**Appendix**

U-Pb Methods

Zircon crystals were extracted from samples by traditional methods of crushing and grinding, followed by separation with a Wilfley table, heavy liquids, and a Frantz magnetic separator.  Samples were processed such that all zircons were retained in the final heavy mineral fraction.  A large split of these grains (generally thousands of grains) was incorporated into a 1-inch epoxy mount together with fragments of our Sri Lanka standard zircon.  The mounts were sanded down to a depth of ~20 microns, polished, imaged, and cleaned prior to isotopic analysis.

U-Pb analyses were conducted by laser ablation multicollector inductively coupled plasma mass spectrometry (LA-MC-ICPMS) at the Arizona LaserChron Center (Gehrels *et al.* 2006, 2008). The analyses involved ablation of zircon with a Photon Machines Analyte G2 excimer laser using a spot diameter of 30 microns. The ablated material is carried in helium into the plasma source of a Nu HR ICPMS, which is equipped with a flight tube of sufficient width that U, Th, and Pb isotopes are measured simultaneously. All measurements are made in static mode, using Faraday detectors with 3x1011 ohm resistors for 238U, 232Th, 208Pb-206Pb, and discrete dynode ion counters for 204Pb and 202Hg.  Ion yields are ~0.8 mv per ppm. Each analysis consists of one 15-second integration on peaks with the laser off (for backgrounds), 15 one-second integrations with the laser firing, and a 30 second delay to purge the previous sample and prepare for the next analysis. The ablation pit is ~15 microns in depth.

For each analysis, the errors in determining 206Pb/238U and 206Pb/204Pb result in a measurement error of ~1-2% (2σ) in the 206Pb/238U age. The errors in measurement of 206Pb/207Pb and 206Pb/204Pb also result in ~1-2% (2σ) uncertainty in age for grains that are >1000 Ma, but are substantially larger for younger grains due to low intensity of the 207Pb signal. For most analyses, the cross-over in precision of 206Pb/238U and 206Pb/207Pb ages occurs at ~1000 Ma.

204Hg interference with 204Pb is accounted for measurement of 202Hg during laser ablation and subtraction of 204Hg according to the natural 202Hg/204Hg of 4.35. This Hg is correction is not significant for most analyses because our Hg backgrounds are low (generally ~150 cps at mass 204).

Common Pb correction is accomplished by using the Hg-corrected 204Pb and assuming an initial Pb composition from Stacey and Kramers (1975). Uncertainties of 1.5 for 206Pb/204Pb and 0.3 for 207Pb/204Pb are applied to these compositional values based on the variation in Pb isotopic composition in crustal rocks.

Inter-element fractionation of Pb/U is generally ~5%, whereas apparent fractionation of Pb isotopes is generally <0.2%. In-run analysis of fragments of a large zircon crystal (generally every fifth measurement) with known age of 563.5 ± 3.2 Ma (2σ) is used to correct for this fractionation. The uncertainty resulting from the calibration correction is generally 1-2% (2σ) for both 206Pb/207Pb and 206Pb/238U ages.

Concentrations of U and Th are calibrated relative to our Sri Lanka zircon, which contains ~518 ppm of U and 68 ppm Th. The analytical data are reported in Supplementary Material available on the Cambridge Journals online website.  Uncertainties shown in these tables are at the 1σ level, and include only measurement errors.  Analyses that are >20% discordant (by comparison of 206Pb/238U and 206Pb/207Pb ages) or >5% reverse discordant (in italics in Supplementary Material) are not considered further.

The resulting interpreted ages are shown on relative age-probability diagrams using the routines in Isoplot (Ludwig, 2008). The age-probability diagrams show each age and its uncertainty (for measurement error only) as a normal distribution, and sum all ages from a sample into a single curve.  Composite age probability plots are made from an in-house Excel program that normalizes each curve according to the number of constituent analyses, such that each curve contains the same area, and then stacks the probability curves.

Thermochronology Methods

 Samples were prepared using standard mechanical, density and magnetic separation techniques. The clearest, most-euhedral apatite grains without inclusions or other impurities or cracks were selected using a binocular microscope. Euhedral zircon grains were selected, but some had visible inclusions. Grain dimensions were measured for the calculation of the alpha-correction factor after Farley *et al.* (1996) for apatite and after Hourigan *et al.* (2005) for zircon. Single grains were packed in Nb-tubes for U-Th/He analysis. In general we analyzed 3-5 aliquots per sample. Helium was measured in the Patterson Helium-extraction line at the University of Tübingen, which is equipped with a 960 nm diode laser. Apatite grains were heated for 5 min at 11 A and zircon grains for 10 min at 20 A. Each grain was re-heated and analyzed to make sure that the grain was degassed entirely in the first step. The re-extracts generally showed <1% of the first signal.

Concentrations of U, Th and Sm were determined by isotope dilution using a Thermo Fisher iCAP ICP-MS equipped with an all-PFA sample introduction system. Apatite samples together with the Nb-tubes were spiked with a calibrated mixed spike of 233U + 230Th + 149Sm and dissolved overnight in 2 ml 5% HNO3 + 0.1% HF at 65 °C. The grain mass of each sample was estimated from measured 43Ca concentrations assuming 39.4 wt % Ca in apatite. Zircon samples were dissolves using a two-step HF+HNO3 and HCl pressure digestion procedure. Zircon grain masses were estimated from measured 91Zr concentrations assuming 49.77 wt % Zr.

The analytical error of the mass spectrometer measurements are generally very low and do not exceed 2%. In contrast, the reproducibility of the sample age constitutes a much larger error. We therefore report the mean U-Th/He age and standard deviation of measured aliquots as the sample error. For single grain ages we apply a 5% (2σ) error based on the reproducibility of standard measurements in the lab.

**References**

Farley, K. A., Wolf, R. A. & Silver, L. T. 1996. The effects of long alpha-stopping distances on (U-Th)/He ages. *Geochimica et Cosmochimica Acta* **60**(21), 4223--9.

Gehrels, G., Valencia, V. & Pullen, A. 2006. Detrital zircon geochronology by laser ablation multicollector ICPMS at the Arizona LaserChron Center. In (ed. T. Olszewski), *Geochronology: Emerging Opportunities: Paleontology Society Papers*, Volume 12, pp. 67--76.

Gehrels, G. E., Valencia, V. & Ruiz, J. 2008. Enhanced precision, accuracy, efficiency, and spatial resolution of U-Pb ages by laser ablation-multicollector-inductively coupled plasma-mass spectrometry: geochemistry, Geophysics, Geosystems, v. 9, Q03017, doi:10.1029/2007GC001805.

Hourigan, J. K., Reiners, P. W. & Brandon, M. T. 2005. U–Th zonation-dependent alpha-ejection in (U–Th)/He chronometry. *Geochimica et Cosmochimica Acta* **69**, 3349--65.

Ludwig, K. R. 2008. Isoplot 3.60. Berkeley Geochronology Center, Special Publication No. 4, 77 pp.

Stacey, J. S. & Kramers, J. D. 1975. Approximation of terrestrial lead isotope evolution by a two‑stage model. *Earth and Planetary Science Letters* **26**, 207–21.