The assembly of magma chambers: Evidence from detailed zircon investigations

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Granitic rocks are the most abundant constituents of the upper continental crust, and have played a significant role in shaping the compositional structure of the crust. If they contain a component of juvenile, mantle-derived material, granitic rocks also contribute to the generation of new crust. Thus, an understanding of their petrogenesis is important for understanding the evolution of the continental crust in general.

Zircon is a common accessory mineral particularly in felsic igneous rocks. Its importance lies in a combination of factors: its incorporation of trace elements (including radionuclides), its chemical and physical durability and its remarkable resistance to high-temperature diffusive re-equilibration. Although low in abundance, it strongly affects the behaviour of many trace elements during the crystallisation of magmas, and therefore is useful for petrological modelling (Griffin et al., 2002; Belousova et al., 2006).

Hafnium (Hf) is a particularly important minor element in zircon, because its isotopic composition is a sensitive tracer of crustal and mantle processes. The basis of using the Hf isotopic ratios is the decay of ^{176}Lu to ^{176}Hf. During mantle melting, Hf is partitioned more strongly into the melts than Lu. Over time the ^{176}Hf/^{177}Hf therefore evolves to higher values in the mantle than in crustal rocks. In granitoid magmas, high values of ^{176}Hf/^{177}Hf (ie $\varepsilon_{Hf} >> 0$) indicate "juvenile" mantle input, either directly via mantle-derived mafic melts, or by remelting of young mantle-derived mafic lower crust. Low values of ^{176}Hf/^{177}Hf ($\varepsilon_{Hf} < 0$) provide evidence for crustal reworking. Mixing of crustally-derived and mantle-derived magmas during granite production can be detected by large ranges in ^{176}Hf/^{177}Hf in zircon populations, and by zoning in ^{176}Hf/^{177}Hf and trace-element abundances.

Petrologists studying magmatic rocks are confronted with the end product of a complex evolution, but little obvious evidence about the sequence of processes in that evolution. The *in situ* analysis of Hf isotopes and trace elements in zircon crystals from individual magmatic rock samples allows the recovery of information about the history and evolution of magma systems; this information is lost in isotopic studies of whole-rock systems. Such studies have demonstrated that magma mixing is probably more significant in the development of magma chambers than is commonly accepted in the petrological community. A detailed study of magmatic complexes in eastern China (Wang et al., 2002; Griffin et al., 2002) showed the presence of several morphologically distinct zircon populations. *In situ* analysis of these zircons showed a wide range of trace element patterns and Hf-isotope compositions between populations, and across single zircon grains. These variations imply the mixing of juvenile and crustally-derived magmas in the deep crust. The data suggest that each batch of magma carried its own zircon population; these zircons continued to grow, and new populations crystallised, following mixing of the magmas to form a magma chamber. Detailed studies of zircons in granitoids from eastern Australia have demonstrated similar complex magma-mixing histories, with correlated changes in zircon morphology, trace-element patterns and Hf isotopes (Belousova et al., 2006).

Another convincing example of the magma mixing process comes from the Georgetown Inlier, North Queensland, Australia (Murgulov et al., 2007). Many of the zircons in the Mt. Surprise granite have resorbed cores of Proterozoic age overgrown by oscillatorily-zoned rims of Siluro-Devonian age (Fig. 1a), offering an opportunity to study magma sources and evolution in two time slices. The Proterozoic cores in Siluro-Devonian zircons, and single grains with Proterozoic ages, are characterised by a wide spread of εHf values, from 11 to –26 (Fig. 1b). The lowest values give model ages (assuming an average crustal source) of more than 3 Ga, while the highest lie near the value for the Depleted Mantle at the time. This suggests mixing between magmas derived from Archean crust (low εHf) and magmas of juvenile origin (high εHf). Correlations between εHf in zircon cores and their magmatic rims suggest that during Siluro-Devonian remelting of the Proterozoic crust, this heterogeneity was inherited by individual magma batches that were mixed to form the final granite. The calculated Lu/Hf of the source rocks that melted to give the different magma batches suggests a range of felsic to intermediate protoliths.

The integration of data on morphology, trace elements and Hf-isotope variations in zircon populations is a powerful tool for studying the genesis of granitic rocks. It offers new insights into the contributions of different source rocks and emphasises the importance of magma mixing in granitic petrogenesis. Such information is rarely obtainable from the analysis of bulk rocks.

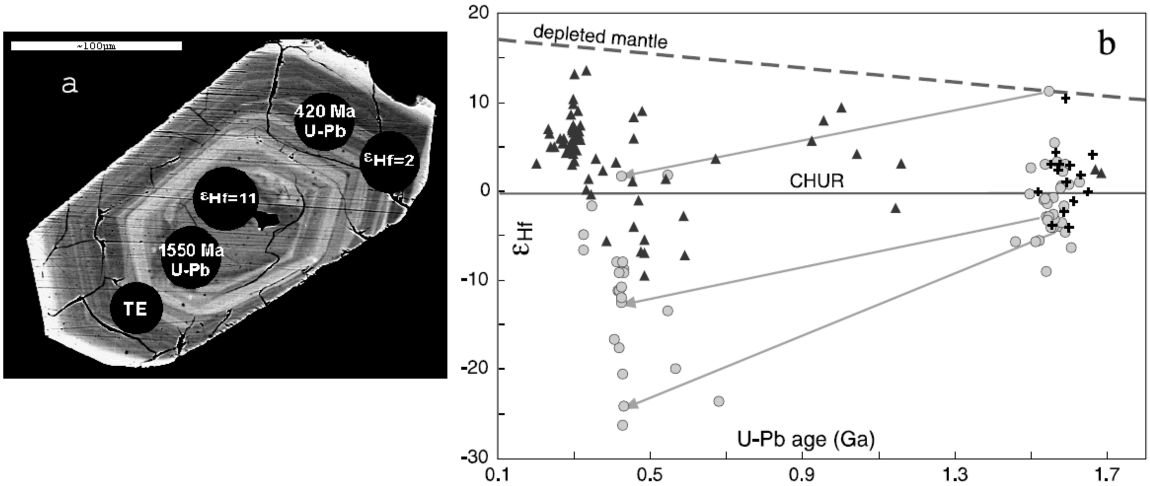

Figure 1: (a) A backscattered electron image of a zircon grain from the Georgetown Inlier, Australia; (b) εHf vs age for Georgetown zircons. Zircons lying below the CHUR (Chondritic reservoir) line are derived largely from crustal sources; those lying between CHUR and Depleted Mantle contain material derived from both crustal and juvenile sources. The arrows connect the Proterozoic core and Siluro-Devonian rim in representative grains from three samples (Murgulov et al., 2007).

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