Mesozoic to Tertiary Evolution of the Antarctic Peninsula Magmatic Arc.

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Summary

The Antarctic Peninsula magmatic arc is built, at least in part, on continental crust with a record of magmatism and metamorphism, that stretches back at least to Cambrian times. Knowledge of its history is being revised and extended with the application of U-Pb zircon geochronology, and it can now be interpreted as the product of several distinct episodes of magma generation that changed with the prevailing tectonics of Gondwana break-up and dispersal. The early stages of Mesozoic plutonism consist of Permo-Triassic (c. 260-225 Ma) S-type granites and migmatites, generated by anatexis of the middle/upper crust. Metaluminous granitoids appear at ca. 205 Ma. Subsequent Jurassic magmatism is widespread: volcanic rocks and sub-volcanic granites occur throughout the eastern and southern parts of the peninsula. This activity, which migrated westwards from 185 to 155 Ma, represents lower/middle crustal melting in response to the rifting and initial break-up of the Pacific margin of Gondwana, apparently under the thermal influence of the Karroo mantle plume. The main phase of subduction-related magmatism followed, from Early Cretaceous to Palaeocene times (140-55 Ma), and resulted in construction of the Antarctic Peninsula batholith along the western side of the peninsula. This mainly corresponds in time to the Andean active margin batholith of Patagonia, but in the northern Antarctic Peninsula there is a significant westward shift in the locus of the batholith with time. Subduction-related magmatism ceased during the Palaeogene, as sea floor became welded to the Antarctic plate. Restricted intra-plate volcanism has occurred since the Late Neogene.

Introduction

The Antarctic Peninsula occupied a central position in the pre-break-up Pacific margin of Gondwana. Although its exact position relative to that of Patagonia, and the relationship of both to cratonic South America, remain disputable (e.g. Miller 1983; Ramos 1984), both are now known to have an Eocambrian–Palaeozoic continental history. Similarly, both are dominated geologically by the effects of Mesozoic-Cenozoic subduction, which resulted in the formation of calc-alkaline coastal batholiths and associated volcanic rocks. In the Antarctic Peninsula, the batholith occupies much of the narrow (ca. 100 km) geographical outcrop area. This paper summarizes the present state of knowledge of the magmatic history of the Antarctic Peninsula, before, during and after batholith emplacement.

The Magmatism of Pre-Break Up Gondwana

Significant refinements have been made in recent years to our understanding of the continental host rocks of the Antarctic Peninsula batholith, most of which are igneous or had an immediate igneous protolith. The basement is only sparsely exposed: it is recognized both from these few outcrops and also as an identifiable crustal signature in later granites. The oldest basement rocks so far characterized by U-Pb zircon studies are ca. 500 Ma orthogneisses with 1000-Ma and older inheritance, from a small outcrop area in eastern Graham Land (Millar, Pankhurst and Fanning, in preparation). Paragneisses associated with orthogneiss in other areas could represent an even older country rock, but show the same general patterns of zircon inheritance as the orthogneisses. A few small granite bodies dated at ca. 400 Ma (Devonian) were intruded into this basement but are more widely evidenced by clasts in conglomerates (Pankhurst 1983; Loske and Miller 1991; Tangeman and Mukasa 1996). At least some parts of the basement underwent metamorphism, partial melting, migmatization and minor granite emplacement in Carboniferous, Permian and Early Triassic times (ca. 325, ca. 260 and ca. 240 Ma, the Permian event being based on revision of a previous Triassic Rb-Sr age). There is little evidence for the tectonic significance of these events.

The first major magmatic episode was Late Triassic to earliest Jurassic in age (230-200 Ma), and was most widely developed in the southern Antarctic Peninsula (Palmer Land). The early phase is almost entirely anatectic (S-type) granite magmatism (Wever et al. 1994), and is at least roughly coincident with migmatitic injection of the older basement gneisses. By 205 Ma, metaluminous I-type granitoids were also being generated and previous authors have usually suggested that the subduction-related plutonism of the Antarctic Peninsula batholith commenced in Triassic times (Pankhurst 1982; Leat et al. 1995). This idea was also influenced by the presence of a Triassic (and younger) turbidite series along the western margin of the northern Antarctic Peninsula – the Trinity Peninsula Group and its correlatives, regarded as an accretionary complex related to active subduction. However, most of the granites of the Triassic episode are not of typical 'Andean' calc-alkaline type, and the whole of this episode is separated in time from the main phase of batholith construction by the Jurassic rifting event (below). For these reasons, we prefer to consider the former as a discrete magmatic stage developed on the margin of Gondwana and only loosely connected to the evolution of the 'Andean' batholith.

Gondwana Rifting Magmatism

The Jurassic period was a time of catastrophic tectonism and disruption of the Pacific margin of Gondwana. Whether the crustal blocks of the West Antarctica region had been a fully integral part of this margin since Neoproterozoic times, or had existed as loosely associated microplates or terranes, this was the time when they began to behave and move independently of each other. The Falkland Islands microplate rotated through 180° away from a position east of the tip of South Africa soon after 193 Ma (Mussett and Taylor 1994), and the Antarctic Peninsula rotated clockwise as it moved away from East Antarctica between ca. 175 and 155 Ma (Grunow 1993). The forces responsible for these plate motions have not been uniquely identified, but the extraordinary amount of within-plate basalt erupted throughout the continental interior in Jurassic times suggests a causal connection with the rise of the Karroo mantle plume.

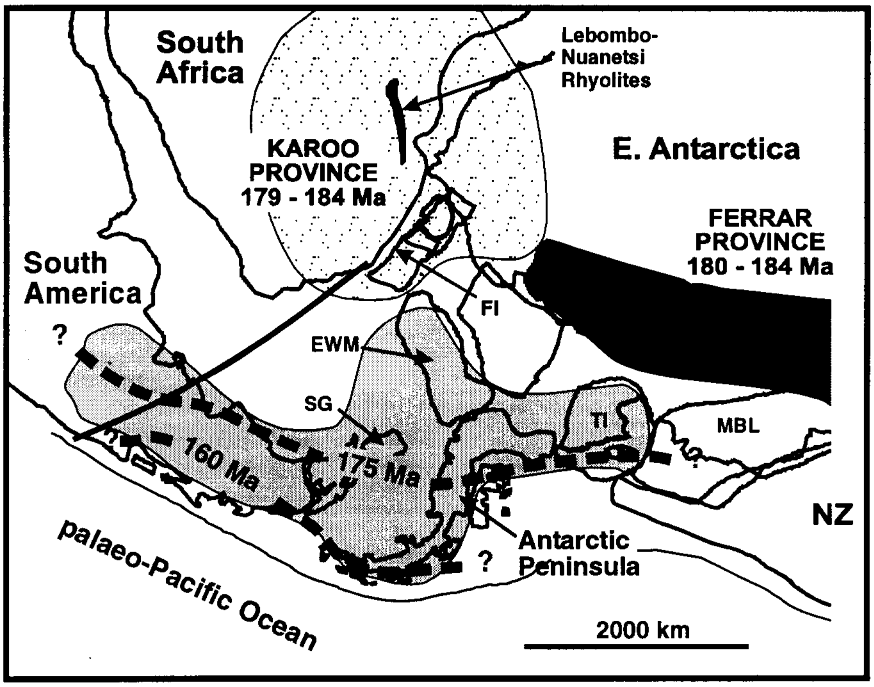

Figure 1: Distribution of Jurassic 'break-up' magmatism in southwestern Gondwana. The area of the Jurassic rhyolite-ignimbrite province of West Antarctica and Patagonia is shaded. The age contours show the progressive spread of silicic volcanism from near the Karroo plume head towards the proto-Pacific margin throughout Jurassic times (from Pankhurst et al. in press).
FI= Falkland Islands, SG= South Georgia, EWM= Ellsworth-Whitmore Mountains, TI= Thurston Island, MBL= Marie Byrd Land.

Break-up magmatism in the Antarctic Peninsula is represented by extensive silicic volcanism, rhyolitic ignimbrite being the most abundant rock type. This volcanic activity is contemporaneous with and compositionally very similar to the Jurassic ignimbrite eruption in Patagonia: altogether this silicic province covers a vast area, probably including much of the submerged Falkland Plateau and other parts of West Antarctica. Precise Ar-Ar geochronology (Feraud et al. 1999) has confirmed the regular migration of silicic volcanism westwards in Patagonia from earliest to latest Jurassic time. A new zircon U-Pb study of the entire province (Pankhurst et al. in press) details the spread of activity away from the continental interior (which included southern Palmer Land), where it began at ca. 188 Ma, reaching the western margin by 154 Ma (Fig. 1). Thus the geographical pattern with time suggests the spreading plume head as a major heat source, as well perhaps as the driving force for plate motion. In the Antarctic Peninsula, subvolcanic plutons related to this rifting episode were also previously ascribed to early growth of the Antarctic Peninsula batholith (e.g. Groups III and IV of Hole et al. 1991a). We now consider that all this Jurassic magmatism should be treated as a separate tectono-magmatic episode, entirely preceding opening of the South Atlantic Ocean and consequent development of the Andean subduction-related margin.

Typical initial $^{87}Sr/^{86}Sr$ ratios for the break-up magmatism are 0.705-0.710; εNdt values are mostly ca. −2 to −5, although the total range is 0 to −9. The data form a sharply defined dog-leg in the εSr-εNd diagram (Fig. 2), which suggests two separate petrogenetic processes rather than a simple mix between 'mantle' and 'crustal' components. An almost identical array is shown by the Triassic granites, with the most primitive compositions being exhibited by the I-type rocks. We favour magma generation in both these episodes by melting of lower crustal material, with some further contamination by mixing with middle and upper crustal material (see Fig. 2).

The Cretaceous-Cenozoic Batholith

Although the Jurassic plutonism described above reached the northwest coast of the Antarctic Peninsula at ca. 154 Ma (even earlier in some areas), the first magmatism unequivocally associated with subduction of the Phoenix plate did not occur until about 140-145 Ma ago, i.e. earliest Cretaceous. This initial phase is best developed in north-western Palmer Land, but the most widespread and voluminous plutonism occurred throughout the Antarctic Peninsula in the interval 125-100 Ma (see Leat et al. 1995 Fig. 3d). In fact, the true peak of emplacement may be even shorter than this – some granites previously dated at ca. 110 Ma have recently given U-Pb zircon ages of ca. 125 Ma. The granitoids of this stage are typically medium- to high-K calc-alkaline granodiorites and hornblende-biotite granites (Leat et al. 1995). Their initial Sr and Nd isotope compositions form a steep linear array in the εSr-εNd diagram which corresponds to the trend of the I-type Triassic granites (Trend 1 in Fig. 2). This implies generation in the lower crust, but with significantly more isotopically primitive material than the earlier plutonic rocks. Leat et al. (1995) suggested melting of 'meta-igneous' lower crust as the main process. It seems likely that this was of a rather mafic composition.

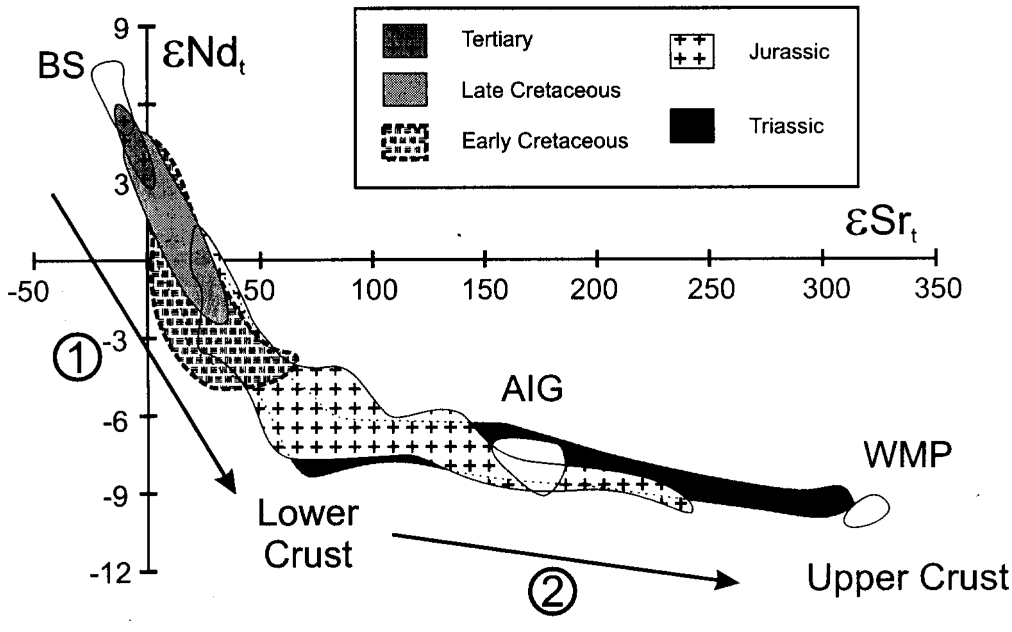

Figure 2. εSrt-εNdt plot for post-Permian plutonic igneous rocks from the Antarctic Peninsula, grouped according to age. The labelled fields are: BS: Bransfield Strait back-arc volcanic rocks (<4 Ma), AIG: Adie Inlet gneiss, WMP: Welch Mountains paragneiss. The latter two are representative of the pre-Carboniferous basement. The two trend lines shown are: 1 - mixing between primitive ('mantle') compositions and lower crust; 2 - mixing between lower crust and middle/upper crust (after Millar et al. in preparation).

Similar plutonism seems to have continued in the Late Cretaceous, but was geographically more restricted. This was also, according to limited K-Ar data, the period during which many mafic dykes were emplaced in the batholith.

The Tertiary part of the batholith is confined to the west coast of the northern Antarctic Peninsula, signifying a major westward jump in the locus of the arc. The most abundant plutonic rocks are Palaeocene (ca. 55-65 Ma) granodiorites and diorites, which extend all along the western coastline. They have even more isotopically primitive compositions than the Early Cretaceous plutons (Fig. 2), with initial $^{87}Sr/^{86}Sr$ ratios in the range 0.7035-0.7045. Although they fall on the same well-defined trend, they are largely in the depleted quadrant, which suggests the presence of much juvenile mantle material in their source region, which could be contemporaneous mafic underplate. There is no involvement of older basement and the arc may well have migrated outboard of the old continental crust by this stage (Pankhurst 1982).

The idea of progressive shut off of Antarctic Peninsula subduction-related magmatism, from 60 Ma in the south to ca. 4 Ma in the north, as successive segments of the Antarctic-Aluk spreading centre collided with the trench, is well established (Barker 1982). One of the final events was the back-arc opening of Bransfield Strait, a 100 km-wide marginal basin in the extreme north, which contains the high-alumina, sodic, calc-alkaline volcano of Deception Island.

Post-subduction Magmatism

Following the cessation of subduction, when the South Pacific and Antarctic plates became fused together, the only igneous activity has been magnesian and alkaline in nature. Relatively small volumes of olivine basalts, basanites and tephrites are known from a number of highly scattered localities throughout the Antarctic Peninsula, with one major centre off the northeast coast (James Ross Island). In age they vary from 10-15 Ma down to less than 1 Ma (many show evidence for eruption beneath ice cover), but only the James Ross Island centre was active throughout most of this period (see Smellie 1999 for summary). The volcanic rocks are isotopically very primitive (initial $^{87}Sr/^{86}Sr$ ratios 0.7028-0.7035) and originated in depleted asthenosphere (Hole et al. 1993). They have been ascribed to mantle upwelling through subduction-slab windows that developed after ridge-trench collision (Hole et al. 1991b).

Conclusions

The multi-stage magmatic history of the Antarctic Peninsula is clearly related to the varied tectonic evolution of southwestern Gondwana. Although the tectonic scenario of granite production in pre-Triassic times is not defined, individual phases of emplacement (Cambrian, Devonian, Carboniferous and Permian) are now reasonably well known. Large-scale anatexis occurred in Triassic times, possibly related to orogenic events (Storey et al. 1987), but the first clear evidence of subduction-related magmatism appeared by the end of this phase. The entire Jurassic period was one of regional rifting and disruption of the supercontinent, with extensional magmatism related to the influence of the Karroo plume. This merged into the Cretaceous-Palaeocene Andean regime, with calc-alkaline magmatism resulting from subduction of 'Pacific' ocean floor beneath the western continental edge. It is this Cretaceous-Palaeocene part of the batholith that corresponds with the well-known magnetic anomaly centred on the west coast of the Antarctic Peninsula (see Garrett 1990). As subduction ceased from Eocene times onwards, slab-windows formed in the previously subducted oceanic crust, resulting in minor alkaline basalt volcanism, although this changeover was prolonged and diachronous. Most of these stages are also recognizable in South America (see Pankhurst, this volume).

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