Tectonic evolution of Marie Byrd Land, Antarctica: Mesozoic breakup and Cenozoic kinematic history

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Summary

Marie Byrd Land records a history of early middle Paleozoic and Mesozoic convergence along a segment of the Gondwana margin. The region shared a common tectonic history with New Zealand that culminated in granite plutonism and exhumation of mid-crustal rocks during Cretaceous rifting between the two provinces. Separation between Marie Byrd Land and New Zealand-Campbell Plateau was induced by encroachment of the Phoenix-Pacific spreading center upon the convergent margin.

Present-day Marie Byrd Land thus represents a region of thinned crust that supports significant topography. The Ford Ranges form the eastern shoulder of the Ross Sea, and elevations increase to >3000m in central Marie Byrd Land. Cenozoic faulting, Oligocene to Quaternary volcanism, and Miocene to Recent glaciation formed the modern tectonic landscape.

Introduction

The Ford Ranges and the central Marie Byrd Land volcanic province are dynamic Cenozoic features developed upon a Paleozoic-Mesozoic terrane. Marie Byrd Land represents a portion of the proto-Pacific convergent margin of Gondwana (Fig. 1), and today forms the largest terrane within West Antarctica, along the southern margin of the Pacific Ocean.

Geological history and tectonic relationships

Marie Byrd Land consists of two tectonic provinces, each with a differing geological history (Pankhurst *et al.* 1998; Bradshaw *et al.* 1997). The Ford Ranges of western Marie Byrd Land characterize the geological relationships of one province, with close ties to western New Zealand, northern Victoria Land (Antarctica), and Australia. The other province corresponds with the eastern coastal belt of Marie Byrd Land. It shares a history of continental arc magmatism with New Zealand's Median Tectonic Zone (central South Island), with further links to Thurston Island terrane and the Antarctic Peninsula (Antarctica). These regions formed an complex, long-standing convergent margin along the Gondwana supercontinent (Fig. 2).

Although the number of rock units is few, the Ford Ranges present the most complete geological record for Paleozoic events in western Marie Byrd Land. In that region, low-grade, immature metasediments of the Swanson Formation were intruded by Devonian-Carboniferous Ford Granodiorite. Of probable Cambrian age, Swanson Formation contains detrital zircons of ~500 Ma (U-Pb SHRIMP analyses; Pankhurst *et al.* 1998; Ireland *et al.* 1994], derived from the Ross Orogen of the Transantarctic Mountains. Ford Granodiorite (I-type) in the Ford Ranges has a U-Pb SHRIMP zircon age of 375±5 Ma and was emplaced during a short pulse of arc magmatism (Pankhurst *et al.* 1998). A second event of I-type magmatism at ~338 Ma is also recorded in western Marie Byrd Land. Granitic plutonism at ~105-100 Ma, with emplacement of Byrd Coast Granite, was a precursor to fragmentation of the continental margin.

The quartzose turbidites of the Swanson Formation have been correlated with the Greenland Group in Western Province of New Zealand (Adams 1986) and the Ford Granodiorites have correlatives in the Karamea Batholith (375±5 Ma) and small S-type bodies of *circa* 330 Ma. In central and eastern Marie Byrd Land, however, early Paleozoic sedimentary and plutonic rocks related to those units are missing. Rather, Ordovician-Silurian arc-related intrusions exist, along with some small, widely separated granodiorite-diorite intrusions of Permian-Triassic age (Pankhurst *et al.* 1998). By Jurassic and Cretaceous time, a continental margin arc developed along the contiguous New Zealand/Marie Byrd Land landmass (Fig. 3). Taken as a whole, eastern Marie Byrd Land has significant ties with New Zealand's Median Tectonic Zone (Bradshaw 1993), and together they record ongoing arc magmatism on the dynamic continental margin of Gondwana (Bradshaw *et al.* 1997), as

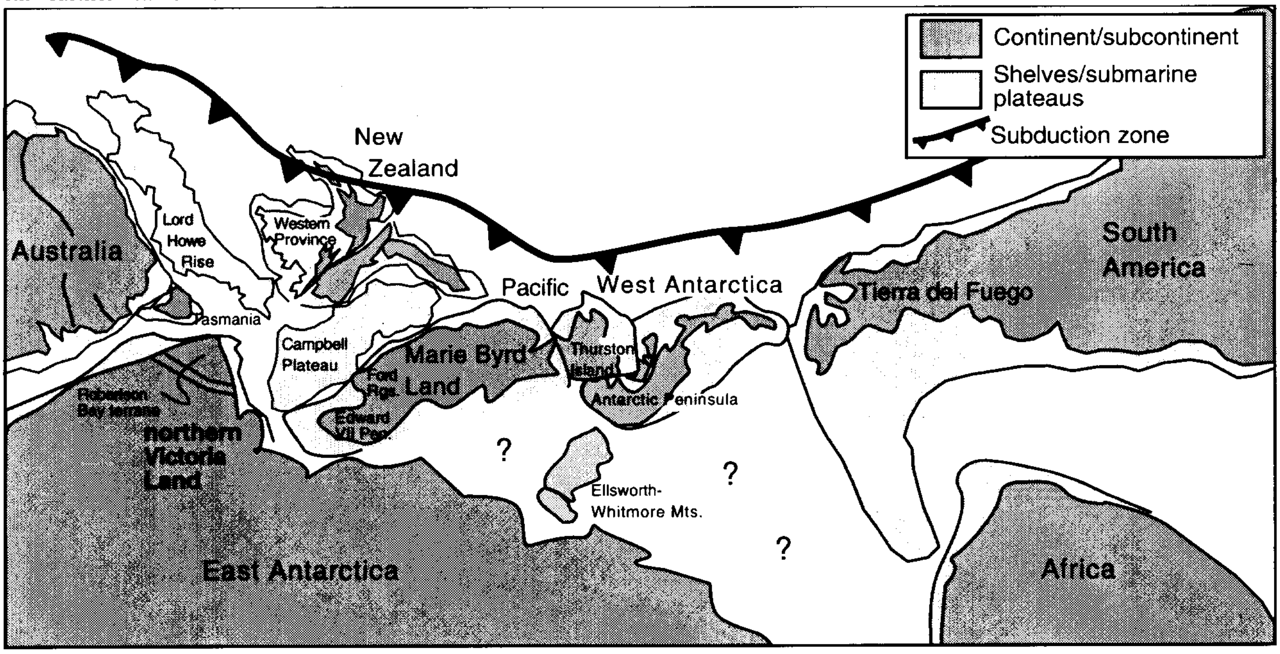

Figure 1. Convergent margin of Gondwana, illustrating the proximity of Marie Byrd Land to New Zealand. The convergent margin is portrayed schematically as a simple subduction zone but the zone was complex, with volcanic arcs, marginal basins, and marginal plateaus. As a result, an intermittent record of magmatism may characterize an individual area, but the duration of the convergent margin is clear when the region is viewed as a whole. For a detail of the Paleozoic configuration, please see Figure 2.

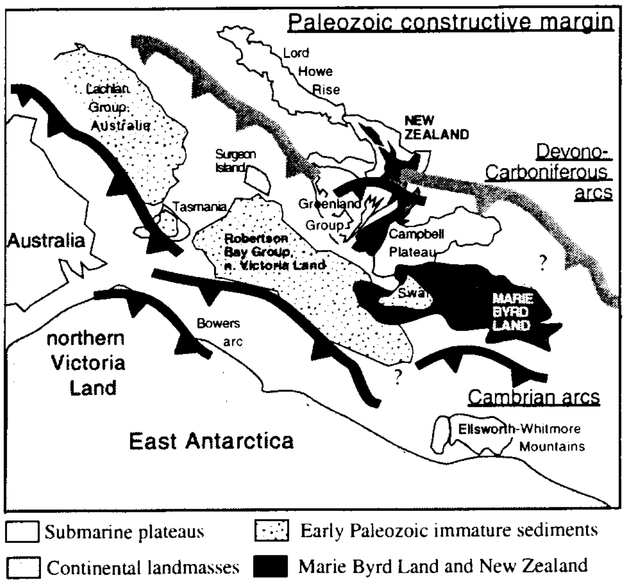

Figure 2. Hypothetical configuration of fringing terranes, arc segments, subduction zones and spreading ridges in Devono-Carboniferous time. Subduction beneath Gondwana continued intermittently throughout Paleozoic and Mesozoic time. Major Paleozoic events were recorded in: 1) the Ross Orogeny and Granite Harbour Intrusives (Cambrian), represented in the diagram by convergent margin segments (heavy, black lines); and 2) the Admiralty Intrusives/Ford Granodiorite associated with Devono-Carboniferous magmatic arcs (grey symbols). The stipple pattern represents argillaceous and turbiditic sediments shed off the Ross Orogen in extensive outboard basins. They include the Swanson, Greenland, Lachlan, and Robertson Bay Groups.

illustrated in Fig. 3.

Cretaceous events

Encroachment of the Phoenix-Pacific spreading center upon the convergent margin (Figs. 3, 4d) brought the demise of the long-standing constructive plate boundary, in late Early Cretaceous time (Stock and Cande 1999; Luyendyk 1995). Granitic magmatism occurred in a tensional environment in western and central Marie Byrd Land; calc-alkaline to alkalic granitoids, with lesser tholeiites, were emplaced (Weaver *et al.* 1994). In the Ford Ranges of western MBL, the tectonic evolution was rapid between 105-90 Ma, based on $^{40}Ar/^{39}Ar$ mineral ages of migmatitic and mylonitic gneisses. Upper amphibolite-grade metamorphic rocks were exhumed from the middle crust and cooled rapidly. High heat flow, attributable to mafic underplating, induced anatectic melting and reduced crustal strength, leading to flattening deformation and regional collapse. Initial stages of opening involved NNE-WSW to NE-SW extension. As deformation continued, Ross Sea opening began and a triaxial strain field may have been in effect. In New Zealand at this time, granitic plutons were emplaced and metamorphic core complexes developed. The plutonism,

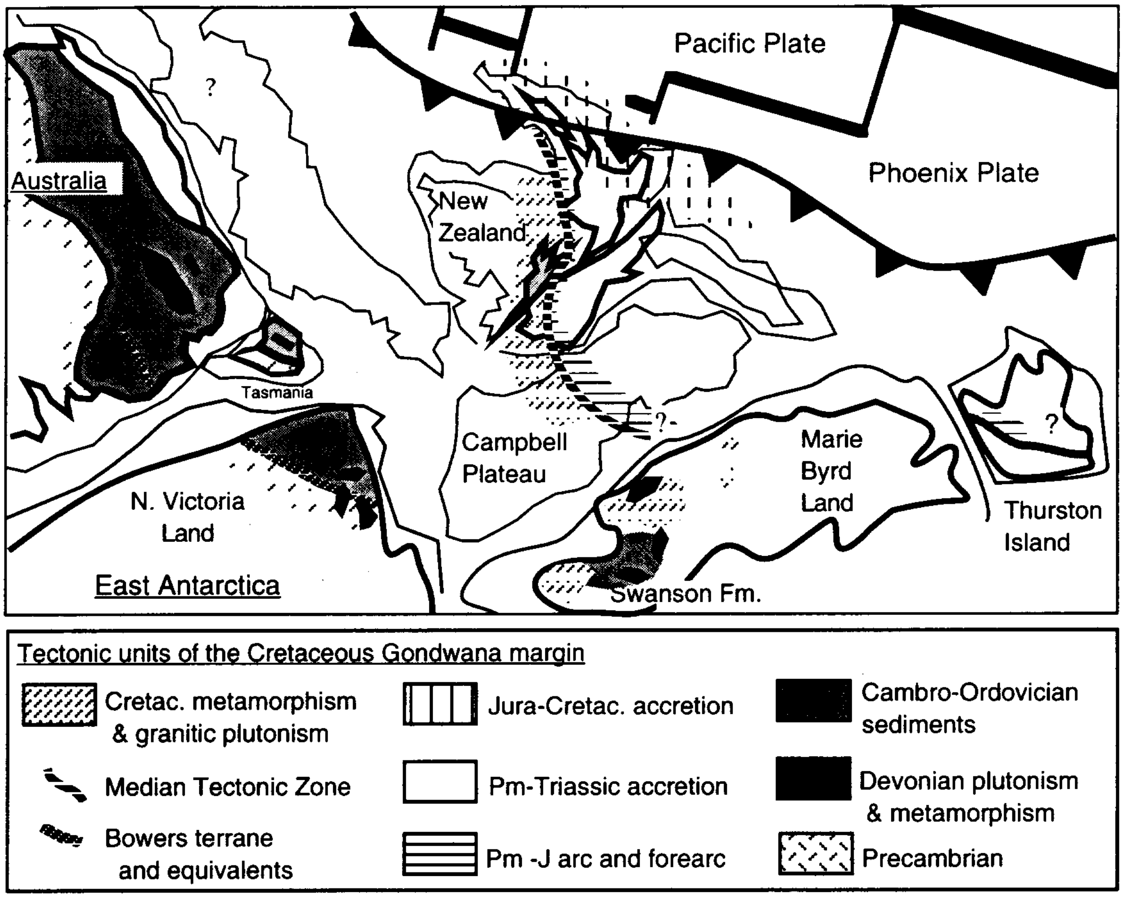

Figure 3. Geological correlations among terranes of the Gondwana margin (Thurston Island, Marie Byrd Land, New Zealand, northern Victoria Land, Tasmania and Australia). Cretaceous ties are strong for the conjugate margins of New Zealand/Campbell Plateau and Marie Byrd Land/Thurston Island prior to separation. Paleozoic elements are present in all the terranes except Thurston Island. Cross-hatched area is extended crust. Figure is compiled from Bradshaw 1989; Bradshaw *et al.* 1993, 1997.

high grade metamorphism, and mylonitic shear zones were precursors to rifting between Marie Byrd Land and New Zealand (Fig. 4a).

Kinematic studies in the Ford Ranges, and Cenozoic tectonic setting

The Ford Ranges form the eastern margin of the Ross Sea in Marie Byrd Land, and represent significant high topography in the thinned crust. Evidence of Neogene tectonic activity includes NW- to E-W-trending basin-and-range-style mountains in the Ford Ranges; regional satellite lineaments; and 1.4 Ma basalts cut by faults. Large-scale structures are concealed by glacier ice; however, kinematic analysis of mesoscopic fault arrays is now being conducted to determine the strain history of the region. Findings to date suggest a four-phase tectonic evolution in Late Cretaceous and Cenozoic time time (Fig. 4), beginning with the breakup of the convergent margin, at 105-84 Ma.

I. The NW- to W- structural grain was established during initial Ross Sea opening and New Zealand--MBL rifting (Fig. 4a). Lateral flow in the middle crust was compensated by brittle faulting in the upper crust during NNE-SSW extension.

II. A pulse of brittle fault activity caused minor block faulting and mountain uplift at 85-70 Ma (Fig. 4b). The interpretation is based on a diffuse apatite fission track pattern that indicates renewed denudation and cooling from 85-70 Ma (Richard *et al.* 1994; Lisker and Olesch 1998). Minor fault arrays record an event of NE-SW to E-W stretching, possibly related to a plate reorganization following capture of the Bellinghausen tectonic plate by the Antarctic plate at this time (Stock and Cande 1999). The Bellingshausen plate was a remnant of the Phoenix oceanic crust that persisted as an independent microplate adjacent to Marie Byrd Land from ~100 Ma to 84 Ma before integration into the Antarctic tectonic plate.

III. Uplift of the Transantarctic Mountains initiated at 55-60 Ma (Fitzgerald 1992). In Marie Byrd Land, NW-oriented faults saw renewed, limited activity during Cenozoic time, to allow minor NE-SW opening at this time (Fig. 4c). NE-striking faults were reactivated in sinistral strike slip.

IV. From 30-18 Ma, and continuing to the present time, the Ross Sea rift developed and the Marie Byrd Land Volcanic Province formed (Fig. 4d; LeMasurier and Rex, 1989). Oligocene to Quaternary alkaline volcanism produced the eighteen large volcanoes in central Marie Byrd Land.

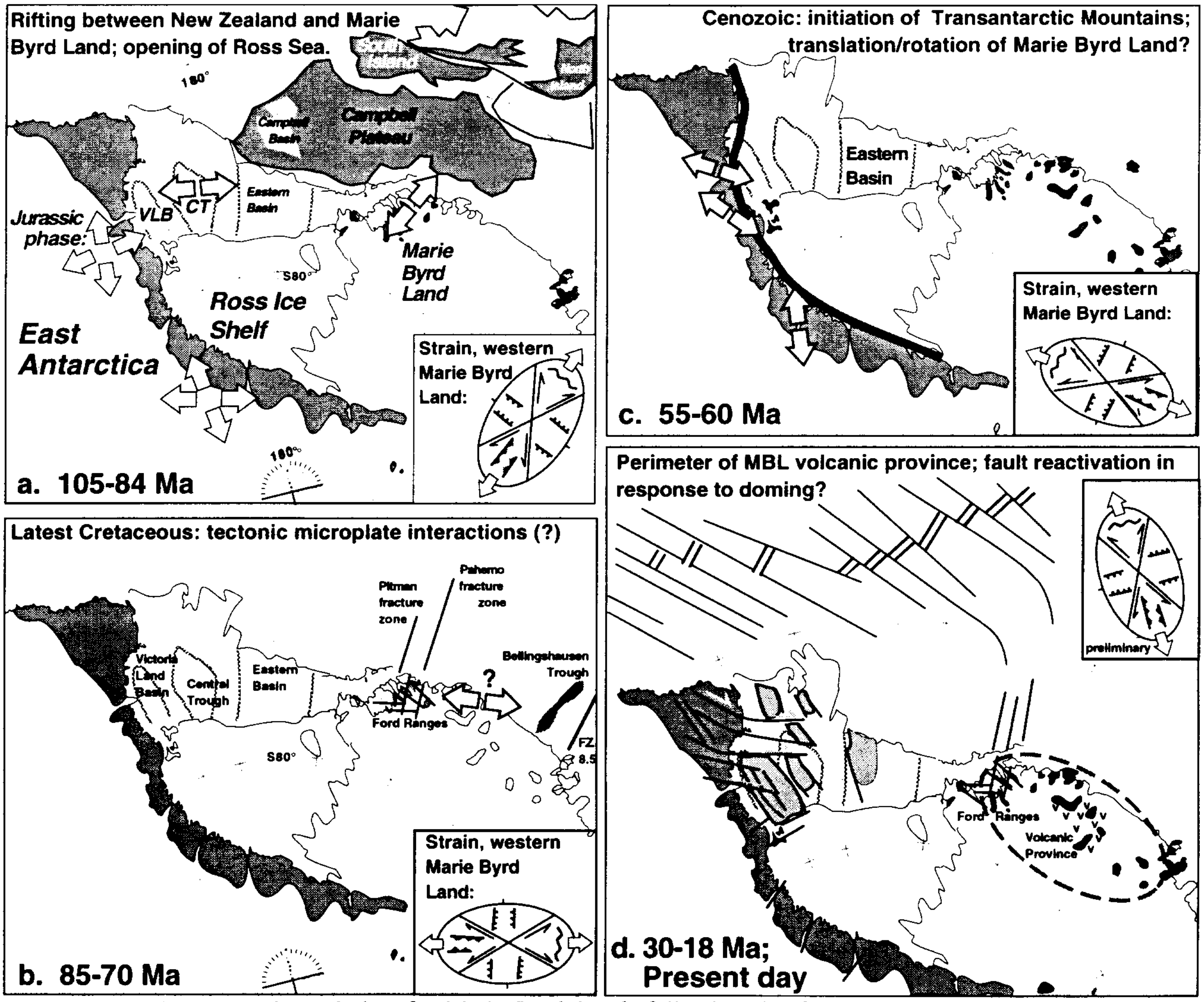

Figure 4. Four phase tectonic evolution for Marie Byrd Land, following the Cretaceous extensional episode (a) that caused Ross Sea opening and rifting of New Zealand-Campbell Plateau away from the Antarctic margin. Dynamic influences on Cenozoic tectonics include plate reorganization (b), uplift of the Transantarctic Mountains(c), and development of the modern West Antarctic Rift System and central Marie Byrd Land volcanic province (d).

Explosive eruptions have occurred in Late Quaternary time (Wilch *et al.* 1999). NE, NW, and W fault arrays were reactivated in the Ford Ranges. The onset of Antarctic glaciation caused interaction between outlet glaciers and regional structures at low ice levels; however, structural relief was insufficient to interrupt generally northerly flow of the West Antarctic ice sheet during maximum ice conditions. North-south faults developed, with W-side-down faults; these are expressed in ice surface topography.

Conclusions

Cenozoic tectonic activity in Marie Byrd Land relates to development of the Ross Sea Rift, with subsidence in the Eastern Basin during Miocene time. Faulting may be a peripheral response to doming in the central Marie Byrd Land volcanic province. Normal faulting on NNW to NNE faults dominates the regional structural pattern at present. Ongoing research seeks to determine the detailed Cenozoic history of western Marie Byrd Land, and to understand the context for development of fault-block mountains that channel outlet glacier flow. An aerogeophysical survey was recently completed over the Ford Ranges, and the new data promise to reveal the crustal-scale structural pattern. The Ford Ranges form the eastern Ross Sea margin, and are of interest because they represent significant topography in an area of crust thinned during Cretaceous rifting between Marie Byrd Land, New Zealand, and East Antarctica.

Acknowledgments

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