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Andean batholiths and marginal basins

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ABSTRACT. — The evolution of the Mesozoic-early Cenozoic batholiths of the Andes models the origin of one type of granitoid at an active, continental plate margin. Crustal extension is associated both with the generation of new, thick crust by the deep-seated extraction of a basic progenitor from the mantle, and with the formation of «back-arc» volcanoclastic basins within the edge of the continental plate. In such a zone of high heat flux episodic movements on deep-reaching transcurrent faults trigger remelting of the basic underplate, whilst in relaxation these faults provide hot conduits for the fractionating magmas to intrude high into the volcaniclastic infill of the marginal basins.

The chain of great granitoid batholiths that cores the Western Cordilleras of the central and southern Andes provides a prime example of silicic magmatism at an active plate edge of a continent (ZEIL, 1979; PITCHER et al., 1985). During the Mesozoic and Palaeogene the primary source of the magmas lay within the upper mantle, and despite emplacement into the continental margin their composition had little to do with the old crust; rather the new magmas made major contributions to the continental plate.

The generative process is associated with the subduction of the oceanic Nazca (Farallon) plate with the establishement of a marginal continental volcanic arc (e.g. JAMES, 1977, 1978). The easterly migration of this arc has been modelled in terms of changing inclination of the dip of the subducting slab and also frontal erosion, whilst the episodic character and varying activity of magmatism can be related to changes in the plate convergence rate (FRUTOS, 1981; SOLER, 1987). However, complications are introduced by the obvious segmentation of the Andes, and the new importance given to strike-slip faults with the likelihood of major terrane displacement.

The early part of the Mesozoic Andean cycle was everywhere a time of crustal extension of the continental edge, albeit with a varied time scale along its length (DALZIEL, 1981; LEVI and AGUIRRE, 1981; AGUIRRE, 1987; ÅBERG et al., 1984). In the central Andes, from the Triassic to the Lower Cretaceous, such extension led to block faulting, subsidence and the growth of fault-controlled, marginal sedimentary basins (MYERS, 1975a; Cobbing, in PITCHER et al., 1985). The latter show a polarity of their sedimentary infill, with clastics derived from the continental interior contrasting with the submarine lavas and detritus of a volcanic arc complete with submarine exhalative mineral deposits (CARDOZO & WAUSCHUHN, 1984; VIDAL, in PITCHER et al., 1985). The great thickness of such volcanic deposits, especially those of Lower Cretaceous age, attests to rapid subsidence within a «back-arc» basinal environment, whilst a primitive composition indicates a mantle source and, furthermore, features of the non-deformative burial metamorphism confirm a contemporary high heat flux (COBBING, ATHERTON et al., AGUIRRE and OFFLER, in PITCHER et al., 1985).

The continental crust underpinning these marginal basins is represented in southern Ecuador, Peru and northern Chile by an ancient Precambrian massif, whilst in central and southern Chile the basement consists of slate belts representing accreted forearc terranes of Palaeozoic age. It was this old crust that was extended, differentially thinned, even ruptured and pulled apart during the Mesozoic, with the result that basic magmas released from the mantle wedge ascended rapidly, making little contact with old crust. In Peru there is the additional geophysical evidence for a deep-crustal arch of high-density material rising into the continental edge underlying the volcanogenic basin (WILSON, ATHERTON et al., in PITCHER et al., 1985). This may represent a new basaltic crust extracted from the mantle wedge during the extensional phase. In north-central Chile spreading combined with subsidence, again associated with the eruption of mantle-derived basalts, is more evident than in Peru (LEVI and AGUIRRE, 1981; AGUIRRE, 1985; p. 333). However in neither case is it thought that oceanic crust was ever generated which contrasts with an analogous situation in Patagonia where the marginal basin is modelled as having been floored by new mafic crust (DALZIEL, 1981).

Within this particular marginal continental environment the multiple granitoid batholiths lie parallel to the tectonic trend and along or near to the axes of precursor volcanogenic basins (PITCHER et al., 1985; AGUIRRE, 1985). The earliest intrusions were often gabbroic, quickly succeded by the granitoids and synplutonic, basic dyke swarms. The whole process conforms to a magmatectonic cycle of vulcanicity, burial metamorphism, mild compression with open folding and transcurrent faulting, followed by plutonic emplacement, then relaxation and dyke intrusion, and finally uplift (CHARRIER, 1973; AGUIRRE, 1985 p. 332). This cycle of overlapping events can be repeated with waning intensity from the mid-Cretaceous to the mid-Cenozoic. Possibly compression inhibited extrusion, extending the residence time sufficiently for the ponded magmas to fractionate.

The Coastal Batholith of Peru illustrates well the nature of this type of silicic magmatism (PITCHER et al., 1985). A 1600 km-long linear array of hundreds of plutons was stoped out of the axial zone of one of these precursor «back-arc» basins of Lower Cretaceous age. Characteristically the first intrusions were largely of gabbro followed, over the next 60 Ma, by the episodic intrusion of short-lived pulses of granitoid magma of decreasing volume. Calc-alkaline, magnetite-bearing, I-type tonalites and granodiorites predominate, though the compositional spectrum is locally widened to include both K-rich diorites and evolved granites. The rocks naturally group into well-defined, time separated, consanguineous rock suites, each with its own identity as defined in terms of chronology, modal and chemical composition, textural characteristics, enclave populations and dyke-swarm association (PITCHER, 1974). The identity of the suites and the number of the successive rhythms varies along the segmented batholith but individual suites maintain their character over hundreds of kilometers despite being distributed within separated plutons (COBBING et al., 1977; PITCHER et al., 1985). Whilst some suites were differentiated in situ within a single pluton many others represent the multi-pulse intrusion from depth of magmas already largely differentiated, possibly in deep-seated and laterally extensive melt cells (PITCHER, 1978; TAYLOR, 1976; ATHERTON, 1981). Each suite conforms to a simple pattern of calc-alkaline variation more characteristic of magmas undergoing crystal fractionation, albeit with variations in the proportions of the separating crystal crops, than of magmas developed by fractional remelting (MCCOURT, 1981; ATHERTON and SANDERSON, in PITCHER et al., 1985).

A characteristic feature of this and analogous batholiths is the presence of coeval, basic dyke swarms (PITCHER & BUSSELL, in PITCHER et al., 1985, cf. PICHOWIAK & BREITKREUZ, 1984). In this connexion the ubiquitous presence of dioritic enclaves, often demonstrably derived from the dismemberment of such synplutonic basic dykes, shows that mixing between new basic magma and various stages of the rest magma was always possible, especially so within the ring-complexes where mixing took place in a fluidized media (BUSSELL, in PITCHER et al., 1985).

Petrographically these granitoids show simple textures and their mineralogy conforms to relatively high-temperature, water-undersaturated magmas lacking in late pegmatitic differentiates and vein systems. Such findings are consonant with the evident upwelling of the magmas to a high, sub-volcanic level in the crust where they were emplaced by stoping aided by brittle fracturing. Appropriately the high-temperature thermal aureoles are relatively narrow and magma cooling is likely to have been rapid (ATHERTON and BRENCHLEY, 1972; MYERS, 1975b; PITCHER, 1978; MUKASA and TILTON, in PITCHER et al., 1985). Good examples of the plutono-volcanic interface are provided by the centred complexes and porphyry-Cu breccia pipes, yet it seems that few plutons represent substantial feeder magma chambers - rather it was the synplutonic dyke swarms that provided the conduits for any coeval extrusives (BUSSELL, PITCHER and WILSON, 1976; BUSSELL and PITCHER, in PITCHER et al., 1985).

The compositional and isotopic data are wholly in accord with a primary mantle source for the magmas. This is especially so in the Lima segment where the batholith is so clearly axial to a marginal basin, but where, as in southern Peru, the granitoids enter into direct contact with the ancient massif, a mild degree of crustal contamination is recorded by both the Pb and Sr isotopes (BECKINSALE in PITCHER et al., 1985; MUKASA, 1986). However an increase in Sr_i, varying in degree during each of the separate magmatic episodes, has been interpreted by SOLER (1987) as due less to direct crustal contamination than to sub-crustal heterogenity - recording a competition between subduction-related alteration of the mantle wedge, a process producing heterogeneity, and mantle-wedge convection, which redresses that process.

Central to the understanding of the origin of the granitoid magmas is the close acid-basic relationship as revealed by the early production of a new dense crust, the precursor basaltic volcanicity, the early appearance of gabbro and the continued synplutonic intrusion of basic dykes. It is envisaged that, during the rapid plate convergence of early Cretaceous times, basalt was melted out from a diapiric upwelling of the mantle wedge to form new crust. This underplate was subsequently locally remelted during episodes of resurgent movement, the resultant batches of magma fractionating to produce the tonalites (COBBING and PITCHER, 1983, Fig. 7). Throughout the process the continuing intrusion of basic magma maintained a high heat flux.

The Coastal Batholith of Peru represents the generation of magma along a single fault-margined, mega-lineament over the long time span of 102-37Ma, and with but limited eastward migration (PITCHER & BUSSELL, 1977). Thus it is suggested that the batches of melt were tapped and channelled by deep faults of long-standing; indeed it may be that it was the episodic movement on such major faults that triggered remelting: a thesis that places less emphasis on subduction mechanics.

Such a lineamental control is also obvious in the even longer-lasting Patagonian Batholith, 155-10Ma, with its like dimensions, near identical compositions, a similar history, and again with a close temporal and spatial relationship with the development of a transcurrent-fault-controlled, «back-arc» basin (SUAREZ, 1977; AGUIRRE, 1985; RAPELA, 1978; NELSON et al., 1988). As in Peru the volume of magma was greatest between 100-75Ma which correlates with the period of high spreading rates. Here, however, it is the earliest intrusions that show evidence of crustal contamination of the mantle-derived magmas, whilst the later intrusions seem to have been insulated from contact with the old crust (NELSON et al., 1978).

Essentially similar batholiths occur in between, in north and central Chile, but in contrast to other segments of the Andes both the plutonic and volcanic belts show a very marked easterly migration with time, and one accompanied by a compositional change which, as in the more subdued example in Peru, is thought to be related more to a mantle source changing in composition with time or distance than to an increasing influence of the old crust (LOPEZ-ESCOBAR et al., 1979; ATHERTON and SANDERSON, 1987). In northern Chile the most westerly batholith is actually emplaced within the basement flanking the compound volcanic belt so providing, in cross-cutting relationships, a direct contrast with the very different, post-tectonic granites belonging to the Upper Palaeozoic magma-tectonic cycle (BERG and BREITKREUZ, 1983; DAMM and PICHOWIAK, 1983).

In the Central Cordillera of Colombia, the old continental margin hosts Mesozoic batholiths similar to those of the central Andes. However this margin is now so sliced up by the sutures associated with the docking of a Pacific island arc that the relationships are obscured between «back-arc» basinal deposits and possible plutonic correlatives (ALVAREZ, 1983; MCCOURT et al., 1984). Nevertheless the granitoids within the island-arc domain of the Western Cordillera show a fundamental contrast to those of the true continental margin, viz. a much lesser volume and a greater compositional restriction to quartz diorites and tonalites which are candidates for the M-type characteristic of island arcs (PITCHER, 1983).

Overall, the evolution of the Mesozoic-early Cenozoic batholiths of the Andes provides a model for the origin of one important type of granitic rocks at an active, continental plate margin (PITCHER, 1987, Fig. 1). In this scenario crustal extension is connected with the generation of new, thick crust by extraction of a basic progenitor from the mantle, and with the siting of a volcanic arc within the edge of the continental plate. In such a zone of high heat flux episodic movements on deep-seated, transcurrent faults trigger remelting at sub-crustal levels, but the associated compression sufficiently seals the continuously thickened crustal carapace to provide the increased travel distances and times necessary to advance fractionation processes; that is until relaxation allows the deep-faults to tap the new magmas (cf. DAMM and PICHOWIAK, 1983), permitting them to intrude high into the volcaniclastic infill of the marginal basins.

It is doubtful whether such a Pacific-type marginal environment with its voluminous production of K-poor, Ca-rich granitoids within huge, lineamental batholiths, ever formed an element in the geological evolution of the European crust.

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