The Development of Andean Magmatism in SW Gondwana.

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Summary

The Andean magmatic belt is constructed on the old margin of Gondwana. Its initiation was intimately related to the break-up of that supercontinent. Here, the Andean plutonic phase only commenced after the effective disruption of a large area of immature continental crust, which had mostly been formed during Neoproterozoic and Early Palaeozoic times. The Jurassic rifting and dispersal of this region into smaller plates was associated with one of the most intense episodes of silicic volcanism in the geological record, as the thinned crust was melted by heat derived from the spreading Karroo plume-head. Subsequent to this cataclysmic break-up event, and contemporaneously with the opening of the Atlantic Ocean, the present Pacific Ocean subduction regime became established. This led to the growth of subduction-related batholiths of this region throughout Cretaceous and Tertiary times. Their structure and geochemistry record changes in the dynamics of the Pacific regime, only slightly moderated by the structural control of deep seated lineaments near the continental margin. The isotopic signatures of the magmas are increasingly dominated by more primitive compositions due to the more rapid cycling of underplated material.

Introduction

Patagonian South America, like the Antarctic Peninsula (Pankhurst and Millar this volume) has a well concealed ?Late Precambrian and Palaeozoic history that is only beginning to be revealed with the application of precise U-Pb geochronology. The idea of Patagonia as a Palaeozoic allochthonous terrane (Ramos 1984) is still not properly resolved. Nevertheless, it was clearly a major part of the SW margin of Gondwana at the start of the Mesozoic era, contiguous with the Antarctic Peninsula and the other microplates that now constitute West Antarctica. The post-Palaeozoic geological evolution of Patagonia, like that of the Antarctic Peninsula, was dominated by two major periods of evolved magmatism: the Jurassic ignimbrite flare-up associated with the rifting of Gondwana, and the Mesozoic-Cenozoic subduction-related magmatism that resulted in the formation of calc-alkaline coastal batholiths and subsequent basalt volcanism. Recent investigations have emphasized the clear separation in time of these events and their products.

Pre-Andean Magmatism of Patagonia

There is no reliable direct evidence for Precambrian magmatism in Patagonia. Cambrian orthogneisses are found, as in the Antarctic Peninsula (Varela et al. 1998; Millar, Pankhurst and Fanning, in preparation). Inherited zircons in both metasedimentary and younger volcanic rocks indicate the availability of 'Grenvillian' and older sources throughout the Palaeozoic. Both 500 Ma and ca. 1000 Ma rocks crop out immediately to the north of the North Patagonian Massif in La Pampa province (Tickyj et al. 1999) and diorite underlying the Magellanes basin in Tierra del Fuego has now been dated at 521 ± 4 Ma (Millar et al. in prep.). Small granite bodies intruded into the Patagonian basement have been dated at 476 ±4 Ma (Ordovician) in the North Patagonian Massif (Varela et al. 1998) and at ca. 410 Ma (Devonian) in the Deseado Massif, and are also present as clasts in conglomerate (Pankhurst and Rapela unpublished Rb-Sr data). Granitoid emplacement occurred in the North Patagonian Massif in Carboniferous and Permian times (c. 345, ca. 270-290 Ma, Basei et al. 1999; Varela et al. 1999). Triassic rhyolites crop out at Lihue Calel and Los Menucos (Rapela et al. 1996); these are the southernmost representatives of the Choyoi ignimbrite event of west-central Argentina. More widespread granite magmatism occurred in both massifs in earliest Jurassic times (c. 200 Ma, Basei et al. 1999; Rapela and Pankhurst 1996). Many of these events can also be recognized in the Antarctic Peninsula, which points to the coherence of the SW Gondwana margin up to this time.

The Jurassic period was a time of catastrophic tectonism and disruption of the Pacific margin of Gondwana. Break-up magmatism in Patagonia is represented by very extensive silicic volcanism, rhyolitic ignimbrite being the most abundant rock type. This silicic province covers a very wide area, including Patagonia, much of the submerged Falkland Plateau, the Antarctic Peninsula, and other parts of West Antarctica. Precise Ar-Ar geochronology (Feraud et al. 1999) has confirmed the regular migration of silicic volcanism westwards in central Patagonia from earliest to latest Jurassic time. A new zircon U-Pb study of the entire province (Pankhurst et al. in press) shows that activity reached three successive peaks of intensity, which record the spread of activity away from the continental interior towards the proto-Pacific margin. The first episode, V1 (178-188 Ma), was the eruption of the Marifil Formation of massive welded ignimbrites on the eastern side of the North Patagonian Massif. The second peak, V2 at 162-172 Ma, encompassed the Chon Aike Formation to the east of the Deseado Massif and parts of the Tobífera Formation in Tierra del Fuego. The final peak, V3 (152-157 Ma) is represented by rhyolites throughout the eastern Deseado Massif and into the Andes (El Quemado and Ibañez formations).

The intense silicic break-up magmatism was mostly generated by lower and middle crustal anatexis, in response to the spread of heat from the Karroo plume, together with crustal extension during the initial stages of supercontinent rifting.

The Andean Batholiths

The Patagonian batholith is one of the largest of the circum-Pacific batholiths, extending over 1600 km from about 40°S to Cape Horn. It is mostly composed of Mesozoic-Cenozoic calc-alkaline granitoids (gabbro to granite). There have been few systematic studies of the regional variations in composition and structure of the plutonic rocks. The area analysed in most detail is that part north of the Taitao Peninsula, centred on the Aysén region (Fig. 1). Here, the host rocks to the east of the batholith are a combination of the Jurassic volcanic sequences (above) and metasedimentary schists and phyllites (see Hervé this volume). To the west, another low-grade turbiditic metasedimentary series is

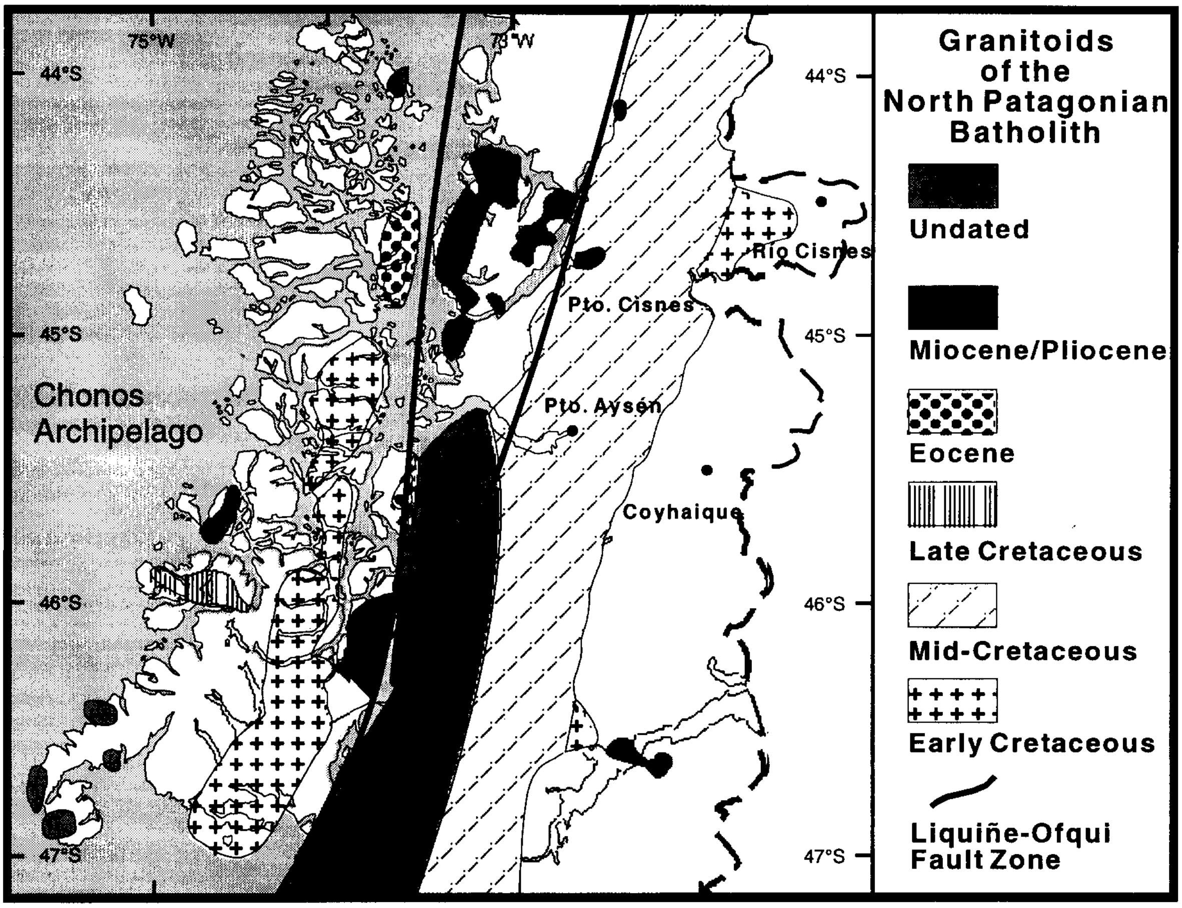

Figure 1. Chronological Zonation of the North Patagonian Batholith in the Aysén region, Southern Chile (after Pankhurst et al. 1999).

exposed in the Chonos Archipelago. Pankhurst et al. (1999) have elucidated the lithological and chronological zonation in this part of the North Patagonian Batholith first noted by Bartholomew and Tarney (1984). The main episodes of emplacement are Early Cretaceous (ca. 135 Ma), mid-Cretaceous (90-120 Ma), Eocene (c. 45 Ma) and Early Miocene to Pliocene (25–10 Ma). These pulses, at least since the Late Cretaceous, appear to be triggered by an increase in the orthogonal component of the subduction rate (Fig. 2). The rocks of these different episodes are disposed north-south belts, with the Cretaceous rocks in the east (the main Cordillera of the Andes) and west (the Chonos Archipelago). The Eocene-Early Miocene rocks were emplaced as smaller plutonic bodies in the central area, where a minor back-arc basin developed along the Liquiñe-Ofqui dextral strike-slip fault. The rise of magma was thus probably controlled by this deep-seated fault zone. The oldest known granites, in the easternmost portion of the batholith, are earliest Cretaceous in age (140-150 Ma) and small satellite plutons emplaced farther east in the country rocks (155 ± 10 Ma, Parada et al. 1997). Thus, in this area as well as in the Antarctic Peninsula (Pankhurst and Millar this volume), it seems that full-scale subduction related magmatism did not become established until after the cessation of rift-related Jurassic volcanism.

The southern part of the Patagonian Batholith is constructed on an even larger scale, with a maximum width of more than 100 km, but it its structural control is less well understood. Geochronological data summarised by Bruce et al. (1991) range from close to 150 Ma down to 13 Ma. The older limit has been confirmed by U-Pb zircon SHRIMP analyses (Hervé, Pankhurst and Fanning, unpublished data). The Late Cretaceous and Tertiary rocks occur in the axial parts of the studied sections, with the Early Cretaceous rocks on either side, although the zonation is not obviously related to lithological variation. This is also true of the southernmost area in Tierra del Fuego, where the axis of the batholith is almost east-west. Bruce et al. (1991) explained this crude zonation as due to 'magmatic inflation', in which the later magmas were intruded into already consolidated plutons along a fixed locus. The oldest rocks, at about 150 Ma (U-Pb on zircon, Bruce et al. 1991), are concentrated along the eastern margin of the batholith, as in the North Patagonian Batholith. The peraluminous Darwin granite suite, re-dated by Mukasa and Dalziel (1996) at 164.1 ± 1.7 Ma, is geochemically related to the Jurassic volcanism of the Tobífera Formation rather than to the calc-alkaline batholithic suite. Thus, as in the North Patagonian Batholith, the oldest calc-alkaline magmatism in the batholith is younger than the youngest U-Pb age for the Jurassic silicic volcanism (Pankhurst et al. in press).

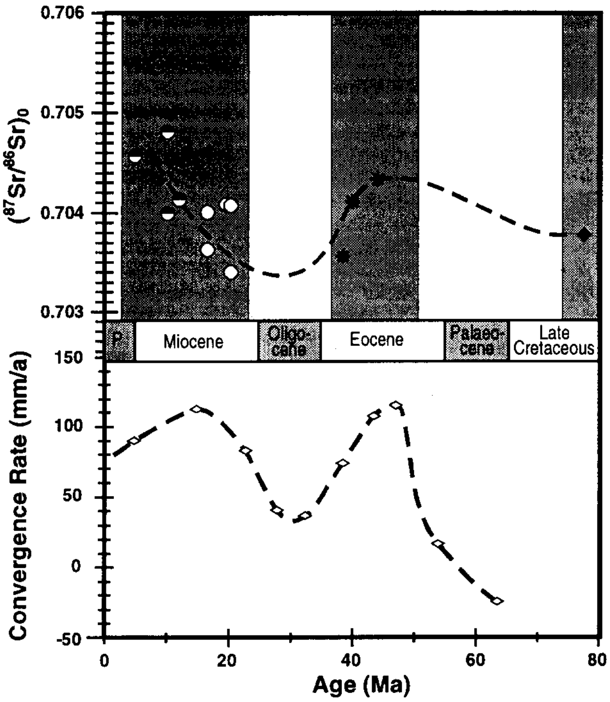

Figure 2. Plots of orthogonal subduction convergence rate and initial $^{87}Sr/^{86}Sr$ ratio for North Patagonian Batholith granitoids with time for the last 80 Ma. The shaded bars in the upper part indicate the main episodes of plutonism, which correspond to increased convergence rate. The $^{87}Sr/^{86}Sr$ ratio reaches a minimum with the opening of the early Miocene back-arc basin. Modified from Pankhurst et al. (1999).

The major and trace geochemical compositions of the batholith rocks vary rather little with time (Pankhurst et al. 1999), but there are shifts towards more primitive Sr- and Nd-isotope compositions, especially in the early Miocene granitoids (Fig. 2). This was explained as due to magma generation in underplated mafic material of varying maturity at the base of the crust. Early Miocene magmas were thought to have been derived from penecontemporaneous underplate as the arc was extended, whereas the Cretaceous magmas, which have initial $^{87}Sr/^{86}Sr$ ratios of 0.704-0.706, could have been derived from older material. In contrast, Weaver et al. (1990) suggested that the main tonalite-to-granite magmas, of which they identified two geochemical types, were formed by fractionation of mantle-derived mafic primary magmas. The considered the isotope compositions of the early magmas to reflect contamination by the country rock material and explained the decrease in initial $^{87}Sr/^{86}Sr$ ratios with time (from 0.7075 to 0.7035) as due to progressive depletion of the source region in the more easily fusible components. A similar hypothesis has been advanced for the similar Cretaceous-Eocene batholith of the Antarctic Peninsula by Leat et al. (1995). In the latter case, however, emplacement was not generally into the axis of the pre-existing batholith; instead there was a pronounced westward migration with time away from the edge of the continent. This suggests that the change in isotopic compositions was more related to different magma source regions.

Finally, small stocks of K-rich leucogranite occur along the eastern sector of the Andes, intruding the older rocks of the batholith (e.g., Paine, FitzRoy, San Lorenzo, behind the austral Volcanic Zone; Pireco and Tristeza behind the Southern Volcanic Zone). Many of these have yielded Rb-Sr ages of 9-18 Ma (Pankhurst and Rapela, unpublished data). Their isotopic compositions are somewhat variable, but indistinguishable from those of the Late Miocene/Pliocene bodies in the western Andes. They are most probably small-volume, highly fractionated products of similar magmas.

Conclusions

The magmatism of the Southern Andes, like that if the adjacent margin of SW Gondwana in the Antarctic Peninsula, is represented by discrete stages and processes. Pre-Jurassic magmatism appears to be essentially intra-continental, although some has calc-alkaline geochemistry. Throughout the Jurassic period, silicic magmatism, almost entirely volcanic in type, is related to and controlled by the break-up of Gondwana. The thermal effects of the spreading Karroo plume head together with severe crustal extension, resulted in massive anatexis of deep crustal rocks and easy access to the surface. The growth of the Andean batholith seems to be essentially post-Jurassic and did not begin until the final episode of Jurassic volcanism had subsided. The typical magmas of this series (mafic, intermediate and silicic) are isotopically more primitive than the Jurassic ones, and may have originated by melting of underplated basaltic lower crust. Individual episodes of granitoid generation were triggered by changes in the kinematics of the subduction process. Emplacement of these magmas in the Southern Andes was controlled by deep-seated faults; in the Antarctic Peninsula, trench roll-back appears to have affected the locus and composition of plutonism.

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