Research article

JGS
Journal of the Geological Society

Published online August 4, 2015

doi:10.1144/jgs2014-110 | Vol. 172 | 2015 | pp. 822–835

Autochthonous v. accreted terrane development of continental margins: a revised *in situ* tectonic history of the Antarctic Peninsula

A. Burton-Johnson* **& T. R. Riley**

British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, UK
* Correspondence: alerto@bas.ac.uk

Abstract: The allochthonous terrane accretion model previously proposed for the geological development of the Antarctic Peninsula continental margin arc is reviewed in light of recent data and the geology is reinterpreted as having evolved as an *in situ* continental arc. This is based upon the following factors: (1) the presence of Early Palaeozoic basement and stratigraphic correlation of sequences between the autochthonous and previously proposed allochthonous terranes; (2) isotopic evidence for similar deep crustal structure across the different terranes; (3) ocean island basalt magmas and deep marine sedimentary rocks formed during continental margin extension within the previously proposed accretionary wedge sequence (i.e. not formed against an active oceanic arc); (4) the distribution of magnetic susceptibility measurements and aeromagnetic data locating the palaeo-subduction zone along the west of the Peninsula; (5) a lack of clear palaeomagnetic distinction between the terranes. The following alternative tectonic history is proposed: (1) amalgamation and persistence of Gondwana; (2) subsequent silicic large igneous province magmatism and extension; (3) development and history of Andean subduction until its cessation in the Cenozoic. A number of features in the Antarctic Peninsula correlate with those of other circum-Pacific margins, supporting a global evaluation of allochthonous v. autochthonous margin development to aid our understanding of crustal growth mechanisms.

Received 29 August 2014; **revised** 14 May 2015; **accepted** 15 June 2015

Convergent continental margins are geologically complex, with the composite units interpreted as developing either *in situ* from autochthonous units (e.g. South China; Zhou *et al*. 2006) or through accretion of allochthonous terranes (e.g. New Zealand; Wandres & Bradshaw 2005). Continental margins represent the dominant sites of Phanerozoic continental crustal growth, therefore an understanding of whether or not this growth occurs dominantly *in situ* (e.g. Kemp *et al.* 2009) or through arc and terrane accretion (e.g. Reymer & Schubert 1984; Draut & Clift 2001) is integral to models of crustal development.

The Antarctic Peninsula was initially interpreted as an autochthonous continental arc of the Gondwanan margin, which developed during Mesozoic subduction beneath the supercontinent (Suárez 1976). However, following the identification of a major shear zone in the southern Antarctic Peninsula (the Eastern Palmer Land Shear Zone; Fig. 1) the composite geology of the Peninsula was reinterpreted as representing a series of allochthonous accreted terranes (Vaughan & Storey 2000). In this paper we evaluate the currently available dataset for the tectonic history of the Peninsula and propose a refined model for the *in situ* development of a geologically complex continental margin and correlate this tectonic history with major continental arcs elsewhere.

Principal geological units of the Antarctic Peninsula

Independent of the overall tectonic model, the geology of the Antarctic Peninsula can be divided into six broad units (Figs 1 and 2): the metamorphic basement; Palaeozoic to Triassic sedimentary rocks; Jurassic to Cenozoic sedimentary rocks; non-metamorphosed intrusive rocks; Jurassic to Palaeogene volcanic rocks; Neogene to Recent alkaline volcanic rocks.

Metamorphic basement

Dominantly composed of orthogneisses and metabasites (Wendt *et al.* 2008), the metamorphic basement crops out in NW and NE Palmer Land and southern Graham Land, with sparser outcrops in eastern Graham Land. The metamorphic basement is most extensive in Palmer Land, with orthogneisses, paragneisses, amphibolites and metasediments recording amphibolite- to granulite-facies metamorphism in NW Palmer Land, and lower grade amphibolite-facies metamorphism in NE Palmer Land (Wendt *et al.* 2008). Ordovician, Permian and Triassic metamorphism of Ordovician and younger protoliths produced amphibolite-grade orthogneisses, metabasites (amphibolites), migmatites and paragneisses in southern and eastern Graham Land (Wendt *et al.* 2008; Riley *et al.* 2012*b*). One small, irregular locality (the *c.* 10 km long Target Hill) in eastern Graham Land records Carboniferous metamorphism of a Devonian igneous protolith with no evidence for later metamorphism (Millar *et al.* 2002; Riley *et al.* 2012*b*), despite being <15 km from similar outcrops that do provide such evidence. This may be related to the Carboniferous metamorphism of the Deseado Massif in Patagonia (Pankhurst *et al.* 2006) and is often viewed as the 'classic' locality for the Peninsula's basement (Milne & Millar 1989), although it is clearly anomalous and misrepresentative.

Although the metamorphic basement was originally assigned to the early Palaeozoic or Archaean (Adie 1954) and later to the early to mid-Palaeozoic (Singleton 1980), it is now clear that its mapped extent (Fig. 1) includes rocks of Ordovician to Jurassic outcrops (Wever *et al.* 1994; Riley *et al.* 2012*b*) and consequently magmatic ages for the metamorphic basement overlap with those of non-metamorphosed intrusive rocks (see below and Fig. 2).

Palaeozoic–Triassic sedimentary rocks

The oldest sedimentary sequence on the Antarctic Peninsula recording continental extension are limited outcrops of quartzite

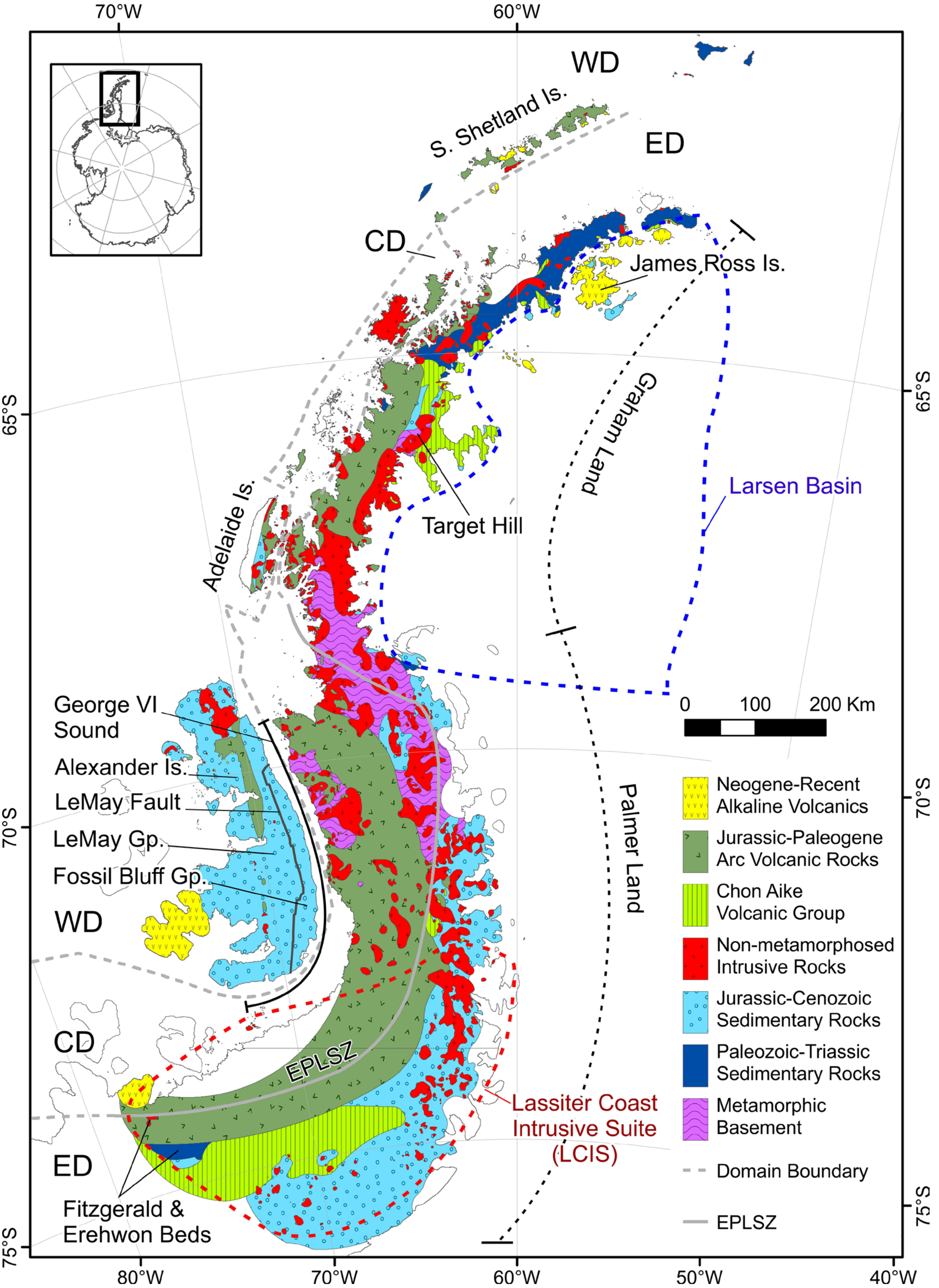

Fig. 1. Geological map of the Antarctic Peninsula, showing the distribution of the principal geological units defined in the text (Fleming & Thomson 1979; Thomson & Harris 1979; Thomson 1981; Thomson *et al.* 1982; Storey *et al.* 1986; Rowley *et al.* 1992; Moyes *et al.* 1993; Riley *et al.* 2011*a*,*b*). EPLSZ, East Palmer Land Shear Zone; WD, Western Domain; CD, Central Domain; ED, Eastern Domain. Domain and Eastern Palmer Land Shear Zone distribution adapted from Vaughan & Storey (2000) and Vaughan *et al.* (2012*a*). Extents of the Larsen Basin and Lassiter Coast Intrusive Suite from Vennum & Rowley (1986), Hathway (2000) and Flowerdew *et al.* (2005).

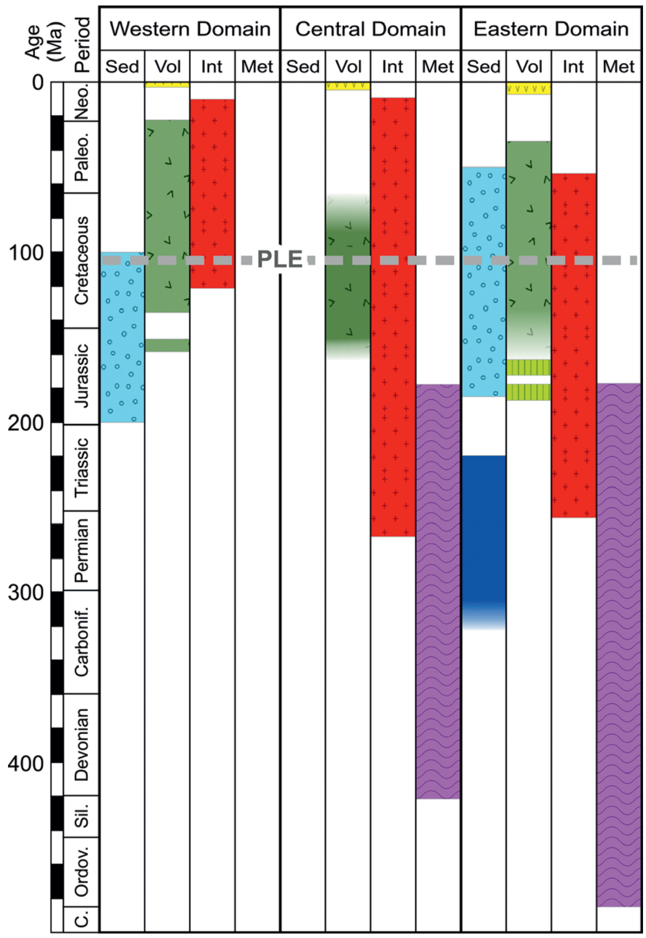

Fig. 2. Time–space plot summarizing the stratigraphy within each proposed domain of the Antarctic Peninsula. Symbols as in Figure 1. Sed, depositional age of sedimentary rocks; Vol, magmatic age of volcanic rocks; Int, emplacement age of non-metamorphosed intrusive rocks; Met, protolith age of metamorphic rocks; PLE, Palmer Land Event (Vaughan *et al*. 2012*a*). Units for the Western Domain are as follows. Sed: LeMay Group, Sinnemurian–Albian (Thomson & Tranter 1986; Holdsworth & Nell 1992); Fossil Bluff Group, Kimmeridgian–Albian (Butterworth *et al.* 1988); Adelaide Is., *c*. 150–113.9 Ma (Thomson 1972; Riley *et al.* 2012*a*). Vol: Alexander Is., 157–152 Ma (Macdonald *et al.* 1999), 80–46 Ma (McCarron 1997) and 2.5–0.5 Ma (Hole 1988); Adelaide Is., 76–39.2 Ma (Griffiths & Oglethorpe 1998; Riley *et al.* 2012*a*); South Shetland Is., 135–22.6 Ma (Smellie *et al.* 1998; Haase *et al.* 2012) and 2.4–0.1 Ma (Pankhurst & Smellie 1983). Int: Alexander Is., 75–56 Ma (McCarron 1997); Adelaide Is., 60–44 Ma (Pankhurst 1982; Griffiths & Oglethorpe 1998; Riley *et al.* 2012*a*). Units for the Central Domain are as follows. Vol: arc magmatism, 153–86 Ma (Rex 1976; Leat & Scarrow 1994); alkali magmatism, 3.1–0.1 Ma (Ringe 1991). Int: 267–8.9 Ma (Ringe 1991; Millar *et al.* 2002). Met: 422–178 Ma (Pankhurst 1983; Millar *et al.* 2002). Units for the Eastern Domain are as follows. Sed: Fitzgerald and Erehwon Beds, Pre-Late Palaeozoic to Latest Permian (Laudon 1991); Trinity Peninsula Group, Latest Carboniferous to Mid-Triassic (Smellie & Millar 1995; Riley *et al.* 2011*b*; Bradshaw *et al.* 2012); Latady Group and Mt Hill Fm, 185–140 Ma (Meneilly *et al.* 1987; Hunter & Cantrill 2006); Larsen Basin, 167 Ma to Paleocene–Eocene (Hathway 2000; Hunter *et al.* 2005). Vol: Chon Aike Group, 188–178 and 172–162 Ma (Pankhurst *et al.* 2000); arc magmatism, <162 to 35 Ma (Rex 1976); alkali magmatism, 6.5–0.5 Ma (Rex 1976). Int: 256–54 Ma (Rex 1976; Riley *et al.* 2012*b*). Met: 487–175 Ma (Gledhill *et al.* 1982; Riley *et al.* 2012*b*).

(the Fitzgerald Beds) in SW Palmer Land (Fig. 1), which were deposited in a pre-Late Palaeozoic passive margin environment predating subduction (Laudon 1991). The fine-grained clastic sedimentary rocks of the Erehwon Beds also crop out only in a restricted area of SW Palmer Land, but were deposited in a Permian back-arc basin (Laudon 1991).

Latest Carboniferous to mid-Triassic sedimentary and low-grade metasedimentary rocks of the Trinity Peninsula Group are exposed extensively across northern Graham Land (Smellie & Millar 1995; Riley *et al.* 2011*b*; Bradshaw *et al.* 2012). They comprise mudstones and sandstones of turbiditic origin with a continental arc provenance (Smellie 1991), although the geographical origin of this source remains unclear. Similar lithologies occur on the South Shetland Islands (the Triassic or Jurassic Miers Bluff Formation and the Mesozoic to Cenozoic Scotia Metamorphic Complex metasediments; Willan *et al.* 1994; Trouw *et al.* 1997; Hervé *et al.* 2006; Barbeau *et al.* 2010) although proposed depositional ages for these units range from Triassic to Paleocene (Willan *et al.* 1994; Trouw *et al.* 1997; Hervé *et al.* 2006; Pimpirev *et al.* 2006).

Jurassic–Cenozoic sedimentary rocks

Lower Jurassic to Lower Cretaceous turbidite sandstones and conglomerates with minor volcanic rocks, chert and siliceous mudstones form the LeMay Group, the lowest stratigraphic strata on Alexander Island (Fig. 1; Thomson & Tranter 1986; Holdsworth & Nell 1992). This sequence is interpreted as representing an accretionary trench-fill assemblage (Suárez 1976; Doubleday *et al.* 1993). East of the LeMay Group on Alexander Island, mainly separated by the LeMay Fault (Fig. 1), arc-derived fluvial, deltaic and submarine fan deposits forearc basin sediments form the Upper Jurassic to Lower Cretaceous Fossil Bluff Group (Storey & Garrett 1985; Butterworth *et al.* 1988). Although the Fossil Bluff Group unconformably overlies the LeMay Group turbidite sequence, the two units are dominantly in faulted contact along the LeMay Fault and overlap temporally (Doubleday *et al.* 1993). Minor Late Jurassic ocean island basalt (OIB)-like sills and submarine lava flows are also found within the LeMay and Fossil Bluff groups (Doubleday *et al.* 1994; Macdonald *et al.* 1999).

Interbedded Jurassic volcanic and sedimentary back-arc basin sediments occur in eastern Palmer Land (the Mount Hill Formation; Meneilly *et al.* 1987) and southern Palmer Land (the Latady Group; Hunter & Cantrill 2006). These two formations are considered to be correlatives (Vaughan & Storey 2000) and record deposition in the Latady Basin during rifting of Gondwana. A thick sequence of Late Jurassic to Cenozoic sediments forms the Larsen Basin (exposed on James Ross Island, surrounding islands and northeastern Graham Land; Fig. 1) with initial sedimentation again occurring during the Jurassic break-up of Gondwana and continuing east of the contemporaneous volcanic arc (Macdonald *et al.* 1988; Hathway 2000). The Larsen Basin includes the dominantly conglomeratic Botany Bay Group alluvial fan sequence, deposited contemporaneously with Jurassic rifting and volcanism (Farquharson 1984; Hunter *et al.* 2005).

Non-metamorphosed intrusive rocks

Mafic to felsic plutonic rocks with dominantly calc-alkaline continental-margin affinities are prevalent on the Antarctic Peninsula (Leat *et al.* 1995). Granitic magmatism in Graham Land and Palmer Land peaked in the Middle Cretaceous (120–90 Ma, Leat *et al.* 1995) including the emplacement of the extensive Lassiter Coast Intrusive Suite in south Palmer Land (Fig. 1; Pankhurst & Rowley 1991).

Jurassic–Palaeogene volcanic rocks

With the exception of waning and post-subduction Cenozoic volcanic rocks (see next subsection), all volcanic rocks on the Antarctic

Peninsula were assigned to the Antarctic Peninsula Volcanic Group (Thomson & Pankhurst 1983). However, this grouping ignored tectonic setting, eruption age or geochemistry and encompassed basalt–rhyolite compositions associated with fore-, intra- and back-arc settings. Subsequent work (Leat & Scarrow 1994; Riley & Leat 1999; Pankhurst *et al.* 2000; Riley *et al.* 2001; Hunter *et al.* 2006) suggests that the Antarctic Peninsula Volcanic Group may be divided into two main groups, as follows.

(1) Jurassic silicic volcanic rocks correlating with the Chon Aike silicic large igneous province (LIP) of South America and associated with the rifting and break-up of Gondwana (termed here the Chon Aike Volcanic Group). This group includes the Graham Land Volcanic Group (Riley *et al.* 2010) of eastern Graham Land and the Mount Poster (Rowley *et al.* 1982) and Brennecke formations (Wever & Storey 1992) in eastern Palmer Land.

(2) Intermediate–mafic composition volcanic rocks exposed along the Peninsula's west coast with a fore- or intra-arc origin and characterized by thick volcaniclastic sequences (Riley *et al*. 2010). Geochronological data from the mainland of the Antarctic Peninsula are sparse (especially in Palmer Land), but existing data indicate that active margin arc magmatism is active subsequent to the Chon Aike Volcanic Group volcanism (Pankhurst *et al.* 2000), ends prior to the Late Neogene to Recent intraplate alkaline volcanism (Smellie 1987) and is most prevalent in the Cretaceous (Rex 1976; Fig. 2).

Neogene–Recent alkaline volcanic rocks

Scattered Neogene–Recent alkaline volcanic rocks along the Antarctic Peninsula record a change in eruptive setting from subduction to extensional regimes (Saunders 1982). Their main exposures are on the South Shetland Islands, around James Ross Island and on Alexander Island (Fig. 1), and indicate a widespread extensional volcanic regime as in the rest of West Antarctica (Gonzalez-Ferran 1982; Smellie 1987).

The allochthonous terrane model and the Eastern Palmer Land Shear Zone

The Eastern Palmer Land Shear Zone (Fig. 1) is a major ductile to brittle–ductile shear zone. It is up to 20 km wide in places and is proposed to have a lateral extent of at least 1500 km, although it may continue for over 3000 km (Vaughan & Storey 2000; Vaughan *et al*. 2012*a*). The course of the shear zone is interpreted from outcrops of breccia, mylonites and pseudotachylites showing reverse to dextral reverse deformation (Vaughan & Storey 2000). The shear zone has an overall westward dip and a NE–NNE transport direction of the hanging wall. ^{40}Ar–^{39}Ar dating of a syndeformation granitic dyke from SE Palmer Land and biotite from a shear zone mylonite from eastern Palmer Land gave ages of 106.9 ± 1.1 Ma and 102.8 ± 3.3 Ma respectively, which were interpreted to date deformation along the Eastern Palmer Land Shear Zone (Vaughan *et al.* 2002*a*,*b*). This period of deformation is generally referred to as the Palmer Land Event and is interpreted as recording the time of proposed terrane accretion (Vaughan *et al*. 2012*b*).

Vaughan & Storey (2000) interpreted the location of this shear zone to separate broad, geologically distinct regions within the Peninsula and drew similarities between them and the composite terranes of New Zealand, where distinct geological terranes representing an autochthonous continental margin and allochthonous arc sequences are separated by major fault zones (Bradshaw 1993). They noted that other regions of the circum-Pacific margin show evidence of allochthonous arc terranes in contact with cratonic or old mobile-belt basement across a deformation zone, similar to the Eastern Palmer Land Shear Zone. Based on these comparisons, Vaughan & Storey (2000) interpreted the Antarctic Peninsula to be composed of three domains of allochthonous and autochthonous accreted geological terranes: the Eastern Domain, Central Domain and Western Domain (Fig. 1). The relative timing of each domain's principal units is summarized in Figure 2.

The Eastern Domain

Located to the east of the Eastern Palmer Land Shear Zone in the east and north of Graham Land and in the east and south of Palmer Land (Fig. 1), this proposed terrane represents the former Gondwanan margin and preserves the autochthonous magmatism and sedimentation associated with subduction along this margin. The oldest outcrops in the domain are the metamorphic basement of eastern Graham Land and represent the Gondwanan basement of the Peninsula.

In Graham Land the Eastern Domain includes the metamorphic basement, Trinity Peninsula Group turbidites (interpreted by Vaughan & Storey 2000, to represent an accretionary complex), the Jurassic Botany Bay Group alluvial fan deposits, extensive Jurassic silicic volcanism of the Chon Aike Volcanic Group, and Neogene to recent alkaline volcanic rocks around James Ross Island (Rex 1976). The geology of eastern Graham Land has been closely correlated with the successions of Patagonia from the Ordovician at the time of the Famatinian arc (Riley *et al.* 2012*b*) to at least the Middle Jurassic during the extensive felsic volcanism associated with the Chon Aike silicic large igneous province (Riley *et al.* 2001) and subsequently from the Late Jurassic to the Early Cretaceous (Farquharson 1982).

In Palmer Land, pre-Mesozoic outcrops in the Eastern Domain are restricted to the limited outcrops of the Fitzgerald Beds and Erehwon Beds in the far south and west of the region (Fig. 1). The Eastern Domain of Palmer Land is dominated by Jurassic-aged shallow marine to terrestrial sandstones and mudstones of the Latady Group and extensive gabbroic to granitic intrusions of the Lassiter Coast Intrusive Suite (Fig. 1), as well as a continuation of the Chon Aike Volcanic Group and more minor Mesozoic mafic volcanic rocks and dykes (Wever & Storey 1992).

Vaughan & Storey (2000) correlated the Eastern Domain of the Antarctic Peninsula with the Western Province of New Zealand where Early Palaeozoic sedimentary rocks and Late Palaeozoic and Cretaceous granitoids represent the autochthonous Gondwanan margin (Wandres & Bradshaw 2005).

The Central Domain

The Central Domain, lying west of the Eastern Palmer Land Shear Zone, is dominantly composed of Mesozoic and older igneous and meta-igneous units, and is interpreted (Vaughan & Storey 2000) as an allochthonous Mesozoic magmatic arc (the Triassic Dyer Arc; Vaughan *et al*. 2012*b*) underlain by older microcontinental basement, accreted to the Eastern Domain during the Palmer Land Event and sutured along the Eastern Palmer Land Shear Zone. The oldest units are orthogneisses of the metamorphic basement in NW Palmer Land (Millar *et al.* 2002), intruded by Jurassic–Cretaceous gabbroic to granitic bodies, associated metavolcanic rocks and dykes (Vaughan & Millar 1996; Scarrow *et al.* 1998; Vaughan *et al*. 2012*b*). Limited intrusive outcrops associated with the Lassiter Coast Intrusive Suite of the Eastern Domain and contemporaneous with the proposed age of terrane accretion also crop out on the SW coast of Palmer Land in the Central Domain (Flowerdew *et al.* 2005).

This domain was correlated by Vaughan & Storey (2000) with the Carboniferous to Cretaceous arc magmatism and sediments of the Median Tectonic Zone of New Zealand, interpreted to be at least partly allochthonous (Bradshaw 1993).

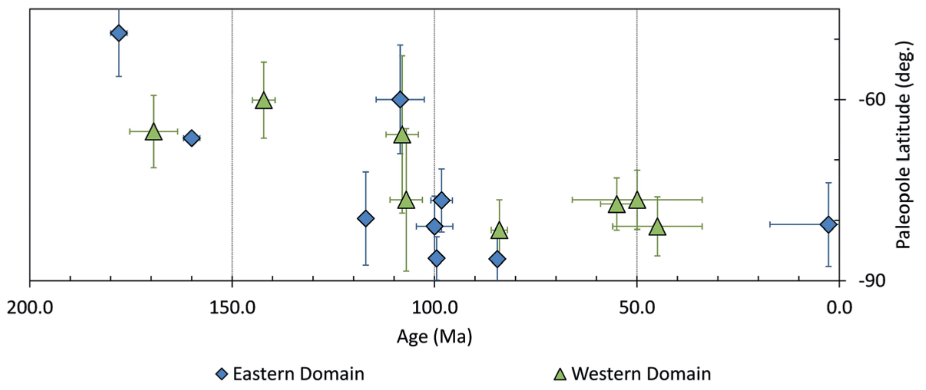

Fig. 3. Age and calculated palaeopole latitudes for the Eastern and Western domains (Kellogg & Reynolds 1978; Longshaw & Griffiths 1983; Kellogg & Rowley 1989; Grunow 1993; Poblete *et al.* 2011). α_{95} plotted as palaeolatitude error.

The Western Domain

The Western Domain of the Antarctic Peninsula is represented by Alexander Island, Adelaide Island (Fig. 1) and potentially by the metasedimentary rocks of the South Shetland and South Orkney islands (Meneilly & Storey 1986; Vaughan & Storey 2000; Vaughan *et al*. 2012*a*). The Western Domain on Alexander Island is separated from the Central Domain by the Late Cretaceous–Early Palaeogene rift of the George VI Sound (Fig. 1; Doubleday & Storey 1998). On Alexander Island the domain is composed of the LeMay Group turbidite deposits; the Fossil Bluff Group forearc sedimentary rocks; minor Late Jurassic lava flows and sills associated with both sedimentary formations (Doubleday *et al.* 1994; Macdonald *et al.* 1999); Late Cretaceous to Eocene forearc volcanic rocks and plutons (McCarron 1997); and Pleistocene alkaline volcanic rocks (Hole 1988). Vaughan & Storey (2000) interpreted the Western Domain as either a subduction–accretion complex to the Central Domain arc or a separate exotic crustal fragment sutured to the Central Domain. In the original terrane model (Vaughan & Storey 2000) Adelaide Island was included in the Central Domain but, because of stratigraphic correlations between the Adelaide Island sediments and the Fossil Bluff Group as well as correlation of the magmatic units of the two islands, Adelaide Island has been reassigned to the Western Domain (Riley *et al.* 2012*a*; Vaughan *et al*. 2012*a*).

Vaughan & Storey (2000) correlated this domain with the Eastern Province of New Zealand, where Permian to Cretaceous igneous and sedimentary units are interpreted as allochthonous arc complexes accreted during plate convergence (Wandres & Bradshaw 2005).

Evaluation of the terrane accretion model

Following the Vaughan & Storey (2000) interpretation of the Antarctic Peninsula as a composite continental margin, numerous new datasets have emerged allowing fresh insight into the geological development of the Antarctic Peninsula such that the terrane accretion model has been further refined (e.g. Vaughan *et al.* 2012*a*,*b*). The aim of this paper is to present these key findings and discuss the implications of the palaeomagnetic, lithological, geochemical and geophysical datasets for the terrane accretion model and discuss why an autochthonous model of margin development is preferable.

Palaeomagnetic evidence for differential terrane movement

The most direct method for testing the terrane hypothesis is through palaeomagnetic analysis. As noted by Vaughan *et al.* (2012*a*), palaeostrain data from the Eastern Palmer Land Shear Zone and plate convergence models indicate that in a terrane accretion model the Central and Western domains originated from the modern-day north, at lower palaeolatitudes than the Eastern Domain. This should mean that Western and Central domain samples formed prior to terrane accretion will have higher palaeopole latitudes than for contemporaneous Eastern Domain samples. This is made more straightforward by the low degrees of rotation of the Peninsula since at least the Cretaceous (Kellogg & Reynolds 1978).

Unfortunately, existing palaeomagnetic data for the Antarctic Peninsula are limited and remagnetization is prevalent in pre-Cretaceous samples (Poblete *et al.* 2011). We have collated and calculated palaeopoles for the existing data in Figure 3. Following the data quality assessment procedure of Van der Voo (1990), we selected only samples that have been radiometrically or stratigraphically dated, that show no evidence for remagnetization, and where the number of samples (n) > 24, precision (k) ≥ 24 and the cone of confidence (α_{95}) ≤ 16.

From Figure 3 it can be seen that for both domains little attitudinal movement has occurred since the Mid-Cretaceous and a reduction in palaeopole latitude occurred during the Middle Jurassic to Early Cretaceous. However, data are limited to the Eastern and Western domains and very few data exist prior to the Mid-Cretaceous when the separate domains are proposed to have been distal. Although Figure 3 shows no distinction between the two domains, for this reason we will have to test alternative lines of evidence until a more robust palaeomagnetic dataset becomes available.

Lithological and sedimentary provenance correlations between terranes

As a number of lithological units from the different proposed terranes share broadly similar lithological descriptions it is critical to any tectonic model to determine whether or not they share a petrogenetic history.

Basement chronology

When Vaughan & Storey (2000) defined the terrane model for the Antarctic Peninsula, the oldest recognized *in situ* rocks from the Eastern Domain were Devonian (*c.* 393 Ma) and Carboniferous (*c.* 323 Ma) intensely deformed granitoid gneisses from Target Hill (Millar *et al.* 1999), whereas in the Central Domain they were pre-Late Triassic granitoid gneisses and marble breccias from the metamorphic basement in NW Palmer Land (Millar *et al.* 1999; Vaughan *et al.* 1999). However, subsequent studies (Millar *et al.* 2002; Riley *et al.* 2012*b*) have identified Silurian orthogneisses from the Central Domain in NW Palmer Land (422 ± 18 Ma) and Ordovician orthogneisses from eastern Graham Land (487 ± 3 Ma). If (as in the terrane model) the two domains represent a magmatic arc (the Central Domain) accreted to the Gondwanan margin (the Eastern Domain) then significantly different basement ages may be expected for the two domains. However, as noted by Millar *et al*. (2002), the presence of old Gondwanan continental basement material in both domains (Fig. 2) does not support this hypothesis, and requires at least that the basement of the Central Domain suspect terrane be rifted from a Gondwana or a similarly old continental margin prior to arc development.

It could also be argued that the absence of any evidence for Carboniferous metamorphism on the Antarctic Peninsula except for at Target Hill where the later metamorphic events recorded elsewhere are absent (Millar *et al.* 2002) indicates different crustal histories on the Peninsula. However, Target Hill is clearly anomalous as extensive Permian and Triassic metamorphism is recorded in both the Central and Eastern domains (Millar *et al.* 2002; Riley *et al.* 2012*a*) and Permian metamorphism has been noted further along the Gondwanan margin in South America and West Antarctica (Pankhurst *et al.* 1998; Herve *et al.* 2010), supporting an authochthonous origin for the proposed domains.

Stratigraphic correlations

The terrane accretion model interprets the sedimentary sequences along the Antarctic Peninsula to be assigned to different domains: (1) the Trinity Peninsula Group and Botany Bay Group of Graham Land, and the Latady Group of Palmer Land to the Eastern Domain; (2) The LeMay and Fossil Bluff groups of Alexander Island, the clastic sedimentary rocks of Adelaide Island and the metasedimentary rocks of the South Shetland and South Orkney islands to the Western Domain. Consequently, provenance and stratigraphic correlations may help test the terrane hypothesis. Stratigraphic and radiometric dating correlations have previously been applied to the volcano-sedimentary sequences of Adelaide Island (Riley *et al.* 2012*a*) and have shown their affinity to the Fossil Bluff Group of the Western Domain rather than their original inclusion in the Central Domain.

In addition to correlating the strata of Adelaide Island with Alexander Island, Riley *et al.* (2012*a*) argued against the hypothesis that the Central and Western domains represent separate terranes prior to accretion (Vaughan & Storey 2000). They noted that the volcaniclastic and conglomeratic strata of these two Western Domain islands (Alexander and Adelaide islands) require provenance from a proximal active volcanic arc from the Late Jurassic to Albian. This correlates with the volcanic activity recorded in the Central Domain of NW Palmer Land from *c*. 153 to *c*. 107 Ma (Leat *et al.* 2009) and agrees with the easterly provenance of the Western Domain palaeo-flow directions and plutonic clast ages from Adelaide Island indicating a NW Palmer Land provenance (Griffiths & Oglethorpe 1998; Riley *et al.* 2012*a*). This supports a common history for the Central and Western domains.

Although it is principally included in the Eastern Domain, previous workers (Willan 2003; Wendt *et al.* 2008; Barbeau *et al.* 2010) have discussed whether the Trinity Peninsula Group is an autochthonous unit of the Eastern Domain or an allochthonous or parautochthonous unit of the Central Domain. The occurrence of Ordovician, Devonian (albeit a minor constituent) and Permian detrital zircon grains in the Trinity Peninsula Group, but the presumed absence or paucity of a similar aged source on the Antarctic Peninsula was used to imply derivation from a more distal source (i.e. the North Patagonian Massif; Willan 2003). The identification of Ordovician and Devonian to Jurassic magmatic and metamorphic zircons igneous and metamorphic rocks in eastern Graham Land (Riley *et al.* 2012*b*) provided a more proximal source for the Palaeozoic detrital grains, comparable with the detrital zircon distribution for the Trinity Peninsula Group, supporting its autochthonous development in the Eastern Domain (Castillo & Lacassie 2009; Barbeau *et al.* 2010).

Geochemical evidence

Geochemical investigations of magmatic rocks from the Antarctic Peninsula have revealed evidence of the deeper crustal structure and tectonic history of the proposed terranes.

Evidence for the deep crustal structure

Radiogenic isotopes are a sensitive measure for the involvement of old crustal material in younger magmatism, and can provide evidence for the deep crustal structure of continental margins. Most granitoids of the Antarctic Peninsula have radiogenic isotope compositions indicating a strong continental affinity with high Sr and low Nd isotope ratios. This requires the involvement of older continental material in their petrogenesis. Flowerdew *et al*. (2005) compiled isotopic data from the Cretaceous Lassiter Coast Intrusive Suite granitoids of the Central and Eastern domains in southern Palmer Land. This suite was dominantly emplaced in the Eastern Domain over a period spanning the proposed age of terrane amalgamation, but some intrusions were emplaced in the Central Domain after this date (Flowerdew *et al.* 2005). They concluded that the granitoids were derived through contamination of a juvenile mantle component by Proterozoic lower crustal material and observed no change in the isotopic signature between the two domains. The Central Domain data were more homogeneous than the Eastern Domain data ($\varepsilon Nd_{(105)}$ values of −1.3 to −3.2 for eight samples, compared with −1.2 to −4.0 for 10 samples, excluding two at −4.0 and +0.2) and were attributed to a subtle change in basement character. However, as the Eastern Domain samples came from a far larger area than the Central Domain samples (*c*. 400000 km distance between the farthest Eastern Domain samples compared with *c*. 200000 km for the Central Domain samples) and 11 rather than three separate plutons, it should be expected for the Eastern Domain samples to show greater heterogeneity.

The $\varepsilon Nd_{(105)}$ values of Flowerdew *et al.* (2005) for the Lassiter Coast Intrusive Suite in both domains ranged from +3 to −4, but 18 out of 20 values were between −1 and −4. This restricted range was attributed to homogenization of the lower crust prior to Cretaceous granitic magmatism (Flowerdew *et al.* 2005), a result of the extensive Jurassic silicic LIP magmatism in Palmer Land. During this Jurassic event, mantle-derived melts underplated, mixed, assimilated and homogenized with lower crustal partial melts prior to eruption, leaving an isotopically homogenized lower crust (Riley *et al.* 2001). Consequently, this homogeneous signature suggests an association of the Central Domain with the Jurassic magmatism associated with Gondwanan break-up and renders a distal origin unlikely.

The lack of any isotopic distinction between magmatism of the Eastern and Central domains (Flowerdew *et al.* 2005) is in agreement with the collated Nd isotopic data of Millar *et al*. (2001) for felsic and mafic intrusions, and volcanic rocks from the Peninsula (Fig. 4). Nd isotopes are particularly sensitive to the involvement of pre-Phanerozoic crust in Phanerozoic magmatism, and have been used to show the involvement of Archaean and Proterozoic crust in evolved Mesozoic and Cenozoic magmatism elsewhere on the circum-Pacific margin (e.g. Liew & McCulloch 1985; Cullen *et al.* 2013). Figure 4 shows that the εNd_i and geochronological data for igneous rocks from the Central and Eastern domains display similar isotopic signatures and model ages through time and similar trends in their evolution, and that both domains require involvement of Proterozoic crustal material (Millar *et al.* 2001). This implies that a similar Proterozoic component is present in the deep crust beneath the different domains and supports a common autochthonous history. However, it is important to note the distinct drop in εNd_i values for the Central Domain plutonic rocks at *c*. 140–130 Ma, recording emplacement of the high εNd magmatism of the Wiley Glacier Complex in NW Palmer Land. This intrusive

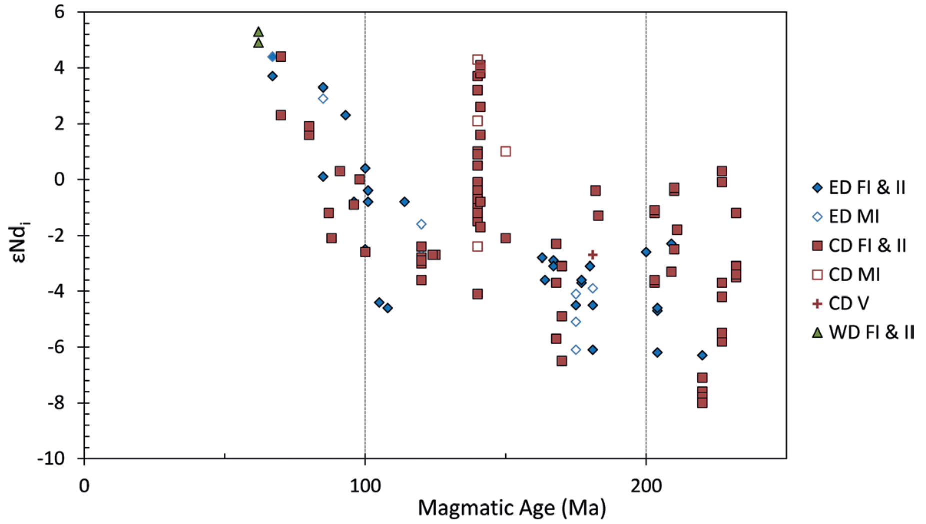

Fig. 4. εNd_i and magmatic ages from Millar *et al.* (2001) for intrusive and volcanic rocks on the Antarctic Peninsula plotted according to their domain. ED, Eastern Domain; CD, Central Domain; WD, Western Domain; FI, felsic intrusions; II, intermediate intrusions; MI, mafic intrusions; V, volcanic rocks.

suite was emplaced in an extensional setting (Vaughan *et al.* 1997) and consequently assimilation of the extended overlying crust by the mantle-derived magmatism was reduced, producing more juvenile isotopic values relative to preceding and subsequent magmatism. Another increase in εNd_i at 182–232 Ma for the Central Domain samples may indicate a similar extensional event in the Late Triassic.

Evidence for the underlying mantle chemistry and its tectonic implications

The chemistry of the mafic magmas can provide a more direct insight into the mantle sources beneath the terranes and their tectonic histories. Late Jurassic (Oxfordian–Kimmeridgian) OIB-like and arc-like pillow basalts and intrusions are recorded from the Fossil Bluff Group of Alexander Island (Macdonald *et al.* 1999), and similar Jurassic pillow basalts and sills of OIB, enriched mid-ocean ridge basalt (E-MORB), normal (N)-MORB and arc-like affinity crop out within the LeMay Group (Doubleday *et al.* 1994). The presence of OIB-like magmas within contemporaneous sedimentary rocks challenges an accretionary wedge model for the formation of the host sediments as petrogenesis of OIB-like magma requires low-degree melting of a fertile, non-metasomatized mantle. This requires subduction to not be locally active at the time of their emplacement and previous subduction cannot have metasomatized the mantle source. Their presence instead supports sedimentation in a back-arc or extensional margin setting (more likely the latter given the lack of a magmatic arc to the west of Alexander Island). The absence of an arc and active subduction zone to develop against supports a model of deposition for the Western Domain sediments against the Gondwanan margin instead of a distal oceanic arc. This is in agreement with the eastern palaeocurrent provenance of turbidite sequences (Edwards 1980) and the Cambrian to Cretaceous detrital zircon ages (Millar *et al.* 2001; Willan 2003).

The close spatial and temporal association of these OIB-like magmas from a non-metasomatized mantle source with E-MORB, N-MORB and arc-like magmas is comparable with the extensional magmatism found in suprasubduction-zone ophiolites produced during the initial period of subduction initiation (Stern *et al.* 2012). Similarly, on the Peninsula this magmatism records a period of lithospheric extension and consequent upwelling of fertile non-metasomatized mantle during the resumption of subduction after a Late Jurassic pause (Macdonald *et al.* 1999). This is supported stratigraphically by the presence of contemporaneous Oxfordian–Kimmeridgian radiolarian cherts associated with pillow basalts and volcanic tuffs within the oldest LeMay Group outcrops (Burn 1984; Holdsworth & Nell 1992), a typical feature of suprasubduction-zone ophiolite sequences (Metcalf & Shervais 2008), and the appearance of volcanolithic material higher up the LeMay Group stratigraphy indicating a proximal mafic arc source (Willan 2003). A similar association of Late Jurassic to Early Cretaceous OIB, E-MORB and arc-like mafic dykes are recorded in the Central Domain in NW Palmer Land (Scarrow *et al.* 1998) and the Eastern Domain in NE Palmer Land (Wever & Storey 1992), further supporting a shared tectonic history of the three terranes.

In addition to the OIB and MORB dykes, tholeiitic and calc alkaline arc-derived mafic dykes on the Peninsula have been used to infer its tectonic history. Vaughan *et al.* (2012*b*) interpreted incompatible element depleted Triassic tholeiitic mafic dykes (predating amphibolite-grade metamorphism at *c.* 200 Ma) in the eastern Central Domain of Palmer Land as representing shallow melting of a depleted mantle beneath an intra-oceanic arc, supporting the terrane hypothesis. However, similar tholeiitic mafic magmas were emplaced during the Cretaceous in NW Palmer Land (Central Domain) at *c.* 150 Ma and 84–72 Ma (Scarrow *et al.* 1998) and in eastern Graham Land (Eastern Domain) at 126–106 Ma (Leat *et al.* 2002). This Cretaceous magmatism represents melting during periods of high lithospheric extension of a subduction-modified asthenospheric mantle, previously depleted by Jurassic magmatism (Scarrow *et al.* 1998; Leat *et al.* 2002; Riley *et al.* 2003). As both the chemically similar Triassic and Cretaceous tholeiitic dykes were emplaced in both the Central and Eastern domains this argues against the requirement for an allochthonous island arc setting for the Triassic magmas, instead indicating a period of subduction-driven lithospheric extension of the Gondwana margin during the Triassic, supported by the increase in granitic εNd_i during the Late Triassic (see above; Fig. 4). The restricted distribution of these dykes in the eastern Central Domain indicates a limited spatial extent of Triassic lithospheric extension.

Geophysical datasets

Multiple geophysical datasets have been collected that allow further insight into the geological characteristics and tectonic histories of the proposed domains and their relationship to each other.

Magnetic susceptibility of the magmatic suites

Analysing the magnetic susceptibility of rocks allows determination of their magnetite content and as such provides an indication of the magma's redox state during emplacement and the degree of crustal contamination (Ishihara 1998). The distribution of magnetite-series (high fO_2) and ilmenite-series (low fO_2) granitoids on the East Pacific margin (Ishihara *et al.* 2000; Hart *et al.* 2004) has shown a tectonic control on oxidation state, with dominantly magnetite-series intrusions occurring closest to the convergent margin where crustal extension reduced the degree of crustal contamination and consequent reduction in oxidation state. In contrast, ilmenite-series granitoids dominantly crop out further inland where crustal contamination of the intruding melts was increased by crustal thickening.

Wendt *et al*. (2013) collected bulk magnetic susceptibility data for the Antarctic Peninsula to investigate the spatial and temporal patterns of the magnetite- and ilmenite-series granitoids so as to understand the magmatic redox states for the proposed terranes. They identified that the Triassic and Cretaceous plutonic rocks are overwhelmingly magnetite series (high fO_2) in the west of the Peninsula (the Central Domain) and ilmenite series (low fO_2) in the east (the Eastern Domain), although all Jurassic plutonic rocks are ilmenite series in both domains. This distribution is at odds with a tectonic model involving a palaeo-subduction zone along the line of the Eastern Palmer Land Shear Zone as this would produce suprasubduction extension and dominantly magnetite-series plutons in the overriding Eastern Domain as well as the volcanic arc of the Central Domain. Instead, the evidence for decreasing fO_2 from west to east supports a simpler model of a single subduction zone west of the Peninsula, placing the magnetite-series granitoids of the Central Domain closer to the convergent margin and the Eastern Domain plutonic rocks farther landward, as seen in North and South America (Ishihara *et al.* 2000; Hart *et al.* 2004). This interpretation of crustal assimilation as the dominant control on magnetic susceptibility is supported by the εNd_i data (see above), which show decreased crustal assimilation during formation of the Early Cretaceous extensional magnetite-series intrusions of the Central Domain.

Aeromagnetic and gravity data for distinct terranes

Aeromagnetic data also provide insight into the bulk magnetic susceptibility of the composite lithologies of the Peninsula, although specific lithologies and relative ages have to be inferred. These data (Fig. 5; Vaughan *et al*. 1998; Ferraccioli *et al*. 2006) broadly agree with those of Wendt *et al*. (2013), with the most extensive high magnetic susceptibilities being on the west of the Peninsula in the Central Domain. The highest magnetic anomalies are focused along a narrow linear feature (the Pacific Margin Anomaly, Fig. 5; Vaughan *et al*. 1998) along the Central Domain's western margin. This anomaly also correlates with a Bouguer gravity high (Ferraccioli *et al.* 2006). Mapping and dating samples from this region indicates that the anomaly is largely caused by highly magnetically susceptible Early Cretaceous (141–129 Ma) gabbroic and tonalitic–granodioritic extensional plutons produced during a peak in magmatic activity (Vaughan *et al.* 1998). Less extensive, shorter wavelength magnetic highs are found in the Eastern Domain of Palmer Land, but the Jurassic gabbroic intrusions producing them are clearly not as prevalent as the mafic bodies in the Central Domain and may be related to Gondwanan rifting rather than arc magmatism (Storey *et al.* 1987; Wever & Storey 1992). Although the data of Ferraccioli *et al.* (2006) were presented in support of the terrane accretion model, no extensive linear magnetic feature follows the trace of the Eastern Palmer Land Shear Zone; this finding argues against the presence of a major tectonic suture separating allochthonous or parautochthonous terranes. Instead, the most prominent linear feature abruptly bisects the Central Domain into a western zone of high magnetic susceptibility and an eastern zone of low susceptibility, reflecting the edge of Pacific Margin Anomaly related mafic magmatism not a terrane boundary.

As with the Wendt *et al*. (2013) data, the aeromagnetic data do not show evidence for high fO_2, magnetite magmatism along the Eastern Palmer Land Shear Zone and the Eastern Domain, as would be expected in a terrane accretion model, nor an expression of the Eastern Palmer Land Shear Zone itself. Again, the data are best explained by a simpler continental margin model with increased dominance of magnetite-series magmatism towards a single convergent margin to the west of the Peninsula.

Proposed tectonic history of the Antarctic Peninsula

From the data discussed above we conclude that the different composite crustal units of the Antarctic Peninsula developed as autochthonous sequences on the remnant Gondwanan margin, not through terrane accretion of allochthonous bodies. We do not, however, dispute the presence of an extensive zone of oblique reverse deformation marked by the Eastern Palmer Land Shear Zone. Thus, returning to the historical model of continental margin growth we propose the following genetic history for the Peninsula (illustrated in Fig. 6) and explain how the units previously proposed as originating in separate terranes fit into a common history of a single, autochthonous arc.

Proterozoic to Carboniferous: basement formation

Although no Proterozoic material is exposed on the Antarctic Peninsula the evidence from Nd isotopes (see above) strongly supports the occurrence of either unexposed Proterozoic crust or sedimentary rocks derived from Proterozoic crust in all three domains. Proterozoic detrital and inherited zircon grains indicate the presence of similarly aged crust within the Gondwanan margin on which the Peninsula developed (Millar *et al.* 2002; Barbeau *et al.* 2010). Protracted periods of arc magmatism along the Gondwanan margin during the Palaeozoic formed the oldest metamorphic basement in Graham Land and north Palmer Land. The scattered distribution of these basement outcrops, their occurrence in both the Central and Eastern domains, and geochemical evidence for its existence in the basement of all domains indicate extension and incorporation of the basement units into the developing margin during subsequent events.

Carboniferous to Triassic: Pangaean margin

Continental margin magmatism continued along the Peninsula during the Carboniferous to Triassic period of final assembly and persistence of Pangaea. Contemporaneous dyke chemistries and the provenance of Central and Eastern Domain sedimentary rocks indicate active and proximal Permian to Triassic arc subduction (Laudon 1991; Vaughan *et al*. 2012*b*). Passive margin clastic sedimentary rocks, back-arc basin sediments and continental margin turbidites were deposited forming the Fitzgerald and Erehwon Beds in SW Palmer Land (Eastern Domain) and the Trinity Peninsula Group in Graham Land (Eastern Domain).

Early–Middle Jurassic: silicic LIP magmatism

The *c.* 182 Ma emplacement of the Karoo–Ferrar mafic large igneous province in Antarctica and Africa (Encarnación *et al.* 1996; Duncan *et al.* 1997; Minor & Mukasa 1997; Riley & Knight 2001) is associated with the onset of Gondwana break-up and is in part contemporaneous with silicic magmatic activity in Patagonia and the Antarctic Peninsula (Riley *et al.* 2001), producing the Chon Aike Volcanic Group on the Peninsula between 188–178 Ma and 172–162 Ma (Pankhurst *et al.* 2000). Magmatism is within the Eastern Domain, but homogenization of the Central and Eastern domains' lower crust (see above) indicates the effect of LIP magmatism in both domains and indicates a close spatial distribution.

Contemporaneous Weddell Sea rifting associated with this magmatism separated South Africa from Antarctica and the

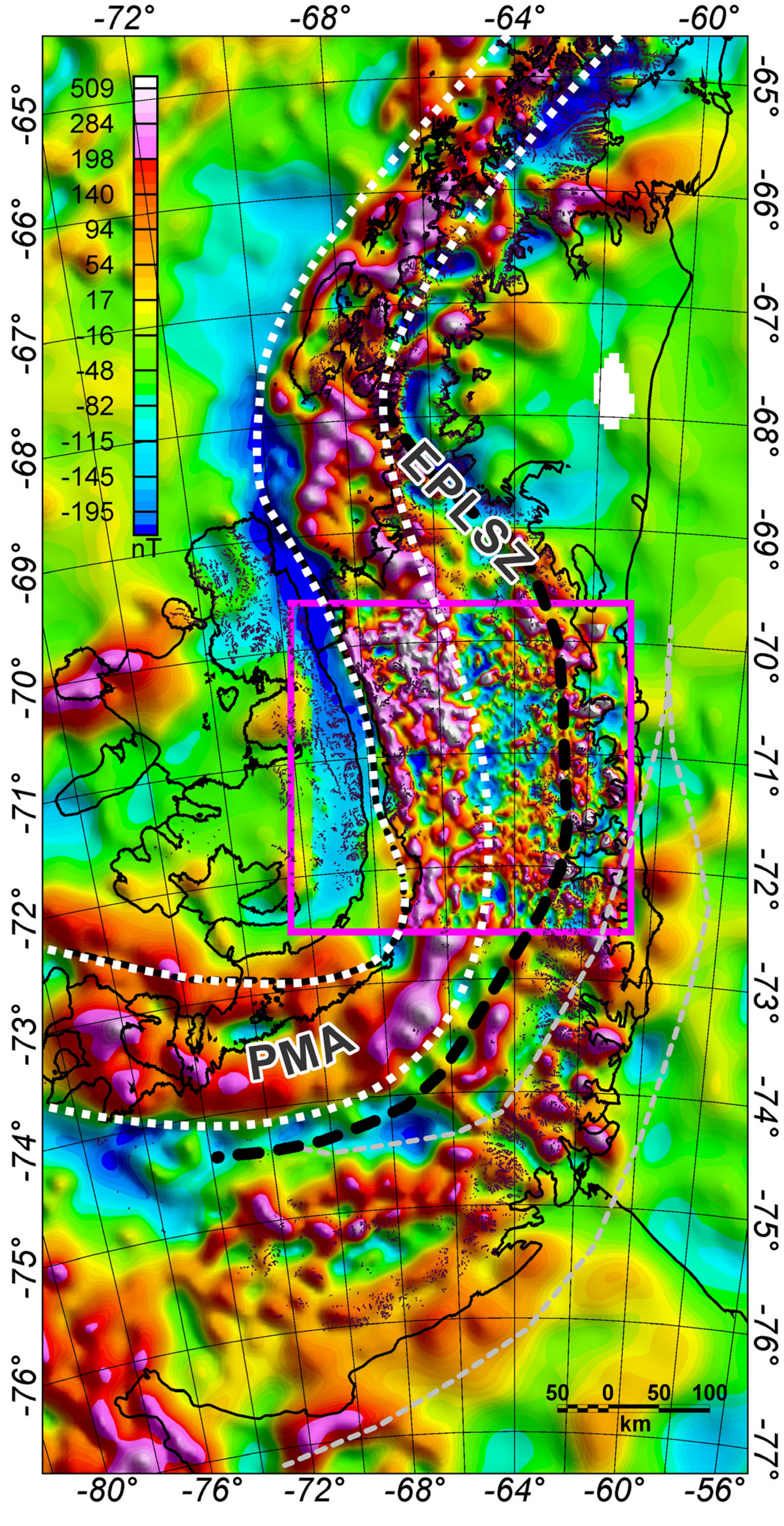

Fig. 5. Aeromagnetic anomaly map of the Antarctic Peninsula from Ferraccioli *et al.* (2006) combining improved resolution (indicated by square outline) and previous data. EPLSZ, East Palmer Land Shear Zone; PMA, Pacific Margin Anomaly. Grey dashed lines show other proposed thrust faults of Vaughan & Storey (2000). Figure reproduced with permission from F. Ferraccioli, British Antarctic Survey.

Antarctic Peninsula from Patagonia (167–140 Ma, König & Jokat 2006). This thinned the crust on the eastern side of the Antarctic Peninsula, as revealed by a decrease in the Bouguer gravity anomaly relative to the Peninsula's spine (Garrett 1990; Ferraccioli *et al.* 2006). The intraplate rifting resulted in the onset of Latady Group and Mount Hill Formation deposition (Eastern Domain) in back-arc basin settings at 188 Ma (Fanning & Laudon 1999; Willan 2003). Terrestrial sedimentation during this period also formed the

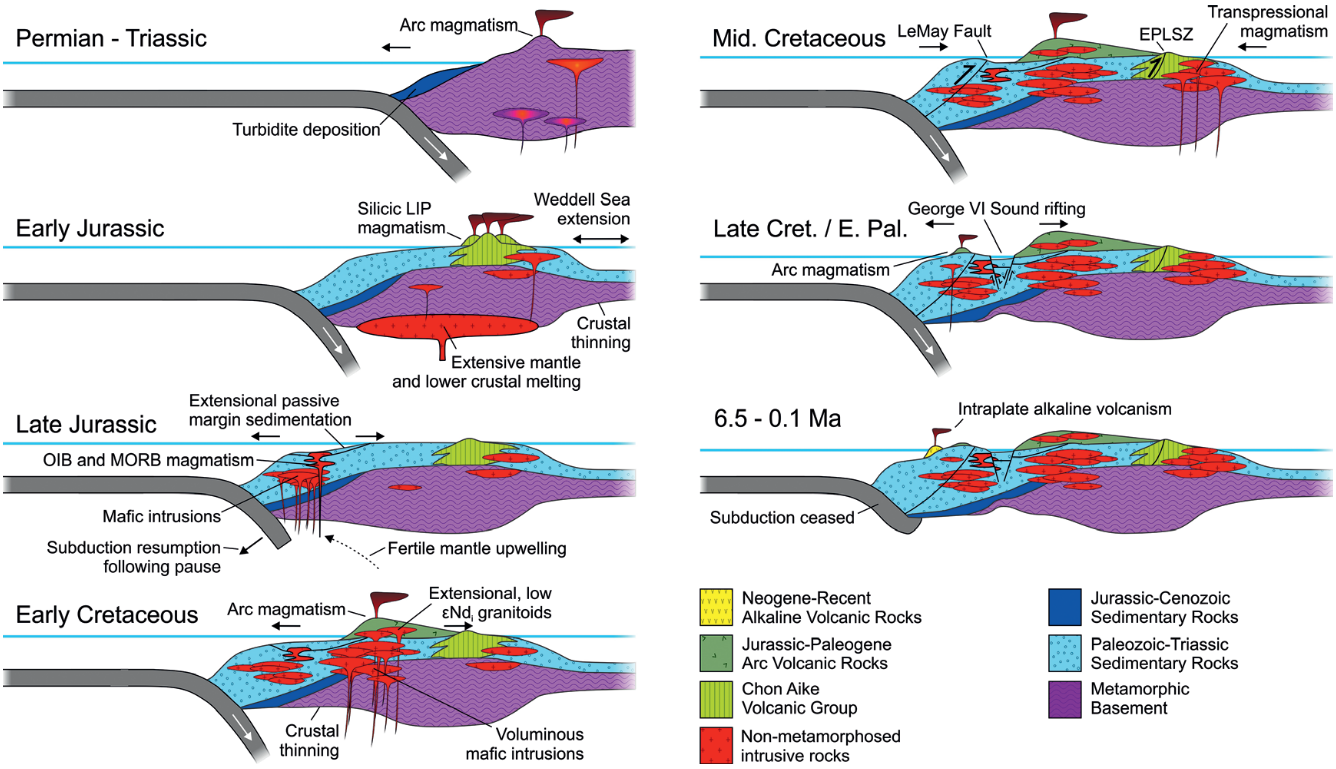

Fig. 6. Illustrative tectonic reconstruction for Palmer Land highlighting the key events in the autochthonous development of the Antarctic Peninsula.

Botany Bay Group in eastern Graham Land (Eastern Domain), and passive margin extension offshore led to the onset of deposition of the LeMay Group of Alexander Island (Western Domain); extension recorded across the Peninsula again illustrating the common tectonic history of the domains.

Late Jurassic: magmatic quiescence and subsequent subduction resumption

Subduction along the Peninsula ceased in the Late Jurassic, reflected by a low in magmatic activity at 156–142 Ma (Leat *et al.* 1995). During the recommencement of active subduction, extensional passive margin tectonics resulted in sedimentation on Alexander Island and Adelaide Island (Western Domain) and OIB- and MORB-like intrusive and volcanic magmatism on Alexander Island as fertile non-metasomatized mantle upwelled. A high isostatic residual gravity anomaly over Alexander Island reveals these mafic intrusions to be extensive at depth, forming up to 7.5 km of the vertical crustal stratigraphy (Garrett 1990; Ferraccioli *et al.* 2006). These events argue against formation of the Western Domain as an accretionary wedge to a distal oceanic arc (see above) and mark the resumption of subduction (see above) and subsequent increase in magmatic activity during the Cretaceous.

The end of LIP magmatism in the Late Jurassic also correlates with a *c.* 160 Ma marked facies change in the Latady Group (Eastern Domain) to higher energy, shallower deposits with a more mafic volcaniclastic input. This indicates a shift from deposition in localized rifts to larger, shallower basins and reflects the compositional shift in magmatic activity from felsic LIP to mafic OIB and arc magmas (Willan & Hunter 2005; Hunter & Cantrill 2006).

Early Cretaceous

Extensive arc and back-arc tectonics across the Peninsula in the Early Cretaceous produced a peak of Phanerozoic intrusive magmatism and crustal growth. Crustal extension followed the onset of subduction and thinned the crust in western Palmer Land, as revealed by the reduced Bouguer anomaly west of the Peninsula's spine (Garrett 1990; Ferraccioli *et al.* 2006). Crustal thinning resulted in mantle melting and low εNd_i magnetite-series magmatism in the Central Domain (Fig. 4). This distinct chemistry marks reduced crustal contamination of juvenile mantle melts resulting from high degrees of crustal extension, not a distinction in the existing crustal structure (see above). The highly magnetic Pacific Margin Anomaly (Fig. 5) over western Palmer Land reveals that similar mafic to intermediate intrusions are far more prevalent in the lower to middle crust and isostasy modelling indicates that they may form about one-third of the crustal thickness beneath the Pacific Margin Anomaly (Garrett 1990; Vaughan *et al.* 1998).

Mid-Cretaceous (120–90 Ma)

Magmatism peaked between 120 and 90 Ma (Leat *et al.* 1995) during transpressional emplacement of the *c.* 13600 km^2 Lassiter Coast Intrusive Suite in SE Palmer Land (Central and Eastern domains; Fig. 1; Pankhurst & Rowley 1991; Flowerdew *et al.* 2005; Vaughan *et al.* 2012*c*) and its contemporaneous calc-alkaline mafic magmatism (Vennum & Rowley 1986; Scarrow *et al.* 1998). Active subduction also resulted in the forearc sedimentary sequences of Alexander Island (Western Domain).

A peak in magmatism (Leat *et al.* 1995), rapid relative sea-level fall in the Alexander Island forearc sequence and reverse deformation of the LeMay Fault (Doubleday & Storey 1998; Nichols & Cantrill 2002) at *c.* 100 Ma coincide with the Palmer Land transpressional event and deformation of the Eastern Palmer Land Shear Zone (107–103 Ma; Vaughan *et al.* 2012*b*). We dispute the interpretation of Vaughan & Storey (2000) that this event marks the collision event of allochthonous terranes, but its origin remains unclear. It has, however, been proposed to reflect a much more extensive, Pacific-wide event (Vaughan 1995; Vaughan & Livermore 2005).

Late Cretaceous and Cenozoic

Magmatic activity began to wane following the Palmer Land Event (Leat *et al.* 1995). Post-inversion extension associated with continuing subduction in the Late Cretaceous–Early Palaeogene produced the rift of the George VI Sound (Doubleday & Storey 1998). Through the Late Cretaceous and Cenozoic magmatism migrated northwards (Leat *et al.* 1995), following the migration of active subduction. Peaks in volcanic activity occurred in the Latest Cretaceous–Eocene, particularly in Adelaide Island, Alexander Island and the South Shetland Islands, and may reflect collision of a spreading ridge with the subduction zone (McCarron 1997; McCarron & Millar 1997; Haase *et al.* 2012; Riley *et al.* 2012*a*). Extension between South America and Antarctica began at *c.* 50 Ma as the Drake Passage began opening, developing a deep-water connection between 34 and 30 Ma (Livermore *et al.* 2005, 2007). Subsequent magmatism on the Antarctic Peninsula waned until the production of scattered intra-plate alkaline volcanism from 6.5 to 0.1 Ma (Rex 1976; Ringe 1991).

Comparisons and correlations with other continental arcs

It is important to understand how globally representative these processes are and whether similar tectonic histories and characteristics can be observed along other continental margins, so here we compare our observations with other circum-Pacific continental margins.

South America

As the continuation of the Gondwanan margin recorded by the Antarctic Peninsula, the Andean chain is the obvious comparison for margin development. Like the Peninsula, the South American margin has had its tectonic history interpreted through autochthonous and allochthonous terrane accretion models.

Arguments against the allochthonous terrane models are similar to those employed here for the Antarctic Peninsula. Ramos *et al.* (1986) proposed a model of Palaeozoic terrane accretion during the formation of Gondwana, constructing the central Andes from three major terranes that collided in two events during the Cambrian–Ordovician and the Devonian. This hypothesis was based on sharp changes in the stratigraphic units across proposed terrane boundaries. However, based largely on the similarity of the magmatic and metamorphic histories and isotopic signatures, as well as an absence of suture zones and large-scale stacking, Lucassen & Franz (2005) disputed this and proposed autochthonous Palaeozoic growth of the margin. An allochthonous origin has also been proposed for Patagonia (Ramos 1984), involving collision with South America in the Permian. However, correlation of sedimentary, igneous and metamorphic units across the proposed suture zone and the lack of geophysical evidence for the suture also support an autochthonous origin of Patagonia, with subduction-related transpression producing the deformation structures *in situ* (Kostadinoff *et al.* 2005; Gregori *et al.* 2008).

Baja California and the North American Pacific Coast

The geophysical similarity of distinct regions of magnetic susceptibilities separated by a proposed suture zone has led to previous comparison of the Antarctic Peninsula with the Mesozoic Peninsula Ranges Batholith of California (Ferraccioli *et al.* 2006). The proposed suture divides the magnetite-series, Early Cretaceous plutons and host crust of the Western Peninsula Ranges Batholith from the ilmenite-series mid-Cretaceous plutons and crust of the Eastern Peninsula Ranges Batholith. The significance of this suture (as with the Eastern Palmer Land Shear Zone) has been interpreted as representing exotic terrane accretion, accretion of a fringing arc or heterogeneities within a single arc (Sedlock 2003, and references therein). However, as with the Antarctic Peninsula granitoids, the similar pattern of ilmenite- and magnetite-series plutons may be related to suprasubduction-zone processes, with magnetite-series intrusions occurring in the extended crust close to the convergent margin and the ilmenite-series produced by increased crustal assimilation inland. This would support autochthonous, single arc development models of the Peninsula Ranges Batholith (e.g. Walawender *et al.* 1991; Ortega-Rivera 2003).

New Zealand

New Zealand is also a continuation of the proto-Pacific Gondwana margin and remains a classic example of terrane accretion during continental growth. It has traditionally been grouped as three distinct provinces (Wandres & Bradshaw 2005, and references therein): (1) the autochthonous Early Palaeozoic metasedimentary sequence and younger granitoids of the Western Province; (2) the multiple allochthonous arc, forearc and accretionary complexes of the Eastern Province; (3) the Carboniferous to Early Cretaceous batholith and volcanic and sedimentary sequences of the Median Tectonic Zone, separating the Western and Eastern provinces. However, on the basis of compiled geochronological, structural and petrogenetic evidence the Median Tectonic Zone has been reinterpreted as a magmatic arc complex that developed along the margin of the Western Province (Mortimer *et al.* 1999; Wandres & Bradshaw 2005), similar to the reinterpretation here of the Mesozoic magmatism in the Antarctic Peninsula's Central and Eastern domains.

Conclusions

The identification of an extensive transpressional shear zone bisecting the Antarctic Peninsula led to a significant reinterpretation of the development of the region's composite geological terranes as a series of two or three accreted terranes. However, in light of the collated stratigraphic, geochronological, geochemical and geophysical datasets we support an alternative tectonic history of autochthonous continental margin development. This reinterpretation is based on the following evidence.

(1) *In situ* Early Palaeozoic meta-igneous basement is present in both the proposed autochthonous Eastern Domain and allochthonous Central Domain.
(2) There is stratigraphic correlation of multiple sedimentary and volcanic sequences between the domains.
(3) The Nd isotopes are similar for igneous units in each domain, indicating similar deep crustal structures.
(4) OIB-like magmas and deep marine extensional sedimentary sequences within the Western Domain stratigraphy support an extensional margin, not a forearc depositional setting.
(5) Magnetic susceptibility of the igneous units increases towards the west of the Peninsula, reflecting extensional suprasubduction magmatism in the Central Domain and a farther landward setting for the Eastern Domain.
(6) There is no distinction in palaeopole latitudes between the domains prior to the proposed accretion event in the current (albeit highly limited) data.

With these arguments for an autochthonous rather than allochthonous margin development a tectonic history is proposed by which the composite geological units of the Antarctic Peninsula can be produced *in situ*. The series of events can be summarized as follows.

(1) Continental margin magmatism and sedimentation occurred during amalgamation and persistence of the Gondwana and Pangaea supercontinents.
(2) Extensional tectonics and silicic LIP magmatism marked the onset of supercontinent break-up.
(3) Amagmatic extensional tectonics and associated sedimentation and low-volume OIB magmatism occurred during a pause and subsequent resumption of arc magmatism.

(4) Large-scale arc and back-arc extensional magmatism developed, including the emplacement of voluminous mafic to intermediate intrusions above the subduction zone.
(5) Transpressional deformation formed laterally extensive faults and shear zones, with voluminous intermediate to felsic back-arc magmatism.
(6) Arc magmatism waned as subduction migrated from the margin.
(7) Intraplate alkaline magmatism followed subduction cessation.

Comparison with other circum-Pacific continental margins shows that similar features to those observed in the Antarctic Peninsula and presented as support for autochthonous development of the margin can be observed elsewhere, including the margins of South America, California and New Zealand where accreted terrane development has also been proposed. Consequently, this paper supports a careful re-evaluation of these margins to investigate whether they too developed *in situ*. These two competing hypotheses of accretional or autochthonous development imply very different processes for crustal growth, and so it is important to determine their relative dominance globally.

Acknowledgements and Funding

This study is part of the British Antarctic Survey Polar Science for Planet Earth programme, funded by the Natural Environment Research Council. This paper has benefited considerably as a result of the helpful review comments of D. Barbeau, I. Fitzsimmons, I. Millar and A. Vaughan. We would also like to thank F. Ferraccioli and S. Boughey for their assistance.

Scientific editing by Ian Millar

References

Adie, R. 1954. *The petrology of Graham Land: I. The Basement Complex; early Palaeozoic plutonic and volcanic rocks*. Falkland Islands Dependencies Survey Scientific Reports, 11.

Barbeau, D.L., Davis, J.T., Murray, K.E., Valencia, V., Gehrels, G.E., Zahid, K.M. & Gombosi, D.J. 2010. Detrital-zircon geochronology of the metasedimentary rocks of north-western Graham Land. *Antarctic Science*, **22**, 65–65, http://doi.org/10.1017/S095410200999054X.

Bradshaw, J.D. 1993. A review of the Median Tectonic Zone: Terrane boundaries and terrane amalgamation near the Median Tectonic Line. *New Zealand Journal of Geology and Geophysics*, **36**, 117–125.

Bradshaw, J.D., Vaughan, A.P.M., Millar, I.L., Flowerdew, M.J., Trouw, R.A., Fanning, C. & Whitehouse, M.J. 2012. Permo-Carboniferous conglomerates in the Trinity Peninsula Group at View Point, Antarctic Peninsula: Sedimentology, geochronology and isotope evidence for provenance and tectonic setting in Gondwana. *Geological Magazine*, **149**, 626–644.

Burn, R.W. 1984. *The Geology of the LeMay Group, Alexander Island*. British Antarctic Survey, Cambridge.

Butterworth, P.J., Crame, J.A., Howlett, P.J. & Macdonald, D.I.M. 1988. Lithostratigraphy of Upper Jurassic–Lower Cretaceous strata of eastern Alexander Island, Antarctica. *Cretaceous Research*, **9**, 249–264.

Castillo, P. Lacassie, J.P., Hervé, F. & Fanning, C.M. 2009. Sedimentary provenance of Trinity Peninsula Group, Antarctic Peninsula: Petrography, geochemistry and SHRIMP U–Pb zircon age constraints. *Geophysical Research Abstracts*, **11**, EGU2009-EGU3084.

Cullen, A., Macpherson, C., Taib, N.I., Burton-Johnson, A., Geist, D., Spell, T. & Banda, R.M. 2013. Age and petrology of the Usun Apau and Linau Balui volcanics: Windows to central Borneo's interior. *Journal of Asian Earth Sciences*, **76**, 372–388, http://doi.org/10.1016/j.jseaes.2013.05.003.

Doubleday, P.A. & Storey, B.C. 1998. Deformation history of a Mesozoic forearc basin sequence on Alexander Island, Antarctic Peninsula. *Journal of South American Earth Sciences*, **11**, 1–21.

Doubleday, P.A., Macdonald, D.I.M. & Nell, P.A.R. 1993. Sedimentology and structure of the trench-slope to forearc basin transition in the Mesozoic of Alexander Island, Antarctica. *Geological Magazine*, **130**, 737–754.

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, http://dx.doi.org/10.1144/gsjgs.151.1.0065.

Draut, A.E. & Clift, P.D. 2001. Geochemical evolution of arc magmatism during arc–continent collision, South Mayo, Ireland. *Geology*, **29**, 543–546.

Duncan, R.A., Hooper, P.R., Rehacek, J., Marsh, J.S. & Duncan, A.R. 1997. The timing and duration of the Karoo igneous event, southern Gondwana. *Journal of Geophysical Research: Solid Earth* , **102**, 18127–18138.

Edwards, C.W. 1980. *The Geology of Eastern and Central Alexander Island, Antarctica*. PhD thesis, University of Birmingham.

Encarnación, J., Fleming, T.H., Elliot, D.H. & Eales, H.V. 1996. Synchronous emplacement of Ferrar and Karoo dolerites and the early breakup of Gondwana. *Geology*, **24**, 535–538.

Fanning, C.M. & Laudon, T.S. 1999. Mesozoic volcanism, plutonism and sedimentation in eastern Ellsworth land, West Antarctic. *In*: Skinner, D.N.B. (ed.) *Abstracts Volume, 8th International Symposium on Antarctic Earth Sciences, Programme and Abstracts*, July 1999, Wellington, New Zealand, The Royal Society of New Zealand, 102.

Farquharson, G.W. 1982. Late Mesozoic sedimentation in the northern Antarctic Peninsula and its relationship to the southern Andes. *Journal of the Geological Society, London*, **139**, 721–727, http://dx.doi.org/10.1144/gsjgs.139.6.0721.

Farquharson, G.W. 1984. Late Mesozoic, non-marine conglomeratic sequences of northern Antarctic Peninsula (the Botany Bay Group). *British Antarctic Survey Bulletin*, **65**, 1–32.

Ferraccioli, F., Jones, P.C., Vaughan, A.P.M. & Leat, P.T. 2006. New aerogeophysical view of the Antarctic Peninsula: More pieces, less puzzle. *Geophysical Research Letters*, **33**, L05310, http://doi.org/10.1029/2005GL024636.

Fleming, E.A. & Thomson, J.W. 1979. *Northern Graham Land and South Shetland Islands. Geological Map, 1:500000*. British Antarctic Survey, BAS 500G Series, Sheet 2.

Flowerdew, M.J., Millar, I.L., Vaughan, A.P.M. & Pankhurst, R.J. 2005. Age and tectonic significance of the Lassiter Coast Intrusive Suite, Eastern Ellsworth Land, Antarctic Peninsula. *Antarctic Science*, **17**, 443–452, http://doi.org/10.1017/S0954102005002877.

Garrett, S.W. 1990. Interpretation of reconnaissance gravity and aeromagnetic surveys of the Antarctic Peninsula. *Journal of Geophysical Research: Solid Earth*, **95**, 6759–6777.

Gledhill, A., Rex, D.C. & Tanner, P.W.G. 1982. Rb–Sr and K–Ar geochronology of rocks from the Antarctic Peninsula between Anvers Island and Marguerite Bay. *In*: Craddock, C. (ed.) *Antarctic Geoscience*. University of Wisconsin Press, Madison, WI, 315–323.

Gonzalez-Ferran, O. 1982. The Antarctic Cenozoic volcanic provinces and their implication in plate tectonic processes. *In*: Craddock, C. (ed.) *Antarctic Geoscience*. University of Wisconsin Press, Madison, WI, 687–694.

Gregori, D.A., Kostadinoff, J., Strazzere, L. & Raniolo, A. 2008. Tectonic significance and consequences of the Gondwanide orogeny in northern Patagonia, Argentina. *Gondwana Research*, **14**, 429–450.

Griffiths, C.J. & Oglethorpe, R.D. 1998. The stratigraphy and geochronology of Adelaide Island. *Antarctic Science*, **10**, 462–475.

Grunow, A.M. 1993. New paleomagnetic data from the Antarctic Peninsula and their tectonic implications. *Journal of Geophysical Research: Solid Earth*, **98**, 13815–13833.

Haase, K.M., Beier, C., Fretzdorff, S., Smellie, J.L. & Garbe-Schönberg, D. 2012. Magmatic evolution of the South Shetland Islands, Antarctica, and implications for continental crust formation. *Contributions to Mineralogy and Petrology*, **163**, 1103–1119.

Hart, C.J., Goldfarb, R.J., Lewis, L.L. & Mair, J.L. 2004. The Northern Cordilleran Mid-Cretaceous plutonic province: ilmenite/magnetite-series granitoids and intrusion-related mineralisation. *Resource Geology*, **54**, 253–280.

Hathway, B. 2000. Continental rift to back-arc basin: Jurassic–Cretaceous stratigraphical and structural evolution of the Larsen Basin, Antarctic Peninsula. *Journal of the Geological Society, London*, **157**, 417–432, http://dx.doi.org/10.1144/jgs.157.2.417.

Hervé, F., Faúndez, V., Brix, M. & Fanning, M. 2006. Jurassic sedimentation of the Miers Bluff Formation, Livingston Island, Antarctica: Evidence from SHRIMP U–Pb ages of detrital and plutonic zircons. *Antarctic Science*, **18**, 229–238.

Hervé, F., Calderon, M., Fanning, M., Kraus, S. & Pankhurst, R. 2010. SHRIMP chronology of the Magallanes Basin basement, Tierra del Fuego: Cambrian plutonism and Permian high-grade metamorphism. *Andean Geology*, **37**, 253–275.

Holdsworth, B.K. & Nell, P.A.R. 1992. Mesozoic radiolarian faunas from the Antarctic Peninsula: Age, tectonic and palaeoceanographic significance. *Journal of the Geological Society, London*, **149**, 1003–1020, http://dx.doi.org/10.1144/gsjgs.149.6.1003.

Hole, M.J. 1988. Post-subduction alkaline volcanism along the Antarctic Peninsula. *Journal of the Geological Society, London*, **145**, 985–998, http://dx.doi.org/10.1144/gsjgs.145.6.0985.

Hunter, M.A. & Cantrill, D.J. 2006. A new stratigraphy for the Latady Basin, Antarctic Peninsula: Part 2, Latady Group and basin evolution. *Geological Magazine*, **143**, 797–819.

Hunter, M.A., Cantrill, D.J., Flowerdew, M.J. & Millar, I.L. 2005. Mid-Jurassic age for the Botany Bay Group: Implications for Weddell Sea Basin creation and southern hemisphere biostratigraphy. *Journal of the Geological Society, London*, **162**, 745–748, http://dx.doi.org/10.1144/0016-764905-051.

Hunter, M.A., Riley, T.R., Cantrill, D.J., Flowerdew, M.J. & Millar, I.L. 2006. A new stratigraphy for the Latady Basin, Antarctic Peninsula: Part 1, Ellsworth Land Volcanic Group. *Geological Magazine*, **143**, 777–796.

Ishihara, S. 1998. Granitoid series and mineralization in the circum-Pacific Phanerozoic granitic belts. *Resource Geology*, **48**, 219–224.

Ishihara, S., Hashimoto, M. & Machida, M. 2000. Magnetite/ilmenite-series classification and magnetic susceptibility of the Mesozoic–Cenozoic batholiths in Peru. *Resource Geology*, **50**, 123–129.

Kellogg, K.S. & Reynolds, R.L. 1978. Paleomagnetic results from the Lassiter Coast, Antarctica, and a test for oroclinal bending of the Antarctic Peninsula. *Journal of Geophysical Research: Solid Earth*, **83**, 2293–2299.

Kellogg, K.S. & Rowley, P. 1989. *Structural geology and tectonics of the Orville Coast region, southern Antarctic Peninsula, Antarctica*. US Geological Survey Professional Papers, **1498**.

Kemp, A.I.S., Hawkesworth, C.J., Collins, W.J., Gray, C.M. & Blevin, P.L. 2009. Isotopic evidence for rapid continental growth in an extensional accretionary orogen: The Tasmanides, eastern Australia. *Earth and Planetary Science Letters*, **284**, 455–466.

König, M. & Jokat, W. 2006. The Mesozoic breakup of the Weddell Sea. *Journal of Geophysical Research*, **111**, http://doi.org/10.1029/2005JB004035.

Kostadinoff, J., Gregori, D.A. & Raniolo, A. 2005. Configuración geofísica–geológica del sector norte de la provincia de Río Negro. *Revista de la Asociación Geológica Argentina*, **60**, 368–376.

Laudon, T.S. 1991. Petrology of sedimentary rocks from the English Coast, eastern Ellsworth Land. *In*: Thomson, M.R.A., Crame, J.A. & Thomson, J.W. (eds) *Geological Evolution of Antarctica*. Cambridge University Press, Cambridge, 455–460.

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.

Leat, P.T., Riley, T.R., Wareham, C.D., Millar, I.L., Kelley, S.P. & Storey, B.C. 2002. Tectonic setting of primitive magmas in volcanic arcs: An example from the Antarctic Peninsula. *Journal of the Geological Society, London*, **159**, 31–44, http://dx.doi.org/10.1144/0016-764900-132.

Leat, P.T., Flowerdew, M.J., Riley, T.R., Whitehouse, M.J., Scarrow, J.H. & Millar, I.L. 2009. Zircon U–Pb dating of Mesozoic volcanic and tectonic events in north-west Palmer Land and south-west Graham Land, Antarctica. *Antarctic Science*, **21**, 633–641, http://doi.org/10.1017/S0954102009990320.

Liew, T. & McCulloch, M. 1985. Genesis of granitoid batholiths of Peninsular Malaysia and implications for models of crustal evolution: Evidence from a Nd–Sr isotopic and U–Pb zircon study. *Geochimica et Cosmochimica Acta*, **49**, 587–600.

Livermore, R., Nankivell, A., Eagles, G. & Morris, P. 2005. Paleogene opening of Drake Passage. *Earth and Planetary Science Letters*, **236**, 459–470.

Livermore, R., Hillenbrand, C.-D., Meredith, M. & Eagles, G. 2007. Drake Passage and Cenozoic climate: An open and shut case? *Geochemistry, Geophysics, Geosystems*, **8**, Q01005, http://dx.doi.org/10.1029/2005GC001224.

Longshaw, S.K. & Griffiths, D.H. 1983. A palaeomagnetic study of Jurassic rocks from the Antarctic Peninsula and its implications. *Journal of the Geological Society, London*, **140**, 945–954, http://dx.doi.org/10.1144/gsjgs.140.6.0945.

Lucassen, F. & Franz, G. 2005. The early Palaeozoic Orogen in the Central Andes: A non-collisional orogen comparable to the Cenozoic high plateau? *In*: Vaughan, A.P.M., Leat, P.T. & Pankhurst, R.J. (eds) *Terrane Processes at the Margins of Gondwana*. Geological Society, London, Special Publications, **246**, 257–273, http://dx.doi.org/10.1144/GSL.SP.2005.246.01.09.

Macdonald, D.I.M., Barker, P.F. *et al*. 1988. A preliminary assessment of the hydrocarbon potential of the Larsen Basin, Antarctica. *Marine and Petroleum Geology*, **5**, 34–53.

Macdonald, D.I.M., Leat, P.T., Doubleday, P.A. & Kelly, S.R.A. 1999. On the origin of fore-arc basins: New evidence of formation by rifting from the Jurassic of Alexander Island, Antarctica. *Terra Nova*, **11**, 186–193.

McCarron, J.J. 1997. A unifying lithostratigraphy of late Cretaceous–early Tertiary fore-arc volcanic sequences on Alexander Island, Antarctica. *Antarctic Science*, **9**, 209–220.

McCarron, J.J. & Millar, I.L. 1997. The age and stratigraphy of fore-arc magmatism on Alexander Island, Antarctica. *Geological Magazine*, **134**, 507–522.

Meneilly, A.W. & Storey, B.C. 1986. Ductile thrusting within subduction complex rocks on Signy Island, South Orkney Islands. *Journal of Structural Geology*, **8**, 457–472.

Meneilly, A.W., Harrison, S.M., Piercy, B.A. & Storey, B.C. 1987. Structural evolution of the magmatic arc in northern Palmer Land, Antarctic Peninsula. *Gondwana Six: Structure, Tectonics, and Geophysics*, 209–219.

Metcalf, R.V. & Shervais, J.W. 2008. Suprasubduction-zone ophiolites: Is there really an ophiolite conundrum? *In*: Wright, J.E. & Shervais, J.W. (eds) *Ophiolites, Arcs, and Batholiths: A Tribute to Cliff Hopson*. Geological Society of America, Special Papers, **438**, 191–222.

Millar, I.L., Pankhurst, R.J. & Fanning, C.M. 1999. U–Pb zircon evidence for the nature of the Antarctic Peninsula basement. *In*: Skinner, D.N.B. (ed.) *Abstracts Volume, 8th International Symposium on Antarctic Earth Sciences, Programme and Abstracts*, July 1999, Wellington, New Zealand, The Royal Society of New Zealand.

Millar, I.L., Willan, R.C.R., Wareham, C.D. & Boyce, A.J. 2001. The role of crustal and mantle sources in the genesis of granitoids of the Antarctic Peninsula and adjacent crustal blocks. *Journal of the Geological Society, London*, **158**, 855–867, http://doi.org/10.1144/0016-764900-139.

Millar, I.L., Pankhurst, R.J. & Fanning, C.M. 2002. Basement chronology of the Antarctic Peninsula: Recurrent magmatism and anatexis in the Palaeozoic Gondwana Margin. *Journal of the Geological Society, London*, **159**, 145–157, http://doi.org/10.1144/0016-764901-020.

Milne, A.J. & Millar, I.L. 1989. The significance of mid-Palaeozoic basement in Graham Land, Antarctic Peninsula. *Journal of the Geological Society, London*, **146**, 207–210, http://doi.org/10.1144/gsjgs.146.2.0207.

Minor, D.R. & Mukasa, S.B. 1997. Zircon U–Pb and hornblende ^{40}Ar–^{39}Ar ages for the Dufek layered mafic intrusion, Antarctica: Implications for the age of the Ferrar large igneous province. *Geochimica et Cosmochimica Acta*, **61**, 2497–2504.

Mortimer, N., Tulloch, A.J., Spark, R.N., Walker, N.W., Ladley, E., Allibone, A. & Kimbrough, D.L. 1999. Overview of the Median Batholith, New Zealand: A new interpretation of the geology of the Median Tectonic Zone and adjacent rocks. *Journal of African Earth Sciences*, **29**, 257–268.

Moyes, A.B., Willan, C.F.H. *et al*. 1993. *Geological Map of Adelaide Island to Foyn Coast, 1:250000*. British Antarctic Survey, BAS Geomap Series, Sheet 3.

Nichols, G.J. & Cantrill, D.J. 2002. Tectonic and climatic controls on a Mesozoic forearc basin succession, Alexander Island, Antarctica. *Geological Magazine*, **139**, 313–330.

Ortega-Rivera, A. 2003. Geochronological constraints on the tectonic history of the Peninsular Ranges batholith of Alta and Baja California: Tectonic implications for western Mexico. *In*: Johnson, S.E., Paterson, S.R., Fletcher, J.M., Girty, G.H., Kimbrough, D.L. & Martín-Barajas, A. (eds) *Tectonic Evolution of North-Western México and the Southwestern USA*. Boulder, Colorado. Geological Society of America, Special Papers, **374**, 297–336.

Pankhurst, R. 1983. Rb–Sr constraints on the ages of basement rocks of the Antarctic Peninsula. *In*: Oliver, R.J., James, P.R. & Jago, J.B. (eds) *Antarctic Earth Science*. Australian Academy of Science, Canberra, ACT, 367–371.

Pankhurst, R.J. 1982. Rb–Sr geochronology of Graham Land, Antarctica. *Journal of the Geological Society, London*, **139**, 701–711, http://doi.org/10.1144/gsjgs.139.6.0701.

Pankhurst, R.J. & Rowley, P.D. 1991. Rb–Sr study of Cretaceous plutons from southern Antarctic Peninsula and eastern Ellsworth Land, Antarctica. *In*: Thomson, M.R.A., Crame, J.A. & Thomson, J.W. (eds) *Geological Evolution of Antarctica*. Cambridge University Press, Cambridge, 387–394.

Pankhurst, R.J. & Smellie, J.L. 1983. K–Ar geochronology of the South Shetland Islands, Lesser Antarctica: Apparent lateral migration of Jurassic to Quaternary island arc volcanism. *Earth and Planetary Science Letters*, **66**, 214–222.

Pankhurst, R.J., Weaver, S.D., Bradshaw, J.D., Storey, B.C. & Ireland, T.R. 1998. Geochronology and geochemistry of pre-Jurassic superterranes in Marie Byrd Land, Antarctica. *Journal of Geophysical Research: Solid Earth*, **103**, 2529–2547.

Pankhurst, R.J., Riley, T.R., Fanning, C.M. & Kelley, S.P. 2000. Episodic silicic volcanism in Patagonia and the Antarctic Peninsula: Chronology of magmatism associated with the break-up of Gondwana. *Journal of Petrology*, **41**, 605–625.

Pankhurst, R.J., Rapela, C.W., Fanning, C.M. & Márquez, M. 2006. Gondwanide continental collision and the origin of Patagonia. *Earth-Science Reviews*, **76**, 235–257, http://doi.org/10.1016/j.earscirev.2006.02.001.

Pimpirev, C., Stoykova, K., Ivanov, M. & Dimov, D. 2006. The sedimentary sequences of Hurd Peninsula, Livingston Island, South Shetland Islands: part of the Late Jurassic–Cretaceous depositional history of the Antarctic Peninsula. *In*: Fütterer, D.K., Damaske, D., Kleinschmidt, G., Miller, H. & Tessensohn, F. (eds) *Antarctica: Contributions to Global Earth Sciences.* Springer, Berlin, 249–253.

Poblete, F., Arriagada, C., Roperch, P., Astudillo, N., Hervé, F., Kraus, S. & Le Roux, J.P. 2011. Paleomagnetism and tectonics of the South Shetland Islands and the northern Antarctic Peninsula. *Earth and Planetary Science Letters*, **302**, 299–313, http://doi.org/10.1016/j.epsl.2010.12.019.

Ramos, V.A. 1984. Patagonia: Un continente paleozoico a la deriva. *In*: *IX Congreso Geológico Argentino (SC Bariloche) Actas I*, 311–325.

Ramos, V.A., Jordan, T.E., Allmendinger, R.W., Mpodozis, C., Kay, S.M., Cortés, J.M. & Palma, M. 1986. Paleozoic terranes of the central Argentine–Chilean Andes. *Tectonics*, **5**, 855–880.

Rex, D.C. 1976. Geochronology in relation to the stratigraphy of the Antarctic Peninsula. *British Antarctic Survey Bulletin*, **43**, 49–58.

Reymer, A. & Schubert, G. 1984. Phanerozoic addition rates to the continental crust and crustal growth. *Tectonics*, **3**, 63–77.

Riley, T.R. & Knight, K. 2001. Age of pre-break-up Gondwana magmatism. *Antarctic Science*, **13**, 99–110.

Riley, T.R. & Leat, P.T. 1999. Large volume silicic volcanism along the proto-Pacific margin of Gondwana: Lithological and stratigraphical investigations from the Antarctic Peninsula. *Geological Magazine*, **136**, 1–16.

Riley, T.R., Leat, P., Pankhurst, R. & Harris, C. 2001. Origins of large volume rhyolitic volcanism in the Antarctic Peninsula and Patagonia by crustal melting. *Journal of Petrology*, **42**, 1043–1065.

Riley, T.R., Leat, P.T., Kelley, S.P., Millar, I.L. & Thirlwall, M.F. 2003. Thinning of the Antarctic Peninsula lithosphere through the Mesozoic: Evidence from Middle Jurassic basaltic lavas. *Lithos*, **67**, 163–179.

Riley, T.R., Flowerdew, M.J., Hunter, M.a & Whitehouse, M.J. 2010. Middle Jurassic rhyolite volcanism of eastern Graham Land, Antarctic Peninsula: Age correlations and stratigraphic relationships. *Geological Magazine*, **147**, 581–595, http://doi.org/10.1017/S0016756809990720.

Riley, T.R., Flowerdew, M.J. & Haselwimmer, C.E. 2011*a*. *Geological Map of Adelaide Island, Graham Land (1:200000 Scale)*. British Antarctic Survey, BAS GEOMAP 2 Series.

Riley, T.R., Flowerdew, M.J. & Haselwimmer, C.E. 2011*b*. *Geological Map of Eastern Graham Land, Antarctic Peninsula (1:625000 Scale)*. British Antarctic Survey, BAS GEOMAP 2 Series.

Riley, T.R., Flowerdew, M.J. & Whitehouse, M.J. 2012*a*. Chrono- and lithostratigraphy of a Mesozoic–Tertiary fore- to intra-arc basin: Adelaide Island, Antarctic Peninsula. *Geological Magazine*, **149**, 768–782.

Riley, T.R., Flowerdew, M.J. & Whitehouse, M.J. 2012*b*. U–Pb ion-microprobe zircon geochronology from the basement inliers of eastern Graham Land, Antarctic Peninsula. *Journal of the Geological Society, London*, **169**, 381–393, http://doi.org/10.1144/0016-76492011-142.

Ringe, M.J. 1991. Volcanism on Brabant Island, Antarctica. *In*: Thomson, M.R.A., Crame, J.A. & Thomson, J.W. (eds) *Geological Evolution of Antarctica*. Cambridge University Press, Cambridge, 515–519.

Rowley, P.D., Schmidt, D.L. & Williams, P.L. 1982. Mount Poster Formation, southern Antarctic Peninsula and eastern Ellsworth Land. *Antarctic Journal of the United States*, **17**, 38–39.

Rowley, P.D., Kellogg, K.S., Williams, P.L., Willan, C.F.H. & Thomson, J.W. 1992. *Southern Palmer Land and Eastern Ellsworth Land. Geological Map, 1:500000*. British Antarctic Survey, BAS 500G Series, Sheet 6.

Saunders, A.D. 1982. Petrology and geochemistry of alkali-basalts from Jason Peninsula, Oscar II Coast, Graham Land. *British Antarctic Survey Bulletin*, **55**, 1–9.

Scarrow, J., Leat, P., Wareham, C.D. & Millar, I. 1998. Geochemistry of mafic dykes in the Antarctic Peninsula continental-margin batholith: A record of arc evolution. *Contributions to Mineralogy and Petrology*, 289–305.

Sedlock, R.L. 2003. Geology and tectonics of the Baja California peninsula and adjacent areas. *In*: Johnson, S.E., Paterson, S.R., Fletcher, J.M., Girty, G.H., Kimbrough, D.L. & Martín-Barajas, A. (eds) *Tectonic Evolution of North-Western México and the Southwestern USA*. Boulder, Colorado. Geological Society of America, Special Papers, **374**, 1–42.

Singleton, D.G. 1980. *The geology of the central Black Coast, Palmer Land*. British Antarctic Survey Scientific Reports, **102**.

Smellie, J.L. 1987. Geochemistry and tectonic setting of alkaline volcanic rocks in the Antarctic Peninsula: A review. *Journal of Volcanology and Geothermal Research*, **32**, 269–285.

Smellie, J.L. 1991. Stratigraphy, provenance and tectonic setting of (?) Late Palaeozoic–Triassic sedimentary sequences in northern Graham Land and South Scotia Ridge. *In*: Thomson, M.R.A., Crame, J.A. & Thomson, J.W. (eds) *Geological Evolution of Antarctica*. Cambridge University Press, Cambridge, 411–417.

Smellie, J.L. & Millar, I.L. 1995. New K–Ar isotopic ages of schists from Nordenskjöld Coast, Antarctic Peninsula: Oldest part of the Trinity Peninsula Group? *Antarctic Science*, **7**, 191–196.

Smellie, J.L., Millar, I.L., Rex, D.C. & Butterworth, P.J. 1998. Subaqueous, basaltic lava dome and carapace breccia on King George Island, South Shetland Islands, Antarctica. *Bulletin of Volcanology*, **59**, 245–261.

Stern, R.J., Reagan, M., Ishizuka, O., Ohara, Y. & Whattam, S. 2012. To understand subduction initiation, study forearc crust: To understand forearc crust, study ophiolites. *Lithosphere*, **4**, 469–483, http://doi.org/10.1130/L183.1.

Storey, B. & Garrett, S. 1985. Crustal growth of the Antarctic Peninsula by accretion, magmatism and extension. *Geological Magazine*, **122**, 5–14.

Storey, B.C., Wever, H.E., Rowley, P.D. & Ford, A.B. 1986. *Geology of the central Black Coast, eastern Palmer Land, 1986–87*. BAS Field Report, **AD6/2R/1986/G2**.

Storey, B.C., Wever, H.E., Rowley, P.D. & Ford, A.B. 1987. Report on Antarctic fieldwork: the geology of the central Black Coast, Eastern Palmer Land. *British Antarctic Survey Bulletin*, **77**, 145–155.

Suárez, M. 1976. Plate-tectonic model for southern Antarctic Peninsula and its relation to southern Andes. *Geology*, **4**, 211–214.

Thomson, M.R.A. 1972. New discoveries of fossils in the Upper Jurassic volcanic group of Adelaide Island. *British Antarctic Survey Bulletin*, **30**, 95–101.

Thomson, J.W. 1981. *Alexander Island. Geological Map, 1:500000*. British Antarctic Survey, BAS 500G Series, Sheet 4.

Thomson, J.W. & Harris, A. 1979. *Southern Graham Land. Geological Map, 1:500000*. British Antarctic Survey, BAS 500G Series, Sheet 3.

Thomson, J.W., Harris, J. *et al*. 1982. *Northern Palmer Land. Geological Map, 1:500000*. British Antarctic Survey, BAS 500G Series, Sheet 5.

Thomson, M.R.A. & Pankhurst, R.J. 1983. Age of post-Gondwanian calc-alkaline volcanism in the Antarctic Peninsula region. *In*: Oliver, R.J., James, P.R. & Jago, J.B. (eds) *Antarctic Earth Science*. Australian Academy of Science, Canberra, ACT, 328–333.

Thomson, M.R.A. & Tranter, T.H. 1986. Early Jurassic fossils from central Alexander Island and their geological setting. *British Antarctic Survey Bulletin*, **70**, 23–39.

Trouw, R.A.J., Pankhurst, R.J. & Ribeiro, A. 1997. On the relation between the Scotia metamorphic complex and the Trinity Peninsula Group, Antarctic Peninsula. *In*: Ricci, C.A. (ed.) *The Antarctic Region: Geological Evolution and Processes*. Terra Antartica, Siena, 383–389.

Van der Voo, R. 1990. The reliability of paleomagnetic data. *Tectonophysics*, **184**, 1–9.

Vaughan, A.P.M. 1995. Circum-Pacific mid-Cretaceous deformation and uplift: A superplume-related event? *Geology*, **23**, 491–494.

Vaughan, A.P.M. & Livermore, R.A. 2005. Episodicity of Mesozoic terrane accretion along the Pacific margin of Gondwana: Implications for superplume–plate interactions. *In*: Vaughan, A.P.M., Leat, P.T. & Pankhurst, R.J. (eds) *Terrane Processes at the Margins of Gondwana*. Geological Society, London, Special Publications, **246**, 143–178, http://dx.doi.org/10.1144/GSL.SP.2005.246.01.05.

Vaughan, A.P.M. & Millar, I.L. 1996. Early Cretaceous magmatism during extensional deformation within the Antarctic Peninsula magmatic arc. *Journal of South American Earth Sciences*, **9**, 121–129.

Vaughan, A.P.M. & Storey, B.C. 2000. The eastern Palmer Land shear zone: A new terrane accretion model for the Mesozoic development of the Antarctic Peninsula. *Journal of the Geological Society, London*, **157**, 1243–1256, http://doi.org/10.1144/jgs.157.6.1243.

Vaughan, A.P.M., Wareham, C.D. & Millar, I.L. 1997. Granitoid pluton formation by spreading of continental crust: The Wiley Glacier complex, northwest Palmer Land, Antarctica. *Tectonophysics*, **283**, 35–60, http://doi.org/10.1016/S0040-1951(97)00150-9.

Vaughan, A.P.M., Wareham, C.D., Johnson, A.C. & Kelley, S.P. 1998. A Lower Cretaceous, syn-extensional magmatic source for a linear belt of positive magnetic anomalies: The Pacific Margin Anomaly (PMA), western Palmer Land, Antarctica. *Earth and Planetary Science Letters*, **158**, 143–155.

Vaughan, A.P.M., Millar, I.L. & Thistlewood, L. 1999. The Auriga Nunataks shear zone: Mesozoic transfer faulting and arc deformation in northwest Palmer Land, Antarctica. *Tectonics*, **18**, 911–928.

Vaughan, A.P.M., Kelley, S.P. & Storey, B.C. 2002*a*. Mid-Cretaceous ductile deformation on the Eastern Palmer Land Shear Zone, Antarctica, and implications for timing of Mesozoic terrane collision. *Geological Magazine*, **139**, 465–471, http://doi.org/10.1017/S0016756802006672.

Vaughan, A.P.M., Pankhurst, R.J. & Fanning, C.M. 2002*b*. A mid-Cretaceous age for the Palmer Land event, Antarctic Peninsula: Implications for terrane accretion timing and Gondwana palaeolatitudes. *Journal of the Geological Society, London*, **159**, 113–116, http://doi.org/10.1144/0016-764901-090.

Vaughan, A.P.M., Eagles, G. & Flowerdew, M.J. 2012*a*. Evidence for a two-phase Palmer Land event from crosscutting structural relationships and emplacement timing of the Lassiter Coast Intrusive Suite, Antarctic Peninsula: Implications for mid-Cretaceous Southern Ocean plate configuration. *Tectonics*, **31**, TC1010.

Vaughan, A.P.M., Leat, P.T., Dean, A.A. & Millar, I.L. 2012*b*. Crustal thickening along the West Antarctic Gondwana margin during mid-Cretaceous deformation of the Triassic intra-oceanic Dyer Arc. *Lithos*, **142–143**, 130–147, http://doi.org/10.1016/j.lithos.2012.03.008.

Vaughan, A.P.M., Storey, C., Kelley, S.P., Barry, T.L. & Curtis, M.L. 2012*c*. Synkinematic emplacement of Lassiter Coast Intrusive Suite plutons during the Palmer Land Event: Evidence for mid-Cretaceous sinistral transpression at the Beaumont Glacier in eastern Palmer Land. *Journal of the Geological Society, London*, **169**, 759–771, http://doi.org/10.1144/jgs2011-160.

Vennum, W. & Rowley, P. 1986. Reconnaissance geochemistry of the Lassiter Coast intrusive suite, southern Antarctic peninsula. *Geological Society of America Bulletin*, **97**, 1521–1533, http://doi.org/10.1130/0016-7606(1986)97<1521:RGOTLC>2.0.CO;2.

Walawender, M.J., Girty, G.H., Lombardi, M.R., Kimbrough, D., Girty, M.S. & Anderson, C. 1991. A synthesis of recent work in the Peninsular Ranges batholith. *In*: Walawender, M.J. & Hanan, B.B. (eds) *Geological Excursions in Southern California and Mexico*. San Diego State University, Department of Geological Sciences, San Diego, CA, 297–312.

Wandres, A.M. & Bradshaw, J.D. 2005. New Zealand tectonostratigraphy and implications from conglomeratic rocks for the configuration of the SW Pacific margin of Gondwana. *In*: Vaughan, A.P.M., Leat, P.T. & Pankhurst, R.J. (eds) *Terrane Processes at the Margins of Gondwana*. Geological Society, London, Special Publications, **246**, 179–216, http://dx.doi.org/10.1144/GSL.SP.2005.246.01.06.

Wendt, A.S., Vaughan, A.P.M. & Tate, A. 2008. Metamorphic rocks in the Antarctic Peninsula region. *Geological Magazine*, **145**, 655–676.

Wendt, A.S., Vaughan, A.P.M., Ferraccioli, F. & Grunow, A.M. 2013. Magnetic susceptibilities of rocks of the Antarctic Peninsula: Implications for the redox state of the batholith and the extent of metamorphic zones. *Tectonophysics*, **585**, 48–67, http://doi.org/10.1016/j.tecto.2012.07.011.

Wever, H.E. & Storey, B.C. 1992. Bimodal magmatism in northeast Palmer Land, Antarctic Peninsula: Geochemical evidence for a Jurassic ensialic back-arc basin. *Tectonophysics*, **205**, 239–259, http://doi.org/10.1016/0040-1951(92)90429-A.

Wever, H.E., Millar, I.L. & Pankhurst, R.J. 1994. Geochronology and radiogenic isotope geology of Mesozoic rocks from eastern Palmer Land, Antarctic Peninsula: Crustal anatexis in arc-related granitoid genesis. *Journal of South American Earth Sciences*, **7**, 69–83.

Willan, R.C.R. 2003. Provenance of Triassic–Cretaceous sandstones in the Antarctic Peninsula: Implications for terrane models during Gondwana breakup. *Journal of Sedimentary Research*, **73**, 1062–1077.

Willan, R.C.R. & Hunter, M.A. 2005. Basin evolution during the transition from continental rifting to subduction: Evidence from the lithofacies and modal petrology of the Jurassic Latady Group, Antarctic Peninsula. *Journal of South American Earth Sciences*, **20**, 171–191.

Willan, R.C.R., Pankhurst, R.J. & Hervé, F. 1994. A probable Early Triassic age for the Miers Bluff Formation, Livingston Island, South Shetland Islands. *Antarctic Science*, **6**, 401–408.

Zhou, X., Sun, T., Shen, W., Shu, L. & Niu, Y. 2006. Petrogenesis of Mesozoic granitoids and volcanic rocks in South China: A response to tectonic evolution. *Episodes*, 26–33.