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# Tracking Magma Mixing: In-situ Hf-isotope Analysis of Zircons

**William L. Griffin** (bill.griffin@mq.edu.au)[1], **Xiang Wang** (xzhou@netra.nju.edu.cn)[2], **Simon E. Jackson** (simon.jackson@mq.edu.au)[1], **Norman J. Pearson** (npearson@laurel.ocs.mq.edu.au)[1], **Suzanne Y. O'Reilly** (sue.oreilly@mq.edu.au)[1] & **Xisheng Xu** (xzhou@netra.nju.edu.cn)[2]

[1] EMOC ARC National Key Centre, Dept. of Earth and Planetary Sciences Sciences, Macquarie University, NSW 2109, Australia
[2] Dept of Earth Sciences, Nanjing University, Nanjing, China

Field relationships in the 115 Ma Pingtandao complex (Fujian Province, SE China) show extensive mingling of mafic and felsic magmas, producing pillow-like enclaves, and suggest formation of at least some intermediate members of the suite (granodiorite, quartz diorite) through hybridisation (Xu et al., 1999). Similar Sr (initial $^{87}Sr/^{86}Sr = 0.7065$) and Nd ($\varepsilon_{Nd} = -1.5$) isotopic compositions imply that both the felsic and the mafic magmas represent contain a significant crustal component, but Nd model ages ($T_{DM} = 1Ga$), significantly younger than known crust in the region (1.4-2.0Ga), suggest a juvenile component as well. To investigate the processes of crust-mantle interaction, and specifically the timing of any mixing of crustal and mantle components, we have carried out a detailed study of the Pingtan rocks, using LAM-MC-ICPMS techniques to analyse Hf isotopes in individual zircon grains.

Zircons (N200x50 µm) were separated from a granite, a granodiorite enclave (pillow) in the granite, a quartz diorite enclave, a granodiorite and a gabbro. The zircons in each rock show several growth stages, recognised by studies of external and internal morphology in cathodoluminescence images. Detailed EMP (Hf, Y, U, Th) and LAM-ICPMS (REE, U, Th, other trace elements) analysis shows that changes in internal morphology or zoning style are accompanied by changes in trace-element patterns, reflecting changes in magma composition and/or physical conditions. These data show that the zircons have acted as recorders of the evolution of the magmas, and that this evolution included abrupt changes in composition.

Hf isotopes were analysed using a Merchantek LUV266 Nd:YAG laser probe, attached to a Nu Plasma multi-collector ICPMS. Typical spot sizes were 30-40 microns; typical internal precision of $^{176}Hf/^{177}Hf$ on 1-2 minute ablations was ±0.00002-6 (2SE). Interferences of $^{176}Lu$ and $^{176}Yb$ on $^{176}Hf$ were corrected by monitoring $^{175}Lu$ and $^{172}Yb$; the accuracy and precision to which these overlaps can be corrected are comparable to the internal precision up to $^{176}Yb/^{177}Hf = 0.3$ (Griffin et al., 2000). Time-resolved data collection commonly showed that distinct "stratigraphy" in Yb/Hf, Hf content and $^{176}Hf/^{177}Hf$ was intersected by the beam during drilling, making it possible to select parts of the signal representing major zones.

Zircons from all samples show a major peak at $^{176}Hf/^{177}Hf = 0.2828 \pm 0.0001$ ($\varepsilon_{Hf} = +2\text{-}+4$, $T_{DM}$ model ages = 600Ma). This is a minimum age for the source and may reflect the remelting of Proterozoic/Paleozoic lower crust. The zircons of the granodiorites and gabbro are mainly of this type, but some have more radiogenic Hf. The quartz diorite and the granite also contain this type, as well as others with less radiogenic Hf ($^{176}Hf/^{177}Hf$ = 0.2825-26; $T_{DM}$ = 1.0-1.2 Ga). Both rocks also contain zircons with more radiogenic Hf ($^{176}Hf/^{177}Hf$ =0.2829-0.2830). Individual grains are typically zoned from less to more radiogenic Hf compositions, but some are reversely zoned. Late-stage zircons in each sample generally have Hf isotope compositions intermediate between the extremes. The isotopic zoning patterns, and the presence of distinct isotopic populations corresponding to recognised growth stages, cannot be explained by fractional crystallisation or restite unmixing, but require the mixing of magmas with disparate Hf-isotope compositions, derived from different sources and having different compositions.

The trace element and Hf isotope data suggest that mixing of crustally-derived magmas with a juvenile component, followed by crystallisation of zircon from the mixed magma, has taken place several times during the evolution of the Pingtandao complex. The repeated input of mantle-derived magmas probably has important provided heat for the production of the granitoid magmas; the isotopic data suggest that the mantle-derived magmas also have contributed new material to the crust.

The use of zircon as a process recorder recovers information on the evolution of magmas that is lost during the analysis of whole-rock samples. The availability of rapid, low-cost *in-situ* microanalysis of trace-element patterns and Hf-isotope compositions of zircons, coupled with the detailed study of internal morphology, is about to bring major advances in our understanding of magma genesis in crustal settings.

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