**Appendix 1. Microprobe methods**

A Joel JXA-8530F Hyperprobe at the CMCA, fitted with five wavelength-dispersive spectrometers (WDS), was used for quantitative analysis of biotite and apatite. Proprietry standards were employed to monitor the accuracy of the analyses.

For WDS analyses of biotite, an accelerating voltage of 15 kV and a beam current of 15 nA were used, in conjunction with a beam size of 5 microns. Counting or dwell time was 30 seconds for Ca, Si, Al, Mg, Mn, Na, K, Cr, Fe, Ti and Cl, and 40 seconds for F.

For apatite analyses, the beam current was set at 15 nA for Ca, P, Na, F and Cl, and 50nA for Sr, Ce, Nd, Si, Mg, Al, S, Mn, La and Fe. Dwell time was 30 seconds for F, 40 seconds for Ca, P, Si, Mg, Al, Na, Fe, Sr and Cl, 60 seconds for Mn, Ce, La and Nd, and 100 seconds for S.

**Appendix 2. LA\_SF\_ICP\_MS**

Apatite trace element concentrations were determined by LA-SF-ICPMS at The University of Western Australia. The LA-SF-ICPMS system used in this study consisted Cetac Analyte G2 193 nm ArF laser coupled to an Element XR ICPMS. The Element XR was operated in high sensitivity mode by employing a higher vacuum interface along with the Jet sample cone and X skimmer cone configuration and the addition of 7 to 9 mL/min N2. A total of 1 L/min of He carrier gas was added through the laser cell and Helix sample cup. Laser ablation analyses were carried out using a fluence of 4 J/cm2, a laser repetition rate of 5Hz, and laser spot diameter of 35 um. Each analysis consisted of a 30 s gas blank, 10 second laser “warm up” period, followed by 60 seconds of ablation time for a total of 300 laser pulses. Each analysis was followed by a 20 s washout period before the next analysis began. The measured masses are listed in the table below. Daily ThO/Th was routinely less than 0.3**%** percent, and 232Th/238U is tuned to be ~1. All analyses were calibrated to the NIST 612 glass standard using the preferred values provided by GeoReM (http://georem.mpch-mainz.gwdg.de/). The MAD and Tory Hill apatite (Fisher et al., 2020) were employed as a secondary standard to monitor the accuracy and reproducibility of the method. Data were reduced with the method described in using the Iolite 4 software platform (**Paton et al., 2011**).

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| **Thermo Fisher ELEMENT XR  (SF-ICP-MS)** | Thermo Fisher Scientific, Bremen, Germany |
| RF forward power | 1350 W |
| RF reflected power | <4 W |
| Cooling gas flow (Ar) | 16 L/min |
| Carrier gas flow (Ar) | 0.95 L/min |
| Make up gas (He+N2) flow | 1.00 L/min He (Cell 0.30 L/min, Cup 0.70 L/min);  7 mL/min N2 |
| Monitored masses | 29Si, 31P, 43Ca, 49Ti, 51V, 55Mn, 63Cu, 75As, 82Se, 85Rb, 88Sr, 89Y, 90Zr, 93Nb, 137Ba, 139La, 140Ce, 141Pr, 146Nd, 147Sm, 153Eu, 157Gd, 159Tb, 163Dy, 165Ho, 166Er, 169Tm, 172Yb, 175Lu, 208Pb, 232Th, 238U |
| Detector mode | Counting or analogue respective to count rate |
| Cycle time | 310ms |
| Other notes | Quartz injector, Ni X skimmer & Jet sample cones, tuned for ThO+/Th+ <0.3%; Th/U ~1 |
|  |  |
| **Photon machines\***  **Analyte G2 excimer laser** | \*now Teledyne Cetac, Omaha, USA |
| Spot diameter | 35µm circle |
| Laser source | ATLEX-LR-I (193nm ArF Excimer; ~4 ns pulse width) |
| Cell | HelEx II 2 volume cell |
| Fluence | 4 J/cm2 |
| Repetition rate | 7 Hz |
| Delay between analyses | 20s |
| Ablation duration | 30s |

PATON, C., HELLSTROM, J., PAUL, B., WOODHEAD, J. & HERGT, J. (2011) Iolite: Freeware for the visualisation and processing of mass spectrometric data. Journal of Analytical Atomic Spectrometry, 25, 2508–2518. https://doi.org/10.1039/c1ja10172b