Deriving the exhumation history of the Alps with thermochronological data

Christoph Glotzbach[1], Sarah Falkowski[1], Paul Eizenhöfer[1], Todd Ehlers[1,2]

1. Department of Geoscience, University of Tübingen, Germany
2. School of Geographical and Earth Sciences, University of Glasgow, Glasgow, UK

DOI: http://dx.doi.org/10.17169/refubium-41099

Thermochronology is a unique tool to derive the exhumation history of rocks over millions of years. Exhumation in orogens is largely controlled by tectonic structures that formed during convergence. Therefore, thermochronological data can be used to reconstruct the geodynamic evolution of mountain ranges and, more precisely, the activity of large fault systems. The Alps are one of the best-studied mountain ranges, with several thousands of low-temperature thermochronological samples dated with a variety of methods (e.g. Herrman et al. 2013; Fox et al. 2015). In this study, we review the most recent thermochronological literature to summarise the exhumation history of the Alps and discuss their driving forces.

The apatite (U-Th)/He system is sensitive to the most recent exhumation (closure temperature of ~60°C) and records in places the (over-)deepening and widening of valleys around the Alps (e.g., Valla et al. 2011; Glotzbach et al. 2011). The higher temperature systems, especially the ZFT system (closure temperature of ~240°C), reveal the location of deeper exhumation (>10 km) caused by large-scale fault activity (Fig. 1). While some parts of the Southern Alps and the northern part of the Western and Eastern Alps were not reset during the Alpine orogeny, most of the internal parts of the Alps reveal reset ZFT ages (Fig. 1). The timing of exhumation of these regions, however, varies significantly with distinct tectonic regions. The most recent ZFT ages are <15 Ma and located in the external crystalline massifs, the Lepontine Dome, and the Tauern Window. The latter two are exhumed by large-scale orogen-parallel extensional faulting and contemporaneous indentation. This event ceased in middle Miocene times when faulting and associated exhumation switched towards the Southern Alps (e.g. Eizenhöfer et al. 2021). Apatite fission-track ages (closure temperature of ~110°C) are the youngest (≤6 Ma) in the external crystalline massifs and record a long-lasting Miocene exhumation, whereas the early Miocene exhumation was caused by vertical tectonics related to rollback of the subducted European slab (e.g. Herwegh et al. 2017; 2019). Ongoing middle to late Miocene exhumation of the external crystalline massifs was instead related to in-sequence thrusting (Herwegh et al. 2019). The young thermochronological ages and related high post-Miocene exhumation in the western external crystalline massifs might be at least partly related to uplift caused by slab detachment (e.g. Fox et al. 2015). In the Eastern Alps, there is no evidence for comparable young (post-Miocene) exhumation ‘hotspots’, suggesting a rather stable geodynamic state and absence of large-scale changes in mantle processes.

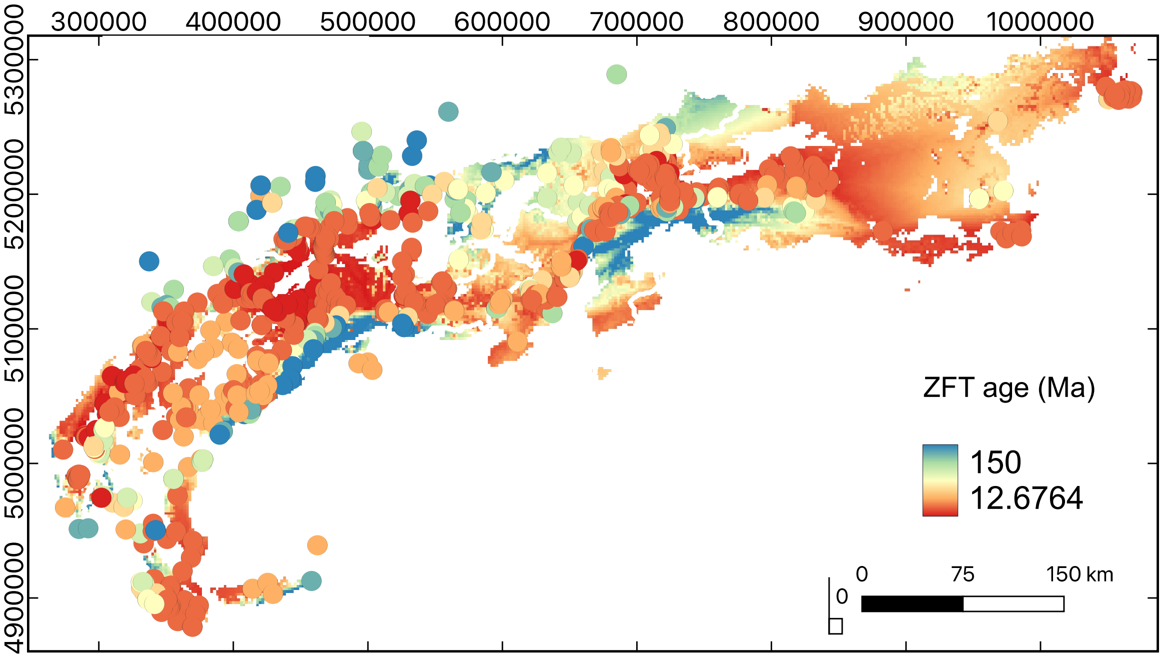

Figure 1: Published ZFT ages and interpolated ZFT age map.

Eizenhöfer, P. R., Glotzbach, C., Büttner, L., Kley, J., & Ehlers, T. A. (2021). Turning the Orogenic Switch: Slab-Reversal in the Eastern Alps Recorded by Low-Temperature Thermochronology. Geophysical Research Letters, 48, 17. https://doi.org/10.1029/2020GL092121

Fox, M., Herman, F., Kissling, E., & Willett, S. D. (2015). Rapid exhumation in the Western Alps driven by slab detachment and glacial erosion. Geology, 43(5), 379–382. https://doi.org/10.1130/G36411.1

Glotzbach, C., van der Beek, P. A., & Spiegel, C. (2011). Episodic exhumation and relief growth in the Mont Blanc massif, Western Alps from numerical modelling of thermochronology data. Earth and Planetary Science Letters, 304(3–4), 417–430. https://doi.org/10.1016/j.epsl.2011.02.020

Herman, F., Seward, D., Valla, P. G., Carter, A., Kohn, B., Willett, S. D., & Ehlers, T. A. (2013). Worldwide acceleration of mountain erosion under a cooling climate. Nature, 504(7480), 423–426. https://doi.org/10.1038/nature12877

Herwegh, M., Berger, A., Baumberger, R., Wehrens, P., & Kissling, E. (2017). Large-Scale Crustal-Block-Extrusion During Late Alpine Collision. Scientific Reports, 7(1), 413. https://doi.org/10.1038/s41598-017-00440-0

Herwegh, M., Berger, A., Glotzbach, C., Wangenheim, C., Mock, S., Wehrens, P., et al. (2020). Late stages of continent-continent collision: Timing, kinematic evolution, and exhumation of the Northern rim (Aar Massif) of the Alps. Earth-Science Reviews, 200, 102959. https://doi.org/10.1016/j.earscirev.2019.102959

Valla, P. G., Shuster, D. L., & van der Beek, P. A. (2011). Significant increase in relief of the European Alps during mid-Pleistocene glaciations. Nature Geosci, 4(10), 688–692. https://doi.org/10.1038/ngeo1242