage. The inset depicts relevant continental-scale Antarctic tectonic structures.

thinner Ross Sea Rift lithosphere and link to southwestern Pacific Ocean transform faults (Salvini *et al.* 1997*a*, *b*) (Fig. 2). Cenozoic intraplate strike-slip faulting may have induced reactivation of the Mesozoic Ross Sea Rift by narrow mode rifting localized in the western Ross Sea and promoted renewed Transantarctic Mountains uplift (Wilson 1995; Salvini *et al.* 1997*a*, *b*; ten Brink *et al.* 1997). Recent geological field investigations have delineated intense brittle deformations along the southern termination of the Priestley Fault (Storti *et al.* 2001), in the area between Reeves Glacier and Mawson Glacier (Rossetti *et al.* 2000) and along the Lanterman Fault (Capponi *et al.* 1999; Rossetti *et al.* 2002) (Figs 1 & 2). The observed deformation patterns are kinematically compatible with major right-lateral strike-slip belts of Cenozoic age over this part of the Transantarctic Mountains (Salvini *et al.* 1997*a*, *b*).

We interpret enhanced aeromagnetic images to provide a new window over some Cenozoic strike-slip faults of the Transantarctic Mountains–Ross Sea Rift region. In particular we focus upon a mostly ice covered right-lateral strike-slip fault system of the Transantarctic Mountains and adjacent hinterland. We name it the Prince Albert Fault System. This fault system is composed of discrete fault zones, some of which match recently proposed strike-slip faults (Salvini & Storti 1999). This fault system has significant implications for the Transantarctic Mountains and most important for the eastern margin of the Wilkes Subglacial

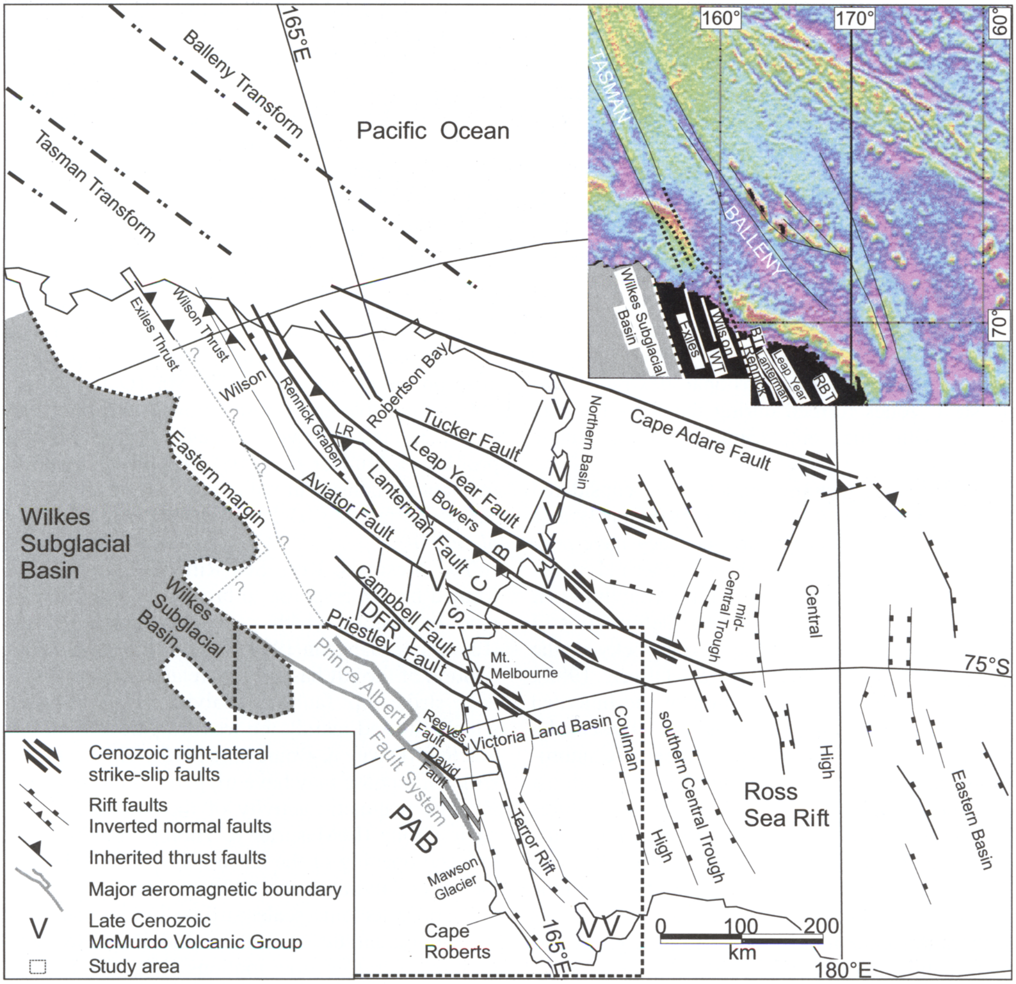


Fig. 2. Tectonic sketch map over major Cenozoic right-lateral strike-slip faults of the Transantarctic Mountains and adjacent Ross Sea Rift, modified from Salvini *et al.* (1997*a*). Dashed line indicates aeromagnetic study area. Major inherited thrust faults from Flöttmann & Kleinschmidt (1991). The newly proposed Prince Albert Fault System, along the eastern margin of the Wilkes Subglacial Basin, is shown with a grey shade. Note its co-linearity with the Reeves Fault and the David Fault from Salvini and Storti (1999) (see text for explanation). Also note the location of Cape Roberts along the western margin of the Ross Sea Rift. The inset shows a satellite-derived free-air gravity anomaly map modified from Sandwell & Smith (1997). It highlights co-linearity between oceanic transform faults and continental faults of the Transantarctic Mountains. Abbreviations: SCB: Southern Cross Block, DFR: Deep Freeze Range block, PAB: Prince Albert Block (Ferraccioli & Bozzo 1999); LR: Lanterman Range.

Basin. We also focus on Cape Roberts, along the western margin of the Ross Sea Rift (Figs 1 & 2). At this location, drilling information, multi-channel seismic reflection, and structural results (Wilson 1995; Cape Roberts Science Team 2000; Hamilton *et al.* 2001) are combined with aeromagnetic images. This leads to the suggestion that Cenozoic transtension may control Cenozoic magma emplacement along the western margin of the Ross Sea Rift. This suggestion is also consistent with observations further north over the Transantarctic Mountains (Salvini & Storti 1999; Rossetti *et al.* 2000).

Structural framework

Northern Victoria Land includes the Robertson Bay Terrane, the Bowers Terrane, and the Wilson Terrane (Bradshaw 1989) (Fig. 2). During the Ross Orogen metamorphic rocks of the Wilson Terrane were intruded by Cambro-Ordovician magmatic arc rocks, the Granite Harbour Intrusives (Ghezzo *et al.* 1989). The Ross Orogen relates to subduction of the palaeo-Pacific plate beneath the East Antarctic Craton (Kleinschmidt & Tessensohn 1987; Ricci *et al.* 1997), as indicated also by aeromagnetic signatures (Finn *et al.* 1999*a*; Ferraccioli *et al.* 2002). NW–SE-striking faults (Fig. 2) developed during the Ross Orogen and include major thrust faults such as the Leap Year Fault, the Lanterman Fault, the Wilson Thrust, and the Exiles Thrust (Flöttmann & Kleinschmidt 1991). In contrast, Musumeci & Pertusati (2000) argue that in the Deep Freeze Range–Eisenhower Range (Fig. 1) transpressional and transtensional dextral strike-slip shear zones formed during the Ross Orogen, coeval with the emplacement of magmatic intrusions.

These diverse tectonic models have considered the structural framework of the region mostly as a fossil early Palaeozoic picture, i.e. they have neglected significant reactivation of inherited structures by Cenozoic strike-slip faulting (Salvini *et al.* 1997*a*; Ferraccioli & Bozzo 1999). Deformation of Triassic Beacon and Jurassic Ferrar rocks in the Lanterman Range (Grindley & Oliver 1983), requires post-Jurassic reactivation of the inherited Lanterman fault zone (Roland & Tessensohn 1987). In the Lanterman Range Cambro-Ordovician Granite Harbour Intrusives are thrust onto Ferrar rocks (LR in Fig. 2). These features may be explained by strike-slip-induced transpression along the Lanterman Fault (Rossetti *et al.* 2002). Timing of reactivation is hard to determine because of the lack of post-Jurassic rocks at this location. A Cenozoic age of the right-lateral Lanterman Fault is, however, suggested by the intimate link with Cenozoic magmatism along its southern onshore termination (Rossetti *et al.* 2002). The Priestley Fault is also a major Cenozoic strike-slip fault zone including a transpressional principal displacement zone and a transtensional splay zone (Storti *et al.* 2001).

The geodynamic model by Salvini *et al.* (1997*a*) predicts that Cenozoic strike-slip faulting may also have controlled emplacement of Cenozoic alkaline magmatism (LeMasurier & Thomson 1990; Tonarini *et al.* 1997). Indeed Mount Melbourne quiescent volcano (Figs 1 & 2) is located at the intersection between the Campbell strike-slip fault and the northern termination of the Cenozoic Terror Rift (Salvini *et al.* 1997*a*; Salvini & Storti 1999; Ferraccioli *et al.* 2000). Transtensional to strike-slip tectonics have been proved to control Cenozoic magma emplacement further south between Reeves and Mawson Glacier (Rossetti *et al.* 2000) (Fig. 1). Near Cape Roberts fault kinematic solutions also indicate a Cenozoic dextral transtensional regime along the Ross Sea Rift margin (Wilson 1995). Transtension may have caused pre-existing faults to become leaky, therefore favouring Cenozoic magma ascent (Wilson 1995). Offshore, within the Ross Sea Rift, Late Cenozoic(?) magmatism is concentrated along Mesozoic trends (Behrendt *et al.* 1996; Behrendt 1999), likely reactivated in response to Cenozoic strike-slip faulting (Salvini *et al.* 1997*a, b*).

Within the Ross Sea Rift, right-lateral strike-slip faulting is seismically constrained to be post-RSU6, i.e post Eocene in age (Busetti 1994; Salvini *et al.* 1997*a*). The RSU6 seismic unit may correlate with an angular unconformity drilled at Cape Roberts, providing an age of 24 Ma (Davey *et al.* 2002). Negative and positive flower structures and Cenozoic fault inversions are evident from seismic profiles (Salvini *et al.* 1998). All these structural features are consistent with post-RSU6 right-lateral strike-slip faulting (Del Ben *et al.* 1993; Salvini *et al.* 1997*a*).

The Mesozoic Ross Sea Rift basins may have formed first in response to broad Basin and Range type extension, which ceased at about 85 Ma (Lawver & Gahagan 1994; Trey *et al.* 1999). Reactivation of the rift basin faults relates to later Cenozoic strike-slip faulting (Salvini *et al.* 1997*a*), which affected mainly the western part of the Ross Sea Rift (Davey & Brancolini 1995). The Cenozoic strike-slip phase may have triggered both Cenozoic alkaline magmatic activity of the McMurdo Volcanic Group (LeMasurier & Thompson 1990) and induced opening of the narrow Terror Rift (Fig. 2) (see also Salvini *et al.* 1997*b*, p. 588, fig. 2).

At plate tectonic scale, strike-slip kinematics of the Transantarctic Mountains and Ross Sea Rift may relate to Cenozoic motions along the Tasman and Balleny Transforms in the southwestern Pacific Ocean (Fig. 2) (Salvini *et al.* 1997*a, b*). A major plate boundary reorganization is evident in the westernmost Pacific–Antarctic Ridge during the Late Miocene (Lodolo & Coren 1997). Moreover, Eocene and Oligocene motion between East and West Antarctica may explain misfits in magnetic anomalies east of the Balleny Transform (Cande *et al.* 2000).

Aeromagnetic data

All available aeromagnetic data collected over the Ross Sea–Transantarctic Mountains region have recently been compiled (Chiappini *et al.* 2002) within the framework of the continental-scale Antarctic Digital Magnetic Anomaly Project (Golynsky *et al.* 2001). This regional compilation provides a new tool for tectonic studies over this part of Antarctica. Only part of the extensive aeromagnetic dataset is used here to focus mainly on the tectonics of the Prince Albert Mountains region within the Transantarctic Mountains and upon the Cape Roberts area, located along the western Ross Sea Rift margin (Figs 1 & 2). The data used in the first part of our study were acquired along reconnaissance survey grids with a 4.4 and 2.2 km line spacing and with a 22 km tie-line interval. Flight altitudes range from 3660 and 2700 m over the Transantarctic Mountains to 610 m over the Ross Sea Rift (Bosum *et al.* 1989; Bozzo *et al.* 1997*a*). Profile lines are oriented WNW–ESE, with perpendicular tie lines. A single draped survey, flown in the Cape Roberts–Ross Island area (Fig. 1), at 305 m above terrain and with a line spacing of 2 km, is also included. Details regarding instrumentation, individual survey layouts, data processing, and survey merging techniques are presented by Chiappini *et al.* (2002 and references therein). In the second part of this study we use high-resolution aeromagnetic data acquired offshore Cape Roberts (Bozzo *et al.* 1997*b*, *c*), flown along E–W flight lines, 500 m apart, and at 125 m above sea level (Fig. 1). All aeromagnetic data used in our study were microlevelled to reduce flight-line related corrugation (Ferraccioli *et al.* 1998).

Aeromagnetic interpretation techniques

We use analyses of amplitude and wavelength of aeromagnetic anomalies and apparent anomaly offsets observed across magnetic lineaments as a tool to identify mostly buried fault systems over this part of the Transantarctic Mountains and adjacent Ross Sea Rift. Magnetic lineaments can be enhanced in shaded relief presentations, such as the one displayed in Figure 3. Recognition of magnetic lineaments based on this type of presentation may be subjective, since it can depend upon the direction of illumination selected for shading. For example, in Figure 3, a NW–SE-trending structural fabric is very evident because shading is applied from the NE. To delineate magnetic lineaments more accurately and objectively we therefore also applied boundary analysis techniques, such as the maximum horizontal gradient of pseudo-gravity (Cordell & Grauch 1985; Blakely & Simpson 1986) and 3D Euler Deconvolution (Reid *et al.* 1990).

The pseudo-gravity map displayed in Figure 4 is obtained by applying a transformation, involving reduction to the pole and vertical integration (Baranov 1957). The term pseudo-gravity takes into account the fact that the magnetic distribution is not necessarily related to a density distribution. The horizontal derivatives act as a high-pass filter, which enhances shallower anomaly sources, such as volcanics. Peaks in the horizontal derivatives are picked with an automated method to locate local maxima (Blakely & Simpson 1986).

In 3D Euler Deconvolution, boundaries and depths-to-source of magnetic anomalies are analysed, using the total magnetic field and its gradient components. The method requires input of a parameter known as the 'structural index' (SI), which for faults is equal to 0.5 or 1 (Reid *et al.* 1990). The most appropriate SI, which is essentially a measure of anomaly fall-off rate with distance, can be interactively selected by picking Euler Deconvolution solutions which exhibit the tightest spatial clustering. An example of the output of this method is displayed in Figure 10b.

Aeromagnetic signatures

Once aeromagnetic lineaments are identified, these are correlated with mapped or inferred faults, where possible. To accomplish a tectonic interpretation, aeromagnetic anomalies are correlated with geological maps and published structural interpretations (e.g. Skinner & Ricker 1968; Warren 1969; Carmignani *et al.* 1989; Kleinschmidt & Matzer 1992; Molzahn *et al.* 1996; Salvini *et al.* 1997*a*; Salvini & Storti 1999; Rossetti *et al.* 2000). Anomalies are also interpreted together with results from rock magnetic property studies over Victoria Land (Bozzo *et al.* 1992; Lanza & Zanella 1993; Lanza & Tonarini 1998).

Aeromagnetic anomaly studies combined with susceptibility constraints and geology over Victoria Land identify typical magnetic anomaly signatures. High-frequency magnetic anomalies with wavelengths of about 5–15 km are correlated with Cenozoic alkaline volcanic rocks and with Jurassic Ferrar dolerite sills (Bosum *et al.* 1989; Behrendt *et al.* 1996; Ferraccioli & Bozzo 1999). Anomaly amplitudes are generally higher over magnetite-rich Cenozoic volcanic rocks (100–1000 nT) than over thin Jurassic dolerite sills (50–100 nT) (Behrendt *et al.* 1991). Higher-amplitude anomalies (over 500 nT) mark Jurassic Kirkpatrick Basalt rocks. The highest observed amplitudes (500–2000 nT) refer to near-circular anomalies, detected over Cenozoic alkaline intrusives (Bosum *et al.* 1989; Tonarini *et al.* 1997; Ferraccioli & Bozzo 1999). Typically, they exhibit a 30 km wavelength. Similar wavelength, but lower amplitude anomalies (100–500 nT) mark some Granite Harbour Intrusives of Ross age (Ferraccioli & Bozzo 1999; Finn *et al.* 1999*a*; Ferraccioli *et al.* 2002).

Crustal blocks and previously delineated strike-slip faults of the Transantarctic Mountains

Crustal blocks bordered by fault systems may exhibit contrasting aeromagnetic patterns, which can

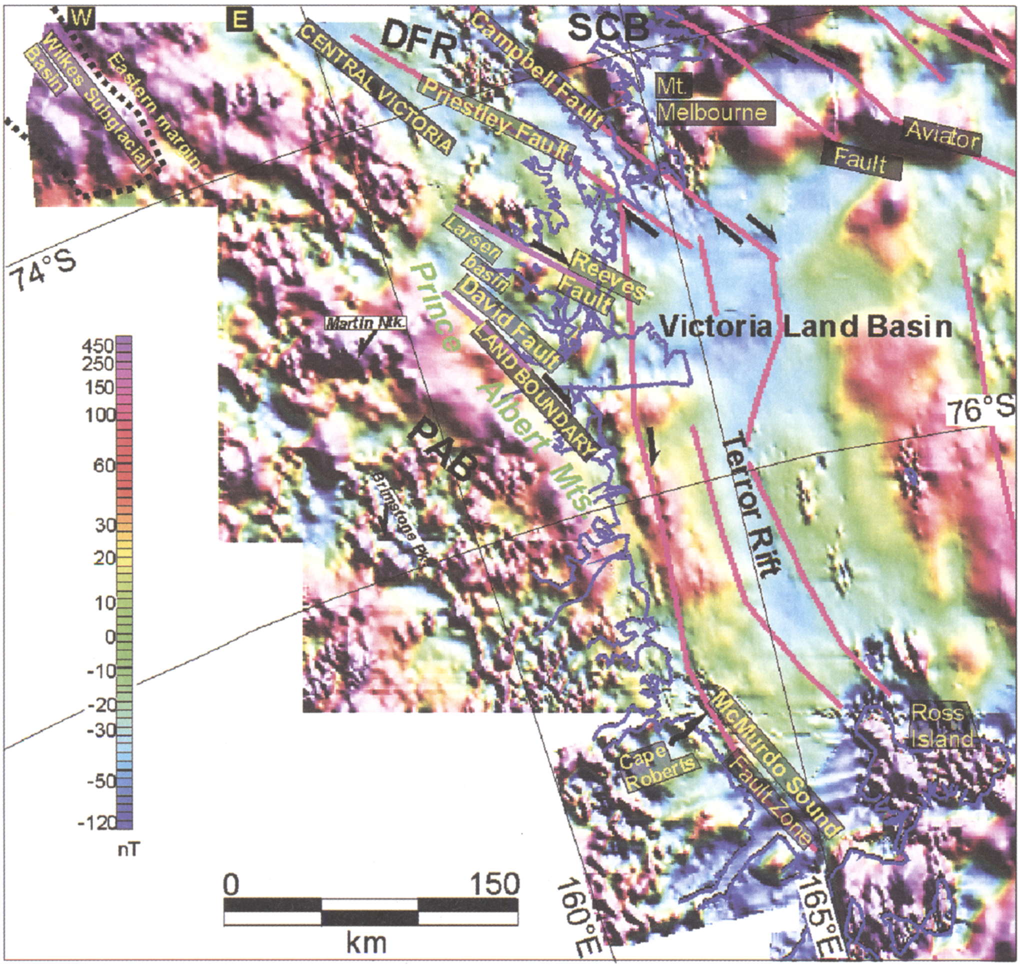


Fig. 3. Total field aeromagnetic anomaly map over the Transantarctic Mountains–Ross Sea Rift region. Red lines indicate faults from Salvini *et al.* (1997*a*) and Salvini & Storti (1999). Note the location of the eastern margin of the Wilkes Subglacial Basin with respect to the Central Victoria Land Boundary, a prominent aeromagnetic lineament system (Ferraccioli & Bozzo 1999).

contribute to their identification (Fig. 3). Tectonic blocks identified from aeromagnetic analysis over the Transantarctic Mountains include the Southern Cross Mountains Block, the Deep Freeze Range block, and the Prince Albert Block (Ferraccioli & Bozzo 1999) (Figs 2, 3 & 4). We propose here that the tectonic block boundaries interpreted from aeromagnetics may correlate with strike-slip faults delineated in the Salvini *et al.* (1997*a*) tectonic map.

The Southern Cross Mountains Block (Fig. 3) features high-amplitude anomalies related to exposed and buried Cenozoic alkaline intrusions and volcanics, often spatially associated with Cenozoic strike-slip faults, such as the Aviator Fault (Salvini *et al.* 1997*a*; Tonarini *et al.* 1997). These Cenozoic plutons terminate to the southwest against the prominent Campbell Fault. This is a Cenozoic strike-slip fault, probably controlling magma ascent in the area of quiescent Mt Melbourne volcano (Salvini *et al.* 1997*a*; Ferraccioli *et al.* 2000). The Campbell and Priestley faults are Cenozoic strike-slip faults which converge at the Ross Sea (Salvini *et al.* 1997*b*; Salvini & Storti 1999; Storti *et al.* 2001). These faults are marked by coincident magnetic lineaments bordering the Deep Freeze Range block. Within this tectonic block magnetic anomalies relate to Jurassic tholeiites (Ferraccioli & Bozzo 1999), including Ferrar sills and locally Kirkpatrick Basalt (Roland & Wörner 1996).

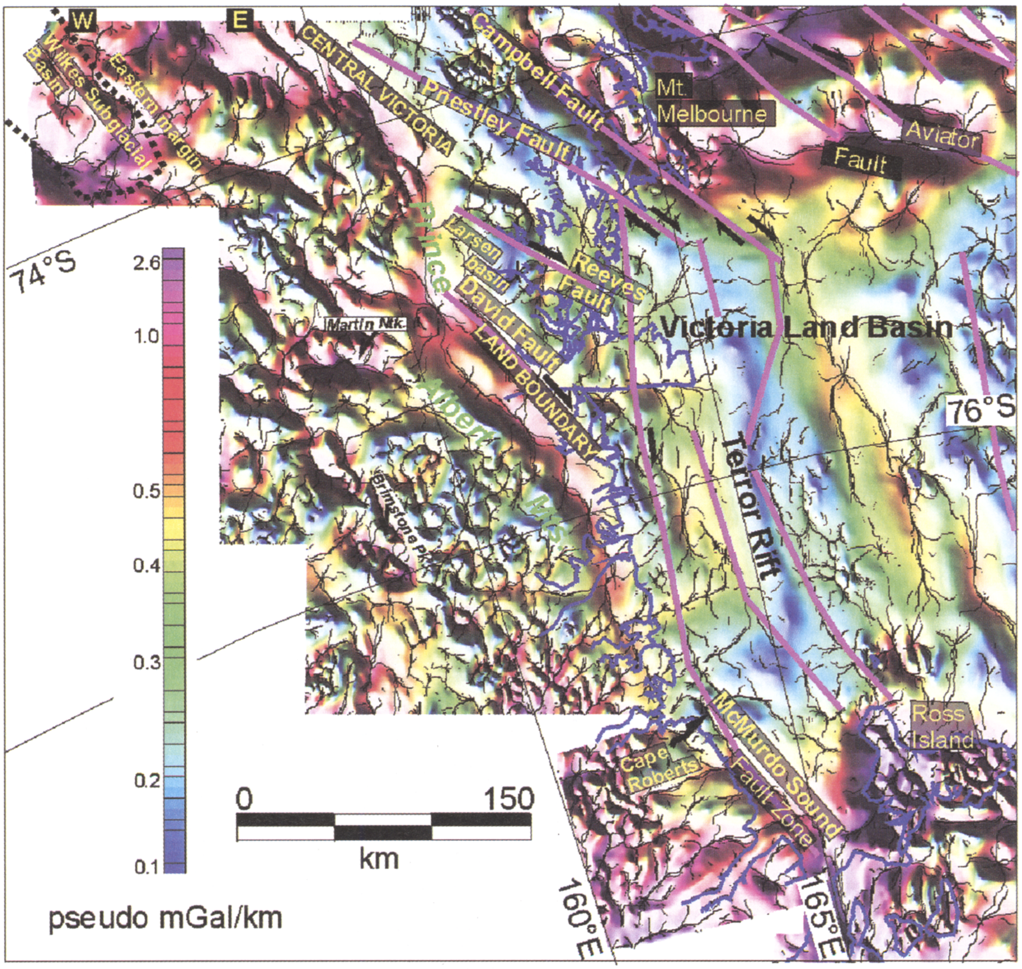


Fig. 4. Maximum horizontal gradient of pseudo-gravity map revealing unprecedented structural detail over the Prince Albert Block and adjacent Ross Sea Rift.

The Southern Cross Mountains and Deep Freeze Range tectonic blocks feature a broad magnetic minima, consistent with virtually non-magnetic basement. Low-susceptibility metamorphic and Granite Harbour basement rocks dominate these blocks (Bozzo *et al.* 1992). In contrast, the Prince Albert Mountains Block is marked by a broad, over 300 km long, magnetic high. The magnetic high is flanked by the prominent NW–SE-trending Central Victoria Land Boundary (Fig. 3). The sources of the long-wavelength aeromagnetic high are mostly buried Granite Harbour Intrusives (Ferraccioli & Bozzo 1999), rather than Precambrian rocks (Bosum *et al.* 1989). High susceptibilities have been measured in the Reeves Glacier (Fig. 1) over a magnetite-rich Granite Harbour Intrusive (Lanza & Tonarini 1998), corroborating this aeromagnetic interpretation. These magnetic arc rocks have been inferred to relate to the buried southern prosecution of the Ross-age Exiles Thrust system (Ferraccioli & Bozzo 1999). This is a speculative inference, since the Exiles Thrust is located over 300 km further north, at the Pacific Coast (Flöttmann & Kleinschmidt 1991). The distant location of the Exiles Thrust, with respect to our study area, is displayed in Figure 2. The speculative aeromagnetic inference is, however, consistent with high susceptibilities measured at the Pacific Coast over Granite Harbour Intrusives (Talarico *et al.* 2001) emplaced along the Exiles Thrust itself (Roland & Olesch 1997). Ferraccioli *et al.* (2002) further proposed that different magnetic signatures of arc rocks across the Central Victoria Land Boundary might reflect differential uplift. Shallow-level, magnetite-rich arc intrusions might have been emplaced directly along this fault zone, while deeper arc segments to the east of the fault contain ilmenite-rich rocks only. A magnetic configuration relating to differential uplift in the Transantarctic Mountains would match the one typically observed over magmatic arcs in California, Chile, and Japan (Gastil 1990).

In the following section we discuss whether the prominent Central Victoria Land magnetic Boundary simply reflects an inherited early Palaeozoic fault and related magmatic arc rocks, as previously proposed, or if it also marks a more recent strike-slip fault of the Transantarctic Mountains.

Tectonic modelling of the Prince Albert Fault System

Tectonic model 1

The maximum horizontal gradient of pseudo-gravity map suggests a considerably more complex structure of the Central Victoria Land Boundary than previously recognized (Fig. 4). One peculiar feature of this aeromagnetic lineament system is its apparent right-lateral step-like geometry northwest of Reeves Glacier. In tectonic model 1 (Fig. 5) we propose that such a configuration reflects the inherited early Palaeozoic geometry of the Exiles Fault(?) system. Such a step-like geometry is not likely to stem from thrusting alone, contrary to previous interpretations (Ferraccioli & Bozzo 1999). A step-like geometry of such a fault system could instead relate to strike-slip stepovers, either in form of a releasing stepover (pull-apart structure) or a restraining stepover (uplift or pop-up structure) (Aydin & Nur 1985). In tectonic model 1 we infer

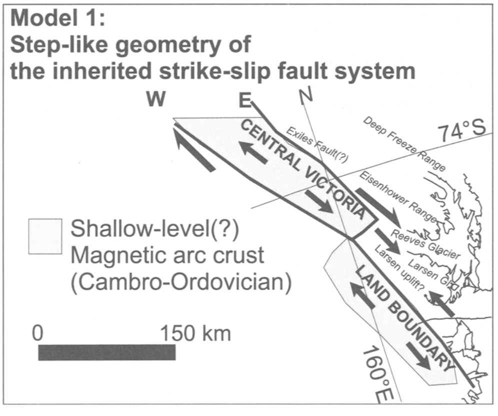


Fig. 5. Tectonic model 1 assumes an inherited Early Palaeozoic step-like geometry of the Central Victoria Land Boundary.

that magnetic plutons along the Central Victoria Land Boundary might represent shallow-level arc segments emplaced in a coeval transtensional shear zone. In contrast the magnetic minima over the Larsen Glacier area (Fig. 1) might indicate ilmenite-rich arc plutons emplaced at a deeper crustal level, in a coeval transpressional shear zone. Tectonic model 1 may be attractive because of its kinship with Late Cambrian–Early Ordovician transpressional and transtensional tectonic and magmatic features, recognizable over the adjacent Eisenhower Range and Deep Freeze Range (Musumeci & Pertusati 2000).

Tectonic model 2

Tectonic model 1 fails to consider that there is not only a long-wavelength magnetic anomaly break across the Central Victoria Land Boundary, but also a break in high-frequency magnetic pattern, which is addressed in tectonic model 2 (Fig. 6a). The high-frequency magnetic anomalies dominate the entire area west of the Central Victoria Land boundary. They are related to Jurassic tholeiites of the Ferrar Supergroup including Ferrar sills and dykes, and Kirkpatrick Basalt rocks (Ferraccioli & Bozzo 1999). This interpretation is strongly suggested by spatial correspondence of some of the anomalies with outcrop and by rock magnetic data, which indicate high susceptibilities ranging between 0.001 and 0.053 SI and Koenigsberger ratios between 1 and 5.5 (Lanza & Zanella 1993). Moreover magnetic modelling along a seismic line across the Prince Albert Mountains reveals Ferrar Supergroup rocks under ice cover (Ferraccioli & Bozzo 1999). This is consistent with seismic and radio-echo sounding evidence for subglacial mesa topography, related to Beacon Supergroup intruded by Ferrar rocks and locally overlain by Kirkpatrick Basalt (Delisle 1994; Della Vedova *et al.* 1997; Ferraccioli *et al.* 1997).

Preferential focusing of Jurassic tholeiitic magmatism along the inherited fault zone might have occurred, explaining the observed difference in high-frequency magnetic anomaly patterns. Alternatively, more recent reactivation of the fault system may involve significant differential uplift across the fault system. A relatively downthrown Prince Albert Block would imply less erosion of the Ferrar Province with respect to the more highly uplifted Deep Freeze Range block (Ferraccioli & Bozzo 1999, p. 25314, fig. 9). Differential uplift provides an explanation for the considerably lower elevations and minor tilt of the Kukri Peneplain, separating basement from Beacon Supergroup over the Prince Albert Mountains compared to northern Victoria Land tectonic blocks (Mazzarini *et al.* 1997). The differential uplift hypothesis might also

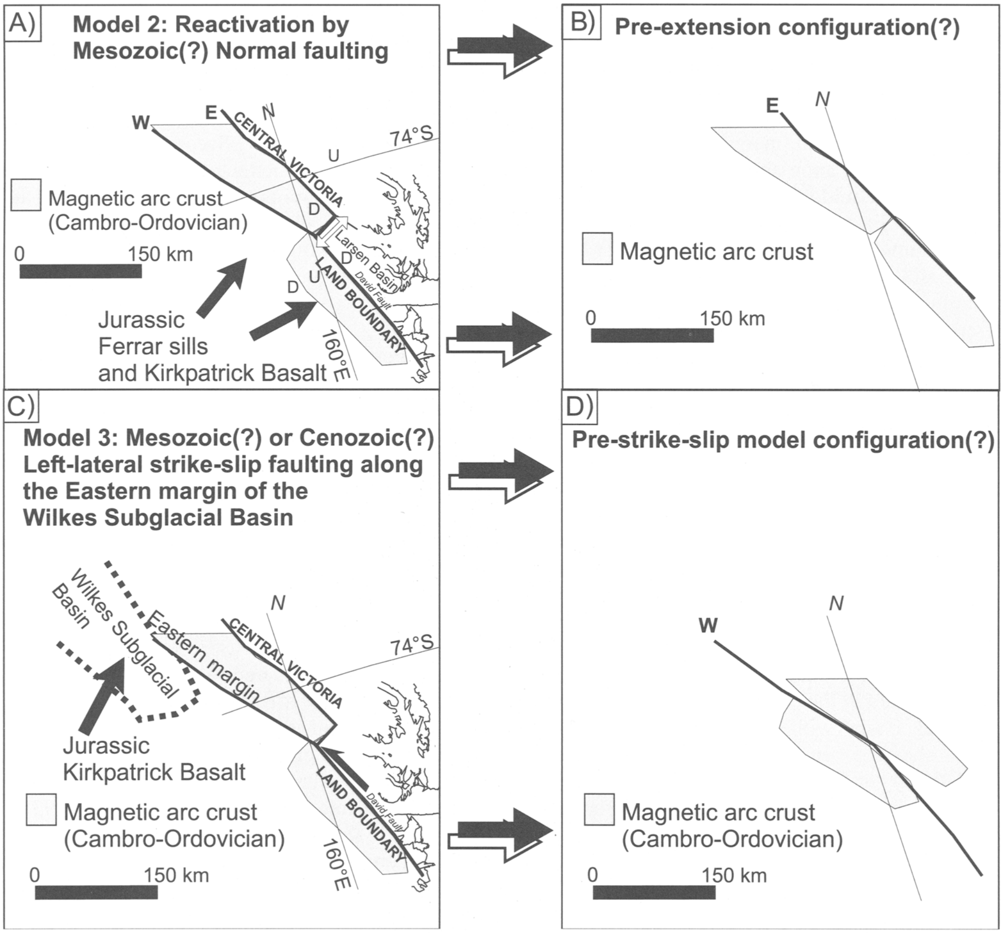


Fig. 6. (**a**) Tectonic model 2 assumes NE–SW-directed extension in the Larsen Basin; (**b**) tectonic model configuration as would be obtained by complete closure of the Larsen Basin; (**c**) tectonic model 3 assumes left-lateral strike-slip faulting along the eastern margin of the Wilkes Subglacial Basin; (**d**) tectonic model configuration prior to strike-slip faulting.

be consistent with apatite fission track data indicating a smaller amount of exhumation and hence a shallower crustal block in the Prince Albert Mountains region (Fitzgerald 1992). It may also explain the different magnetic signature of Early Palaeozoic arc rocks over the Prince Albert Block. In tectonic model 2, we propose that the Central Victoria Land Boundary may therefore have been reactivated as a major normal fault system. Pertusati *et al.* (1999) presented a geological map indicating an inferred normal fault, termed the David Fault, coinciding with a segment of the Central Victoria Land Boundary. In this framework we predict that the magnetic minima over the Larsen Glacier area might relate to syn-Ferrar or later crustal extension, resulting in downthrown magnetic basement at this location. Assuming that the direction of extension was NE–SW directed, then a possible pre-extension end-member configuration would involve an original close to linear geometry of the magnetic arc batholith (Fig. 6b).

Tectonic model 3

In tectonic model 3 (Fig. 6c), we consider an additional factor with respect to model 2. This important factor is the spatial association of the northwestern part of the aeromagnetic lineament system with a segment of the eastern margin of Wilkes Subglacial Basin (Drewry 1976; Steed 1983). Recently the Wilkes Subglacial Basin has been interpreted as relating to crustal extension (Ferraccioli *et al.* 2001), rather than to lithospheric flexure (Stern & ten Brink 1989; ten Brink & Stern

1992; ten Brink *et al.* 1997). Consequently in model 3 we propose the existence of a major fault, lying on strike with the eastern margin of the Wilkes Subglacial Basin itself. High-amplitude magnetic anomalies are located within the Wilkes Subglacial Basin at the margin of the survey area. Previously these anomalies were interpreted as reflecting mafic middle to late Proterozoic igneous rocks of the East Antarctic Craton, in analogy to similar anomalies observed over the Gawler Craton in Australia (Finn *et al.* 1999*b*). However, we put forward a different interpretation, i.e. thick Jurassic Kirkpatrick Basalt preserved from erosion in a down-faulted Wilkes Subglacial Basin. The interpretation that Ferrar Supergroup rocks, including Kirkpatrick Basalt, may continue into the basin is consistent with new magnetic models across the Wilkes Subglacial Basin (Ferraccioli *et al.* 2001). Tectonic model 3 predicts left-lateral strike-slip displacement of early Palaeozoic magnetic arc crust along a single fault zone, lying on strike with the eastern margin of the Wilkes Subglacial Basin. A hypothetical pre-strike-slip configuration would lead to a broad, over 100 km wide region of magnetic arc crust. Following this model it might also be tempting to correlate inferred left-lateral strike-slip faulting along the eastern margin of the Wilkes Subglacial Basin with regional Cretaceous left-lateral shearing in northern Victoria Land, speculatively inferred by Tessensohn (1994). Indeed, a previous upward continued aeromagnetic anomaly map suggested that the Central Victoria Land Boundary was truncated by Cenozoic faults of the Victoria Land Basin (Ferraccioli & Bozzo 1999, p. 25306, plate 2). This observation could be consistent with a Cretaceous rather than Cenozoic age of reactivation of the fault zone. The new horizontal gradient map suggests, however, that this previously observed crosscutting relationship may not hold true, eliminating the requirement for a pre-Cenozoic age of reactivation of the fault zone (Fig. 4).

Tectonic model 4

Tectonic model 4 is our preferred model (Fig. 7). It relies upon analysis of many more features than considered in model 3 or in any other previous tectonic model of the area. It takes into account (a) the magnetic minima over the Larsen Glacier region; (b) high-frequency anomalies along the western margin of the Victoria Land Basin, within the Ross Sea Rift; (c) high-amplitude anomalies at the eastern margin of the Wilkes Sublgacial Basin; and (d) anomaly patterns within the Prince Albert Block. Most importantly, the tectonic model also incorporates recent geological constraints (Salvini & Storti 1999; Rossetti *et al.* 2000). Model 4 predicts that the Central Victoria Land magnetic boundary images a complex right-lateral strike-slip fault system, which we name the Prince Albert Fault System, of likely Cenozoic age (Fig. 8). This name is proposed first following its location in the Prince Albert Mountains. Second, this nomenclature is introduced to better relate this fault system to the previously proposed Prince Albert Mountains Tectonic Block (Ferraccioli & Bozzo 1999). The NW–SE-striking segment of the fault system includes the Reeves Fault and the David Fault described by Salvini & Storti (1999) as Cenozoic right-lateral strike-slip fault systems. In the Larsen/Reeves Glacier area the geometry of the fault system may resemble a sinuous right-lateral pull-apart or release bend structure, which we name the Larsen pull-apart. This structure connects segments of the right-lateral Reeves Fault and David Fault (Salvini & Storti 1999). If this hypothesis holds true, magnetic basement may be downthrown in a pull-apart-like structure, as a result of NW–SE-directed transtension oblique to the Ross Sea Rift basins (Figs 7 & 8).

Clockwise bending of the NW–SE strike-slip fault system to a NNW–SSE orientation occurs between David Glacier and Mawson Glacier. South of Mawson Glacier it rotates to a N–S orientation. This fault segment is subparallel, but distinct with respect to the western margin of the Ross Sea Rift, where right-lateral strike-slip faulting is distinctly imaged in seismic profiles (Del Ben *et al.* 1993, p. 82, fig. 68; Salvini *et al.* 1997*a*, p. 24,672, fig. 3). The southern segment of the Ross Sea Rift margin has been referred to as the McMurdo Sound Fault Zone (Hamilton *et al.* 2001). This fault zone is clearly punctuated by high-frequency magnetic anomalies (Fig. 3), related to preferential clustering of Cenozoic magmatic rocks along the fault zone itself (Behrendt *et al.* 1996; Ferraccioli & Bozzo 1999). Transtension may develop along the coastal region of the Prince Albert Mountains block because of a right-lateral simple shear couplet between the Prince Albert and McMurdo Sound Fault Zones. This interpretation is consistent with tension gash-like arrangements of Cenozoic dykes within the master faults and left-stepping dyke arrays in the intrafault zones between Reeves and Mawson Glaciers (Rossetti *et al.* 2000). However, the regional character of the aeromagnetic dataset makes it impossible to image the Cenozoic dyke systems at this location (Fig. 8).

Other elements speak in favour of a tectonic model predicting that the Prince Albert Fault System is a major post-Jurassic right-lateral strike-slip fault system. High-amplitude (over 500 nT) anomalies reveal Jurassic Kirkpatrick Basalt rocks in the region (Ferraccioli *et al.* 1997). The horizontal gradient map suggests that Kirkpatrick Basalt rocks

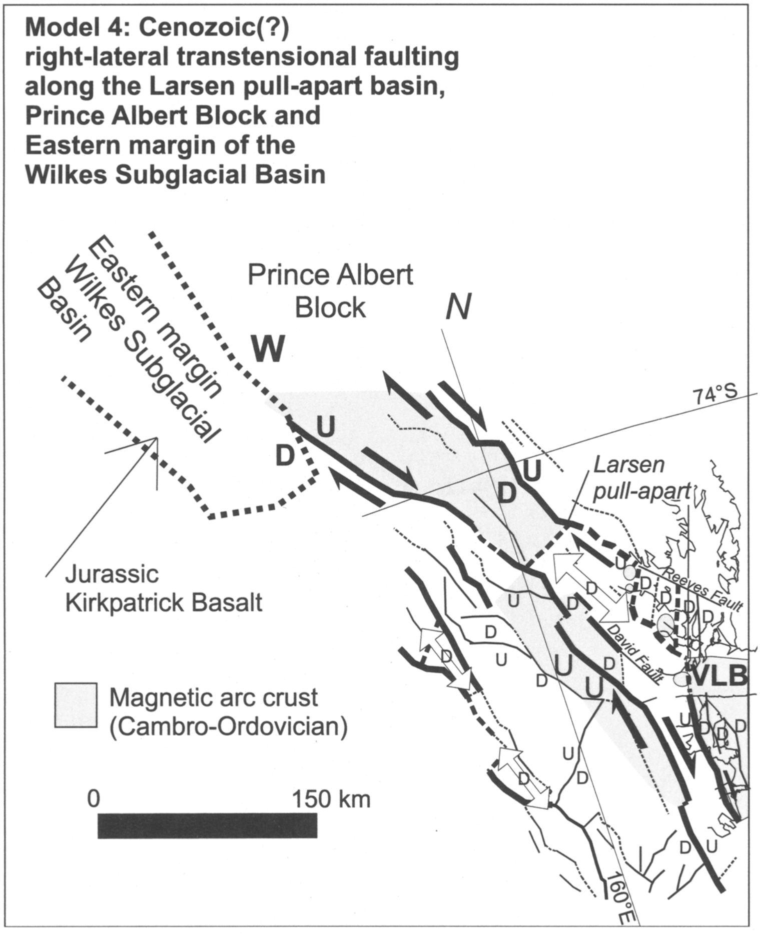


Fig. 7. Tectonic model 4 is our preferred model. It involves complex right-lateral NW–SE-trending transtensional faulting in the Prince Albert Block region. White arrows indicate interpreted extension directions oblique to the Ross Sea Rift basins, such as the Victoria Land Basin (VLB).

are confined to lozenge-shaped right-lateral pull-apart-structures along the western margin of the Prince Albert Block (Fig. 4). The alignment of Kirkpatrick Basalt rocks of the Prince Albert Mountains lies on strike with the eastern margin of the Wilkes Subglacial Basin. Since Kirkpatrick Basalt rocks outcrop at Brimstone Peak (Gunn & Warren 1962) we have termed this composite structural feature as the Brimstone pull-apart (Fig. 8). Moreover a high-amplitude anomaly at Martin Nunataks relates to Kirkpatrick Basalt (Carmignani *et al.* 1989). Kirkpatrick Basalt within this block may relate to a down-faulted sigmoidal-shaped tension-gash-like structure (Fig. 8). However, the WNW orientation of this feature differs from the one typically expected for a tension gash formed in a right-lateral strike-slip fault zone.

Also particularly noteworthy are the high-frequency magnetic trends marking Ferrar Super-group rocks. These are generally oblique to the Ross Sea Rift basins. There is an indication of clockwise rotation of these magnetic trends from NNE to NE and finally to ENE proceeding south-wards. Such magnetic trends might be imaging oblique-slip fault arrays relating to post-Ferrar oblique extension, induced by strike-slip fault motion within the Prince Albert Fault System. At least one major NNE magnetic trend, within the Ferrar-related pattern, is clearly associated with a major post-Jurassic fault zone, the Hollingworth Fault, presently of unknown kinematic character (Pertusati *et al.* 1999). There may a relation between NNE to ENE-trending aeromagnetic lineaments and normal–oblique Cenozoic faults

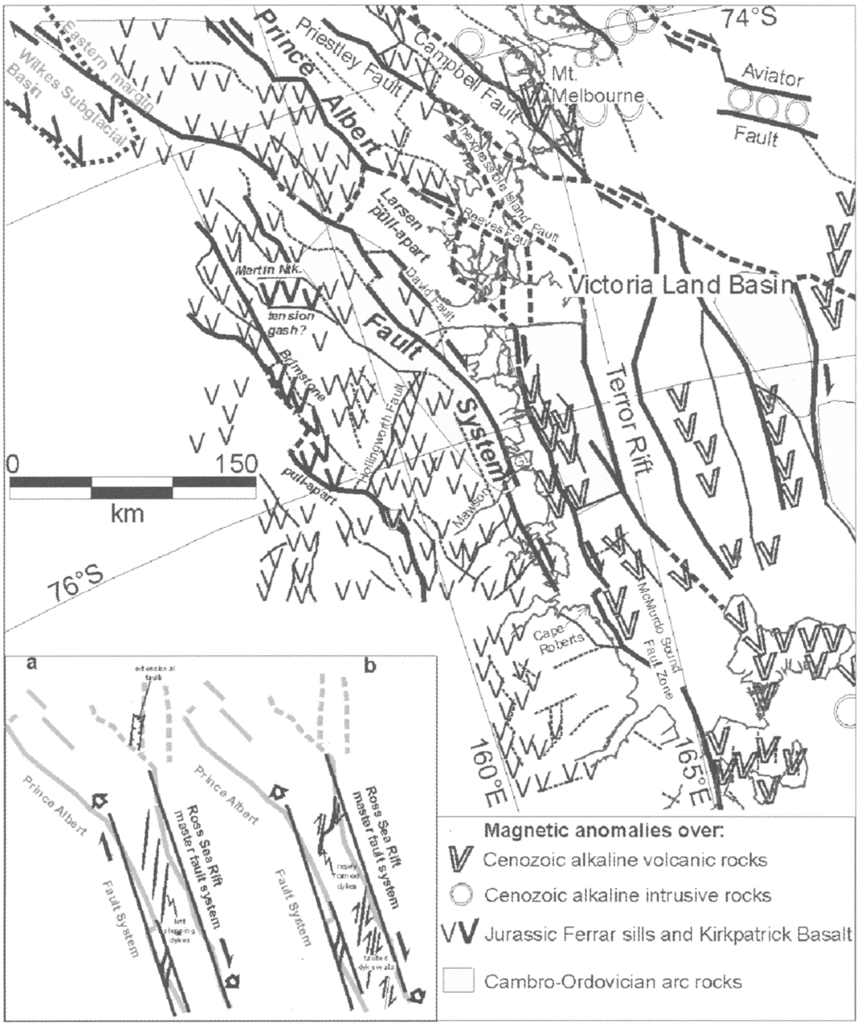


Fig. 8. Tectonic sketch map constructed from new aeromagnetic interpretation of the Prince Albert Fault System and adjacent NW–SE strike-slip fault belts (Salvini & Storti 1999; Ferraccioli *et al.* 2000; Storti *et al.* 2001). The two-stage Cenozoic transtensional evolution along the western margin of the Ross Sea Rift involves a late-stage increase in the strike-slip component, as interpreted from Cenozoic dyke and fault arrays by Rossetti *et al.* (2000). This structural interpretation maybe consistent with the shear couplet along the Prince Albert Fault System and McMurdo Sound Fault Zone, as interpreted here from aeromagnetic patterns (see lower left inset). Our aeromagnetic interpretation implies a strike-slip-induced coupling between the eastern margin of the Wilkes Subglacial Basin, the Transantarctic Mountains, and the western margin of the Ross Sea Rift.

observed in the Cape Roberts area (Wilson 1995).

Aeromagnetic anomalies and faults in the Cape Roberts Rift region

The Cape Roberts region is a key area to address in further detail the geometry and kinematics of strike-slip faulting and its control on Cenozoic magmatism at the boundary between the Transantarctic Mountains and the Ross Sea Rift. At this location high-resolution aeromagnetic data were acquired as part of the site survey for drilling within the Cape Roberts Drilling Project (Barrett *et al.* 1995; Bozzo *et al.* 1997*b*). The drilling project has now been completed providing new constraints for tectonic interpretation (Cape Roberts Science Team, 2000). Also new multi-channel seismic reflection results are available (Hamilton *et al.* 1998, 2001) allowing for a more detailed structural analysis of aeromagnetic patterns than previously possible (Bozzo *et al.* 1997*c*).

To address correlation between magnetic lineaments and faults the tectonic sketch map of Hamilton *et al.* (2001) constructed from seismic interpretation is superimposed upon a set of enhanced aeromagnetic anomaly images for the Cape Roberts region (Figs 9 & 10). The tectonic sketch map depicts faults on top of seismic unit V4b, which has been drilled yielding an age of 23.7 to 24.1 Ma (Hamilton *et al.* 2001). A major aeromagnetic lineament (L1) is evident in the total field shaded relief map (Fig. 9a). It forms the western flank of the Cape Roberts anomaly, originally called 'Anomaly A' along multi-channel seismic line USGS-403 (Behrendt *et al.* 1987). This anomaly has been interpreted as arising from a submarine volcano, the 'Barrett volcano', with an associated shallow-level intrusion (Behrendt, p. 89 of LeMasurier & Thomson 1990). Magnetic lineament L1 coincides with fault zone B, which forms the western flank of the Cape Roberts Rift Basin. Diffractions and changes in amplitude and shape of seismic traces are consistent with high-angle basement faulting and associated magmatic intrusions (Hamilton *et al.* 1998). The L1 lineament is offset by NE to ENE-trending transverse features (T and T′). These transverse magnetic features lie subparallel to ENE fault systems delineated from seismic data in the Roberts Ridge region (e.g. J in Fig. 9a). These faults have an estimated vertical separation of as much as 800 m and exhibit a left-oblique component (Hamilton *et al.* 1998).

A horizontal derivative aeromagnetic map (Fig. 9b) enhances lineament L1 and highlights lineament system L2 along the eastern flank of the Cape Roberts Rift Basin. Lineament L2b lies at an angle with respect to NNE-trending fault zones D and E but is subparallel to fault zone G. Lineament L2a lies on strike and close to fault zone H. This map also delineates high-frequency lineament arrays both in the Mackay Sea Valley region and over Roberts Ridge. In the Mackay Sea Valley area NE and N–S trends are easily recognized. NE trends also occur close to Cape Roberts. The Roberts Ridge area features, in contrast, dominant NNW trends.

The maximum horizontal gradient of pseudo-gravity map confirms the right-stepping en echelon geometry of L1 (Fig. 10a). A subparallel trend (L0) is also detected and exhibits an opposite left-stepping en echelon geometry with respect to L1. Notably, L0 also appears to crosscut trend M of the Mackay Sea Valley. There is an apparent right-lateral displacement of M across L0. The map also indicates a horsetail-like splay (HT) of L2 into two distinct lineaments L2b and L2a. The latter trend exhibits a sinuous anastomosing geometry with opposite curvature to fault H. NNW trends are located at the tip of fault H in the Roberts Ridge region. These trends appear to be truncated by a NE trend at the southwestern edge of survey area.

The 3D Euler Deconvolution map, calculated for structural index 1.0, is used for further lineament location and for a crude depth estimate of source bodies (Fig. 10b). This map clearly delineates the ENE-trending transverse structure T truncating the Cape Roberts Rift Basin to the north. Along the western flank of the basin magnetic source depth ranges from about 500 m below sea level, corresponding to sea floor, to about 2 km below sea level. This is in general agreement with results obtained from 2 and $\frac{3}{4}$ dimensional modelling of the Cape Roberts igneous complex (Bozzo *et al.* 1997*b*, p. 1131, fig. 2). Some deeper solutions (more that 3 km below sea level) are apparently located west of fault zone B within crystalline basement. In plan view the overall S-shaped geometry of the Cape Roberts igneous complex closely resembles a sigmoidal tension-gash-like feature.

In Figure 11a we display the total field magnetic anomaly and the maximum horizontal gradient of pseudo-gravity profile along seismic line NBP97 (see Fig. 9a for location). The non-migrated seismic section is taken from Hamilton *et al.* (2001). Here correlation of L1 with the McMurdo Sound Fault zone, i.e with the master fault zone along the western side of the Ross Sea Rift, is evident. The double peak anomaly over the Cape Roberts Rift has been previously modelled along seismic line USGS 403 by introducing a non-magnetic body placed directly below the centre of the anomaly, flanked by magnetic bodies on both sides (Behrendt *et al.* 1987, p.163, fig. 6). The non-magnetic body was further interpreted as a molten magma chamber or a recently solidified magma chamber, i.e. rock above the Curie temperature. However, seismically imaged faulting within the Cape Roberts Rift (Hamilton *et al.* 2001) can explain the observed magnetic pattern without requiring such a recent hot body. Also faulting provides an explanation for the apparent east-dipping attitude of the magnetic intrusive as modelled by Bozzo *et al.* (1997*b*). This magnetic intrusive has an apparent susceptibility of 0.029 SI units, which is within the range of values measured over Cenozoic lavas and flows of the McMurdo volcanic group, and is higher than typically measured over Jurassic Ferrar dolerites (0.012) (Behrendt *et al.* 1987; Bozzo *et al.* 1992). There is a spatial correlation of lineament L2a with negative flower structure H as interpreted by Hamilton *et al.* (2001)

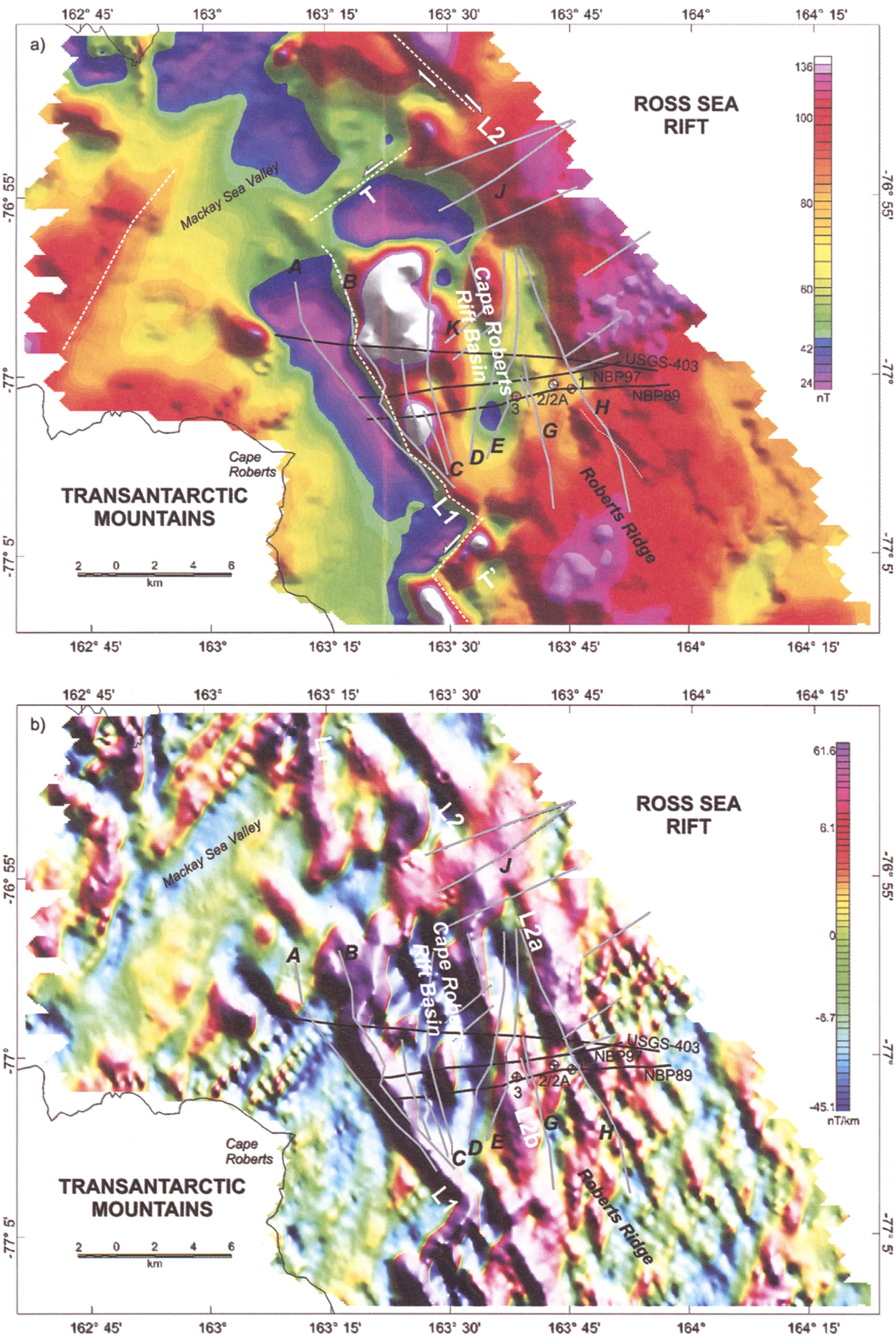


Fig. 9. (**a**) Total field shaded relief aeromagnetic anomaly map in the area of the Cape Roberts Rift Basin; (**b**) horizontal derivative map. Lettering A–H refers to faults at top of seismic unit V4b as proposed by Hamilton *et al.* (2001). The location of selected seismic lines and of drill-sites (CRP-1, CRP 2/2A, and CRP 3) is also reported.

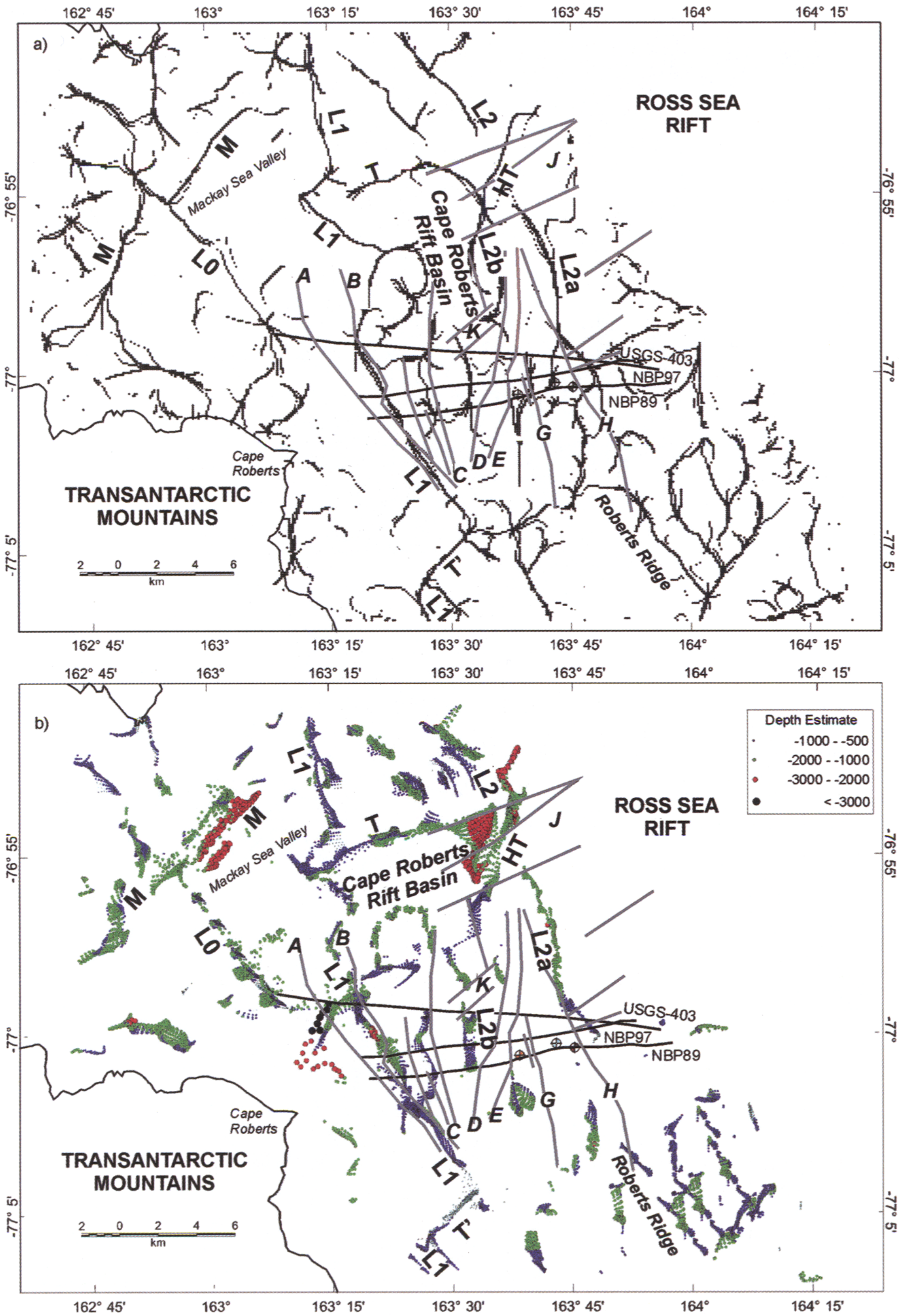
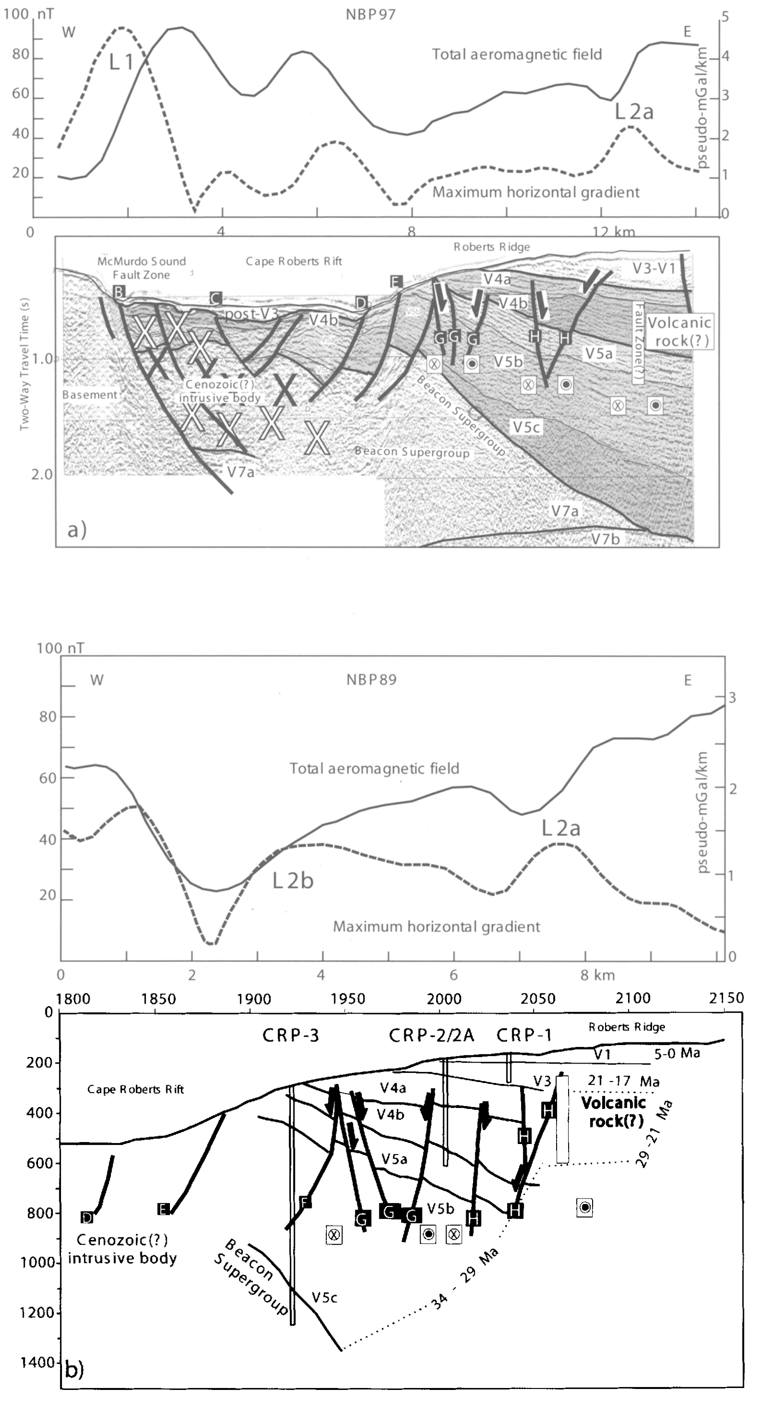


Fig. 10. (**a**) Maximum horizontal gradient of pseudo-gravity map in the area of the Cape Roberts Rift Basin; (**b**) 3D Euler Deconvolution map.


NBP97
W
E
100 nT
80
60
40
20
0
4
8
12 km
5
4
3
2
1
0
pseudo-mGal/km
L1
L2a
Total aeromagnetic field
Maximum horizontal gradient
McMurdo Sound Fault Zone
Cape Roberts Rift
Roberts Ridge
Two-Way Travel Time (s)
1.0
2.0
Basement
post-V3
V4a
V4b
V5a
V5b
V5c
V7a
V7b
V3-V1
Volcanic rock(?)
Fault Zone(?)
Cenozoic(?) intrusive body
Beacon Supergroup
a)
NBP89
W
E
100 nT
80
60
40
20
0
2
4
6
8 km
3
2
1
0
pseudo-mGal/km
L2a
L2b
Total aeromagnetic field
Maximum horizontal gradient
1800
1850
1900
1950
2000
2050
2100
2150
0
200
400
600
800
1000
1200
1400
CRP-3
CRP-2/2A
CRP-1
Roberts Ridge
Cape Roberts Rift
V1
5-0 Ma
V3
21 -17 Ma
Volcanic rock(?)
29 -21 Ma
V4a
V4b
V5a
V5b
V5c
Cenozoic(?) intrusive body
Beacon Supergroup
34 - 29 Ma
b)

beneath the Roberts Ridge region. The observed magnetic signature might stem from Cenozoic volcanic rock emplaced in intimate spatial association with the inferred right-lateral strike-slip fault zone. A blow-up of flower structures H and G, as interpreted from seismic profiles, is displayed in fig. 5 by Hamilton *et al.* (2001).

Another important observation is the regional eastward magnetic gradient over the Roberts Ridge. This may be explained by eastward thickening of Cenozoic volcanic rock in the upper part of the sedimentary sequence (Behrendt *et al.* 1987) or, at depth, by Jurassic Ferrar sills within Beacon Supergroup, forming eastward-dipping magnetic basement, as modelled by Bozzo *et al.* (1997*b*). A further explanation might be magnetic arc(?) basement at even greater depth dipping to the west towards the Cape Roberts Rift. If true, this westward-dipping geometry of deep magnetic basement could speculatively be related to a proposed low-angle detachment fault marked by the V7b acoustic basement reflection (Hamilton *et al.* 2001).

In Figure 11b we display the total field magnetic anomaly and the maximum horizontal gradient of pseudo-gravity profile along seismic line NBP89 (see Fig. 9a for location). A simplified line-drawing and the projected location of the Cape Roberts drillholes are also reported (Cape Roberts Science Team 2000; Hamilton *et al.* 2001). Here we observe that lineament L2b may correspond to flower structure G, which displaces seismic unit V4b (Hamilton *et al.* 2001). Lineament L2a matches again flower structure H, which can be traced also within 21–17 Ma strata (V3).

CRP-2/2A recovered volcanic ash layers dated between at 21.44 ± 0.005 Ma and 24.22 ± 0.06 Ma by $^{40}Ar/^{39}Ar$ (Fielding & Thomson 1999). These ash layers have been interpreted to require a fairly proximal former volcanic centre. We propose that the about 2 km thick intrusive complex, modelled by Bozzo *et al.* (1997*b*) as causing the Cape Roberts Rift magnetic anomaly, might be related to this former Cenozoic volcanic centre, consistent with Hamilton *et al.* (2001) hypothesis. A thinner sheet-like body underlying V5 was modelled by Bozzo *et al.* (1997*b*) to the east of the Cape Roberts Rift, beneath the Roberts Ridge. This body exhibits an apparent susceptibility of 0.012 SI units, i.e. similar to mean measured values over Ferrar sills. Indeed the Cape Roberts Science Team (2000) drilled an igneous body intruding Beacon strata at CRP-3 between 901 and 918 m below sea level. The drilled body could be a thin sill, related to the approximately 500 m thick magnetic sill, which may explain the aeromagnetic high east of the Cape Roberts Rift (Bozzo *et al.* 1997*b*, p. 1131, fig. 2). This drilled body may represent an anomalous phase of Jurassic Ferrar dolerite or a hitherto unrecognized subalkaline episode of early rift-related magmatism, older than 34 Ma (Cape Roberts Science Team 2000).

Fig. 11. (**a**) Profile view of total field and maximum horizontal gradient of pseudo-gravity along seismic line NBP97. Non-migrated seismic section modified from Hamilton *et al.* (2001). Note the Cenozoic(?) intrusive body beneath the Cape Roberts Rift and correspondence between magnetic lineament L1 and the McMurdo Sound Fault Zone. Lineament L2a lies just east of negative flower structure H; arrow tips show dextral sense of displacement. (**b**) Detail over the Cape Roberts drill-sites in the Roberts Ridge region along seismic line NBP89 (modified from Cape Roberts Science Team 2000 and Hamilton *et al.* 2001). Lineament L2b is marked by a broad maximum horizontal peak over fault zone F and negative flower structure G, while L2b is a shorter-wavelength peak closely matching negative flower structure H; arrows tips as per upper panel.

Discussion

Cenozoic transtension in the Cape Roberts Rift region

A new tectonic sketch map was compiled by combining enhanced aeromagnetic imaging, multichannel seismic results, and brittle fault analyses onshore (Wilson 1995) over the Cape Roberts region (Fig. 12a). We propose that the newly recognized Cape Roberts Rift Basin (Hamilton *et al.* 2001) is a pull-apart or release bend structure which accommodates right-lateral transtensional faulting along the western Ross Sea Rift margin. To the east of the aeromagnetic survey area local transpressive deformation and a positive flower structure is consistent with regional right-lateral strike-slip faulting (Del Ben *et al.* 1993; p. 82, fig. 68). This positive flower structure may be counter to the negative flower structures identified along the southeastern margin of the right-lateral Cape Roberts pull-apart (Fig. 11a, b and Hamilton *et al.* 2001). Cenozoic igneous bodies were likely emplaced during right-lateral transtension in the Cape Roberts pull-apart basin. The overall sigmoidal shape of the main Cenozoic intrusive complex is similar to a tension-gash-structure formed in a right-lateral NW–SE-trending fault zone. The ENE to NE faults probably link en echelon fault segments of the NNW–trending master fault system, marked by the McMurdo Sound Fault Zone (Hamilton *et al.* 2001). The ENE faults may represent left-oblique fault systems which accommodated differential right-lateral strike-slip motion along the NNW fault segments or maybe conjugate left-lateral strike-slip faults. At least one NNE fault

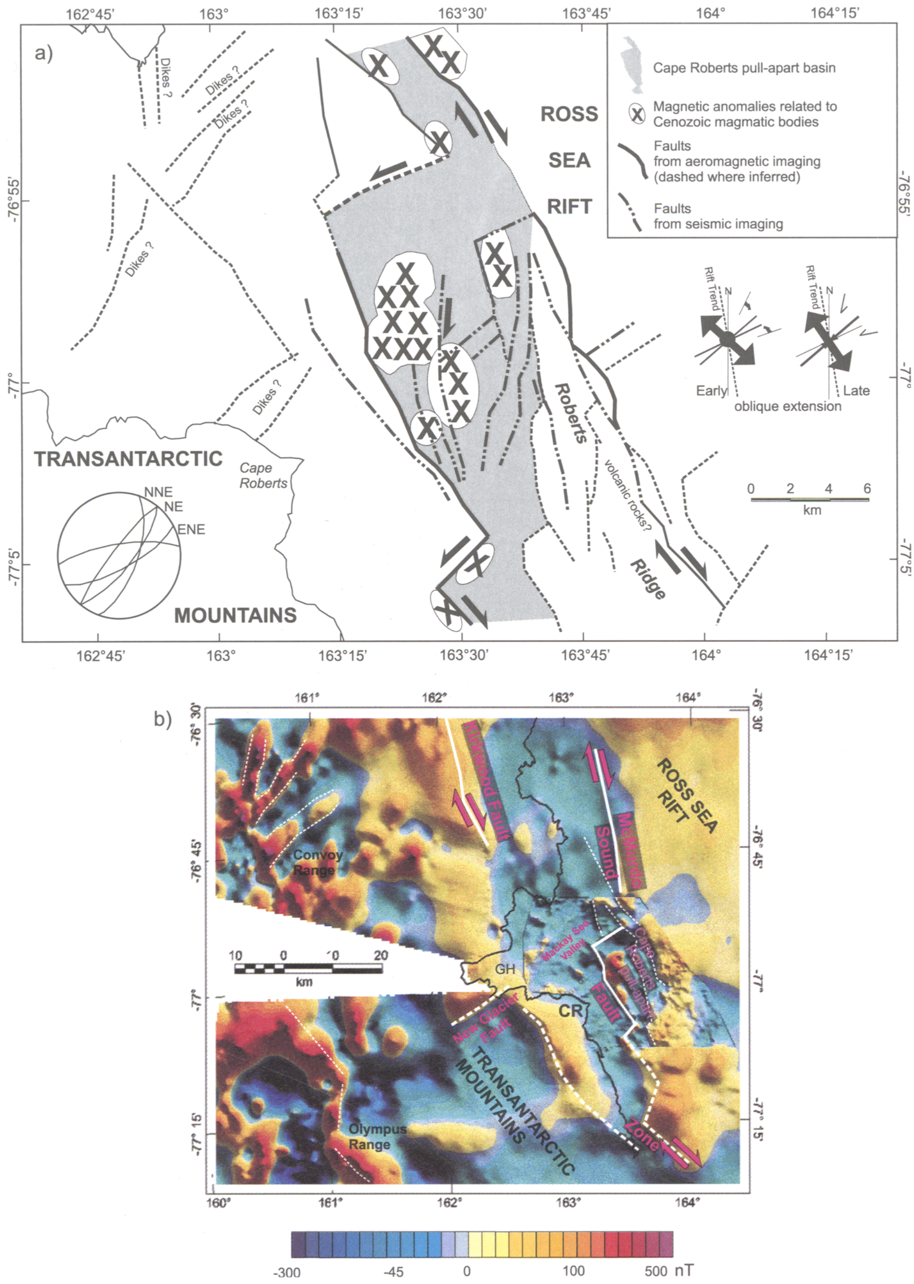


Fig. 12. (**a**) Tectonic sketch map constructed from aeromagnetic, seismic, and brittle fault interpretation, suggesting that the Cape Roberts pull-apart and associated magmatism stems from Cenozoic transtension along the western margin of the Ross Sea Rift. Lower left inset depicts Cenozoic brittle fault orientations over the Transantarctic Mountains (Wilson 1995). Right inset shows two-stage fault kinematics in the Cenozoic, as interpreted by Wilson (1995). In the early stage faults exhibit normal–oblique displacements, extension is subhorizontal and NW–SE directed (bold arrow), and contraction is subvertical (solid circle); in the following stage faults feature low-angle oblique or strike-slip displacements, the extension direction is NNW–SSE and the contraction is subhorizontal and NE–SW directed (see Wilson 1995 for further explanation). (**b**) Regional aeromagnetic map and interpreted faults at the transition between the Ross Sea Rift and the Transantarctic Mountains; Abbreviations: CR: Cape Roberts; GH: Granite Harbour.

exhibits apparent dextral offset of Cenozoic igneous bodies. Hamilton *et al.* (2001) argued that the NNE faults are dominantly normal faults which may have accommodated a minor clockwise vertical axis rotation, in analogy to structures detected over other dextral oblique rifts (Luyendyk 1991).

The rhomboid geometry of the Cape Roberts pull-apart basin, is broadly similar to that predicted in analogue modelling of pull-apart basins for 90° releasing offset sidesteps (Dooley & McClay 1997). In particular, the apparent V shape defined in plan view by faults within the southern part of the basin (Hamilton *et al.* 2001) may relate to cross-basin fault systems, which cut the floor of the pull-apart and tend to link the stepped principal displacement zones (Dooley & McClay 1997). When compared to other natural examples of pull-apart basins, such as the sinistral Dead Sea Basin, which is about 132 km long and 7–16 km wide (ten Brink & Ben-Avraham 1989; ten Brink *et al.* 1993), the newly proposed Cape Roberts pull-apart basin is a relatively small feature, being about 20 km long and 6–8 km wide. Its plan dimensions are more comparable to (a) the Mesquite Basin, developed at a releasing sidestep of the Brawley–Imperial dextral strike-slip fault zone, in southern California (Dooley & McClay 1997, p. 1820, fig. 14) and (b) a pull-apart structure located along the dextral Athos fault zone in the North Aegean Trough (Dooley & McClay 1997, p. 1823, fig.18).

We propose that Cenozoic dyke arrays with a NE trend may have formed to the west of the NNW master fault bounding the Cape Roberts pull-apart, in the Mackay Valley region and offshore Cape Roberts (Fig. 12a). In analogy to dyke emplacement mechanisms observed by Rossetti *et al.* (2000) further north, between Reeves and Mawson Glaciers (Fig. 8), dykes in the Cape Roberts area may have been emplaced during non-coaxial Cenozoic transtension along the rift margin. These interpreted NE-trending Cenozoic dyke arrays are not imaged to the east of the Cape Roberts pull-apart, possibly indicating decoupling across the McMurdo Sound Fault Zone.

Onshore, brittle fault arrays over the Transantarctic Mountains include NNE, NE, and ENE oblique-slip faults with a consistent oblique orientation to the Ross Sea Rift margin (lower left inset in Fig. 12a from Wilson 1995). The integrated geophysical dataset and drilling results strongly corroborate a Cenozoic age for these oblique-slip fault arrays, which lie subparallel to those identified offshore along the Ross Sea Rift margin. Kinematic analysis of these Cenozoic fault arrays over the Transantarctic Mountains suggests an oblique extensional or transtensional tectonic regime followed by a dominantly transcurrent regime (right inset in Fig. 12a from Wilson 1995). We propose that the Cape Roberts pull-apart basin relates to this Cenozoic transtensional tectonic setting along the Ross Sea Rift margin.

Strike-slip faulting and regional oblique rifting

By combining Cape Roberts high-resolution data with reconnaissance aeromagnetic anomaly data it is possible to further discuss relationships between strike-slip faulting in the Ross Sea Rift and over the Transantarctic Mountains (Fig. 12b). The right-stepping geometry of the McMurdo Sound Fault Zone may continue also to the south of Cape Roberts, though its definition is less secure owing to the regional character of the aeromagnetic data. To the north, the McMurdo Sound Fault Zone may parallel the Kirkwood Fault of the Transantarctic Mountains (Gunn & Warren 1962; Ferraccioli & Bozzo 1999). We propose that the Kirkwood Fault may in turn represent a transtensional splay of the major right-lateral Prince Albert Fault System identified to the north over the Transantarctic Mountains (Fig. 8). Apparently the Kirkwood Fault or some associated fault zone continues also to the south in the Cape Roberts region, where dextral transtension is proven by structural data (Wilson 1995).

Hamilton *et al.* (2001) noted that oblique fault array geometries and associated displacements in the Cape Roberts region (Wilson 1995) match typical patterns observed in analogue fault models of oblique rift systems (Clifton *et al.* 2000) and over the oblique extensional Malawi Rift in Africa (Chorowicz & Sorlein 1992). We propose that magnetic basement presently flooring the Ross Sea Rift (Behrendt *et al.* 1996, p. 672, plate 4; Ferraccioli & Bozzo 1999, p. 25306, plate 2) may have been, in a pre-rift configuration, adjacent to similar magnetic basement detected over the Prince Albert Block (Fig. 8). Restoration of these two basement blocks in an originally adjacent position would clearly require significant NW–SE-directed oblique extension in the Transantarctic Mountains–Ross Sea Rift region. Non-coaxial NW–SE-directed Cenozoic transtension, as interpreted between Reeves and Mawson Glaciers (Rossetti *et al.* 2000), may relate to strike-slip faulting along the Prince Albert Fault System and McMurdo Fault Zone. At a more regional scale, oblique extension could be related to differential NW–SE-directed intraplate strike-slip displacements, accommodating transform fault shearing in the southwestern Pacific Ocean, as described in the Salvini *et al.* (1997*a*) geodynamical model (Fig. 2). Bosum *et al.* (1989) also proposed a similar geodynamical model, based upon kinematic interpretation of aeromagnetic patterns over the Ross Sea Rift and

Transantarctic Mountains, predicting that regional NW–SE-oriented oblique extension may relate to transform fault motion in the southwestern Pacific Ocean (Bosum *et al.* 1989, p. 225 and 227, figs 46 and 47). Sutherland (1999) showed that Cenozoic and possibly Late Cretaceous oblique rifting in the Ross Sea is required for closure of the Australia–New Zealand–Antarctica plate tectonic circuit at chron 33 (74Ma).

Strike-slip faulting and uplift of the Transantarctic Mountains

Structural and aeromagnetic evidence for oblique extension induced by strike-slip faulting is hard to reconcile with rift flank models of the Transantarctic Mountains, which rely upon perpendicular extension in the Ross Sea Rift (e.g. Bott & Stern 1989; van der Beek *et al.* 1994). Wilson (1995) noted that only small isostatic uplift of the Transantarctic Mountains would be induced by Cenozoic transtension along the Ross Sea Rift margin, unless the proportion of divergence and thus of orthogonal unloading were dominant. Salvini *et al.* (1997*a*) proposed that uplift of the Transantarctic Mountains was related to isostatic rebound of the Ross Sea Rift shoulder with virtually no contribution from Cenozoic strike-slip tectonics. Hamilton *et al.* (2001) interpreted initial uplift of the Transantarctic Mountains to have occurred between 55(?) and 34 Ma ago. This uplift phase could relate to E–W extension and low-angle detachment faulting along the east side of the Victoria Land Basin and extending westward beneath the Transantarctic Mountains. Between 34 and 17 Ma ago, when strike-slip faulting and NW–SE-directed oblique extension became important, uplift of the Transantarctic Mountains decreased (Hamilton *et al.* 2001, p. 339, fig. 8).

In contrast, refined flexural modelling indicates that Cenozoic transtension may have broken the once continuous Antarctic lithosphere along the Transantarctic Mountains front, changing both elevation and surface slope of the range, and that these effects accelerated denudation (ten Brink *et al.* 1997). The presence of a major lithospheric break along the Ross Sea Rift margin is consistent with the prominent aeromagnetic signature of the McMurdo Sound Fault Zone and Prince Albert Fault System (Fig. 3). Most important, steep gravity gradients across the rift margin also require a contrast between highly extended crust beneath the Ross Sea Rift and thicker crust beneath the range (Reitmayr 1997; Trey *et al.* 1999; Ferraccioli *et al.* 2001). Such a crustal thickness contrast is apparent also from seismic data further north over the Transantarctic Mountains (O'Connell & Stepp 1993; Della Vedova *et al.* 1997). As noted by ten Brink *et al.* (1997), steep Moho dips have been observed across transform plate boundaries. This and a variety of other lines of evidence have been used to support the idea that uplift of the Transantarctic Mountains may represent a transform flank, rather than a rift flank phenomenon (ten Brink *et al.* 1997). We infer that such a model may well apply to uplift of the Prince Albert Block of the Transantarctic Mountains.

Strike-slip faulting along the eastern margin of the Wilkes Subglacial Basin

None of the regional geodynamic models or uplift models of the Transantarctic Mountains put forward so far has considered the possibility that Cenozoic strike-slip faulting may extend further to the west towards the Wilkes Subglacial Basin region. We have presented a tectonic model based upon aeromagnetic patterns and structural data, suggesting that Cenozoic strike-slip faulting, identified along the Prince Albert Fault System, may continue along the eastern margin of the Wilkes Subglacial Basin (Figs 7 & 8). This new inference, if correct, may contrast with models predicting that the Wilkes Subglacial Basin simply represents a broad flexural depression induced by uplift of the Transantarctic Mountains (Stern & ten Brink 1989; ten Brink & Stern 1992; ten Brink *et al.* 1997). This hypothesis may also be at odds with a simple continental rift model for the Wilkes Subglacial Basin (Drewry 1976; Steed 1983). Finally, it may also appear to contradict a more recent model depicting the Wilkes Subglacial Basin as a broad extended terrane (Ferraccioli *et al.* 2001).

Following the geodynamic model of Salvini *et al.* (1997*a*) for the adjacent Transantarctic Mountains region, we speculate that strike-slip faulting may extend to the Wilkes Subglacial Basin eastern margin as a result of shearing along the Tasman transform, which is co-linear with the basin margin itself (inset in Fig. 2). Continental overlap in Late Cretaceous Australia–Antarctica sea floor reconstructions may be reduced by assuming that continental extension occurred in the Wilkes Subglacial Basin region (Tikku & Cande 1999). We put forward the hypothesis that the assumed crustal extension may at least in part relate to inferred strike-slip faulting. In analogy to better constrained observations along the Ross Sea Rift margin, we infer that strike-slip faulting may have reactivated the eastern margin of the Wilkes Subglacial Basin in a dominantly transtensional tectonic setting. Our aeromagnetic connection shows that strike-slip faulting along part of the eastern margin of the Wilkes Subglacial Basin may continue along the Prince Albert Block and link to strike-slip faulting along the western margin of the Ross Sea Rift (Fig. 8).

New aeromagnetic data are clearly needed between the Pacific Coast and the Prince Albert Mountains region to test our suggestion that Cenozoic(?) strike-slip faulting may characterize the eastern margin of the Wilkes Subglacial Basin (Fig. 2). New radar data could refine the geometry of the eastern margin of the Wilkes Subglacial Basin and analyse possible bedrock faulting. Aerogravity data could better constrain whether there is crustal thinning beneath Wilkes Subglacial Basin, as proposed in a recent gravity model (Ferraccioli *et al.* 2001), or conversely if there is thick crust beneath the basin (Stern & ten Brink 1989; ten Brink & Stern 1992; ten Brink *et al.* 1997). Oversnow seismic experiments could then be targeted to defining crustal structure and tectonics across the newly suggested strike-slip fault zone along the eastern margin of the Wilkes Subglacial Basin. Seismic data should be acquired also offshore, at the Pacific Coast, to test the speculative link between the eastern margin of the Wilkes Subglacial Basin and the Tasman transform.

Conclusions

The utility of aeromagnetics for intraplate strike-slip fault identification and tectonic analysis is demonstrated by our study. This is particularly the case of the Transantarctic Mountains–Ross Sea Rift region of Antarctica, where right-lateral Cenozoic strike-slip belts reactivate the inherited Early Palaeozoic structural architecture. Our main results are as follows:

1. Major aeromagnetic lineaments identify the right-lateral Prince Albert Fault System, which is imposed upon an inherited fault zone. The right-lateral Prince Albert Fault System continues along the eastern margin of the Wilkes Subglacial Basin, which may therefore be coupled to the strike-slip, dominantly transtensional, tectonic framework of the Transantarctic Mountains and Ross Sea Rift.
2. The NW–SE-striking segment of the Prince Albert Fault System includes two Cenozoic right-lateral strike-slip faults of the Transantarctic Mountains, namely the Reeves Fault and David Fault. The N–S-striking segment of the Prince Albert Fault System continues southwards, where it parallels the McMurdo Sound Fault Zone, marking the Cenozoic western margin of the Ross Sea Rift.
3. The Cenozoic shear couplet between the Prince Albert Fault System and the McMurdo Sound Fault Zone induced NW–SE-oriented oblique extension along the eastern margin of the Prince Albert Block. NW–SE-directed transtension explains geometries of pull-aparts or release bends in the Prince Albert Fault System. It also provides a suitable kinematic framework to restore magnetic basement presently underlying the Ross Sea Rift basins, against the Prince Albert Block.
4. Structural and aeromagnetic evidence for oblique extension suggests that the Prince Albert Block of the Transantarctic Mountains cannot be regarded as a simple rift flank uplift.
5. Aeromagnetic images offshore Cape Roberts indicate that transtension along the western Ross Sea Rift margin may have controlled emplacement of a Cenozoic intrusion, associated with the Cape Roberts pull-apart basin. This structure developed at a releasing sidestep in the McMurdo Sound Fault Zone.

This research is a contribution to two PNRA projects: *Mesozoic and Cenozoic evolution in the Ross Sea area*, co-ordinated by F. Salvini (Dip. Sci. Geol., Univ. Roma Tre) and *WIBEM: Wilkes Subglacial Basin Eastern Margin*, co-ordinated by E. Bozzo (DIP.TE.RIS. Univ. Genova). E. Lodolo and J. C. Behrendt accomplished helpful and constructive reviews. F. Storti provided important suggestions, which clarified interpretation and also improved upon text organization.

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