VESPA Dating Study Supplemental File 1. Analytical methods

$^{40}Ar/^{39}Ar$ geochronology

Most Ar–Ar dating was done at the University of California Santa Barbara (UCSB). Laboratory methods and interpretive workflows were identical to those described in Mortimer et al. (2014), but with the additional investigation of the groundmass of some samples by electron probe microanalysis on a Cameca SX-100 electron microprobe to better characterise the nature of groundmass K reservoirs and their K/Ca values. This comprised X-ray element mapping of groundmass and wavelength dispersive major element analysis to identify groundmass minerals.

Samples for radiometric dating were separated by standard sieving, heavy liquid, and magnetic separation techniques at GNS Science. Further magnetic separation and final handpicking were done at the University of California Santa Barbara (UCSB). Splits of each sample ranging from 1 to 120 mg were encapsulated in copper packets and loaded into a sealed quartz vial interspersed with packaged flux monitors. Vials were irradiated in a cadmium-lined tube at the TRIGA (Training, Research, Isotopes, General Atomics) reactor at Oregon State University in several different irradiations for durations of 8 to 20 hours depending on the estimated ages of the samples. Samples were analysed in the $^{40}Ar/^{39}Ar$ geochronology laboratory at UCSB by heating in a Staudacher-type resistance furnace with isotopic analysis on a MAP 216 mass spectrometer using the general procedures and system described by Gans (1997). The flux monitor used for all irradiations was Taylor Creek Rhyolite with an assigned age of 27.92 Ma (Dalrymple and Duffield, 1988). For comparison, we obtain an age of 27.60 Ma on Fish Canyon Tuff sanidine, another widely used standard. In the main paper and in all Supplemental Files, calculated ages are updated to a Fish Canyon sanidine calibration of 28.198 Ma. Raw data and plots are presented in Supplemental File 6. Quoted precision in figures and tables in Supplemental File 6 are $\pm 1\sigma$ propagated errors, but all errors in the text, tables and figures of the main paper are $\pm 2\sigma$. For calculating errors of weighted mean ages of adjacent steps which do not form statistical plateaus, we followed Fleck et al. (2014) in multiplying the propagated errors by the square root of the mean square of weighted deviates (MSWD) in cases where MSWD>1.

Plagioclase from one sample in our dataset, DR43Ai (P82418), was dated at the U.S. Geological Survey in Menlo Park. Neutron flux was measured using Taylor Creek Rhyolite sanidine (TCR-2) fluence monitors with an assigned age of 28.35 Ma, equivalent ($R = 1.00881 \pm 0.00046$) to the widely used Fish Canyon sanidine at 28.10 Ma (Spell & McDougall, 2003). Argon was extracted in a Mo crucible in a Staudacher-type custom resistance furnace attached to the MAP 216 mass spectrometer i.e., similar to that used at UCSB. Mass spectrometer discrimination and system blanks were determined using the techniques of Calvert & Lanphere (2006). Results are updated to calibration with a Fish Canyon sanidine age of 28.198 Ma.

U/Pb geochronology

Zircon grains for U-Pb dating were handpicked and mounted in epoxy. Cathodoluminescence images were taken of zircon grains to detect composite core-overgrowth grains and to guide analysis spot placement. U-Pb dating was done at the Centre for Trace Element Analysis, University of Otago by laser ablation inductively coupled mass spectrometry (LA-ICP-MS) on a Resonetics RESOlution M-50-LR laser ablation system incorporating a Coherent COMPexPro 102 193 nm ArF excimer laser and Laurin Technic two-volume sample cell. The laser was operated at 100 mJ and 12.5% transmission giving a typical fluence value of 4 J/cm^2, using a spot diameter of 33 μm and a 5 Hz repetition rate. Ablated material was carried by He gas (650–750 ml/min) from a two-volume sample cell, mixed with Ar (650-750 ml/min) and N_2 (2–6 ml/min) and input to an Agilent 7500cs quadrupole ICP-MS. Background data were acquired for 20 s followed by 40 s with the laser on, giving approximately 100 mass scans and a penetration depth of ~20 μm. Depth related inter-element fractionation of Pb, Th and U were corrected by reference to the TEMORA-2 zircon standard (Black et al., 2004). TEMORA-2 (x2), R33 and DR/P73479 (secondary standards) and NIST glass 610 were measured at the beginning of each analytical session and then once every 15 unknown analyses. Measured ^{207}Pb/^{206}Pb, ^{206}Pb/^{238}U and ^{208}Pb/^{232}Th ratios in the TEMORA-2 zircon standard and ^{232}Th/^{238}U ratios in NIST610 silicate glass were averaged and used to calculate correction factors based on published, accepted values (Pearce et al., 1997; Black et al., 2003). Data were reduced using Iolite software (Paton et al., 2011). Probability density plots and peak deconvolution were produced using Isoplot software (Ludwig, 2003). Ages reported in the main paper and in Supplemental File 6 are ^{206}Pb/^{238}U ages; all errors quoted are ±2σ and/or apply at the 95% confidence level.

Biostratigraphy
Micropaleontological dating methods are explained in Crundwell et al. (2016) which is included with this VESPA Dating Study as Supplemental File 8. Mudstone samples were dried, soaked in water, disaggregated by hand, and washed over a 75 μm screen. Limestone samples were dried, crushed, washed and the 1-5 mm fraction treated in 80% acetic acid for 9–10 days. The >150 μm fraction of each sample was examined under a binocular microscope for key age and environmentally significant foraminifera. Biostratigraphic ages are reported in terms of standard planktic foraminiferal N-zones of Banner and Blow (1965) and Blow (1969) and adopted ages in terms of the New Zealand timescale of Raine et al. (2015). All material and results are curated in the GNS Science F-number catalogue and the NZ Fossil Record database.

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