

## (U-Th)/He thermochronology — methodology and a case study: dating of faulting in the Southern Alps *Vortrag*

István Dunkl<sup>1</sup> Martin Danišik<sup>2</sup> Vincenzo Picotti<sup>3</sup> Wolfgang Frisch<sup>2</sup>  
Hilmar von Eynatten<sup>1</sup> Alberto Castellarin<sup>3</sup>

### History of He thermochronology

The radiogenic  $^4\text{He}$  isotope is continuously forming in the lithosphere mainly by the alpha-decay of U, Th and Sm. This decay process was discovered already at the beginning of the 20<sup>th</sup> century, and the first U/He dating was made by Rutherford (1905). Although his result indicated that the dimensions of the Earth's history ranges to millions of years, the U/He method was used only scarcely later on because the minerals are usually not closed to the decay product. The helium is extremely mobile and diffuse through the crystal lattices. Thus, the apparent U/He ages were always younger than the radiometric ages determined by other isotope geochronometers like U/Pb, Rb/Sr or K/Ar. The current renaissance of the method has been started at the end of eighties, when H. Lippolt, P. Zeitler, K. Farley and their co-workers have described the parameters of diffusion of some uranium-bearing minerals (e.g. Lippolt & Weigel 1987, Zeitler et al. 1987). It turned out that the (U-Th)/He apparent ages do carry meaningful geological information. The closure temperature of the most widely used apatite-He system is around 70°C. Thus, by the usage of this

<sup>1</sup> University of Göttingen, Germany <sup>2</sup> University of Tübingen, Germany <sup>3</sup> University of Bologna, Italy

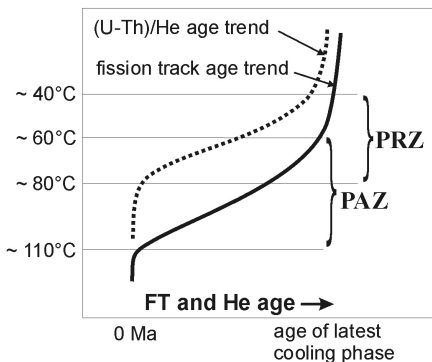


Figure 1: Schematic vertical trend of apatite FT and He ages in the uppermost part of the lithosphere in a tectonically stagnating block (after Stockli et al. 2000).

mineral/method pair it became possible to date low-temperature geological processes, which were undatable by other geochronometers.

### Typical applications

The vertical trends of apparent fission track (FT) and He ages in a stagnating lithosphere show convergence to the age of the latest exhumation phase at the surface and they have total reset (= zero age) at the depth where the temperature does not allow the accumulation of decay products and nuclear tracks (Fig. 1). In between these values there is a gradually changing section where the apparent ages are the result of the balance of continuous accumulation of decay products and their disappearance. This transitional section is called as ‘partial annealing zone’ (PAZ) in the fission track thermochronology and ‘helium partial retention zone’ (PRZ), which is defined as a temperature range where between 5% and 95% of the He is retained in a crystal. The rapid expansion of the application of (U-Th)/He

method in different fields can be related to its low closure temperature.

- This allows determining the final phase of exhumation of structural blocks in the upper crust (e.g. Stockli et al. 2000).
- In ideal conditions (proper granitoid lithology, possibility of 3D sampling in a high mountains, in a subsurface mine or in boreholes) the sensitivity of the He-thermochronology allows to date and determine the magnitude of vertical offset along faults (McInnes et al., 1999).
- In cratonic areas, where the typical lithologies are high-grade rocks and the sedimentary record is usually poor the post-orogenic thermal events can be well recorded by apatite fission track and He-thermochronology.
- Not only cooling and exhuming geodynamic scenarios, but the early phase of burial warming of sedimentary basins can also be well dated. This has prominent importance in the hydrocarbon prospecting, because the temperature range of He reset in apatite corresponds to the beginning of ‘oil-window’.
- The depth of the ca. 70°C isotherm depends on the geothermal gradient, the local surface morphology and the areal variation of rate of erosional removal. This opens the door for apatite He-thermochronology in geomorphological and morphotectonic studies (House et al. 1997).

## Methodology

The (U-Th)/He age determination is performed on single or more crystals in multiple aliquots. Only completely clear, mineral and fluid inclusion free crystals are datable. Crystals with fissures and damaged external surface have to be avoided. The documentation of the dimensions and shape of the crystals is crucial. By the radioactive decay the alpha-particles has significant kinetic energy and ‘jump’ ca. 20–30 µm through the lattice of apatite crystals. Consequently, the rim of the crystals is depleted as the part of helium atoms is ejected from the crystals. This causes a predictable loss, but this can be corrected by consideration of the dimensions and shape (surface/volume ratio) of the dated crystals. After the selection, the crystals are degassed in a full-metal vacuum oven and the released helium is purified from the reactive gases by getters. The He content is measured by mass spectrometer using isotope dilution. The mother elements (U, Th and Sm) are measured after the dissolution of the degassed crystals by ICP-MS.

## Our case study in the Dolomites

The Dolomites of the eastern Southern Alps were formed from the Permian-Triassic sedimentary cover of the slightly deformed South Alpine in the Tertiary. The different parts of the Dolomites have suffered two times Alpine deformation, and the shortening process is actually still active along the southernmost thrusts. The immediate dating of the deformation is possible only in the southern zones, where sediments are involved in the thrusts, while the northern areas no or rather scarce geological evidences exists on the timing of structural evolution.

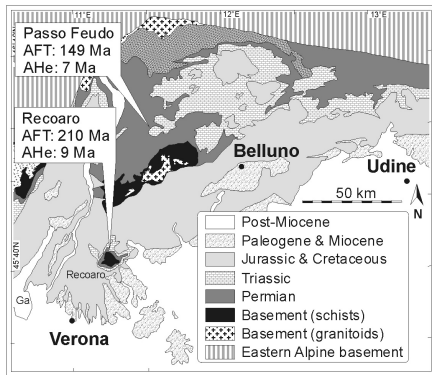


Figure 2: Simplified geological map of Dolomites with the apatite ages, where FT chronometer suffered minor reset, but the more sensitive He ages indicate Late Miocene exhumation.

The isotope geochronological dating is also difficult because the sedimentary successions are dominantly composed of carbonate rocks. We could use only the Triassic volcanic dikes and tuff horizons for thermochronology. The apatite fission track ages are ranging between 210 and 6 Ma. The oldest ages indicate the presence of slightly reset areas and date the exhumation of some structural blocks to be Late Miocene. The apatite (U-Th)/He ages are younger than the FT ages in every sample. In the western Dolomites, where the Neogene thermal reset is not detected by the apatite fission track thermochronometer, the He ages show Late Miocene reset (Fig. 2) due to the lower closure temperature of the later method. From the significant contrast between the FT and He ages we can conclude that the dated stratigraphic horizons were deeper than the total reset depth of He method but shallower than the reset depth of the FT method

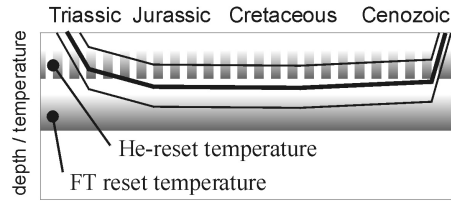


Figure 3: Schematic burial history of the samples from western Dolomites. The thick black line represents the position of the dated samples. They were in a hotter environment than the helium retention temperature, but below the complete FT reset temperature.

between the Late Triassic and Late Miocene. We suppose that beyond the general Miocene uplift of the Dolomites mainly the displacements along the Stava Line and Schio-Vicenza Fault or Bassano Thrust are responsible for the exhumation of Passo Feudo and Recoaro area, respectively. Figure 3 shows a supposed burial path for the samples presented in Figure 2.

## References

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