New aerogeophysical view of the Antarctic Peninsula: More pieces, less puzzle

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[1] New airborne geophysical data reveal subglacial imprints of crustal growth of the Antarctic Peninsula by Mesozoic arc magmatism and terrane accretion along the paleo-Pacific margin of Gondwana. Potential field signatures indicate that the Antarctic Peninsula batholith is a composite magmatic arc terrane comprising two distinct arcs, separated by a >1500 km-long suture zone, similar to the Peninsular Ranges batholith in southern and Baja California. Aeromagnetic, aerogravity and geological data suggest that a mafic Early Cretaceous western arc was juxtaposed against a more felsic eastern arc which, in mid-Cretaceous times, was intruded by highly magnetic tonalitic/granodioritic plutons of island arc affinity. Suturing of the two arcs against the Gondwana margin caused the mid-Cretaceous Palmer Land orogenic event. Convergence and suturing may have been driven by two subduction zones or, alternatively, by a decrease in slab dip, leading to an inboard migration of the arc, as in California.

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1. Introduction

[2] Seismic experiments across the Izu-Bonin and Aleutian arcs [*Suyehiro et al.*, 1996; *Holbrook et al.*, 1999] and gravity models across western Pacific arcs [*Dimalanta et al.*, 2002] reveal that arc magmatism is a primary mechanism by which new crust is generated. Addition of island arc, oceanic, and ocean-captured fragments to continental margins is typical of accretionary orogens and leads to significant crustal growth [*Tagami and Hasebe*, 1999]. Geophysical investigations are important in understanding accretionary orogens and processes. Specifically, aeromagnetic and gravity data may contribute to terrane analysis in such orogens by; 1) imaging mafic terranes, ophiolites, segments of arc crust, volcanics and basement, and 2) revealing buried terrane boundaries, intra-terrane faults and suture zones. This is true over Alaska, where aeromagnetic and gravity studies have imaged the complex North American Cordillera terrane collage [*Saltus et al.*, 1999, 2001].

[3] We present new aeromagnetic and aerogravity data acquired to investigate controversial glaciated terranes of the Antarctic Peninsula. Although the Antarctic Peninsula has traditionally been regarded as an arc system built "in situ" on Gondwana basement [*Storey and Garrett*, 1985; *Tangeman et al.*, 1996], the discovery of a major fault zone within the magmatic arc has led to an alternative model involving accretion of exotic(?) arc terranes against the Gondwana margin [*Vaughan and Storey*, 2000]. Here, we analyse aerogeophysical signatures over Palmer Land, site of the terrane hypothesis, then combine our new aeromagnetic data with previous data for the region [*Golynsky et al.*, 2002], and exploit a geophysical analogy with southern and Baja California, to propose a new tectonic model for crustal accretion along this part of the paleo-Pacific margin of Gondwana.

2. Geological Framework

[4] The Pacific margin of Gondwana forming the Antarctic Peninsula was a Mesozoic subduction complex [*Storey and Garrett*, 1985]. Geochronological data suggest that the magmatic arcs may be underlain by largely unexposed Paleozoic basement of Gondwana affinity, and this may argue against the presence of exotic terranes [*Tangeman et al.*, 1996]. In contrast, structural data support the occurrence of Mesozoic terrane accretion processes [*Vaughan and Storey*, 2000]. Accretionary complex rocks of the Western Domain (WD) and magmatic arc rocks of the Central Domain (CD) may have docked against the para-authochtonous Eastern Domain (ED) (Figure 1), causing the Palmer Land orogenic event [*Vaughan et al.*, 2002]. This model envisages the Eastern Palmer Land shear zone as a suture zone between the CD and the ED. Mesozoic volcanic and sedimentary rocks of the ED were deformed by east-directed thrusting along the shear zone [*Vaughan and Storey*, 2000]. Mylonitized mafic rocks along the shear zone are related to mid-Cretaceous terrane docking [*Vaughan et al.*, 2002].

[5] The CD hosts most of the Antarctic Peninsula batholith, dominated by Early Cretaceous plutons and Mesozoic calc-alkaline lavas [*Leat et al.*, 1995]. Early Cretaceous adakitic plutons, ranging from gabbro to leucogranite, intruded into Triassic–Jurassic gneiss and plutonic rocks [*Wareham et al.*, 1997]. The WD includes a Lower Jurassic to Early Cretaceous subduction-accretion complex and Upper Jurassic fore-arc basin sediments [*Macdonald et al.*, 1999].

3. Aerogeophysical Survey and Data Processing

[6] Over 20,000 km of new aeromagnetic and aerogravity data were acquired over Palmer Land during the 2002–2003 Antarctic campaign. Profile lines were oriented E-W with N-S tie lines. Line spacing was 5 km, tie lines were 25 km apart and nominal flight altitude was 2800 m. Aeromagnetic processing included magnetic compensation,

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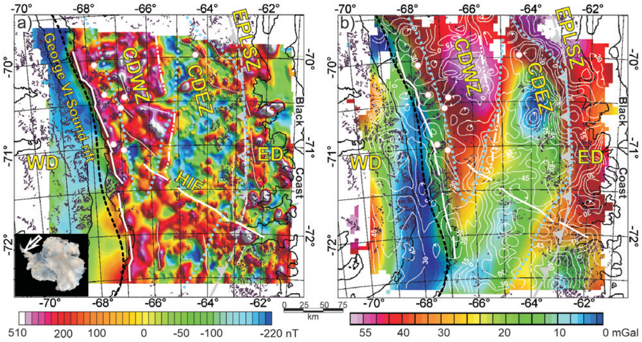

Figure 1. (a) Aeromagnetic anomaly map over Palmer Land. White lines, magnetic lineaments; dash-dotted line, magnetic boundary between the western and eastern zones of the Central Domain; dotted blue lines, major gravity gradients; dashed black line, previously inferred fault separating the WD from the CD; dashed grey line, Eastern shear zone; black outlines, outcrops; white circles, basement rocks. (b) Airborne gravity map. White contours, Bouguer anomaly values. The color grid displays low-pass filtered isostatic anomalies. Major magnetic lineaments and the magnetic boundary between western and eastern zone of the CD is shown for comparison. HIF, Hilton Inlet fault. Inset: arrow shows the Antarctic Peninsula.

IGRF removal, diurnal correction, and levelling. Mean cross-over errors after microlevelling were <1 nT. Aeromagnetic data were gridded (1 km cell size) and reduced to the pole (Figure 1a). Differential, carrier phase, kinematic GPS processing methods provided the vertical and horizontal accelerations, which dominate the raw aerogravity signal. Levelled airborne gravity data have mean accuracies of 3 mGal. The complete Bouguer gravity anomaly grid was obtained by calculating the 3D gravitational effect associated with the density contrast between the ice (900 kg m^{-3}) and air, and between the bedrock (2670 kg m^{-3}) and the ice. An isostatic residual gravity anomaly grid [*Jachens and Griscom*, 1985] separates the anomalies caused by intra-crustal density contrasts from the Bouguer anomalies that result from isostatic compensation of topography. The isostatic anomalies were low pass filtered to emphasize deeper sources (Figure 1b).

4. Aerogeophysical Signatures

[7] The new aeromagnetic and airborne gravity data image several previously unrecognized compositional and structural boundaries in Palmer Land. The WD features a magnetic low (Figure 1a), typical for accretionary complexes (e.g., Japan [*Finn*, 1994]). A Bouguer gravity high overlies western WD (Figure 1b). This is enhanced by the isostatic residual anomaly map, which reveals dense bodies correlated with partially exposed accreted basalts of seafloor or ocean-island affinity [*Doubleday et al.*, 1994]. A magnetic low overlies the sedimentary sequences of the fore-arc basin of the WD [*Macdonald et al.*, 1999], and the linear magnetic and gravity low over George VI Sound delineates a rift [*Bell and King*, 1998] which exploited the fault separating the fore-arc from the arc.

[8] Our images suggest that the CD is not a single microcontinental arc, as previously defined [*Vaughan and Storey*, 2000]. Instead, we redefine the CD as a composite magmatic arc terrane, comprising two distinct geophysical zones; the western zone (CDWZ) and the eastern zone (CDEZ). The CDWZ features a long-wavelength positive magnetic anomaly, with super-imposed mostly short-wavelength positive magnetic anomalies. The CDEZ is a broad magnetic low punctuated with similar, but lower amplitude, short-wavelength anomalies. Anomaly peaks within the CDWZ overlie Early Cretaceous tonalite, granodiorite and gabbro [*Vaughan et al.*, 1998]. The long-wavelength positive magnetic anomaly is part of the Pacific Margin Anomaly (PMA) (Figure 2a). The source of this anomaly has been modeled as a 20 km thick magnetite-rich magmatic arc batholith [*Garrett*, 1990; *Johnson*, 1999]. The isostatic residual map over Palmer Land (Figure 1b) requires a mafic bulk composition for the western batholith, in contrast to the more felsic eastern batholith. A mafic bulk composition for the PMA has also been inferred from sparser land-gravity data further north over Graham Land [*Garrett*, 1990]. An S-shaped, >1500 km long magnetic boundary, separates western and eastern Antarctic Peninsula batholiths (Figure 2a).

[9] High-amplitude magnetic and gravity anomalies over the ED image Jurassic(?) gabbroic intrusions emplaced along the Weddell Sea Coast [*Maslanyj et al.*, 1991; *Wever and Storey*, 1992]. These intrusions appear to be truncated along the Eastern shear zone, which is marked by a sharp linear gravity gradient (Figure 1b). In contrast, the aeromagnetic signature of the shear zone is subtler. This may reflect the existence of several fault strands within a broad shear zone and demagnetization processes within the associated mafic mylonites. A prominent aeromagnetic lineament, we name the Hilton Inlet fault, trends oblique to the shear zone. It is parallel (Figure 2a) to transverse faults previously imaged over the transition zone between Palmer Land and Graham Land and north of the Orville Coast block [*Johnson*, 1999; *Golynsky et al.*, 2002].

5. Comparison With Southern and Baja California and Tectonic Model

[10] The boundary between the CDWZ and the CDEZ, and its >1500 continuation, may mark a fundamental boundary within the Gondwana margin. It is akin to the suture zone separating the western and eastern zones of the Mesozoic Peninsular Ranges batholith in southern and Baja California (Figure 2b). The major lithospheric boundary separating the western from eastern zones of this batholith is revealed by geologic, petrologic, isotopic and geophysical evidence [*Johnson et al.*, 1999]. Magnetite-bearing plutons dominate the western zone, in contrast to ilmenite-rich intrusions in the eastern zone [*Langenheim and Jachens*, 2003]. The isostatic residual gravity patterns over the Antarctic Peninsula also match those over California [*Jachens and Griscom*, 1985]. The contrasts between the eastern and western belts of the Peninsular Ranges batholith may reflect either accretion of an exotic oceanic arc terrane to the continental margin underlying its eastern part [*Johnson et al.*, 1999], or mid-Cretaceous suturing between a fringing arc and North America by back-arc basin closure [*Busby et al.*, 2004].

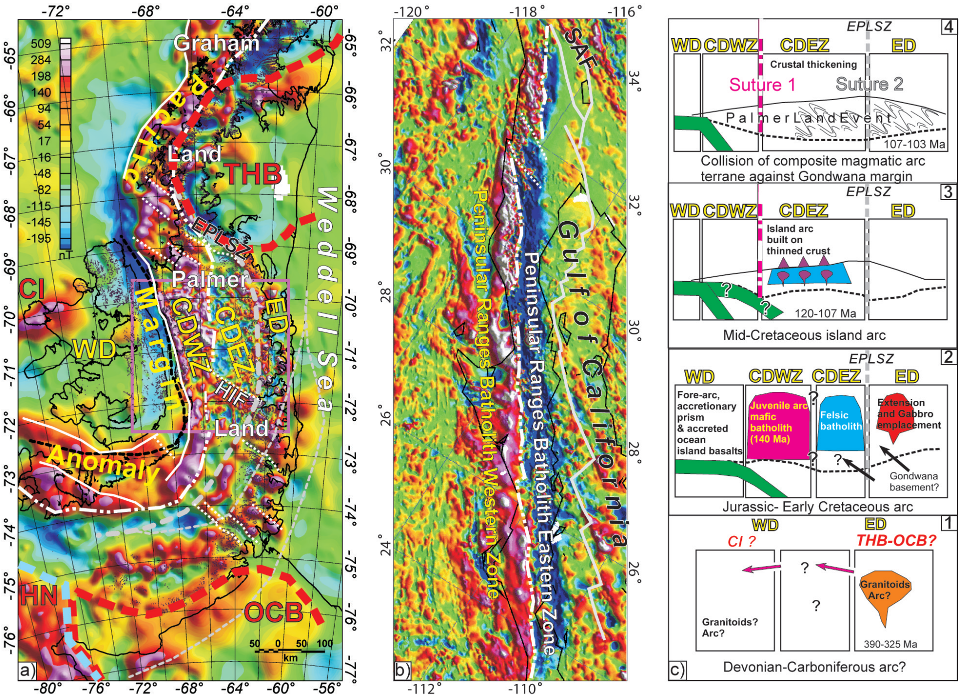

Figure 2. (a) Aeromagnetic anomaly map for the Antarctic Peninsula obtained by combining the new (rectangle) and previous aeromagnetic data. The boundary between the CDWZ and the CDEZ (dash-dotted line) appears to merge with the EPLSZ along the eastern edge of the Target Hill block (THB) and to form part of a >1500 km long zone. Other basement blocks: CI, Charcot Island; OCB, Orville Coast block; HN, Haag Nunataks. HIF as in Figure 1. (b) Aeromagnetic anomaly map over southern and Baja California at the same scale, showing a similar distinction between a western and eastern zone of the magmatic arc, separated by a major suture zone. The EPLSZ may be akin to the San Andreas Fault (SAF). (c) Crustal accretion stages of the Antarctic Peninsula that may account for the airborne geophysical signatures and available geological constraints.

[11] We use this geophysical analogy with southern and Baja California, and independent geochronogical and geochemical constraints, to propose the following tectonic model for the Antarctic Peninsula (Figure 2c). Remnants of a Devonian-Carboniferous arc (stage 1) underlie part of the ED, as indicated by aeromagnetic signatures over the Target Hill block [*Johnson*, 1999]. However, over Palmer Land, airborne geophysical signatures reflect mainly the development of a Jurassic to Early Cretaceous arc (stage 2). Crustal extension within the ED led to voluminous emplacement of highly magnetic and dense gabbros, perhaps in a oblique-slip margin akin to the present Gulf of California. A magnetite-rich batholith was emplaced syn-extensionally in the CDWZ at about 140 Ma [*Vaughan et al.*, 1998]. The Early Cretaceous adakitic rocks of the CDWZ resemble mantle-derived magmas of oceanic island arcs, although some pre-existing continental crust crops out (Figure 1) and was involved in magma generation [*Wareham et al.*, 1997]. Mafic underplating could be the source of the long-wavelength isostatic anomaly. The ilmenite-rich and more felsic batholith of the CDEZ developed further away from the trench, on thicker metasedimentary crust of the Gondwana margin, as suggested for the ilmenite-rich western Peninsular Ranges batholith [*Gastil et al.*, 1990]. At 120-107 Ma tholeiitic dykes were emplaced in the CDEZ indicating island arc magmatism on thinned CDEZ crust (stage 3). Tonalitic/granodioritic plutons of this arc cause the short wavelength magnetic anomalies over the CDEZ. The origin of the arc inboard of the CDWZ is enigmatic. Inboard migration of the arc axis may relate to a second subduction zone beneath the CDEZ, or to a decrease in the dip of the slab which originated the CDWZ arc (see *Johnson et al.* [1999] and *Busby* [2004] for similar models for Baja California). Final suturing of the two arcs against the Gondwana margin (stage 4) caused the Palmer Land event and likely led to crustal thickening and deformation of the margin at about 107–103 Ma [*Vaughan et al.*, 2002].

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