SOME MODERN CONCEPTS ON LACHLAN GRANITE PETROGENESIS

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Summary

This presentation will show, based on field, geophysical, geochemical and isotopic studies, that Silurian-Devonian plutonism in the eastern Lachlan Fold Belt (LFB) was intimately involved with mafic magmatism. Most of the granite plutons reflect open-system, disequilibrium processes involving magma mixing. Mixing below and at the base of batholiths generated much of the isotopic diversity observed in LFB granites, and subsequent fractionation processes in the upper crustal magma chambers, including restite unmixing, generated much of the chemical diversity. The dominant stress regime during LFB granite generation and emplacement was extensional and the tectonic environment was interarc to backarc rift, based on the composition of primitive syn-plutonic mafic rocks. Rapid eastward slab retreat is evident from the age distribution of eastern LFB granites, and this retreating or extensional accretionary orogen is ideal for generating vast amounts of mantle-derived magmas, necessary to melt and mix with the crustally derived magmas to produce the voluminous and widespread granites of this region.

Introduction

Detailed field and gravity studies from S-type (Murrumbidgee) and I-type (Bega) batholiths are combined with geochemical/isotopic results to understand the *physical* processes associated with granite generation, emplacement and subsequent fractionation in the eastern LFB. The results require a re-evaluation of models for LFB granite petrogenesis. In particular, it will be shown that the studied plutons are open systems that can often be viewed as sedimentary deposits. They provide stratigraphic sections that record input from various source components and commonly give "way-up" features, allowing the pluton top and bottom to be identified. The plutons are commonly fed by "clean" felsic and mafic dyke material, which can mix and mingle in the ascent conduits or in the magma chamber itself.

Tuross Head pluton: Bega Batholith

The Tuross Head pluton is part of the Moruya Suite from the Bega Batholith. It is well exposed as coastal outcrops at Bingie Point and Tuross Head. Gravity and magnetic surveys have shown that the mafic rocks are km-scale layers concentrically arranged and dipping toward the pluton interior. The arrangement is consistent with inward dipping nature of the mafic layers, which is concordant with a variably developed feldspar foliation and with the orientation of elongate enclaves in the tonalite. The mafic layers are asymmetric, planar on one side and lobate to irregular on the other. The lobate contacts outline m-scale load-cast structures, and asymmetric granitic veining and scarce felsic pipes along these contacts are "way-up" structures that indicate the tops of all mafic layers face towards the interior of the pluton.

Mafic to intermediate enclaves have textures, modes and mineralogy that are similar to those of the mafic sheets. They range from globular and nearly equant bodies with obvious magmatic textures to highly elongate bodies in zones where a magmatic foliation is well developed. They are most concentrated above mafic layers, and local contact relations and textural features suggest they are magma globules ripped off the top of those layers. The field relations demonstrate that these mafic enclaves, which have been called restite by some workers, are derived from mafic magma infusions into the tonalitic magma chamber.

A detailed study of Tuross Head shows that it can be divided into three zones (A,B,C) with a combined thickness of at least 1500 metres. Zone A is lowermost and consists of a silicic tonalite ($SiO2$ ~65%) with few mafic enclaves and discrete mafic crystals. It is overlain by Zone B, which contains wedge-shaped gabbro/diorite layers and tonalites of generally lower silica contents (61-64%) with abundant mafic enclaves and some mafic clots. The upper layer (Zone C) consists of strongly foliated, very mafic tonalites (57-59% $SiO2$) and highly dismembered gabbro/diorite layers, which are progressively disaggregated to mineral aggregate-scale clots.

Interpretation. The mafic sheets of Zone B represent replenishment of mafic magma into the Tuross magma chamber and mark various positions of the aggrading floor of that chamber. Since the elongate enclaves and the feldspar foliation in the tonalite are parallel to and intercalated with the mafic sheets, they also define the position of the floor. The intercalation of mafic layers and tonalite strongly suggests that, even though layering is not apparent, the tonalite was also deposited gradually on the chamber floor between episodes of mafic input. Therefore, the Tuross Tonalite probably has a stratigraphic record comparable to that seen in mafic layered intrusions, and the sequence of deposits should provide a time-stratigraphic record of processes in the magma chamber.

Higher up, in Zone C, the coexisting layered mafic and silicic magmas were strongly disrupted during magmatic flow, and the two components mechanically mixed to produce the mafic tonalite. Abundant mafic clots, derived by disaggregation of the mafic layers, characterise this mafic tonalite. They are also seen in Zone B, but are rare in A, and correlate negatively with silica abundance. Incorporation of these clots generates the composition diversity of granites at Tuross Head, with magmas becoming more mafic with time. This reflects open system mixing processes, rather than closed system restite fractionation, where magmas should become more felsic with time.

Kameruka pluton: Bega Batholith

Field and petrographic evidence indicates that the Kameruka suite plutons of the Bega Batholith, eastern Australia, also grew by crystal accumulation on the magma chamber floor. Depositional features in the plutons, including mafic enclave channels, asymmetric enclave pillows and exotic rafts, load casts and flame structures, and graded and trough cross-beds indicate that the pluton built also progressively upward, like the Tuross pluton. Km-scale mafic infusions are also present, and are associated with large enclave swarms, but they are rare. The general eastward dip of depositional features in the Kameruka pluton implies a lower western and upper eastern contact, consistent with a gradational granite-migmatite contact in the west and a sharp, stoped, hornfelsic contact in the east. Mafic, felsic and composite dykes, most common near and below the lower (western) contact, are interpreted as conduits for magma chamber replenishment and imply open-system behaviour during pluton construction.

Textural relations are consistent with an open-system, cumulate origin. Typically, cm-scale grains of quartz, plagioclase and megacrystic alkali feldspar form a touching framework with interstices filled with smaller biotite flakes, normally zoned overgrowths on plagioclase cores, and smaller intercumulus quartz and feldspar crystals. The bulk composition of cumulate mush, represented by the granodiorite, cannot represent the emplaced magma. Chemical variation can be modelled by variable degrees of crystal accumulation from a parental, silica-rich melt represented by the silicic dykes, consistent with isotopic evidence. As dykes periodically fed the magma chamber, crystals accumulated on the floor and more evolved melts probably erupted from its roof. Thus, the average composition of the magma and the cumulus minerals may have remained relatively constant, and the sublinear chemical trends that typify the Kameruka suite simply reflect differing proportions of melt and cumulate material. Chemical and isotopic analysis of the migmatites underlying the Kameruka pluton indicates minimal interaction with the granitic magmas.

The Kameruka pluton is one of a number of elongate, meridional, wedge-shaped bodies that thicken eastward in the Bega Batholith. The E-dipping, primary magmatic accumulation fabric, which becomes steeper to the west in the deeper parts of the pluton, is comparable to sedimentary layers formed by floor depression in syn-rift settings. Syn-rift sediments and co-magmatic volcanics (Long Flat volcanics) directly overlying northern extension of the Bega Batholith suggest that it is the deeper, plutonic expression of a hot, active rift. Displacement along syn-emplacement lateral transfer faults (Burragate and Tantawangelo) suggests up to 25 km of E-W extension during batholith construction The model is not consistent with the restite model, which requires *en mass* diapiric rise of unmelted source and felsic melt, followed by separation of the solid (restite) fragments. This flat-bottomed, laccolithic pluton was fed by silicic (microgranite) dykes that do not contain mafic clots.

Murrumbidgee Batholith

The Murrumbidgee Batholith is typical of other composite S-type granite batholiths in the Lachlan Fold Belt of southeastern Australia, consisting of discrete peraluminous, cogenetic granite suites, although it contains a unique (Murrumbucka) suite at its southern extremity that has chemical and petrological features transitional with metaluminous I-type granites. Detailed structural and metamorphic studies have shown that the batholith is tilted northward, exposing subvolcanic plutons in the north and the root zones in the south, located at depths of ~10 km. A transition from mafic, foliated, sheet-like granites in the south to felsic, generally non-foliated, homogenous granites in the north is consistent with magma ascent via subvertical, structurally controlled sheets to emplacement in an overlying magma chamber.

In the inferred root zones, the Murrumbucka suite hosts migmatitic metasedimentary and gabbroic rocks, both of which have transitional contacts and show evidence for interaction with the host. The migmatites extend southward to become part of the high-T, low-P Cooma Metamorphic Complex, which contains a core of heterogeneous diatexitic granite (Cooma suite), lenses of which also occur throughout the southern (deeper) parts of the Murrumbidgee batholith. The composition of mafic granites from the batholith lie on a chemical tie-line between Cooma suite granites and the gabbros, for almost all elements. This chemical coincidence is interpreted to reflect derivation of parental Murrumbidgee S-type granite magmas by mixing between a felsic (crustal) and mafic (mantle) components, consistent with Sr and Nd isotopic results and field observations. Based on the tie-lines, the Murrumbucka suite is estimated to be a 45:55 mix of mantle and crust, whereas the more peraluminous and widespread Clear Range suite, which is very typical of Lachlan S-type granites, is a 40:60 mix. Chemical variation trends diverge from the mixing lines and suggest that much of the fractionation processes operated after mixing. Mixing occurred within sheets during ascent of the magmas whereas fractionation, including restite separation, was the dominant process generating chemical diversity during emplacement at higher crustal levels.

Tectonic Setting

Silurian-Devonian syn-orogenic basalts and gabbros have oceanic affinities, and are very similar to those formed in the present-day SW Pacific. The compositions indicate generation under lithosphere that was <30 km thick until the Late Devonian. Given normal subcontinental lithospheric thicknesses are >100 km, this evidence strongly favours extensional tectonic models for the eastern LFB during generation and emplacement of LFB granites. Emplacement of Bega Batholith plutons into active half-grabens is consistent with an extensional tectonic model.

The Silurian-Devonian deformation record indicates at least five periods of intermittent contraction, early and late Benambran, Bowning, Bindian, Tabberabberan (390-380 Ma) and Kanimblan. These events were short-lived (~10 Ma), diachronous and complex, resulting in crustal thickening. Nonetheless, these events coincided with the development of widespread rift-basins, and the basalt compositions imply that lithospheric thickening began only in the Middle Devonian (~390 Ma), coinciding with attainment of relative tectonic stability in the LFB. A solution to this paradox involves rapid reversal of prolonged slab retreat by arrival of a buoyant oceanic plateau at the trench, inducing flat subduction and transmission of horizontal compressive stress throughout the orogen. After subduction of the plateau, the ambient mode of slab retreat is re-established and the orogen experiences another phase of regional extension until arrival of the next plateau.

Petrogenetic and Tectonic Implications

1) The analysed I- and S-type granites are crust-mantle mixes, with the dominant crustal component in the Murrumbidgee Batholith being migmatite, derived from directly underlying Ordovician metasediment. I-type magmas of the Bega Batholith did not significantly interact with their underlying migmatites.
2) mafic enclaves and clots in I-types, occasionally interpreted as restite, represent mantle-derived magma that mixed with crustal magmas, either in the ascent zone (Murrumbucka), in dykes below the magma chamber (Kameruka), or in the magma chamber itself (Tuross).
3) The plutons typically reflect open-system processes, mainly associated with magma mixing and deposition of crystal slurries. Stratigraphic sections can be mapped and "way-up" structures identified, from which the top and bottom of plutons can be identified.
4) Mafic (hornblende-biotite) clots in I-type granites are demonstrably disrupted mineral aggregates from coeval mafic magmas, rather than restite. Mafic (cordierite-biotite) inclusions in S-type are demonstrably restite if a gneissic texture is preserved. Similarly, mineral inclusion trails in cordierite cores probably reflect restite, but those crystals without such features cannot be unequivocally regarded as restite.
5) The presence of "clean" feeder dykes in and below I-type plutons suggest that melt segregation and ascent from the source was efficient, involving minimal wall-rock contamination and transport of restite material. On the other hand, S-type magma generation below the Murrumbidgee Batholith involved wholesale breakup of migmatite and transport of solid restitic material, at least initially.
6) basement terranes, an outgrowth of the restite model, do not exist in the eastern LFB.
7) the mantle contribution to LFB petrogenesis was two-fold: as the major supplier of advective heat to the LFB, and a major supplier of material (source component) to the LFB granites.
8) plutons were generally emplaced during extension, as implied by the basalt data and field relations
9) Subduction models are viable and necessary for the LFB. Tectono-stratigraphic data indicate an extensional arc-backarc tectonic setting. Magma migration patterns indicate eastward retreat of a W-dipping slab in a convergent margin, subduction setting.

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