Antarctic Science 9 (3): 268–280 (1997)

Cenozoic tectonic evolution of the Marguerite Bay area, Antarctic Peninsula, interpreted from geophysical data

A.C. JOHNSON

British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET, UK

Abstract: Magnetic, gravity and bathymetric data from Marguerite Bay are used to study the relationships between oceanic and continental tectonic evolution in the arc and fore-arc of the Antarctic Peninsula. The data are used to redefine the crustal structure of the Marguerite Bay area, providing evidence for a northward continuation of George VI Sound and the Alexander Island Mesozoic accretionary prism almost to the continental shelf edge. A two-stage model of extension, associated with changes in spreading rates and approaching ridge segments, is proposed to explain the crustal structure and Cenozoic tectonic evolution of the area. The model involves the opening of George VI trough by Tertiary dextral transtension, followed by oblique extension in an area bounded by the Tula and Adelaide fracture zones. This interpretation confirms previous work linking oceanic tectonic processes with continental arc and fore-arc structural development.

Received 18 June 1996, accepted 11 April 1997

Key words: Aeromagnetic, bathymetry, gravity, fore-arc, extension

Introduction

Marguerite Bay (Fig. 1) is a major embayment in the Pacific coast of the Antarctic Peninsula, between Adelaide Island to the north and Alexander Island to the south. It is approximately 175 km N–S and 150 km E–W. The bay is adjacent to the transition zone of the Antarctic Peninsula which forms a major divide between Graham Land to the north and Palmer Land to the south (Wyeth 1977). The Graham Land coast rises steeply to a narrow (40–70 km wide) plateau *c.* 1400 m above sea level (a.s.l.), whereas Palmer Land is 250–280 km wide, with a mean plateau elevation *c.* 1800 m a.s.l.. To the south of the bay, George VI Sound, a 30 km wide trough, separates Alexander Island to the west from Palmer Land to the east. The transition zone has been interpreted as a distinct segment of Antarctic Peninsula crust, or zone between two other major segments (Wyeth 1977, Garrett 1990). The Adelaide and Tula fracture zones lie offshore of the transition zone and correspond to the northern and southern limits of Marguerite Bay respectively. Previous workers have suggested a link between these fracture zones (FZs) and the tectonic segmentation of the Antarctic Peninsula in the transition zone (Hawkes 1982, Barker 1982, Garrett & Storey 1987, Garrett 1990, Johnson & Swain 1995) based on changes in physiography, geology and geophysical anomaly trends.

Geological setting

The Antarctic Peninsula magmatic arc formed during the eastward subduction of proto-Pacific ocean floor beneath its western margin. Pre-Mesozoic basement gneiss and orthogneiss is exposed in eastern Graham Land (Milne & Millar 1989) and in north-west Palmer Land (Harrison & Piercy 1991). Calc-alkaline volcanic and plutonic rocks crop out along the length of the peninsula (Pankhurst 1982, Thomson 1982). The plutonic rocks form the Antarctic Peninsula batholith (Leat *et al.* 1995), one of the major batholiths of the circum-Pacific rim. Volcanic rocks of the Antarctic Peninsula Volcanic Group (Thomson 1982) are genetically related to the plutonic rocks of northern Palmer Land (Leat & Scarrow 1994). Magmatism reached a peak in Early Cretaceous times, with intrusions of this age dated in all parts of the peninsula (145.6–97 Ma; Leat *et al.* 1995). Cenozoic arc-related magmatism appears to have been limited to the western side of the peninsula, prompting some workers to suggest a westward migration of the arc (Saunders *et al.* 1982, Pankhurst 1982).

Arc plutons as young as 60 Ma crop out on Adelaide Island and on many of the islands in Marguerite Bay (Thomson & Harris 1981, Thomson *et al.* 1982, Moyes *et al.* 1994). Adelaide Island is also the site of a Jurassic–(?)Early Tertiary sedimentary basin (Moyes *et al.* 1994). Fore-arc basin sedimentary rocks are well represented on Alexander Island as the Middle Jurassic–Albian Fossil Bluff Group (Moncrieff & Kelly 1993). The basement of Alexander Island consists of deformed sedimentary rocks of the LeMay Group, interpreted as part of an accretionary prism (Burn 1984). Volcanic and plutonic rocks of Cretaceous to early Tertiary age intrude the LeMay Group (Burn 1984, McCarron 1995). Neogene post-subduction alkaline volcanic rocks also form several small outcrops on Alexander Island.

Longitudinal faults are widespread along the Antarctic Peninsula and have been described by a number of authors (Wyeth 1977 and references therein) mainly from physiographic rather than clear geological evidence. It has been suggested that these longitudinal faults bounded uplift of the central Antarctic Peninsula plateau. This uplift has

https://doi.org/10.1017/S0954102097000369 Published online by Cambridge University Press

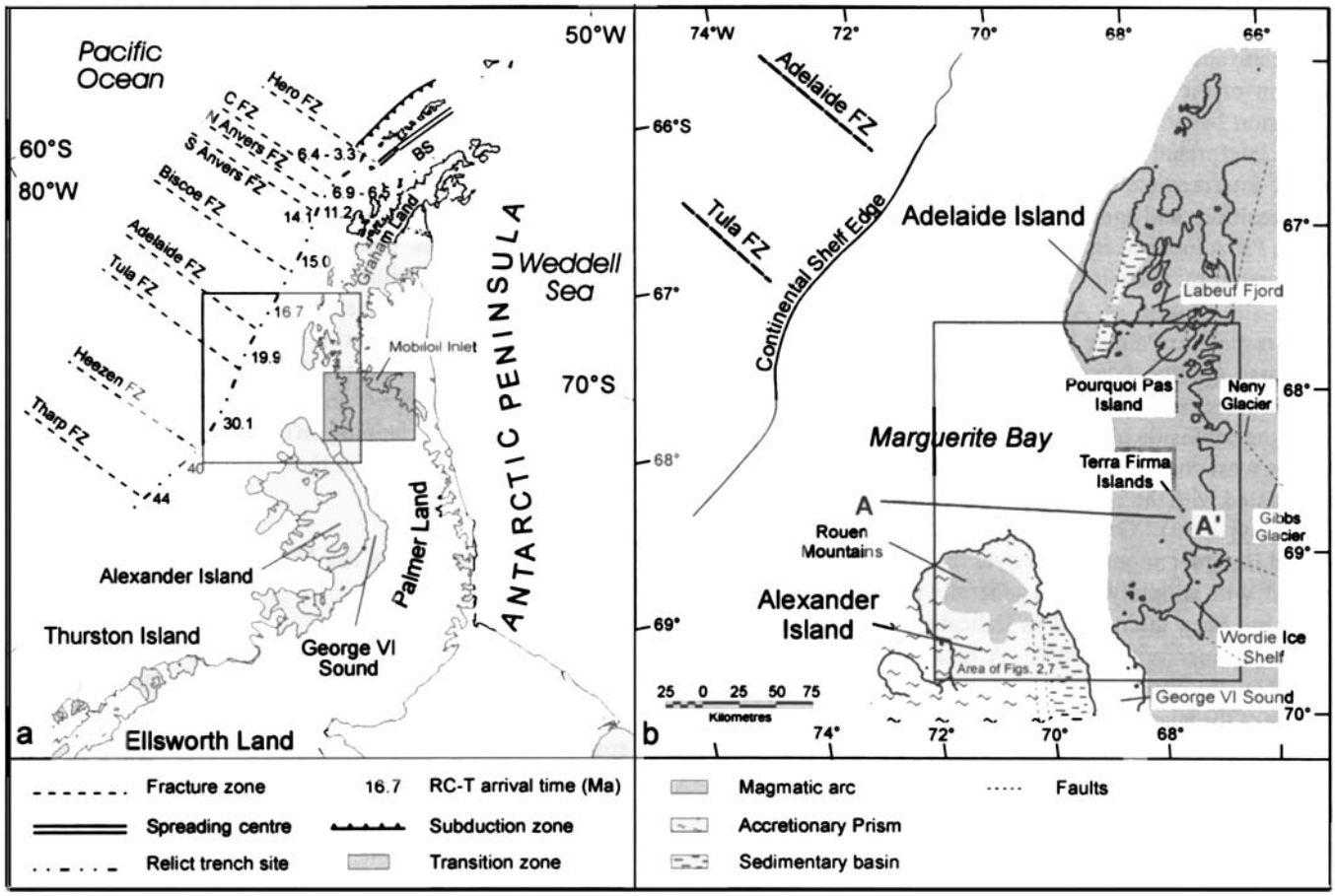


Fig. 1. Location maps of the Antarctic Peninsula and Marguerite Bay areas. **a.** Sketch map of the Antarctic Peninsula with approximate positions of oceanic fracture zones (FZ) and dates of ridge segment arrivals at the trench. BS: Bransfield Strait. RC–T: Ridge Crest – Trench. Box marks location of Fig. 1b. **b.** Sketch map of Marguerite Bay study area, with schematic geology. AA' marks position of modelled profile. Inset box shows area of Figs 2 & 7.

been interpreted as both pre- and post-erosion of the plateau surface (Wyeth 1977) but the absolute age of the faults is unknown. North-striking faults on Adelaide Island were reported by Dewar (1970) to be of 'relatively recent age', post-dating the youngest Andean-type dykes (?Middle or Late Tertiary, Dewar 1970). In the transition zone, Wyeth (1977) reported similar N–S, peninsula-parallel faulting and suggested that this faulting occurred before uplift, possibly along re-activated Mesozoic faults.

The physiography of the transition zone 'strongly suggests' large-scale transverse faulting along the NW–SE Neny and Gibbs glaciers (Wyeth 1977). NW–SE faults have also been mapped on the eastern side of the Antarctic Peninsula (Fraser & Grimley 1972) to the south of Mobiloil Inlet, downthrown to the north-east by up to 1300 m, with possible horizontal movement.

Plate tectonic setting

Subduction along the western margin of the Antarctic Peninsula appears to have been continuous from Late Triassic (Pankhurst 1982) until Cenozoic time, when subduction ceased progressively northward. This cessation was caused by the arrival of segments of the Antarctic–Phoenix (Antarctic–Aluk) ridge at the subduction trench (Herron & Tucholke 1976), resulting in the formation of a passive margin at the boundary between the trailing flank of the ridge and the Peninsula, which were both part of the Antarctic Plate (Barker 1982, Larter & Barker 1991a). Arrival dates of the ridge segments in the Marguerite Bay region have recently been calculated by Larter *et al.* (in press), using the geomagnetic polarity time scale of Cande & Kent (1995), and these are shown in Fig. 1. Recent re-evaluation of a marine magnetic profile between the Tharp and Heezen FZs suggests that the arrival time of the ridge segment was between 44–40 Ma (R. D. Larter & J.J. McCarron personal communication 1996).

Previous geophysical work

Reconnaissance aeromagnetic data over the Antarctic Peninsula (Renner *et al.* 1985, Maslanyj *et al.* 1991,

https://doi.org/10.1017/S0954102097000369 Published online by Cambridge University Press

Johnson & Smith 1992) reveal a curvilinear belt of positive magnetic anomalies stretching for 2000 km along the Pacific margin of the Antarctic Peninsula, and possibly as far as Thurston Island. The Pacific Margin Anomaly (PMA) has been interpreted as reflecting the presence of a complex mafic-intermediate batholith with intrusions of a variety of compositions and ages (Garrett 1990). Two apparent offsets in the PMA in the Marguerite Bay region (Fig. 2a) have been interpreted by Garrett (1990) as indicating up to 75 km of strike-slip motion of Alexander Island and Graham Land with respect to Palmer Land.

Sparse gravity data collected in the Antarctic Peninsula region (Renner *et al.* 1985) show a Bouguer anomaly low over the peninsula plateau, with a local high visible in places on the west coast, notably in Palmer Land, where it has been correlated with the interpreted PMA batholith (Garrett 1990, Maslanyj 1991). Gravity data on Alexander Island show a broad Bouguer anomaly low over the north and centre of the island, with anomaly values generally increasing southward. This has been interpreted as indicating thicker crust in the north (Renner *et al.* 1985). A local, linear, 20 km wide, 20 mGal amplitude, positive anomaly runs N–S through the centre of the island (Butler 1975), possibly related to accreted ocean island material (Garrett 1990, Doubleday *et al.* 1994). George VI Sound exhibits an alternating positive–negative–positive anomaly pattern along the sound, with a Bouguer anomaly low in the central part with highs to the north and south (Maslanyj 1991). A 45 mGal positive anomaly has been observed in the northern part of Marguerite Bay (Renner *et al.* 1985, Johnson *et al.* 1994), which together with the reconnaissance aeromagnetic data for the same area, has been interpreted as being caused by part of the dense, magnetic PMA batholith.

A number of intermediate-resolution single-channel seismic profiles offshore Marguerite Bay (e.g. Bart & Anderson 1995) have been interpreted as showing a number of sedimentary sequences, increasing in thickness to the continental edge and lapping on to continental basement. No direct age control exists for these sedimentary rocks.

Geophysical data from the Marguerite Bay area

Aeromagnetic map

A relatively detailed aeromagnetic survey was flown by the British Antarctic Survey over Marguerite Bay during the 1990–91 Antarctic field season (Fig. 2). Flight lines were spaced at 3 km intervals, and a constant barometric height of

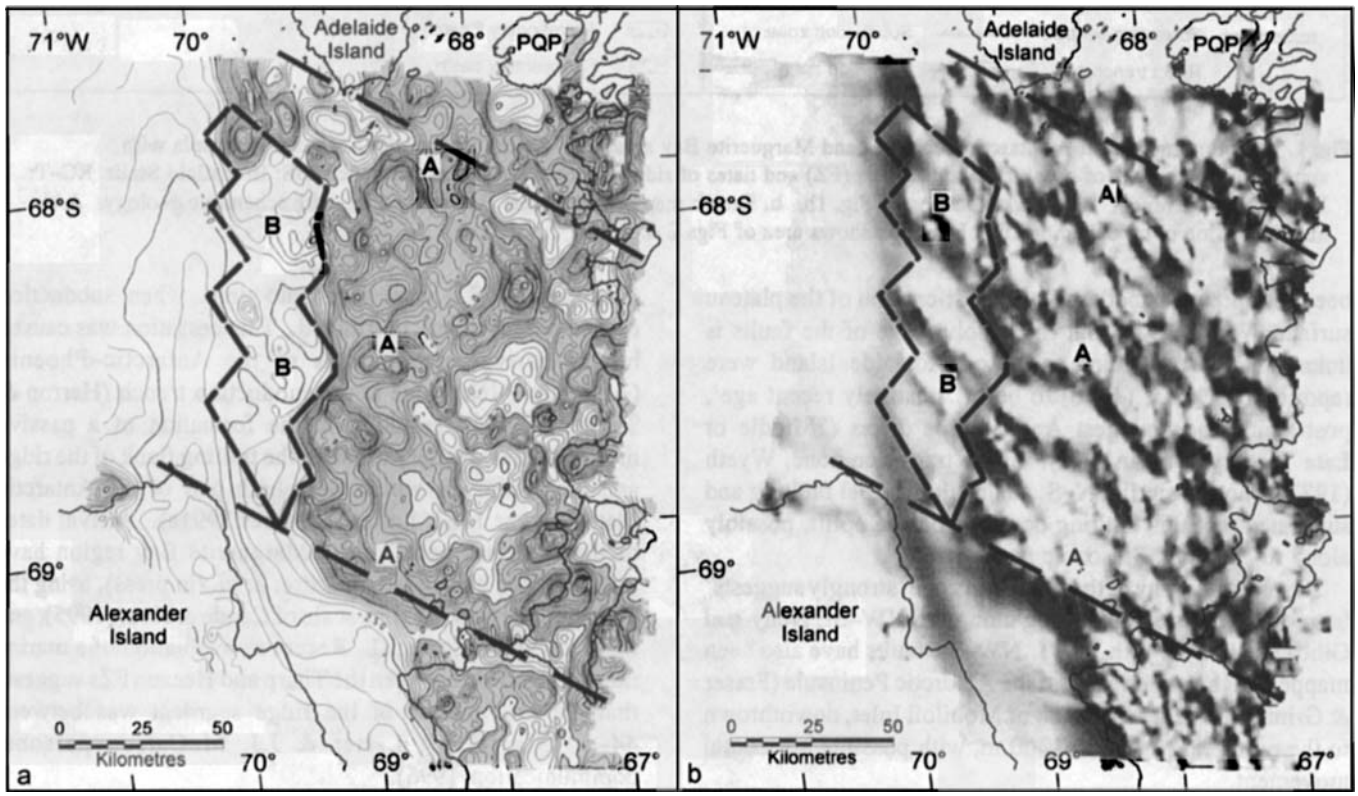


Fig. 2. Magnetic anomaly map of Marguerite Bay. Anomaly A: Pacific Margin Anomaly. Dashed line outlines the interpreted down-faulted block (B) of PMA batholith, from Johnson & Swain (1995). Heavy dashed lines mark interpreted offsets from Garrett (1990). PQP: Pourquoi Pas Island. **a.** Contour map, with contours at 50 nT intervals, and positive anomalies shaded. **b.** Shaded-relief image of the same magnetic anomaly data, with shading from the NE.

https://doi.org/10.1017/S0954102097000369 Published online by Cambridge University Press

1250 m a.s.l. was maintained. The data have been reduced to the pole, and gridded with a 750 m cell size. Details of data acquisition and processing can be found in Johnson & Swain (1995).

The prominent N–S trending belt of positive anomalies in the centre of the map, which is *c.* 40 km wide and has amplitudes up to 900 nT (A in Fig 2a), is the western component of the PMA. The two apparent offsets in the PMA (Garrett 1990) are marked at approximately 68°S and 69°S (Fig. 2a). A strong NW–SE fabric in the magnetic field, parallel to the trends of offshore fracture zones, is evident across the map (Fig. 2b). A distinct area of subdued anomalies is present between the two apparent PMA offsets (B in Fig. 2b), which also shows the NW–SE fabric and has 'sawtooth' eastern and western boundaries (Fig 2b).

New bathymetry map

Bathymetric data from a wide variety of original sources have been digitized from the Hydrographic Office Chart 3571 (Hydrographic Office 1991). The sampling interval and accuracy of each data point varies with collection method. At one extreme are lead-line soundings taken in the early part of this century, from vessels using celestial navigation methods; at the other, echo sounding data from modern survey ships using satellite navigation systems. All the data from the chart were digitized and a coarse digital coastline set at the zero level was appended. Digitally recorded bathymetry data from the British Antarctic Survey marine geophysics database were also added to the data set. The data were gridded with a 3.5 km grid cell spacing using a spline in tension method (Smith & Wessel 1990), then smoothed with a single pass of a 3 x 3 Hanning filter before being automatically contoured (Fig. 3).

The main feature of the map is the NNW-trending George VI trough (Kennedy & Anderson 1989) extending from George VI Sound. The trend of the trough changes to N–S at about 67°15'S before returning to the NNW trend at 67°S. The northern part of the trough, which has been referred to as Marguerite trough (Pope & Anderson 1992), then continues almost to the shelf edge.

George VI Sound is 25–40 km wide and reaches depths of 1000 m below msl (Maslanyj 1991). The northern end of George VI Sound is truncated by a shallower E–W trending ridge at 68°40'S, but the bathymetric low clearly continues NNW as George VI trough, widening rapidly to *c.* 60 km wide. George VI trough reaches depths of >800 m and is asymmetrical in cross-section, with a steeper margin to the east than to the west.

Bathymetric features to the east of this trough appear similar to those shown on previous maps (e.g. Kennedy & Anderson 1989) in showing a rugged sea floor with a number of deep, steep-sided (>5°) troughs. One such trough, the Adelaide trough (Kennedy & Anderson 1989), extends south-west from between Adelaide and Pourquoi Pas islands to 68°S. The west and north-west parts of the map show low-relief bathymetry over the outer part of the continental shelf, with depths generally decreasing toward the shelf edge.

Free-air anomaly map

Data from the ERS-1 and GEOSAT missions have been combined to produce a free-air anomaly map of the southern oceans (Smith & Sandwell 1995). Figure 4 shows the available data for Marguerite Bay and the adjacent area, re-gridded at a 3.5 km interval.

A positive anomaly along the shelf edge (C in Fig. 4) is clearly visible in the north-west of the map. Oceanward of this, a NW–SE trending gradient is approximately coincident with the position of the Adelaide FZ. Landward of the shelf edge, and parallel to it, a linear negative anomaly separates the shelf edge anomaly from another broadly linear positive anomaly (D in Fig. 4). This anomaly may mark the position of the mid-shelf high (MSH), an extensive structural high seen on numerous seismic reflection profiles that cross the continental shelf west of Graham Land (Larter & Barker 1991b, Larter *et al.* in press). In the north-east of the map this

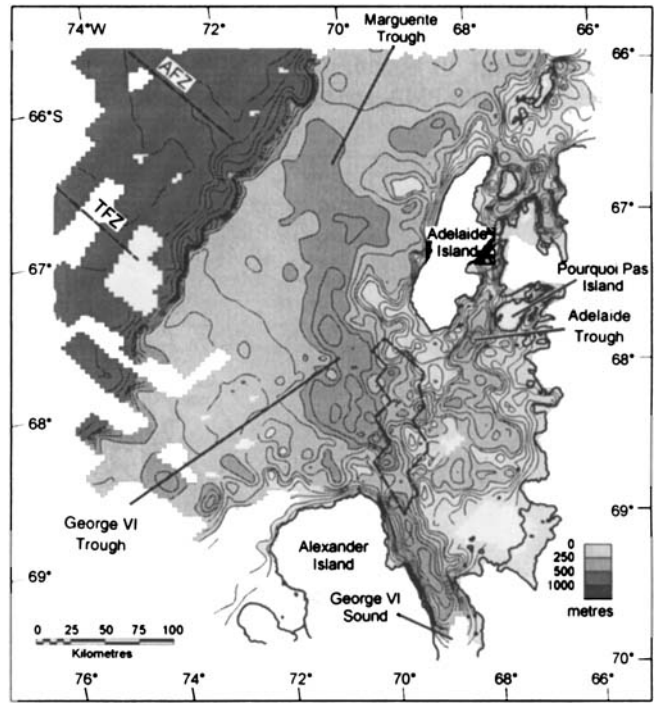


Fig. 3. Bathymetry map for Marguerite Bay area, from digitised Hydrographic Office Chart 3571, together with satellite-navigated soundings from British Antarctic Survey marine geoscience cruises, National Geophysical Data Centre and other sources. Contours are at 50 m intervals between 0–300 m, at 100m intervals between 300–1000m, and at 250m intervals thereafter. Digitised bathymetry ©Crown Copyright. Reproduced from Admiralty chart 3571 by permission of the Controller of Her Majesty's Stationery Office.

https://doi.org/10.1017/S0954102097000369 Published online by Cambridge University Press

anomaly is 30 km wide, but further to the south-west, at approximately 67°S 71°W, it begins to widen and diverges slightly from the shelf edge. The anomaly appears to merge at this position with a positive anomaly *c.* 70 km wide (E in Fig. 4), trending northwards from Alexander Island. The MSH may continue parallel to the shelf edge to the west of Alexander Island (?D in Fig.4), but the associated gravity anomaly is not as clear in this area and is disrupted by a number of smaller, shorter wavelength (20 km) anomalies.

A prominent negative anomaly is visible, coincident with George VI trough (F in Fig. 4). It has a comparable width to the bathymetric feature: 25 km close to George VI Sound increasing to 40 km farther north. At 67°45'S, the anomaly is disrupted slightly by a local high, but then continues northward before changing direction to run parallel the shelf edge to the west of Adelaide Island (G in Fig. 4). The anomaly in that area is 50 km wide, and coincides with a sedimentary basin seen on seismic reflection profiles (Anderson *et al.* 1990, Larter *et al.* in press). Marguerite trough does not have a clear expression in the free-air anomaly data. In the centre of Marguerite Bay, a N–S trending positive anomaly (A in Fig. 4), 35 km wide, coincides with the western component of the PMA (Fig. 2). This positive anomaly is offset in the same positions as the apparent PMA offsets, to the south of Adelaide Island and north of George VI Sound. Between the positive anomaly coincident with the PMA, and the negative anomaly coincident with George VI trough, three small ridges of positive anomalies extend roughly E–W (B in Fig. 4), covering a similar area to the proposed down-faulted block interpreted from the magnetic data (B in Fig. 2b).

New Bouguer anomaly map

Simple Bouguer anomalies were calculated from the bathymetry and satellite free air anomaly, using a crustal density of 2.67 Mg m^{-3} and a density for sea water of 1.03 Mg m^{-3}. The Bouguer anomaly map was then contoured at 5 mGal intervals (Fig. 5). The accuracy of the Bouguer anomaly grid is limited by the track spacing of the satellite data and more so by the inaccuracies in the older bathymetry data. There is, however, an encouraging correlation between profiles derived from the map and data from the few marine gravity profiles in the area (U. Meyer, personal communication 1995).

A large positive Bouguer gravity field (>200 mGal) is seen over the deep water area to the NW of the shelf edge (C in Fig. 5). This is expected, as this is thought to be an area of normal ocean floor, with mantle at shallow depths. Landward of the shelf edge, however, the pattern of broadly linear highs and lows seen in the free-air anomaly data (Fig. 4) is still evident (C, D in Fig. 5). The sparse bathymetry data in the

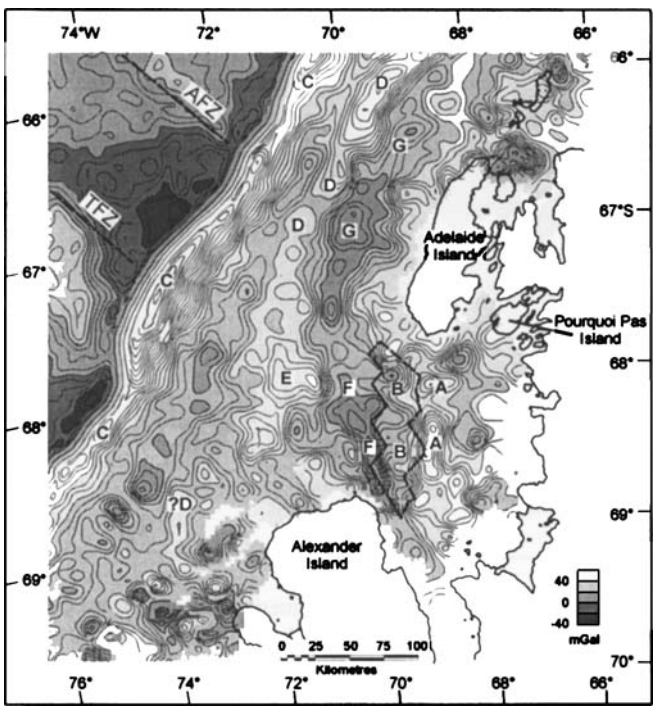


Fig. 4. Satellite altimetry-derived free-air anomaly map for the Marguerite Bay area from Smith & Sandwell (1995). Contours are at 5 mGal intervals. A-G refer to text. AFZ: Adelaide fracture zone, TFZ: Tula fracture zone.

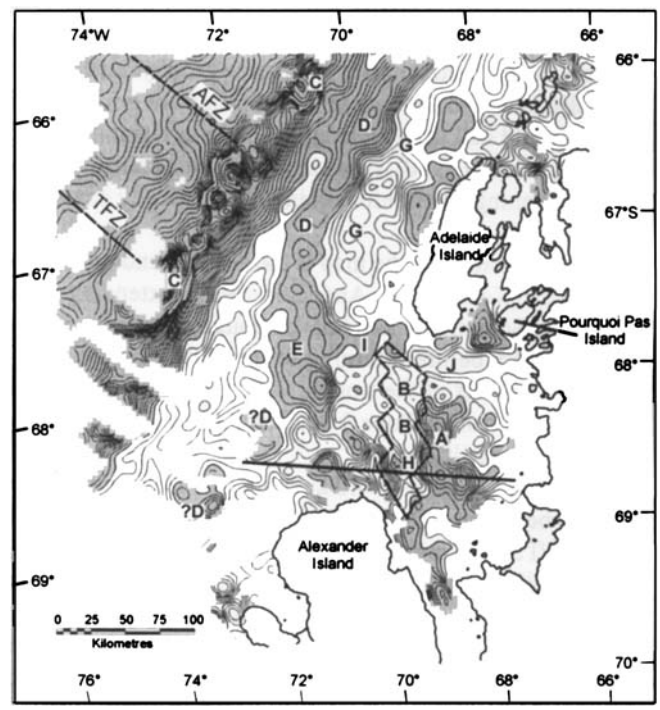


Fig. 5. Bouguer anomaly map for the Marguerite Bay area, constructed from digitised bathymetry and satellite free-air anomalies. Contour interval 5 mGal, anomalies > 45 mGal are shaded. A-J refer to text. AFZ: Adelaide fracture zone, TFZ: Tula fracture zone. Solid line marks position of modelled profile (Fig. 7).

https://doi.org/10.1017/S0954102097000369 Published online by Cambridge University Press

extreme south-west of the map prohibit calculation of Bouguer Anomaly for much of this area, but it appears that the linear negative Bouguer anomaly inshore of the shelf edge anomaly continues to the south-west (?D in Fig. 5). The seismically-mapped basin to the west of Adelaide Island (Anderson *et al.* 1990, Larter *et al.* in press) is clearly imaged as a relative Bouguer anomaly low (G in Fig. 5). The biggest difference between free-air and Bouguer gravity maps is in the region of George VI trough. At the entrance to George VI Sound, a Bouguer anomaly high is apparent (F in Fig. 5). At roughly 68°30'S 69°45'W, on the eastern edge of the bathymetric trough, a 25 km long, 10 km wide positive anomaly, flanked by steep gradients, trends NW–SE (H in Fig. 5). Farther north, the anomaly over the trough becomes negative, with less steep sides before being truncated by an E–W trending positive anomaly (I in Fig. 5) at 67°45'S. In the centre of Marguerite Bay, the N–S trending positive Bouguer anomaly (A in Fig. 5) associated with the PMA is truncated to the south of Adelaide Island by an E–W trending negative anomaly (J in Fig. 5).

Pseudogravity map

Pseudogravity (Baranov 1957) effectively shows the gravity field to be expected if the susceptibility distribution was converted to a density distribution. It emphasises the longer-wavelength component of the magnetic field, which is attributable to sources deeper within the crust, over shorter-wavelength near-surface features. The pseudogravity anomalies over the PMA and George VI trough (A, F in Fig. 6) correlate particularly well with the free-air anomalies (A, F in Fig. 4). The correlation of the pseudogravity field (A in Fig. 6) to the calculated simple Bouguer anomaly field (A in Fig. 5) is also good, though the E–W truncation of the Bouguer anomaly at about 68°S (J in Fig. 5) is not so apparent on the pseudogravity map. The pseudogravity transformation uses a single value for the ratio of susceptibility to density, which is a generalisation, and no account is taken of near-surface non-magnetic sedimentary rocks which may cause significant Bouguer anomalies. Both these factors, and the inaccuracies in the Bouguer anomaly map noted above, may account for the differences between the two maps.

Interpretation

2.5D gravity and magnetic model

A simple gravity and magnetic model (Fig. 7) has been constructed for profile AA' (location on Figs 1 & 5) across the Marguerite Bay area. The general N–S trend and extent of longer-wavelength gravity (Fig. 5) and magnetic (Fig. 2) anomalies in the area justify the two-dimensionality of the model. The gravity data have been modelled for the long-wavelength component features only, owing to the above-described inaccuracies of the Bouguer gravity data, and also the absence of seismic control on sediment thicknesses.

The mean density for all Antarctic Peninsula rocks (excluding Alexander Island) is 2.72 Mg m^{-3}. The mean density excluding gabbro is 2.70 Mg m^{-3} with a mean value for gabbro of 2.84 Mg m^{-3} (Garrett 1990). Mesozoic accretionary complex metasedimentary rocks from Alexander Island have a mean density of 2.74 Mg m^{-3} and basalt and tuff from the same accretionary complex have a mean density of 2.86 Mg m^{-3} (Garrett 1990). Susceptibility values for gabbros from Graham Land and Palmer Land vary from 26.4 to 56.7 x 10^{-3} SI, and for granites, 0.9 to 18.7 x 10^{-3} SI. Intermediate rocks have susceptibilities from 1.2 to 46.7 x 10^{-3} SI (Maslanyj *et al.* 1991). For Alexander Island, accretionary prism rocks have a mean susceptibility of 0.6 x10^{-3} SI, with plutonic and volcanic rock mean values of 16.8 x10^{-3} SI and 9.7 x 10^{-3} SI respectively (Maslanyj *et al.* 1991). Many rocks from the peninsula show remanent intensities of up to 1 Am^{-1} with Königsberger ratios close to unity (Maslanyj *et al.* 1991). Stable remanence directions are generally close to the modern field (declination 10°–30°E, inclination -55° to -65°), so susceptibilities used in modelling can be up to double the measured values.

Crustal thicknesses used, 18–24 km, increasing towards the east, are consistent with preliminary results of a recent wide-angle seismic reflection and refraction experiment

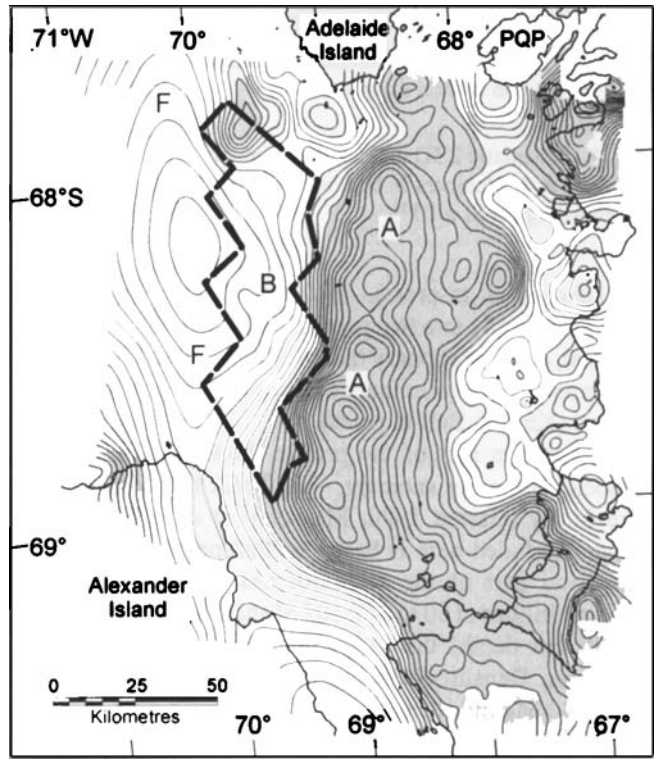


Fig. 6. Pseudogravity anomaly map for Marguerite Bay, calculated from data shown in Fig. 2. Units are arbitrary, positive anomalies are shaded. A,B,F, refer to text. PQP: Pourquoi Pas Island.

https://doi.org/10.1017/S0954102097000369 Published online by Cambridge University Press

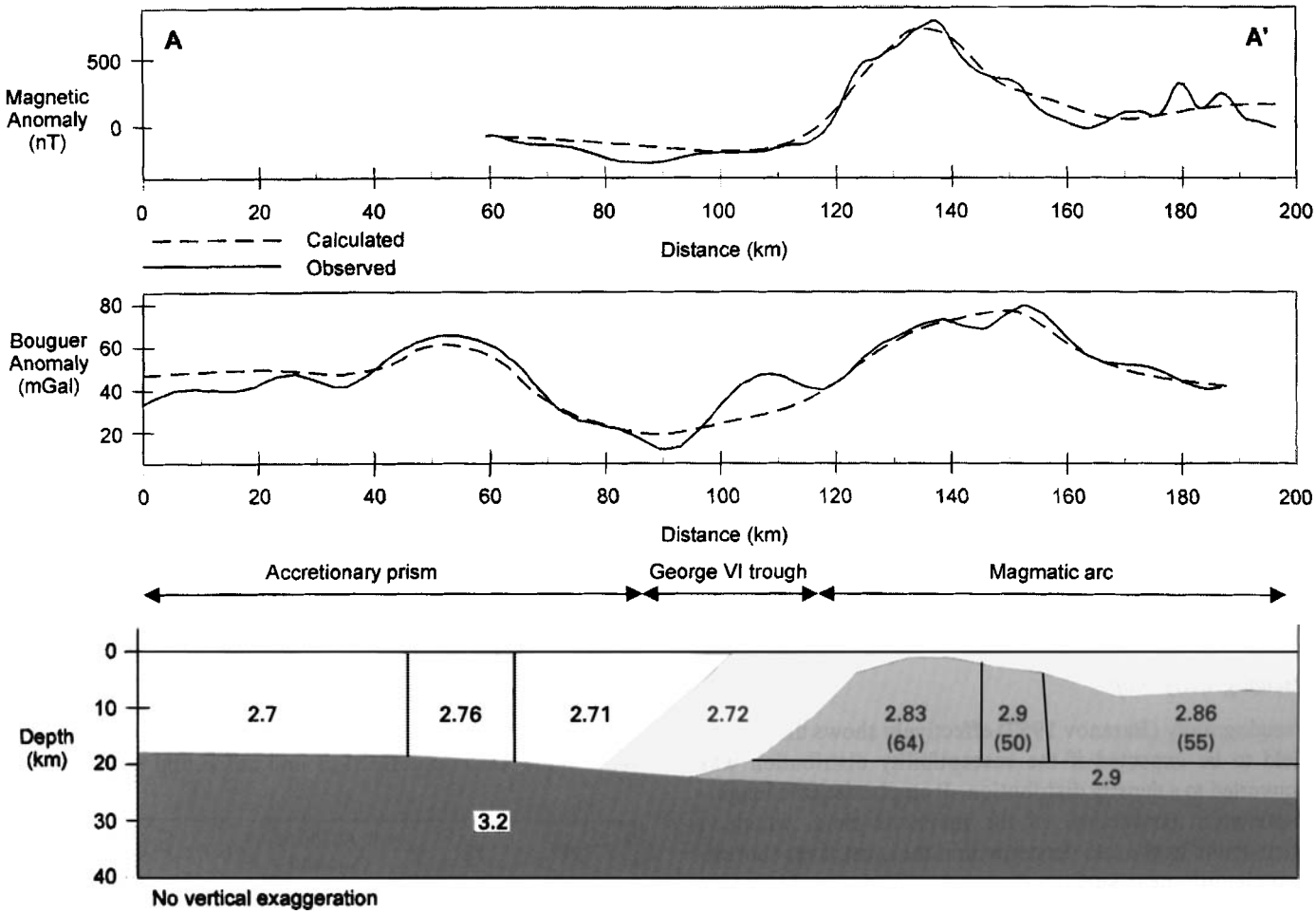


Fig. 7. Schematic 2.5D magnetic and gravity model of profile AA' across Marguerite Bay. Location of modelled profile is shown in Figs 1 & 5. Numbers in bold are densities used in modelling (in Mg m^{-3}), numbers in brackets are values of susceptibility used in modelling (in SI x 10^{-3}).

(Reading *et al.* in press). In the model, the upper crust is divided laterally into two parts, representing magmatic arc to the east, and accretionary material to the west. This division is supported by preliminary seismic results from George VI Sound (King & Bell in press).

The eastern part of the profile shows the PMA and its associated gravity anomaly. The PMA has been modelled previously (Garrett 1990, Maslanyj *et al.* 1991), and the model included here is based on that previous work. The magnetic part of the batholith has been modelled with susceptibilities of 50 to 64 x 10^{-3} SI and is shown as extending to 20 km depth, the assumed depth of the Curie Point isotherm. Densities have been varied laterally between 2.83 and 2.90 Mg m^{-3}, consistent with measured rock properties (above) and previous models. The lower (> 20 km depth) part of the batholith has been assigned a density of 2.9 Mg m^{-3}. The crust surrounding the batholith has been assigned a density of 2.72 Mg m^{-3}, the mean density of magmatic arc rocks from the Antarctic Peninsula. The model is consistent with the interpretation of the PMA as caused by a mafic-intermediate batholith with a variety of compositions. The model batholith comes within 2 km of the sea floor, but may crop out elsewhere in Marguerite Bay, possibly as gabbro on the Terra Firma Islands (Thomson *et al.* 1982). The steep western margin of the modelled batholith and the linear nature of this boundary suggest that it is fault-controlled. The magmatic arc is modelled as underlying at least part of George VI trough, again consistent with the preliminary interpretation of seismic data from George VI Sound (King & Bell in press). Average densities for magmatic rocks of the Antarctic Peninsula and LeMay Group rocks are similar, so the Bouguer anomaly low at their junction may be due to differences in crustal thickness or the presence of sediments in George VI trough.

The western part of the profile has been modelled as lateral variations in the density of the upper crust, varying from 2.7 to 2.76 Mg m^{-3}, consistent with densities measured for Alexander Island rocks (above). The magnetic data do not extend farther west than is shown, but the western end of the magnetic profile appears very flat. Reconnaissance

https://doi.org/10.1017/S0954102097000369 Published online by Cambridge University Press

aeromagnetic data over Alexander Island (Maslanyj *et al.* 1991) also show a generally subdued magnetic field. Alternatively, a discreet, higher-density body with an upper surface approximately 4 km below sea level could cause the gravity high seen between 40 and 70 km from the western end of the modelled profile. Such a body could be analogous to the Rouen Mountains batholith.

Mapped lineaments and trends

A sketch map of trends (Fig. 8) has been drawn using the magnetic anomaly (Fig. 2), bathymetry (Fig. 3), free-air gravity (Fig. 4) and Bouguer gravity (Fig. 5) maps. The shelf edge and mid shelf high anomalies trend NE–SW across the western part of the map (C, D in Fig. 8), and several trends parallel to this can be seen closer to the Antarctic Peninsula. Within Marguerite Bay itself, the predominant trend directions are approximately NW–SE, though other trends are clearly visible (N–S, NE–SW and E–W). All the data sets show NW–SE trends, but it appears that the free-air anomaly trends are less steep (WNW–ESE). The trend of George VI Sound and George VI trough cross the map at a steeper angle (NNW–SSE, F in Fig. 8).

The coincidence of a number of interpreted magnetic, gravity and bathymetric trends in the centre of Marguerite Bay (e.g. area B in Fig. 8) suggests fault control. The NW–SE trends are parallel to the trends of the offshore fracture zones, and some of the mapped physiographic trends (?faults) detailed above. The spine of the Antarctic Peninsula is aligned approximately N–S in this area, parallel to some large-scale trends seen in the geophysical data, such as the generalised trend of the edge of the PMA.

Crustal structure

Accretionary prism

Renner *et al.* (1985) showed that the long-wavelength Bouguer gravity field over Alexander Island varies from a broad negative field (-40 mGal) in the north, to a positive (30 mGal) field in the south. They interpreted this as an increase in crustal thickness in the north of the island to 30 km, possibly due to Airy crustal isostatic compensation of the Rouen Mountains. I interpret the increase in Bouguer anomaly to the north of Alexander Island, to >75 mGal (E in Fig. 5), as indicating a northward continuation of the Mesozoic accretionary prism accompanied by thinner crust. This proposed accretionary prism is bounded to the east by George VI trough. Single-channel seismic data across this area (Bart & Anderson 1995) show seismically opaque 'basement' oceanward of George VI trough. Bart & Anderson (1995) interpreted this 'basement' as folded or faulted strata which may have been intruded by plutons or metamorphosed, which is consistent with the continuation of the Alexander Island Mesozoic accretionary prism proposed here.

Fore-arc basins and mid shelf high

The sedimentary basin to the west of Adelaide Island and the prograded wedge of sediments on the outer shelf have a clear expression in the gravity data (C, G in Figs 4 & 5), which provides confirmation of the extent of these features as clearly imaged on seismic data (Larter *et al.* in press).

The Bouguer anomaly high, interpreted as part of the Alexander island accretionary prism (E in Fig. 5), merges to the north-north-west with the linear NE–SW gravity high (D in Fig. 5) associated with the mid shelf high (MSH). The similar character of these gravity anomalies suggests that the MSH may also be accretionary prism material, although this cannot be determined unambiguously. Multi-channel seismic data across the MSH offshore of Adelaide Island and farther north (Larter & Barker 1991b), have shown that the MSH is a structural, and in places bathymetric, high. It was uplifted between 1–4 million years after the arrival of the ridge segment at the adjacent part of the margin, and has been subsiding since then. As the ridge segments arrived earlier to the south-west of the peninsula, the more subdued nature of this linear gravity anomaly to the west of Alexander Island (?D in Figs 4 & 5) could reflect the greater amount of subsidence in this area owing to the longer time since ridge segment arrival and the onset of subsidence.

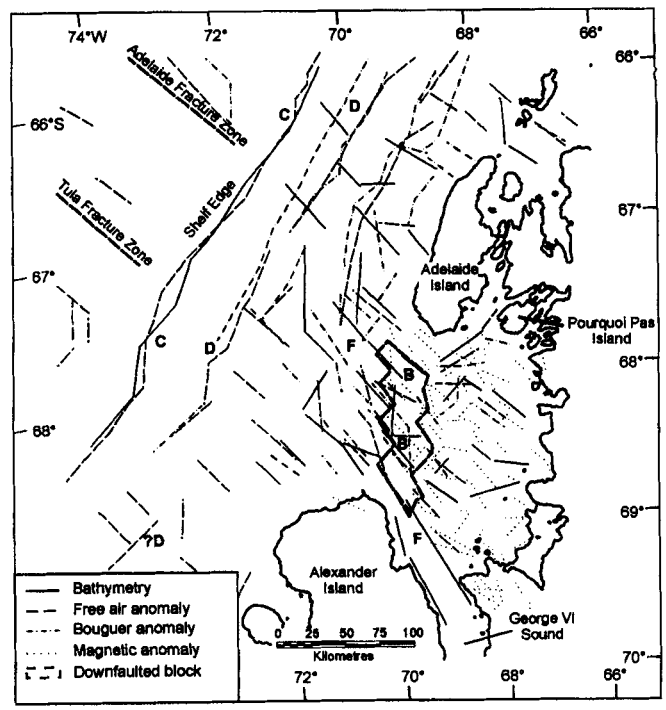


Fig. 8. Sketch map of geophysical and bathymetric trends in the Marguerite Bay region. The trends were drawn from pseudo-relief images of the data in Figs 2, 3, 4 & 5, illuminated from a variety of angles. B–F refer to text.

https://doi.org/10.1017/S0954102097000369 Published online by Cambridge University Press

PMA batholith

The coincidence of magnetic, pseudogravity and Bouguer gravity anomalies in Marguerite Bay (Figs 2, 4, 5 & 6) strongly supports the interpretation of the PMA (Garrett 1990, Johnson 1996) as a complex mafic-intermediate batholith, which is both magnetic and dense compared to the surrounding crust (Fig. 7). The PMA batholith clearly underlies much of the inshore part of Marguerite Bay. The area of subdued magnetic anomalies (B in Fig. 2), to the west of the main PMA anomaly, has been interpreted by Johnson & Swain (1995) as representing a down-faulted block of PMA batholith. The proposed down-faulted block also coincides with subdued free-air anomalies (Fig. 4) and intermediate-depth bathymetry (Fig. 3), supporting the interpretation.

An alternative interpretation of the geophysical anomalies in area B (e.g. Fig. 2) is that they represent a series of discrete plutons, intruded along NE–SW faults at the edge of the PMA batholith. This interpretation cannot be ruled out entirely, but the similarity of magnetic fabric across the whole of Marguerite Bay (Fig. 2b) suggests that the anomalies in area B are of a similar origin to the rest of the PMA. The coincidence of bathymetric and geophysical trends, particularly at the margins of area B, also support the preferred interpretation of a lower block of PMA batholith.

George VI trough

The bathymetric (Fig. 3) and free-air anomaly (Fig. 4) maps show George VI trough to continue NNW to approximately 67°45'S, and possibly farther. The coincidence of the linear magnetic gradient at the edge of the PMA (Fig. 2), and the steepness of the modelled batholith boundary (Fig. 7) argue for structural control at least to the eastern side of the trough.

George VI trough is interpreted as a continuation of George VI Sound, bounded to the east by the Antarctic Peninsula magmatic arc, including the PMA batholith, and to the west by the interpreted continuation of the Alexander Island accretionary prism. Most authors have suggested that George VI Sound has a primarily structural origin (Crabtree *et al.* 1985, Storey & Nell 1988, Maslanyj 1991) rather than a purely erosional one (Nichols 1953), though all workers agree that the feature has been subsequently altered by glacial action. Recent acquisition of multi-channel seismic data across this feature (King & Bell in press) strengthen the argument for a tectonic, rather than purely glacial origin. Preliminary interpretation of these data shows magmatic arc rocks extending roughly half-way across the sound, where they appear to become overlain by normal-faulted sedimentary rocks interpreted as belonging to the Fossil Bluff Group. Pockets and lenses of Cenozoic sediment at least 250 m thick were also inferred as underlying the bed of George VI Sound (King & Bell in press).

Faults and fractures

The steeply dipping western edge of the PMA batholith model (Fig. 7), the coincidence of magnetic, gravity and bathymetric trends (Fig. 8) and the presence of the interpreted down-faulted block of PMA batholith are all indicative of a faulted margin. The N–S trending pseudogravity gradient farther inshore at about 68°W (Fig. 6) also suggests faulting, implying that the western component of the PMA is a fault-bounded block of PMA batholith beneath the centre of Marguerite Bay. Johnson *et al.* (1994) suggested this interpretation for northern Marguerite Bay and Laubeuf Fjord, arguing that, if the lithosphere was placed under tension soon after emplacement of the batholith, the dense batholith may have subsided, at least in part, causing major normal faulting and possibly grabens.

The presence of the interpreted down-faulted block to the west of the PMA (B in Fig 2b,) suggests the offsets in the PMA at 68°S and 69°S represent strike-slip displacements of less than 10 km (Johnson & Swain 1995), rather than 75 km (Garrett 1990). From the magnetic map (Fig. 2b) it appears that the block may be subdivided into four or more sub-blocks, implying a more even distribution of strike-slip across Marguerite Bay, giving a total offset close to the magnitude suggested by Garrett (1990).

The northern and southern boundaries of the interpreted down-faulted block lie close to the extrapolated trends of the Adelaide and Tula fracture zones respectively (e.g. Figs 3 & 4). These trends also line up with other features, such as changes in trend or width of George VI trough and possible breaks in the Mid Shelf High. Onshore features such as the end of Adelaide Island, the edge of the Rouen Mountains intrusion and the edge of Wordie Ice Shelf (see Fig. 1 for location) also align with these trends. I interpret these trends as large-scale fault zones bounding the inshore part of Marguerite Bay.

Summary

Figure 9 is a sketch map of the main elements of crustal structure of the Marguerite Bay area, interpreted from the geophysical data outlined here. The MSH lies inshore and roughly parallel to the shelf edge, and is broken in at least two places. The continuation of the MSH towards the south-west is suggested but is not clear. The accretionary prism mapped as the LeMay Group on Alexander Island is interpreted as underlying the outer part of Marguerite Bay. George VI trough is interpreted as being a continuation of George VI Sound, and separating the accretionary prism from the magmatic arc. A sedimentary basin, mapped seismically, lies offshore Adelaide Island, at least partly overlapping with George VI trough. A large dense batholith associated with the PMA and part of the Antarctic Peninsula magmatic arc, underlies most of the inshore part of Marguerite Bay. A block of down-faulted PMA batholith lies at the western edge of the

https://doi.org/10.1017/S0954102097000369 Published online by Cambridge University Press

PMA, bounded to the west by George VI trough. Two large-scale NW–SE fault zones are interpreted as bounding Marguerite Bay. These fault zones either offset or bound most of the features described above. The trend of the northern and southern fault zones appears to be a broad continuation of the trend of the Adelaide and Tula fracture zones respectively, suggesting a link between oceanic tectonic processes and continental structures.

Integrated tectonic model for Cenozoic evolution

Hamilton (1995) (and many previous workers) suggested that the typical regime in overriding plates is extensional, but emphasized that arc systems are complex, dynamic and change rapidly. Extensional processes have been suggested as the cause of many features along the Antarctic Peninsula (e.g. Garrett & Storey 1987). A number of features suggest that extension has been an important factor in the tectonic development of the Marguerite Bay area. These include the inferred faulted boundaries of the PMA batholith, the interpretation of George VI trough as a continuation of George VI Sound and the predominant NW–SE trends seen in many of the geophysical data sets. The two inferred fault zones (Fig. 9), which form a continuation of the trends of the Adelaide and Tula fracture zones, together with the NW–SE geophysical trends suggest a link between extension in the overriding plate and the oceanic tectonic history.

I propose a two-stage model of extension to explain the Cenozoic tectonic evolution of the Marguerite Bay area, which is summarised in Fig. 10.

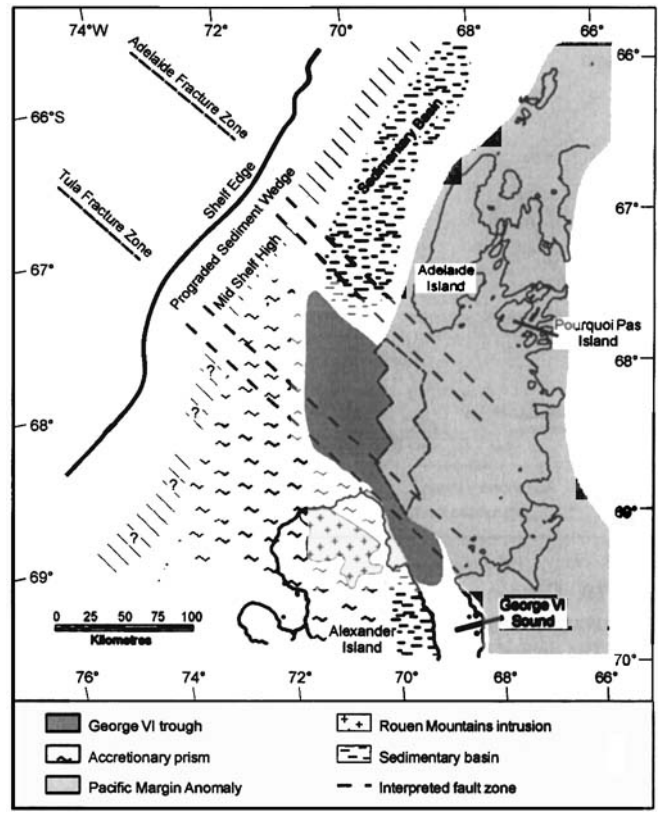


Fig. 9. Sketch map of the main structural features of the Marguerite Bay area, interpreted from geophysical data. Down-faulted block of Pacific Margin Anomaly batholith is shown with dashed outline.

Stage one

The starting point for the model (Fig. 10a) assumes no separation between the accretionary prism and the magmatic arc prior to *c.* 52 Ma. The first stage of extension assumes that as George VI trough is a continuation of George VI Sound, it was formed at the same time and by the same process. Structural data from the accretionary complex and Fossil Bluff Group on Alexander Island have been interpreted as indicating that George VI Sound opened in a NW direction by dextral transtension (Fig. 10a, Storey & Nell 1988, Nell & Storey 1991), an interpretation also consistent with the interpretation of geophysical data from George VI Sound (Maslanyj 1991). Storey *et al.* (1996) suggested that the dextral transtension may have been a result of a rapid reduction in spreading rates on the Antarctic–Phoenix ridge in Early Tertiary times (Cande *et al.* 1982, Barker 1982), leading to increased slab roll-back.

It is important to note that, owing to the unusual plate geometry (the trailing flank of the ridge and the over-riding lithosphere at the subduction zone being two parts of the same plate), convergence rates at the margin were the same as full spreading rates at the ridge (Barker 1982, Larter & Barker 1991a). Recent re-evaluation of marine magnetic data (R.D. Larter & J.J. McCarron, personal communication 1996) shows half spreading rates decreased from 51 mm y^{-1} to 21 mm y^{-1} at anomaly C23r time (52.3 Ma, Cande & Kent 1995), corresponding to a convergence rate decrease from 102–42 mm y^{-1}. This decrease in spreading and convergence rates, and therefore any extension associated with it, occurred before the arrival of the ridge segment between the Tharp and Heezen FZs, opposite the southern end of Alexander Island (Fig. 1). Extension at this time may have affected the whole Pacific margin of the Antarctic Peninsula.

The arrival of a ridge crest at the trench is likely to have caused extension either to cease, or to decrease significantly for that particular segment, as trench suction forces were eliminated when the arrival of the ridge juxtaposed two sections of the same plate. Subduction, and possibly extension, would have continued in the segments to the north-east.

Stage two

The second stage of the proposed model is the continuation of extension in the Marguerite Bay area after the arrival of the Heezen–Tula segment (30.1 Ma, Fig. 10b), prior to the arrival of the Tula–Adelaide segment (19.9 Ma, Fig. 10c). Extension at this time within the bay may account for the

https://doi.org/10.1017/S0954102097000369 Published online by Cambridge University Press

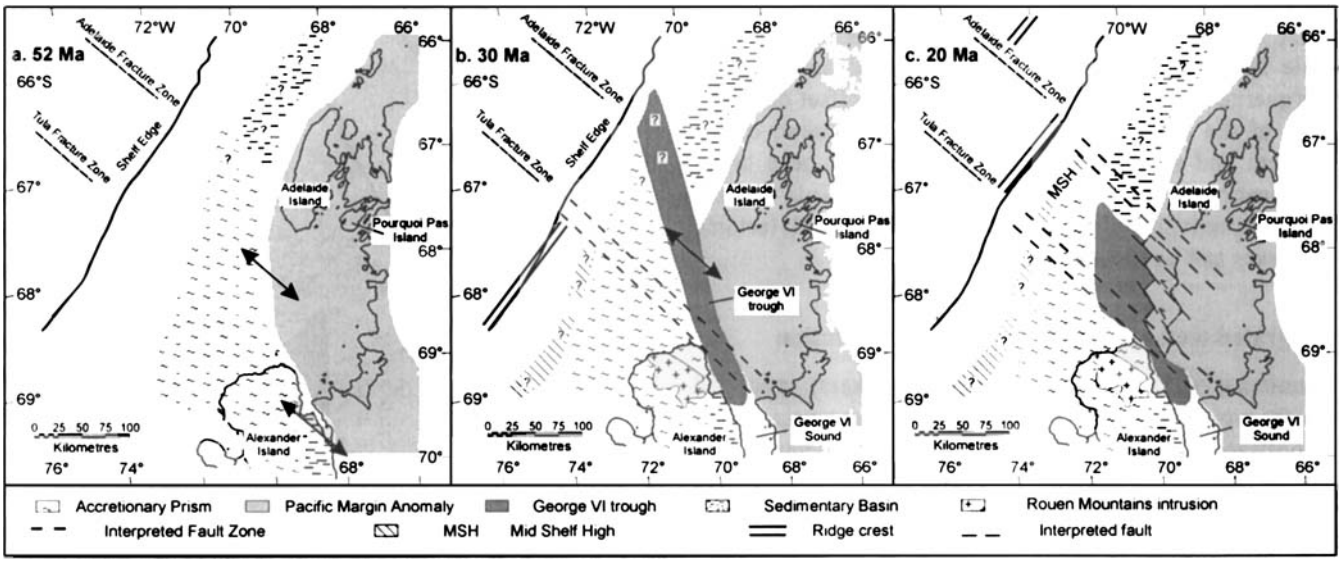


Fig. 10. Cartoon of proposed model of Cenozoic tectonic development of the Marguerite Bay area. **a.** A rapid slow-down in plate convergence rates at *c.* 52 Ma initiates the opening of George VI Sound and George VI trough in a dextral transtension regime. **b.** The arrival of the Heezen–Tula ridge segment at *c.* 30 Ma stops extension to the south of the Tula fracture zone: extension continues to the north, causing George VI trough to widen, and faulting at the edge of the PMA batholith. **c.** Oblique extension in the Tula–Adelaide segment causes a series of normal and transfer faults which give rise to the down-faulted block of PMA batholith. The arrival of the ridge crest at *c.* 20 Ma stops the extension in the Marguerite Bay area.

lower level of the accretionary prism north of Alexander Island and the wider George VI trough (though this may be a result of later erosion). Normal faulting within the PMA batholith, including the interpreted down-faulted block at its western edge, and the topographic depression that is Marguerite Bay itself may also originate from this time. It is not clear whether this extension continued as dextral transtension, or simply oblique extension. The sawtooth edges of the down-faulted block of PMA batholith may be a series of normal faults, parallel to the shelf edge, separated by NW–SE transfer faults (Fig. 10c). This suggests a greater element of oblique (NW–SE) extension than NNW–SSE strike-slip motion. The southern fault zone may also be a transfer fault which offsets George VI Sound and George VI trough.

The continued Cenozoic extension proposed for the Marguerite Bay area, prior to the arrival of the Tula-Adelaide ridge segment, may also partly account for the pervasive late-Tertiary block faulting seen in the area, although as noted above, the exact age of this faulting is not known. The opening of George VI trough presumably exploited weaknesses at the junction of the magmatic arc and accretionary prism, but it is not clear whether any pre-existing faults have been re-activated elsewhere

Conclusions

Digitized bathymetry and satellite gravity indicate that George VI trough is a continuation of George VI Sound in a north-north-westerly direction across Marguerite Bay. To the west of the trough, an increase in the Bouguer gravity and free-air gravity fields is interpreted as marking the continuation of the Alexander Island Mesozoic accretionary complex northwards. The correlation of magnetic, Bouguer gravity, free-air gravity and pseudogravity anomalies over the Pacific Margin Anomaly batholith to the east of George VI trough supports previous interpretations of the mafic-intermediate nature of the batholith. The gravity data also confirm the presence of a down-faulted block of PMA batholith in the centre of Marguerite Bay.

A two stage model for the Cenozoic evolution of the Marguerite Bay area has been proposed. In the first stage, George VI trough opened at the same time and by the same dextral transtensional process as George VI Sound. In the second stage, the arrival of the Heezen-Tula ridge segment stopped the extension to the south-east of the Tula FZ, but oblique NW–SE extension continued to the north-east. This extension was then terminated by the arrival of the Tula–Adelaide ridge segment. The linking of oceanic tectonic processes with continental crustal development is this area is an important step in assessing the causes of segmentation of magmatic arcs world-wide.

Acknowledgements

I wish to thank Rob Larter and Joe McCarron for useful discussions and for access to manuscripts in press, Bryan Storey for discussions about Alexander Island and George VI Sound, Anya Reading for discussion of seismic refraction data for the Marguerite Bay area, and Ed King and Tony Bell

https://doi.org/10.1017/S0954102097000369 Published online by Cambridge University Press

for access to manuscripts in press. Terry Wilson and Steve Garrett provided thorough reviews, which led to considerable improvements in the manuscript.

References

ANDERSON, J.B., POPE, P.G. & THOMAS, M.A. 1990. Evolution and hydrocarbon potential of the northern Antarctic Peninsula continental shelf. *In* ST. JOHN, B., *ed. Antarctica as an exploration frontier*. American Association of Petroleum Geologists, Studies in Geology, No. 31, 1-12.

BARANOV, V. 1957. A new method for interpretation of aeromagnetic maps:pseudo-gravimetric anomalies. *Geophysics*, **22**, 359-383.

BARKER, P.F. 1982. The Cenozoic subduction history of the Pacific Margin of the Antarctic Peninsula: ridge crest-trench interactions. *Journal of the Geological Society, London*, **139**, 787-801.

BART, P.J. & ANDERSON, J.B. 1995. Seismic record of glacial events affecting the Pacific margin of the northwestern Antarctic Peninsula. *Antarctic Research Series*, **68**, 74-95.

BURN, R.W. 1984. The geology of the LeMay Group, Alexander Island. *British Antarctic Survey Scientific Reports*, No. 109, 65 pp.

BUTLER, P.F. 1975. A linear Bouguer anomaly in central Alexander Island. *British Antarctic Survey Bulletin*, No. 41, 147-150.

CANDE, S.C. & KENT, D.V. 1995. Revised calibration of the geomagnetic polarity timescale for the Late Cretaceous and Cenozoic. *Journal of Geophysical Research*, **100**, 6093-6095.

CANDE, S.C., HERRON, E.M. & HALL, B.R. 1982. The early Cenozoic tectonic history of the southeast Pacific. *Earth and Planetary Science Letters*, **57**, 63-74.

CRABTREE, R.D., STOREY, B.C. & DOAKE, C.S.M. 1985. The structural evolution of George VI Sound, Antarctic Peninsula. *Tectonophysics*, **114**, 431-442.

DEWAR, G.J. 1970. The geology of Adelaide Island. *British Antarctic Survey Scientific Reports*, No. 59, 1-84.

DOUBLEDAY, P.A., LEAT, P.T., ALABASTER, T., NELL, P.A.R. & TRANTER, T.H. 1994. Allochthonous oceanic basalts within the Mesozoic accretionary complex of Alexander Island, Antarctica: remnants of proto-Pacific oceanic crust. *Journal of the Geological Society, London*, **151**, 65-78.

FRASER, A.G. & GRIMLEY, P.H. 1972. The geology of part of the Bowman and Wilkins coasts, Antarctic Peninsula. *British Antarctic Survey Scientific Reports*, No. 67, 1-59.

GARRETT, S.W. 1990. Interpretation of reconnaissance gravity and aeromagnetic surveys of the Antarctic Peninsula. *Journal of Geophysical Research*, **95**, 6759-6777.

GARRETT, S.W. & STOREY, B.C. 1987. Lithospheric extension on the Antarctic Peninsula during Cenozoic subduction. *In* COWARD, M.P., DEWEY, J.F. & HANCOCK, P.L., *eds. Continental extensional tectonics*. Geological Society Special Publication, No. 28, 419-431.

HAMILTON, W.B. 1995. Subduction systems and magmatism. *In* SMELLIE, J.L., *ed. Volcanism associated with extension at consuming plate margins*. Geological Society Special Publication, No. 81, 3-28.

HARRISON, S.M. & PIERCY, B.A. 1991. Basement gneisses in north-western Palmer Land: further evidence for pre-Mesozoic rocks in Lesser Antarctica. *In* THOMSON, M.R.A., CRAME, J.A. & THOMSON, J.W., *eds. Geological evolution of Antarctica*. Cambridge: Cambridge University Press, 341-344.

HAWKES, D.D. 1982. Tectonic segmentation of the northern Antarctic Peninsula. *Geology*, **9**, 220-224.

HERRON, E.M. & TUCHOLKE, B.E. 1976. Sea-floor magnetic patterns and basement structure in the southeastern Pacific. *In* HOLLISTER, C.D. *et al. Initial Reports of the Deep-Sea Drilling Project*, **35**. Washington, DC: US Government Printing Office, 263-278.

HYDROGRAPHIC OFFICE. 1991. *Lavoisier Island to Alexander Island, Admiralty Chart No 3571*, 1:500 000. London: HMSO.

JOHNSON A.C. 1996. Arc evolution: a magnetic perspective from the Antarctic Peninsula. *Geological Magazine*, **133**, 637-644.

JOHNSON A.C. & SMITH, A.M. 1992. New aeromagnetic anomaly map of West Antarctic (Weddell Sea sector): introduction to important features. *In* YOSHIDA, Y., KAMINUMA, K. & SHIRAISHI, K., *eds. Recent progress in Antarctic earth science*. Tokyo: Terra Scientific Publishing Company, 555-562.

JOHNSON, A.C. & SWAIN, C.J. 1995. Further evidence of fracture-zone induced tectonic segmentation of the Antarctic Peninsula from detailed aeromagnetic anomalies. *Geophysical Research Letters*, **22**, 1917-1920.

JOHNSON, A.C., GARRETT, S.W. & SMITH, A.M. 1994. Chapter 8: Geophysics. *In* MOYES, A.B., WILLAN, C.F.H., THOMSON, J.W. *et al. Geological map of Adelaide Island to Foyn Coast*. BAS GEOMAP Series, Sheet 3, 1:250 000, with supplementary text. Cambridge: British Antarctic Survey, 39-45.

KENNEDY, D.S. & ANDERSON, J.B. 1989. Glacial-marine sedimentation and quaternary glacial history of Marguerite Bay, Antarctic Peninsula. *Quaternary Research*, **31**, 255-276.

KING E.C. & BELL, A.C. *in press*. Seismic reflection investigation of George VI Sound, Antarctic Peninsula. *In* RICCI, C.A., *ed. The Antarctic region: geological evolution and processes*. Siena: Museo Nazionale dell' Antartide.

LARTER, R.D. & BARKER, P.F. 1991a. Effects of ridge crest-trench interaction on Antarctic-Phoenix spreading: forces on a young subducting plate. *Journal of Geophysical Research*, **96**, 19 583-19 607.

LARTER, R.D. & BARKER, P.F. 1991b. Neogene interaction of tectonic and glacial processes at the Pacific margin of the Antarctic Peninsula. *In* MACDONALD, D.I.M., *ed. Sedimentation, tectonics and eustasy*. International Association of Sedimentolgy Special Publication, No. 12, 165-186.

LARTER, R.D., REBESCO, M., VANNESTE, L.E., GAMBOA, L.A.P. & BARKER, P.F. in press. Cenozoic tectonic, sedimentary and glacial history of the continental shelf west of Graham Land, Antarctic Peninsula. *Antarctic Research Series*.

LEAT P.T. & SCARROW, J.H. 1994. Central volcanoes as sources for the Antarctic Peninsula Volcanic Group. *Antarctic Science*, **6**, 365-374.

LEAT, P.T., SCARROW, J.H. & MILLAR, I.L. 1995. On the Antarctic Peninsula batholith. *Geological Magazine*, **132**, 399-412.

MASLANYJ, M.P. 1991. Geophysical investigation of George VI Sound, Antarctic Peninsula. *In* THOMSON, M.R.A., CRAME, J.A. & THOMSON, J.W., *eds. Geological evolution of Antarctica*. Cambridge: Cambridge University Press, 527-530.

MASLANYJ, M.P., GARRETT, S.W., JOHNSON, A.C., RENNER, R.G.B. & SMITH, A.M. 1991. *Aeromagnetic anomaly map of West Antarctica (Weddell Sea Sector)*. 1:2 500 000, British Antarctic Survey GEOMAP series Sheet 2, with supplementary text. Cambridge: British Antarctic Survey, 32 pp.

MCCARRON, J.J. 1995. *Evolution and tectonic implications of late Cretaceous- early Tertiary fore-arc magmatism: Alexander Island, Antarctica*. Ph.D. thesis, University of Cambridge, 161 pp. [Unpublished.]

MILNE, A.J. & MILLAR, I.L. 1989. The significance of mid-Palaeozoic basment in Graham Land, Antarctic Peninsula. *Journal of the Geological Society, London*, **146**, 207-210.

MONCRIEFF, A.M. & KELLY, S.R.A. 1993. Lithostratigraphy of the uppermost Fossil Bluff Group (Early Cretaceous) of Alexander Island, Antarctica: history of an Albian regression. *Cretaceous Research*, **14**, 1-15.

MOYES, A.B., WILLAN, C.F.H., THOMSON, J.W. *et al.* 1994. *Geological map of Adelaide Island to Foyn Coast*. BAS GEOMAP Series, Sheet 3, 1:250 000, with supplementary text. Cambridge: British Antarctic Survey, 60 pp.

https://doi.org/10.1017/S0954102097000369 Published online by Cambridge University Press

NELL, P.A.R. & STOREY, B.C. 1991. Strike-slip tectonics within the Antarctic Peninsula fore-arc. *In* THOMSON, M.R.A., CRAME, J.A. & THOMSON, J.W., *eds. Geological evolution of Antarctica*. Cambridge: Cambridge University Press, 443-448.

NICHOLS, R.L. 1953. *Geomorphology of Marguerite Bay, Palmer Peninsula, Antarctica*. Washington, DC: Department of the Navy, Office of Naval Research, 151 pp.

PANKHURST, R.J. 1982. Rb-Sr geochronology of Graham Land, Antarctica. *Journal of the Geological Society, London*, **139**, 701-711.

POPE, P.G. & ANDERSON, J.B. 1992. Late Quaternary glacial history of the northern Antarctic Peninsula's western continental shelf: evidence from the marine record. *Antarctic Research Series*, **57**, 63-91.

READING, A.M., PIPAN, M. & KING, E.C. in press. Seismic investigation of crustal structure between Adelaide Island and Marguerite Bay, Antarctic Peninsula: Preliminary results. *In* RICCI, C.A., *ed. The Antarctic region: geological evolution and processes*. Siena: Museo Nazionale dell'Antartide.

RENNER, R.G.B., STURGEON, L.J.S. & GARRETT, S.W. 1985. Reconnaissance gravity and aeromagnetic surveys of the Antarctic Peninsula. *British Antarctic Survey Scientific Reports*, No. 110, 1-50.

SAUNDERS, A.D., WEAVER, S.D. & TARNEY, J. 1982. The pattern of Antarctic Peninsula plutonism. *In* CRADDOCK, C., *ed. Antarctic geoscience*. Wisconsin: University of Wisconsin Press, 305-314.

SMITH. W.H.F. & SANDWELL, D.T. 1995. Marine gravity field from declassified Geosat and ERS-1 altimetry. *EOS, Transactions of the American Geophysical Union*, **76**(46), F156.

SMITH, W.H.F. & WESSEL, P. 1990. Gridding with continuous curvature splines in tension. *Geophysics*, **55**, 293-305.

STOREY, B.C. & NELL, P.A.R. 1988. Role of strike-slip faulting in the tectonic evolution of the Antarctic Peninsula. *Journal of the Geological Society of London*, **145**, 333-337.

STOREY, B.C., BROWN, R.W., CARTER, A., DOUBLEDAY, P.A., HURFORD, A.J., MACDONALD, D.I.M. & NELL, P.A.R. 1996. Fission-track evidence for the thermotectonic evolution of a Mesozoic-Cenozoic fore-arc, Antarctica. *Journal of the Geological Society, London*, **153**, 65-82.

THOMSON, J.W. & HARRIS, J. (compilers). 1981. *Southern Graham Land*. Geological Map, 1: 500 000, BAS 500G series Sheet 3. Cambridge: British Antarctic Survey.

THOMSON, J.W., HARRIS, J., ROWLEY, P.D., KELLOGG, K.S., BOYER, S.J., VENNUM, W.R., WAITT, R.B. & KAMENEV, E.N. (compilers). 1982. *Northern Palmer Land*. Geological Map, 1: 500 000, BAS 500G series Sheet 5. Cambridge: British Antarctic Survey.

THOMSON, M.R.A. 1982. Mesozoic paleogeography of West Antarctica. *In* CRADDOCK C., *ed. Antarctic geoscience*. Wisconsin: University of Wisconsin Press, 331-337.

WYETH, R.B. 1977. The physiography and significance of the transition zone between Graham Land and Palmer Land. *British Antarctic Survey Bulletin*, No. 46, 39-58.

https://doi.org/10.1017/S0954102097000369 Published online by Cambridge University Press