

## ANALYTICAL PROCEDURES

### U-Th-Pb dating of titanite

Titanite crystals were analyzed in situ using a Coherent Scientific 193 nm Ar-F gas laser coupled with a Resonetics M50 ablation cell and an Agilent 7500cs quadrupole ICPMS at the University of Tasmania. Analysis was performed using a 47  $\mu\text{m}$  spot size, a repetition rate of 5 Hz and energy density 2.0 J/cm<sup>2</sup> for 30 seconds preceded by a 30 second gas blank. Ablation was carried out in a He atmosphere (0.35 litres/minute) while transfer of material within the ablation plume to the ICPMS torch occurred in an argon-helium mixture. The isotopes measured were <sup>31</sup>P, <sup>49</sup>Ti, <sup>43</sup>Ca, <sup>56</sup>Fe, <sup>140</sup>Ce, <sup>202</sup>Hg, <sup>204</sup>Pb, <sup>206</sup>Pb, <sup>207</sup>Pb, <sup>208</sup>Pb, <sup>232</sup>Th and <sup>238</sup>U (5 ms dwell time for the major and trace elements, 20 ms Pb isotopes, and 10 ms for Th and U).

Raw analytical data were corrected with reference to a titanite primary standard (AUR100606) from a hornblende gabbro in north Queensland (Best 2012). AUR100606 was standardized using isotope dilution thermal ionisation mass spectrometry (ID-TIMS) at the University of British Columbia by Richard Friedman (reported by Best 2012) giving a near-concordant age  $432.02 \pm 0.63$  Ma. The age of the standard titanite was within error of the zircon analyzed from the same gabbro ( $430.4 \pm 4.1$  Ma LA-ICPMS; Best 2012). The primary standard was analyzed at the beginning of each session and between sets of 15 unknowns (i.e., roughly every 30 minutes). Pb mass bias was monitored using 2 large spot of NIST610 analyzed at the beginning and end of the day and corrected using the values recommended by Baker et al. (2004). Common Pb corrections based on <sup>207</sup>Pb were done for both the primary standards and the unknowns as suggested in Chew et al. (2014); the remainder of the data reduction and error propagation has been described in Halpin et al. (2014).

### U-Th-Pb, Rb-Sr and Sm-Nd isotopes:

Radiogenic isotope analyses of Avebury dunites were carried out at the University of Melbourne, using methods adapted from Maas et al. (2005). Due to low elemental concentrations (e.g. 170-974 ppb Sr, 32-465 ppb Nd), Rb-Sr and Sm-Nd isotope dilution analyses were done on relatively large (0.5-0.6 grams) splits of agate-milled sample powder. To minimize dissolution problems with such large, Mg-rich samples, the powders were repeatedly leached with HCl (6M HCl, hotplate, 120°C, 12 hrs each) to remove much of the Mg (e.g., Makishima and Nakamura, 1991) prior to reaction with hydrofluoric acid (3:1 HF-HNO<sub>3</sub>, 120°C, 3 days, 2 dry-downs with conc. HNO<sub>3</sub>) and final dissolution in 6M HCl (2 days, 120°C). Double-distilled suprapure acids were used throughout. At the end of the procedure, all liquid was recombined and spiked with <sup>85</sup>Rb-<sup>84</sup>Sr and <sup>149</sup>Sm-<sup>150</sup>Nd tracers; no residues or gels were observed at this stage. Fractions rich in Rb, Sr and LREE were extracted on 4 ml columns of new AG50-X8 (200-400 mesh) cation resin, using 2M HCl, 2.5M HNO<sub>3</sub> and 6M HCl. To avoid overloading the columns, samples were split and the splits passed over the same column sequentially. Rb and Sr fractions were further purified on small (0.1 ml) beds of Eichrom Sr resin, while Sm and Nd were isolated on 1 ml columns of Eichrom LN-resin. Total blanks were ~0.1 ng Sr and Nd (Rb/Sr=0.3, Sm/Nd=0.2). Pb isotope analyses were carried out on ~0.06 g of powder dissolved on a hotplate. Pb was extracted with 2 passes on small (0.1 ml) beds of AG1-X8 (100-200 mesh) anion resin, using HBr-HCl chemistry. The procedural blank (~0.1 ng) was negligible relative to sample sizes  $\geq 260$  ng Pb.

Isotopic analyses were carried out on a Nu Plasma multi-collector ICP-MS coupled to a CETAC Aridus desolvating system and low-uptake PFA nebuliser. Instrumental mass bias in Sr and Nd

isotope analyses was corrected by normalizing to  $^{88}\text{Sr}/^{86}\text{Sr} = 8.37521$  and  $^{146}\text{Nd}/^{145}\text{Nd} = 2.0719425$  (equivalent to  $^{146}\text{Nd}/^{144}\text{Nd} = 0.7219$ ), using the exponential law as part of an on-line iterative spike-stripping/internal normalisation procedure. Data are reported relative to SRM987 = 0.710230 and La Jolla Nd = 0.511860, respectively. Mass bias corrections for Rb isotope dilution runs were done using Zr doping. External precision (2sd) is  $\pm 0.5\%$  for  $^{87}\text{Rb}/^{86}\text{Sr}$ ,  $\pm 0.00004$  for  $^{87}\text{Sr}/^{86}\text{Sr}$ ,  $\pm 0.2\%$  for  $^{147}\text{Sm}/^{144}\text{Nd}$  and  $\pm 0.000020$  for  $^{143}\text{Nd}/^{144}\text{Nd}$ .

USGS basalt standard BCR-2 yields  $^{87}\text{Rb}/^{86}\text{Sr} = 0.400 \pm 5$ ,  $^{87}\text{Sr}/^{86}\text{Sr} = 0.704997 \pm 53$  ( $n=40$ ),  $^{147}\text{Sm}/^{144}\text{Nd} = 0.1382 \pm 2$  and  $^{143}\text{Nd}/^{144}\text{Nd} = 0.512642 \pm 24$  ( $n=54$ , all errors  $\pm 2\text{sd}$ ).  $\epsilon_{\text{Nd}}$  values are calculated for a modern CHUR reservoir with  $^{147}\text{Sm}/^{144}\text{Nd} = 0.1960$  and  $^{143}\text{Nd}/^{144}\text{Nd} = 0.512632$  (Bouvier et al. 2008). Instrumental mass bias in Pb isotope analyses was corrected using the thallium-doping technique of Woodhead (2002). This produces routine external precisions of 0.05-0.08% (2sd). BCR-2 averages  $^{206}\text{Pb}/^{204}\text{Pb} = 18.758 \pm 0.048\%$ ,  $^{207}\text{Pb}/^{204}\text{Pb} = 15.619 \pm 0.064\%$  and  $^{208}\text{Pb}/^{204}\text{Pb} = 38.726 \pm 0.090\%$  (2sd, error correlations  $\sim 0.75$ , 2011-2013,  $n=41$ ), consistent with TIMS and MC-ICPMS reference values.  $^{238}\text{U}/^{204}\text{Pb}$  and  $^{232}\text{Th}/^{204}\text{Pb}$  ratios were calculated from trace element results and have a precision of  $\pm 5\%$ . Decay constants are:  $^{87}\text{Rb}$   $1.395 \times 10^{-11}/\text{yr}$ ,  $^{147}\text{Sm}$   $6.54 \times 10^{-12}/\text{yr}$ ,  $^{238}\text{U}$   $0.155125 \times 10^{-9}/\text{yr}$ ,  $^{235}\text{U}$   $0.98485 \times 10^{-9}/\text{yr}$ ,  $^{232}\text{Th}$   $0.049485 \times 10^{-9}/\text{yr}$ .

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