Supplementary Material

**Laboratory analytical procedures.**

* (U-Th)/He on apatites at Université Paris Saclay.

Apatite crystals were carefully selected for AHe dating based on size, morphology, and on the absence of any optically detectable inclusion. Single crystals AHe analysis were carried out at the GEOPS laboratory (Université Paris Saclay, France). Crystal dimensions were evaluated under a binocular microscope, and equivalent sphere radii (Rs) were calculated to represent the He diffusion domain (e.g.Gautheron and Tassan-Got (2010)). Ejection factors (FT) were determined using Monte Carlo simulation (Gautheron et al., 2012; Ketcham et al., 2011). Individual crystals were placed in a platinium baskets that were heated twice using a diode laser at 1030±50°C for 5 min, to allow total He degassing and to check the presence of He trapped in small inclusions. Samples with a second reheating gas level higher than the blank level at more than 5% are discarded from this study. The 4He content was determined by comparison with a known 3He spike for the samples analyzed using a prisma quadrupole. After He extraction, platinum baskets were placed into single-use polypropylene vials. Apatite grains were dissolved for 1 h at 90°C in a 50 ml HNO3 solution containing a known amount of 235U, 230Th and 149Sm, and then filled with 1 ml of ultrapure MQ water. The final solution was measured for U, Th and Sm concentrations by quadrupole ICP-QMS (seriesII CCT Thermo-Electron at LSCE (Gif sur Yvette; France)). A procedure similar to Evans et al. (2005) for the determination of the U and Th content was followed and the results for 4He.

* (U-Th)/He on zircons and apatites in CRPG Nancy

Part of the AHe data-set has been initially measured at CRPG (Nancy) with the current ZHe procedure (Tibari et al., 2016), which do not allow single grain measurements for apatites. This dataset has been measured on aliquots of 6 to 13 grains of apatites and prepared identically as for single grains, except that FT factors represent the mean of the individual grain’s population. For ZHe measured at CRPG, grains have been selected and packed individually in Pt basquets. The aliquots were subsequently loaded into an Ultra-High Vacuum chamber and outgassed a first time at around 1500°C for 35 min, using a Dilas Fiber-Coupled Compact Diode Laser System combined with a Dilas Pyrometer Processing Head. Grains were subsequently analyzed for 4He concentrations with a MKS Quadrupole mass-spectrometer using a calibrated 3He spike. A second outgassing was performed on each aliquot to check that 4He extraction was complete. We considered this was the case when the second measured 4He concentration was inferior to 5% of the total 4He extracted. A maximum of two outgassing phases was chosen in order to limit uncertainties. After complete 4He extraction, Pt packets were retrieved for U, Th, and Sm measurements using a Thermo Fischer Scientific X7 ICP-MS at the Service d’Analyse des Roches et des Minéraux (SARM, CRPG), following the procedure developed by Tibari et al. (2016). For this procedure, precision of ZHe ages determined on external Fish Canyon Tuff standard is about 6% (1σ).

* (U-Th)/He on zircons in Austin, Texas

One to five unbroken, euhedral, inclusion‐free zircons >70 μm in width picked from each sample and measured for standard geometric alpha particle ejection correction (Farley et al., 1996) . Single‐grain aliquots were packed in Pt tubes, laser heated to extract 4He, and analyzed on a Balzers Prisma QMS‐200 quadrupole mass spectrometer. Aliquots were reheated until completely degassed (<1% He on second heating). Fish Canyon Tuff zircon grains were analyzed as standards. After complete degassing, aliquots were unpacked and dissolved in hydrofluoric and nitric acid in high‐pressure digestion vessels, spiked with a 7 N nitric solution enriched in 235U, 230Th, and 149Sm and analyzed for 238U, 235U, 230Th, and 147Sm on a Thermo Element2 high‐resolution magnetic sector inductively coupled plasma mass spectrometer operated in solution mode. A standard analytical error of 8% is applied to each aliquot based on the internal laboratory reproducibility of the Fish Canyon Tuff standard (Reiners et al., 2002; Reiners et al., 2004). Mean dates are reported for each sample. Error is reported as the larger standard error of the mean standard error .

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**Figure S1**. Radial plot of the AFT data using radial plotter software (Vermeesch, 2009). This representation shows the dispersion of the indicidual grain ages together with the uncertainty on the ages (x axis), points with larger x values have a larger precision. Color code corresponds to the Dpar value of the grains when measured. No significant relationship between Dpar and AFT age is found.

**Figure S2**. Age-eU relationship for the ZHe data from the Clarens, Cieutat and Louslitges boreholes.

**Figure S3**. Age-eU relationship for the AHe data from Bielsa, Neouvielle and Bordères Louron massifs. The (U-Th)/He ages perfomed on single grains or on several grains together have been plot separately.

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