EMPLACEMENT OF PLUTONIC COMPLEXES, STRAIN AND STRAIN PARTITIONING IN THE COASTAL CORDILLERA, (25°- 27°S), N CHILE

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INTRODUCTION

Emplacement of plutonic complexes in the Coastal Cordillera was associated with deformation in ductile shear zones. Undeformed plutonic rocks and mylonites in adjacent wall rocks yield $^{40}Ar/^{39}Ar$ hornblende and muscovite cooling ages and zircon ages for the undeformed pluton that are, within error, identical. Therefore: (1) plutons were emplaced at high level and cooled rapidly; (2) heat to allow ductile deformation advected to high levels within the arc during magmatism. To account for arc asymmetry defined by east-younging plutonic rocks and east-down displacements in associated shear belts, Grocott and others (1994) proposed that Lower Jurassic to Lower Cretaceous plutons were emplaced as sheets at dilational jogs in an east-dipping extensional fault system. They identified also a change in arc kinematics during Early Cretaceous time (c130 Ma) when ductile deformation became dominated by sinistral strike slip. Farther north in the Cordillera, authors report a Late Jurassic to Early Cretaceous transtensional regime partitioned into arc-normal and arc-parallel sinistral strike-slip components (Scheuber et al. 1995). Recent research on granite emplacement has emphasised that it is not necessary to create space at a dilational site within a fault system to emplace plutonic complexes. Rather, magma pressure is capable of dilating any fracture where it exceeds the regional normal stress component acting across it allowing intrusions to be emplaced as sheets by magma wedging (Ingram & Hutton, 1994). Successively emplaced sheets may build into composite bodies of batholithic proportions (McCaffrey and others 1996). Here, we re-evaluate emplacement models for plutonic complexes in the Coastal Cordillera in the light of this new work, and use new AMS (anisotropy of magnetic susceptibility) data to demonstrate strain partitioning during emplacement of the Lower Cretaceous Las Tazas plutonic complex.

PERMIAN AND TRIASSIC (P-T) PLUTONIC COMPLEXES

These tonalite to leucogranite plutonic complexes are N-S elongate, composite sheets folded by upright, low amplitude, large wavelength E-W open folds and earlier, inclined, close to tight NE-trending folds. They are located close to the present-day coast (Fig. 1) and have map dimensions typically 30km x 10km and thicknesses >1 km. Plutons were emplaced into strongly deformed Devonian-Carboniferous metasedimentary rocks. Structures within the metasediments include SW-vergent major recumbent folds and mylonite belts. The plutonic complexes were emplaced sub-parallel to the pre-existing foliation and have gentle dips imposed by later folding. Where composition was appropriate, andalusite and muscovite mark a narrow contact aureole, though little ductile deformation is present in the country rocks. Neither magmatic state nor crystal-plastic fabrics have been recorded in the plutons. The main upper and lower contacts are well-defined but there is interleaving of thin, concordant granitoid sheets with metasedimentary country rock above and below the main contacts. Laterally, the plutons interfinger with country rocks in the manner described by McCaffrey and others (1996) for the Lake District batholith, N England. At the edges of the intrusions contacts are steeply-dipping implying that sheet edges are blunt rather than tapered. We conclude that P-T plutons were emplaced as composite, sub-horizontal sheets parallel to the anisotropy of the metasedimentary rocks. Their orientation, absence of direct association with faults and lack of internal and external deformation are consistent with emplacement by dilation of sub-horizontal, mode 1 fractures induced by magma pressure.

LOWER (LJ) AND UPPER JURASSIC (UJ) PLUTONIC COMPLEXES

Evidence from LJ tonalitic to granodioritic plutons (Fig. 1) has provided strong arguments for emplacement at dilational jogs in an east-dipping extensional fault system fed by a dyke-transport magma ascent mechanism (Dallmeyer, et al., 1996). Plutons were emplaced within mylonitic metasedimentary rocks and are now exposed at roof level. The mylonites contain both pre- and syn-tectonic contact-metamorphic muscovite and andalusite and this implies that Palaeozoic shear zones were reactivated during emplacement. Stretched andalusite defines an WNW-ESE extension lineation associated with top-east shear sense indicators that appear to confirm low-angle normal-slip displacements linked to pluton emplacement.

A dioritic UJ plutonic complex (Las Animas) lies inboard of the LJ plutonic rocks. It is elongate N-S and passes upward into a folded sill complex that cuts arc volcanic rocks of the La Negra Formation (Fig. 1). In exposure, pluton margins are steep though the wide aureole implies that the pluton is a moderately east-dipping sheet. A narrow belt of high temperature mylonites with steep extension lineations is present in country rock along the western margin of the complex and has the same $^{40}Ar/^{39}Ar$ cooling age as the pluton. Farther W, vertical, NE-SW trending swarms of basaltic andesite yield similar $^{40}Ar/^{39}Ar$ ages to the plutonic complex and may be representative of dyke feeder(s) of the UJ plutonic and the sill complexes. The emplacement mechanism for this pluton is uncertain and we have no data on its internal structure. There is however, no specific evidence pointing to emplacement at a dilational jog. Instead, the steep high temperature shear zone at the western margin is consistent with emplacement as an east-dipping sheet within a dip-slip shear zone.

LOWER CRETACEOUS (LK) PLUTONIC COMPLEXES

Las Tazas plutonic complex (Fig. 1) was emplaced at c.130 Ma inboard of the UJ plutonic complex and is bounded by the western and central branches of the Atacama Fault Zone (AFZ). The complex contains two plutons, one of which is a composite N-S trending vertical sheet with dimensions 60km x10km. Along the western margin of this sheet a broad N-S belt of high-temperature mylonite has vertical foliation and steeply pitching stretching fabric. The vorticity vector (Robin & Cruden, 1995) is perpendicular to the stretching lineation and deformation non-coaxial with a kinematic vorticity number approaching 1. Kinematic indicators demonstrate east (pluton)-side-down displacements. Again, $^{40}Ar/^{39}Ar$ are similar for the mylonites and the pluton indicating that cooling rates for both pluton and mylonites were rapid. The western margin of the pluton cuts the mylonitic rocks and we suggest that deformation partitioned immediately into the magma as it was emplaced. Late syn-plutonic strain, reflected by anisotropy of magnetic susceptibility (AMS) and magmatic state fabrics, is characterised by a margin-parallel flattening with a weak, steeply south-pitching, linear element. The AMS data show that the late-synplutonic deformation of the pluton was characterised by a coaxial strain partitioned into the pluton with a weak, oblique-slip non-coaxial component. Locally developed low-temperature crystal-plastic fabrics within the pluton also reveal east-down displacements parallel to a steep stretching fabric. Major and trace element geochemistry shows that the pluton was emplaced from west to east as a sequence of vertical sheets. The south-pitching linear element of the AMS fabric becomes shallower eastward in the younger sheets due to an increasing dextral component in the non-coaxial portion of the strain. In the eastern country rocks of the complex mylonitic deformation was polyphase. Dextral kinematic indicators on horizontal sections are overprinted by low-temperature (greenschist facies) mylonites with sinistral strike-slip displacements associated with a sub-horizontal stretching lineation. According to Grocott and others (1994), Las Tazas complex was emplaced at a dilational jog in an extensional fault system. The new AMS data does not support this interpretation and the pluton may simply have dilated the north-south trending belt of mylonitic rocks now exposed at its western margin when magma pressure overcame the normal stress acting across the ductile shear belt.

Remolino plutonic complex (Fig. 1) covers an area of 130km x 40km. The internal structure of the pluton is unknown. At its eastern margin a broad belt of greenschist facies, sinistral strike-slip mylonitic rocks has the same $^{40}Ar/^{39}Ar$ hornblende cooling age (c.125 Ma) as the undeformed pluton. This mylonite belt can be traced south for at least 60km on the western side of the Lower Cretaceous batholith (Arévalo, 1995). The eastern country rock of the pluton is characterised by a narrow belt of high-temperature mylonite with a vertical N-S trending foliation and a down-dip stretching fabric. This shows that, although sinistral strike-slip is the dominant style of ductile deformation in the magmatic arc post-c.130 Ma, dip-slip deformation continues to be associated with the early stages of the emplacement of arc plutonic complexes.

La Borracha pluton has a $^{40}Ar/^{39}Ar$ hornblende cooling age of c.106 Ma and is the youngest plutonic complex we have so far dated in the Lower Cretaceous batholith. Like Las Tazas and Remolino complexes it appears to be a vertical sheet emplaced along the AFZ. Its dimensions are 100km x 10 km, it trends NNW-SSE and cuts the sinistral shear belt at the margin of Remolino complex (Fig. 1). In a shear zone developed in country rock at the western margin of the pluton, steeply pitching stretching lineations with east-down kinematic indicators are present. Locally, low temperature sinistral strike-slip mylonitic deformation was superimposed on the dip-slip fabric. The trend and shape of the pluton and dip-slip mylonites imply emplacement at a releasing bend in the AFZ (Fig. 1).

CONCLUSIONS

Re-evaluation of pluton emplacement mechanisms in the Coastal Cordillera between 25°-27°S indicates that P-T plutonic complexes were emplaced as sub-horizontal sheets at high crustal levels. LJ, UJ and earliest LK plutons were mainly emplaced as sheets by magma wedging rather than at specific dilational sites in fault systems. The plutons were emplaced in an extensional arc with an increasing strike-slip component through time and transtension certainly provides the most satisfactory setting for the youngest LK plutonic complex studied (La Borracha). However, we now have AMS evidence for at least local arc-normal shortening during emplacement of the earliest LK plutons at 26°S.

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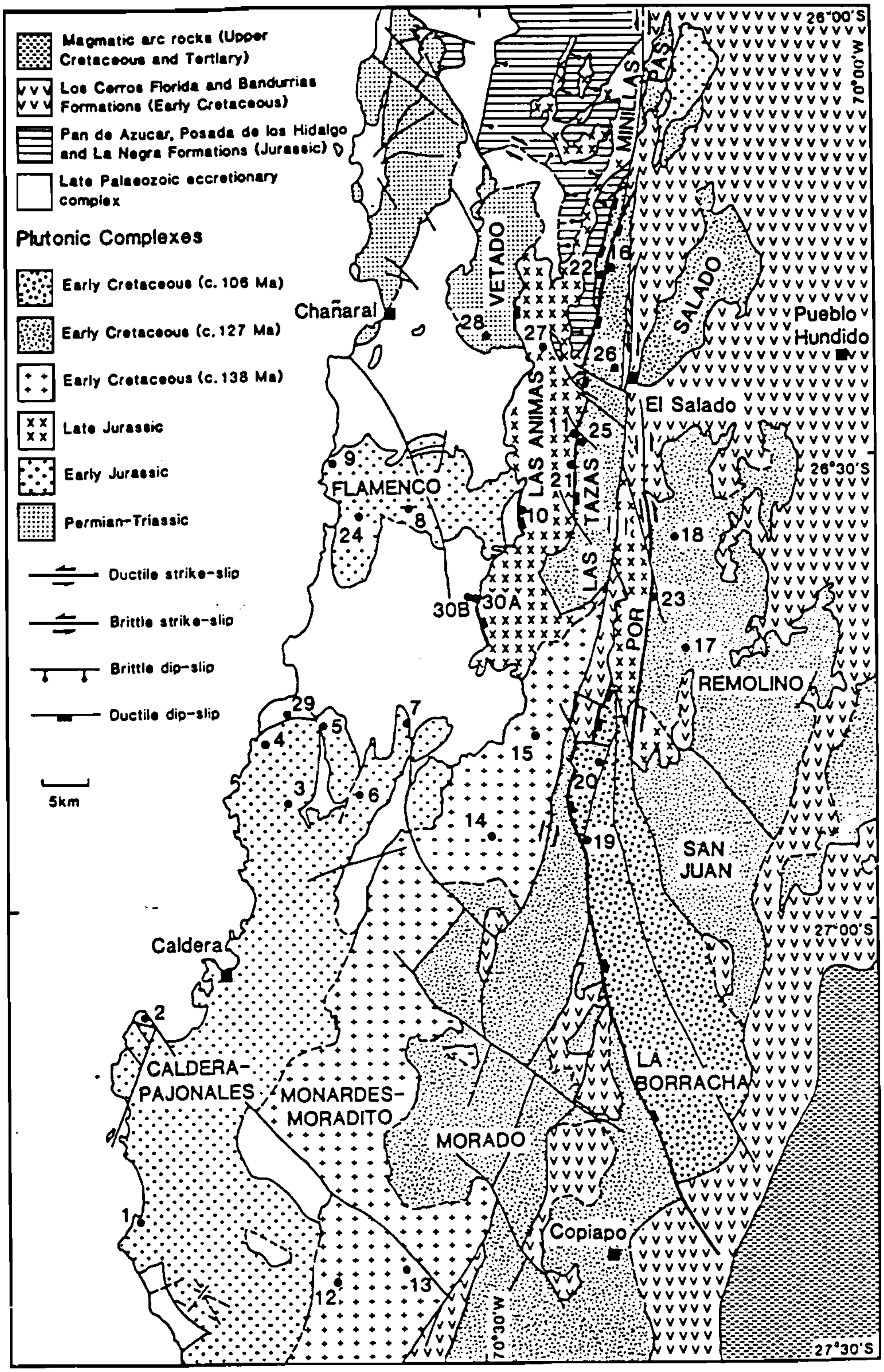

Figure 1. Detailed geological map of the area between 26°S and 27°30'S, Atacama Region, North Chile showing the plutonic complexes and main zones of ductile and brittle deformation referred to in the text. $^{40}Ar/^{39}Ar$ sample localities of Dallmeyer *et al* (1996) are indicated. POR is the Porvenir plutonic complex, PAS is the Pastenes plutonic complex. (From Dallmeyer *et al*, 1996)