**A Bayesian age estimate from dispersed plagioclase and zircon dates in the Los Chocoyos ash, Central America**

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**Supplemental Materials**

**Text S1:** U-Th disequilibrium, 40Ar/39Ar, Weighted Mean Average, and Bayesian modeling analytical methods

**Table S1:** Summary of U-Th disequilibrium ages

**Table S2:** Summary of 40Ar/39Ar ages

**Code S1:** Ar Closure Distribution Bootstrapping, Los Chocoyos Ash Bayesian age, and Youngest Toba Tuff Bayesian and Julia scripts and data

**SUPPLEMENTAL MATERIALS**

**METHODS**

**40Ar/39Ar ANALYTICAL METHODS**

Plagioclase crystals were extracted from rhyolitic pumice using a series of physical and chemical processes, including crushing, sieving, and magnetic sorting. The resulting samples were subjected to ultrasonic leaching using a 10-25% hydrochloric acid solution followed by ultrasonic leaching with 1.5M hydrofluoric acid for several minutes. The plagioclase crystals with the highest potassium content were identified using a variable pressure scanning electron microscope. The plagioclase separates were wrapped in aluminum foil and placed in a 4mm diameter well in a 2.5cm aluminum disk. The samples were then irradiated for two hours in the cadmium-lined in-core tube at the Oregon State University reactor, using the 1.1864 million-year-old Alder Creek sanidine as a neutron fluence monitor. Sixty-eight single crystal fusion experiments were conducted using a 55 W CO2 laser in the WiscAr laboratory at the University of Wisconsin-Madison. The resulting data were analyzed using a Noblesse multi-collector mass spectrometer, following the analytical and data correction procedures outlined in Jicha et al. (2016). An additional 49 single crystal fusions were analyzed using the NGX-600 mass spectrometer (Mixon et al. 2022). All 40Ar/39Ar dates were calculated using the decay constants of Min et al. (2000), and the atmospheric argon composition used was that of Lee et al. (2006).

**U-Th ANALYTICAL METHODS**

Zircon crystals were isolated utilizing an array of physical and chemical processes, which included crushing, sieving, magnetic sorting, and density separation employing methylene iodide. To eliminate adhering volcanic glass, all examined crystals underwent ultrasonic leaching utilizing a hydrochloric acid solution of 10-25% concentration. Individual zircon crystals were manually chosen, and 66 zircon crystals were placed oriented on a glass slide and pressed into deformable indium metal. Euhedral zircons from the “early” Bishop Tuff (767.1 ± 0.9 ka, Crowley et al., 2007) were co-mounted and employed as standards for measuring 238U-230Th secular equilibrium. The mounting procedure resulted in primarily flat, non-polished crystal surfaces exposed parallel to the mount surface. Prior to analysis, all grains were visualized with reflected light on a petrographic microscope to detect physical defects such as fractured or malformed crystal faces. Before introducing the indium-mounted zircons into the SHRIMP-RG instrument, they were immersed in soapy water, followed by a 10% ethylenediaminetetraacetic acid (EDTA) wash for approximately 2 minutes each, thoroughly washed in distilled water, and then dried at 50°C in a vacuum oven. Prior to SHRIMP-RG analyses, the sample surface was coated with about 50 nm of gold for surface conductivity.

The zircon U-Th disequilibrium analyses were conducted by secondary ion mass spectrometry (SIMS) using the SHRIMP-RG ion microprobe employing an O2− primary ion beam with an intensity of 19 nA, resulting in an analysis pit of around 40 μm diameter and approximately 4 μm depth. Each analysis lasted approximately 35 minutes, including a pre-analysis raster of the sample surface by the primary beam for roughly 20 seconds. The acquisition routine comprised analysis of 90Zr216O+, 238U+, 232Th12C+, 230Th16O+, background measured 0.050 amu above the 230Th16O+ peak, 232Th16O+, and 238U16O+. Monitoring 232Th12C+ was conducted to assess carbide interference on 230Th16O+ (e.g., Schmitt et al., 2006). No analyses had 232Th12C+ count rates above the 0.5 cps threshold taken to indicate contamination. The SHRIMP-RG was calibrated for a mass resolution of 8000-9000 (10% peak height), and the energy selection window was set to accept high-energy ions into the collector to maximize abundance sensitivity and minimize background at 230Th16O+. Using secular equilibrium “early” Bishop Tuff zircon with high U (~1000–4000 ppm) rim surfaces, the position of the energy window was shifted to a positive eV offset until the signal-to-noise ratio was greater than 200 on 230Th16O+ (e.g., Burgess et al., 2021). Measured 238U/232Th values for the unknowns were adjusted for relative U/Th ionization, which is characteristic of SIMS, using a session-specific relative sensitivity factor derived from interspersed analyses of 230Th/238U in the co-mounted Bishop Tuff zircons (e.g., Anderson et al., 2019). Uranium concentrations are calculated from a session-specific analysis of MAD-559 reference zircon (3940 ppm, Coble et al., 2018).

**WEIGHTED MEAN AVERAGE**

Weighted mean average ages of the dispersed 40Ar/39Ar and U-Th disequilibrium age distributions were calculated according to Schaen et al. (2021) low MSWD (method 1). The oldest crystal ages in each dataset is omitted until the MSWD of the weighted mean ages is as close to 1 as possible. Each separate weighted mean ages and combined weighted mean ages reported are calculated individually. IsoplotR: a free and open toolbox for geochronology (Vermeesh P., 2018) was used for all calculations.

**BAYESIAN MODELING**

Dispersed 40Ar/39Ar and U-Th disequilibrium age distributions preclude calculation of a weighted mean age, leading us to adopt a Bayesian approach to eruption age estimation based on the algorithm of Keller et al. (2018) (e.g., van Zalinge et al., 2022). Bayesian eruption age estimation requires a previous estimate of the relative age distribution of crystallization (zircon U-Th: equivalent to that of zircon U-Pb) or apparent closure (feldspar Ar-Ar) ages before eruption, which are estimated by bootstrapping (e.g., Suckale et al., 2018; closure distributions U-Th are equivalent to U-Pb due to date zircon crystallization). Incorporating all then-available 40Ar/39Ar age distributions that featured well-resolved pre-eruptive heterogeneity, van Zalinge et al. (2022) found that bootstrapping by kernel density estimation revealed a consistent, exponential form of the relative closure age distribution suggestive of an underlying survivorship process (for example, incomplete partial degassing of antecrysts or xenocrysts during eruption or cold storage). For excess Ar, the observed continuum of ages would not be expected. Using this exponential age distribution, we find the resulting eruption age estimates based on 40Ar/39Ar plagioclase ages are indistinguishable within uncertainty from those based on U-Th disequilibrium zircon crystallization ages. In accordance with the methods used in van Zalinge et al (2022), we applied the Markov chain Monte Carlo eruption age estimation algorithm in the Chron.jl software package (Keller et al., 2018) to each ignimbrite, using a half-normal relative crystallization distribution for all zircon ages, and our previously determined exponential relative closure distribution for all sanidine 40Ar/39Ar ages. Systematic uncertainties were propagated using the ‘optimization intercalibration’ with the decay constants of Min et al. (2000) for 40Ar/39Ar ages, and the decay constants Cheng et al. (2013) for U-Th disequilibrium ages. A comparison between U-Th disequilibrium datasets from Cisneros de León et al. (2021) and this study show systematic differences in age range. The systematic differences were unable to be pinpointed, however separate Bayesian ages were calculated for each dataset and a weighted mean average was determined from the two Bayesian ages to balance the systematic uncertainties between U-Th datasets.

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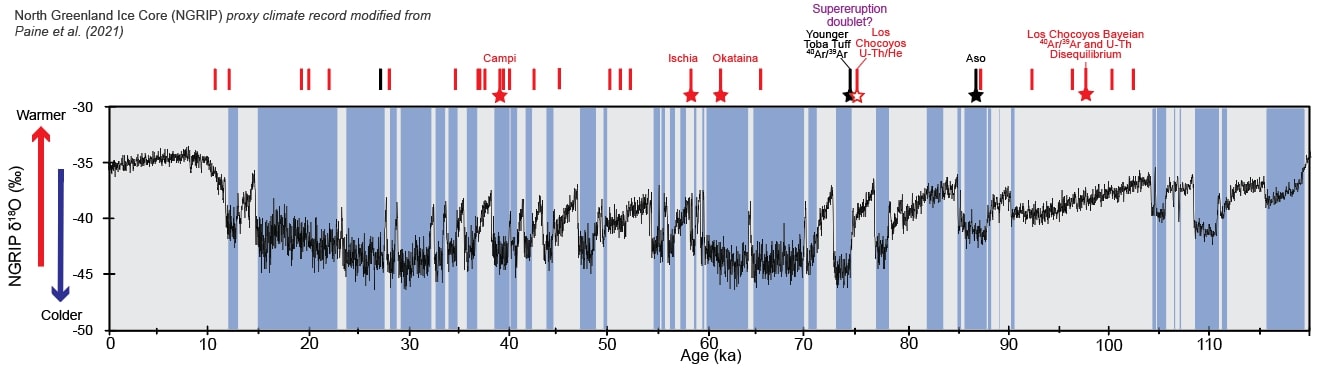
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**Figures**

**A map of the earth and rocks

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**Figure 1** A. Distribution of the Los Chocoyos ash (pink) relative to Atitlan Caldera, Guatemala, with sample site at San Juan Ostancalco as yellow star (modified from Cisneros de León et al., 2021). Map is a hill shade created from a 12.5-meter resolution ALOS-PALSAR DEM. B. Isopach map of Los Chocoyos ash thickness (modified from Kutterolf et al., 2016), with location of marine sediment cores V19-29 and V19-30 (Drexler et al., 1980) and K 120 and K 127 (Kennett and Huddlestun, 1972) from which ages of 84 ka and 95 ka have been inferred, respectively, for the Los Chocoyos ash. C. Outcrop in quarry at San Juan Ostancalco sampling site (14.86747 °N, 91.61147 °E, WGS84 GPS) showing white basal airfall bed overlain by pink ignimbrite; note 30 cm hammer for scale. Photo from 1974 courtesy of Bill Rose. D. Pumice blocks from which plagioclase and zircon were separated for measurements reported here.

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**Figure 2.** North Greenland Ice Core Project (NGRIP) record of oxygen isotope variations during the last 120 ka. Heavier values indicate warm periods in grey, whereas cold periods known as stadials are in blue (Rasmussen et al., 2014). Exceptionally large known eruptions are represented as red (7<M<8) and black (M>8) bars, whereas those with radioisotopic ages are shown with stars (Zielinski et al., 1996). The U-Th/He age proposed for the Los Chocoyos ash of Cisneros de León et al. (2021) is denoted by the white star with red outline, whereas the Los Chocoyos age determined here is denoted by the filled red star. The Youngest Toba Tuff date is from Storey et al. (2012).

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**Figure 3**. U-Th disequilibrium zircon from Cisneros de León et al. (2021) (A), 40Ar/39Ar plagioclase (B) and U-Th disequilibrium zircon (C) dates from this work and U-Th/He ZDD dates from Cisneros de León et al. (2021) (D), as indicated. The Bayesian estimates of eruption age for the three sets of dates are shown as vertical green, blue, and orange lines with ±2σ uncertainty envelopes. The combined Bayesian eruption age of 98 ± 6 ka from these 308 dates is denoted as a vertical magenta line and ±2σ uncertainty envelope. The dotted gray line and uncertainty envelope indicates the O isotope-based eruption age of 84 ± 5 ka from Drexler et al. (1980). Left panel (A) is a close up of the summary ages.

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**Figure 4**. K/Ca ratio vs. apparent 40Ar/39Ar age for plagioclase crystals in Los Chocoyos ash.

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**Figure 5**. Inverse isochron plot of data from 118 plagioclase crystals from the H-fall pumice. The isochron shown here is for the 74 crystals that yield the youngest apparent 40Ar/39Ar ages – these are shown with solid outlines on the error ellipses. Crystals that give older apparent ages are shown with dashed error ellipses. Note that the 36Ar/40Aro intercept value of 298.1 ± 1.2 is indistinguishable from the atmospheric ratio of 298.56 ± 0.62 of Lee et al. (2006). Regression of all 118 data yields a 36Ar/40Aro intercept value of 299.7 ± 0.9 that also is indistinguishable from the atmospheric ratio.

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**Figure 6**. Estimating the form of the relative closure distribution for Ar in feldspar both as a Probability Density Function (PDF, top) and Cumulative Distribution Function (CDF, bottom) from highly resolved 40Ar/39Ar datasets, extending the approach of Keller et al. (2018) and van Zalinge et al. (2022). For cumulative probability, the individual CDFs of eleven highly resolved samples are shown (increasing towards younger ages, left), while for probability density individual and bootstrapped kernel density functions are shown (colored and blue lines), alongside an exponential fit representing a survivorship process (black). Both the estimated PDF and CDF take an approximately exponential form, consistent with a survivorship process. The similarity between the two distributions is expected, given that the CDF is the integral of the PDF, and the derivative of an exponential function is an exponential function.

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**Figure 7**. U-Th disequilibriumzircon and 40Ar/39Ar sanidine dates from Mucek et al. (2017) (A), Tierney et al. (2019) (B), Storey et al. (2012) (C), Mucek et al. (2021) (D), as indicated. The Bayesian estimates of eruption age for the three sets of dates are shown as vertical green, blue, orange, and red lines with ±2σ uncertainty envelopes. The combined Bayesian eruption age of 72.4 ± 1.3 ka from these 331 dates is denoted as a vertical magenta line and ±2σ uncertainty envelope. Left panel (A) is a close up of the summary ages.

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**Figure 8.** The influence of the accuracy of analytical uncertainties on Bayesian eruption age estimates. A synthetic dataset is shown, with N=64 analyses drawn from a uniform crystallization distribution alongside Gaussian analytical uncertainty, with the duration of the uniform crystallization distribution equal to twice the standard deviation of the analytical Gaussian (Δt/σ = 2). Underestimation of analytical uncertainties leads to younger Bayesian eruption estimates, while overestimation of analytical uncertainties leads to Bayesian eruption estimates that more closely approach a weighted mean. The weighted mean retains a larger relative error in both cases however, as underestimation of analytical uncertainties leads to further underestimation of the weighted mean uncertainty, while in the case of overestimation of uncertainty the Bayesian estimate will always remain younger (and thus closer to the true eruption age) than the weighted mean.

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