Evolution of a low-relief landscape in the Eastern Alps

constrained by low-temperature thermochronology and cosmogenic nuclides

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Objectives of the study

The relief history of mountain belts is strongly influenced by the interplay of tectonics and surface processes, which both shape Earth´s landscapes. In this context, the quantification of the rates of long-term and short-term processes is key for understanding landscape evolution and requires the application of methods that integrate over different timescales. In this study, we apply low-temperature thermochronology and cosmogenic nuclides to quantify the geological and geomorphic evolution of an elevated low-relief landscape in the Eastern Alps, the so-called Nock Mountains, which are situated to the east of the Tauern Window (Figure 1). We took samples for apatite and zircon fission track (AFT, ZFT) and apatite and zircon (U-Th)/He (AHe, ZHe) analysis as well as for cosmogenic ^{10}Be analysis, including stream sediments samples for determining catchment-wide erosion rates and samples from glacially polished quartz veins to determine surface exposure ages (Figure 2).

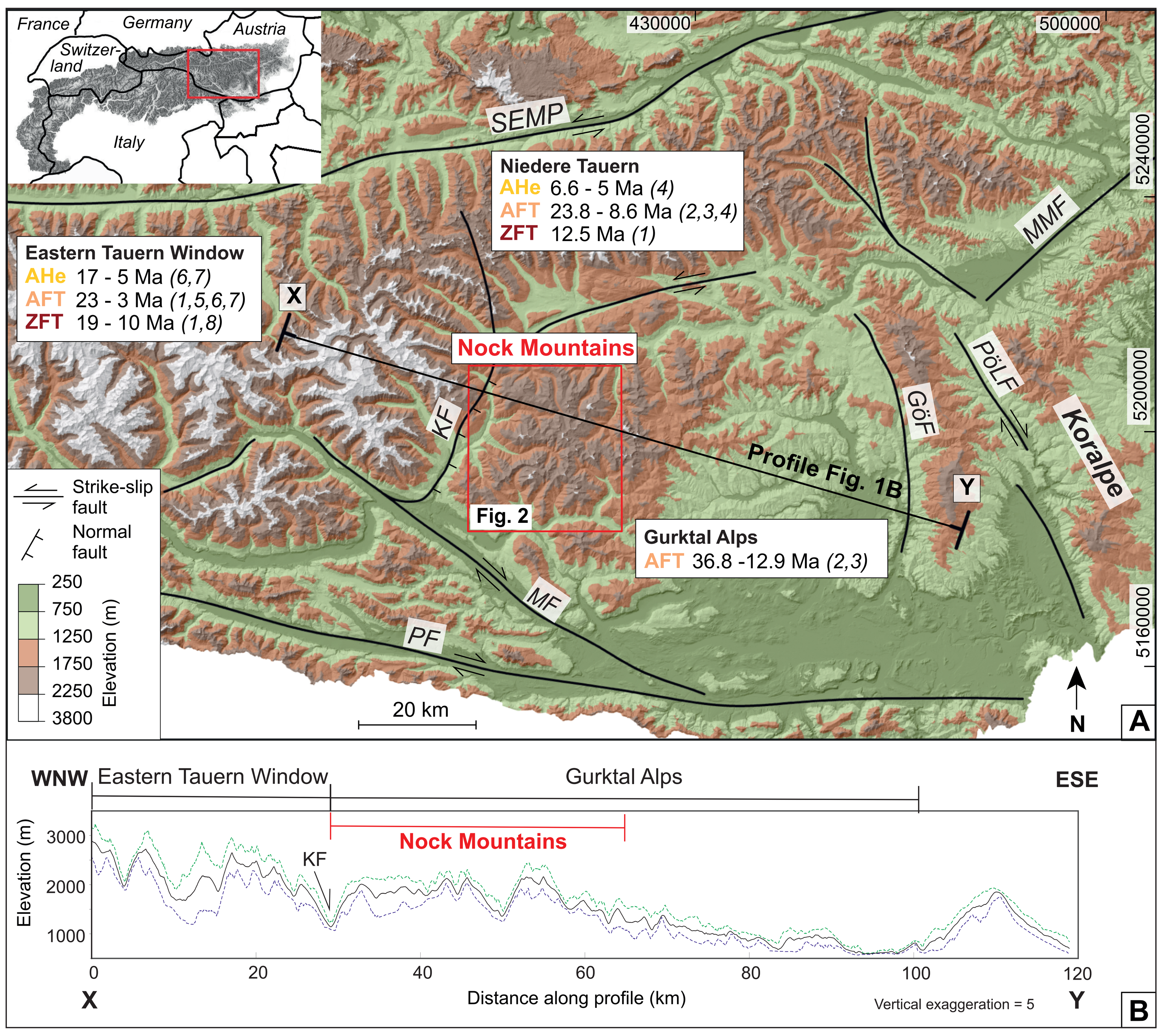

Fig. 1. (A) Shaded relief image of the eastern part of the Eastern Alps with published thermochronological data. The inset shows location of the study area within the European Alps. KF: Katschberg Normal Fault; SEMP: Salzach-Enns-Mariazell-Puchberg Fault; MMF: Mur-Mürz Fault; PF: Periadriatic Fault; MF: Mölltal Fault; GöF: Görtschitstal Fault; PöLF: Pöls-Lavanttal Fault. Numbers refer to (1) Bertrand et al. (2017); (2) Hejl (1997); (3) Reinecker (2000); (4) Wölfler et al. (2016); (5) Staufenberg (1987); (6) Wölfler et al. (2008); (7) Foeken et al. (2007); (8) Dunkl et al. (2003). (B) Swath profile WNW to ESE delineating the change in topography from the Eastern Tauern Window across the Gurktal Alps. The Nock Mountains exhibit an elevation of ~2000 m.

Results

Low-temperature thermochronology

- The apatite samples are characterized by unimodal track length distributions and relatively long mean track length (13.91 to 14.09 µm) with standard deviations of 1.00 to 1.26 µm.
- Mean Dpar values range from 1.54 to 1.73 µm, pointing to a homogeneous chemical composition.
- AFT ages range from 36.8±5.8 to 33.4±5.0 Ma; AHe ages are between 35.1±5.1 and 31.3±3.0 Ma.
- One single sample of ZFT yield an age of 93.4±12.9 Ma and a ZHe age of 85.6±2.9 Ma.

Cosmogenic nuclides

- ^{10}Be-derived erosion rates for the five studied catchments range from 83±7 mm/kyr to 205±18 mm/kyr.
- Exposure ages from glacially polished quartz veins vary between 14.5±1.4 and 16.8±1.6 kyr.

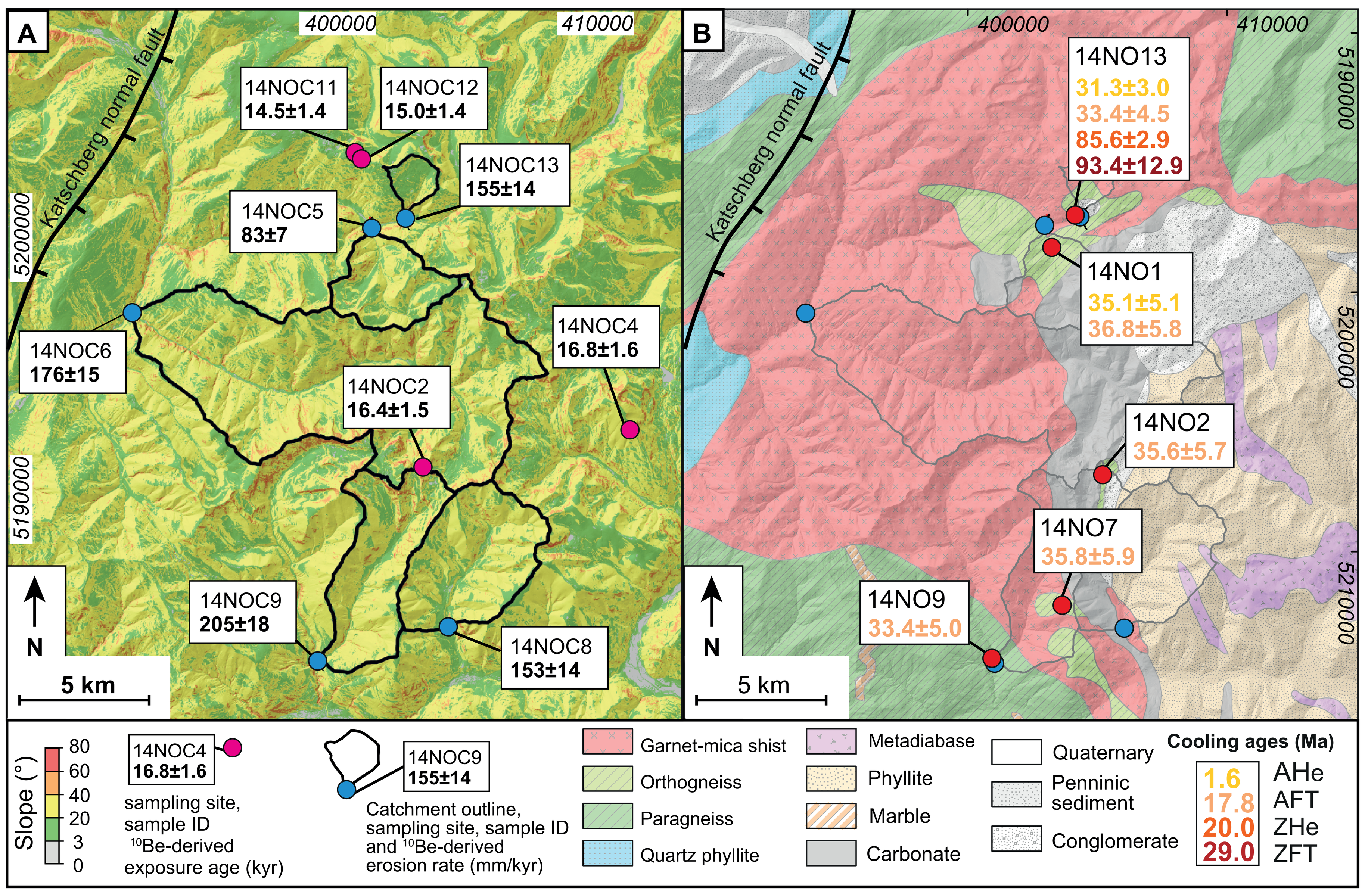

Fig. 2. (A) Slope map of the Nock Mountains with new erosion rates and exposure ages from cosmogenic ^{10}Be analysis. (B) Simplified geological map of the Nock Mountains with results from new low-temperature thermochronology.

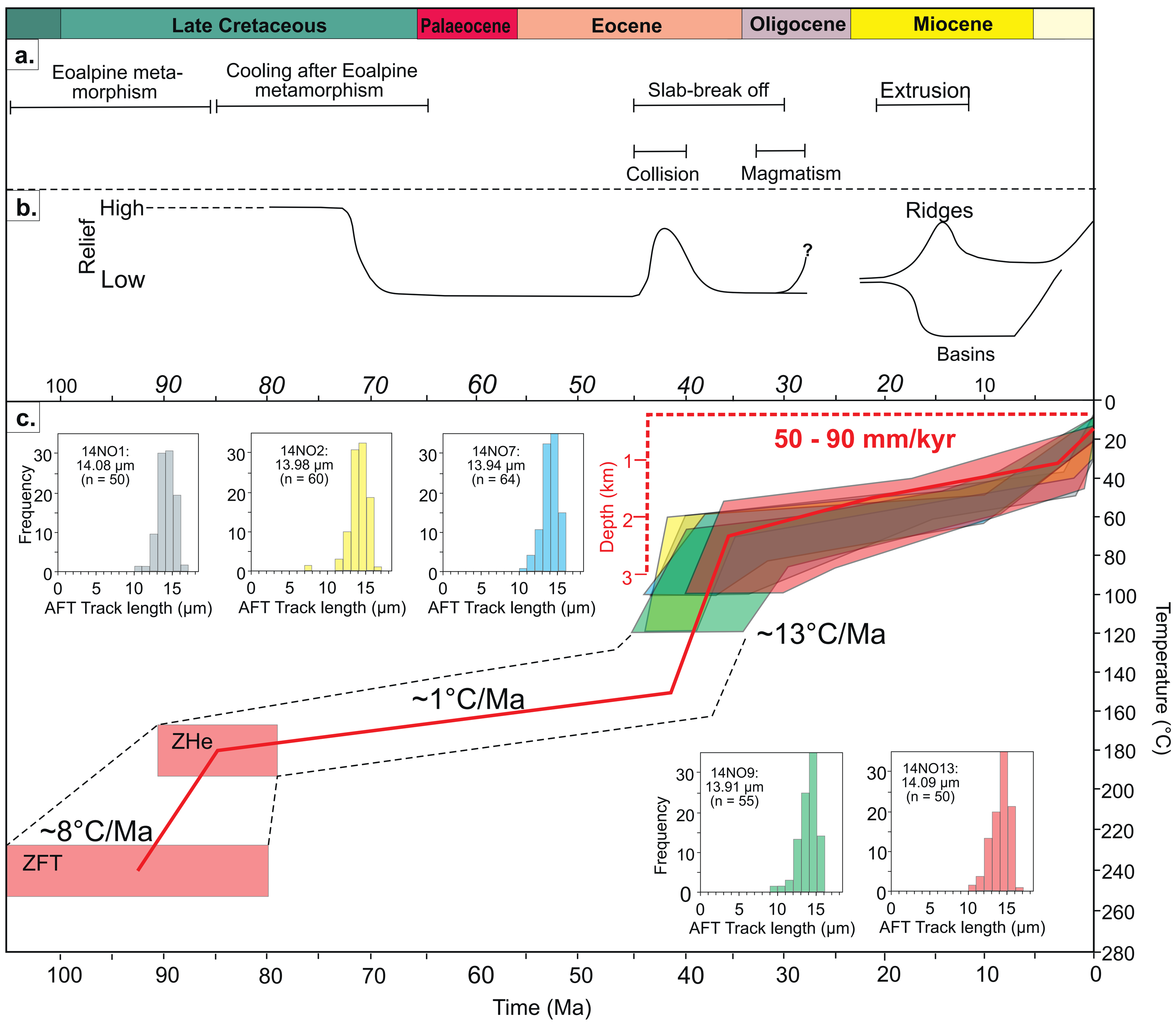

Fig. 3 Comparison of major tectonic events and relief evolution of the Eastern Alps with modelled cooling histories of thermochronological data. (a) Summary of major events that affected the Eastern Alps, modified after Dunkl et al. (2005) and reference therein. (b) Relief evolution of the eastern parts of the Eastern Alps with alternation in relief development, stagnation and decay. (c) Cooling histories of five samples modelled with the program HeFTy.

Interpretation

- Thermal history modelling (Figure 3) indicates that the Nock Mountains have been at upper crustal levels since ~40 to 35 Ma.
- Assuming that rock exhumation is driven by erosion, long-term average erosion rates range between ~50 - 90 mm/kyr.
- The Cretaceous and Early Cainozoic evolution of the Nock Mountains are characterized by two cooling periods. ZFT and ZHe data document the post Eo-Alpine cooling phase. Fast cooling during Late Eocene reflects increasing relief due to shortening, folding and thrusting, triggered by the onset of collision tectonics.
- Catchment-wide erosion rates are comparable to rates from the Koralpe but are lower than rates in the Tauern Window or Niedere Tauern (Dixon et al. 2016).
- Long-term and short-term erosion rates in the Nock Mountains are remarkable similar, despite the different timescales over which the two methods integrate. Therefore, average erosion rates in the Nock Mountains did not change significantly during the last ~40 Myr, although we cannot rule out temporal variations in erosion rates especially during the Quaternary glacial-interglacial cycles
- Our thermochronological data indicate that no more than 2-3 km of rock have been eroded since the Eocene, supporting the notion that the low-relief landscape of the Nock Mountains is a long-lived geomorphological feature in the eastern Alps.

Conclusions

- Cooling ages indicate that the study area has remained largely unaffected by tectonic or magmatic processes compared to the general evolution of the Eastern Alps.
- A comparison between long-term and short-term erosion rates indicates that average erosion rates in the Nock Mountains did not change significantly during the last ~40 Ma.
- Erosion rates from cosmogenic ^{10}Be analysis are one magnitude lower than those from the areas of the Niedere and Hohe Tauern.
- ^{10}Be exposure dating constrains the retreat of the ice cover shortly after the oldest Dryas stadial.

References

Bertrand, A., Rosenberg, C., Rabaute, A., Herman, F., and Fügenschuh, B., 2017. Exhumation mechanisms of the Tauern Window (Eastern Alps) inferred from apatite and zircon fission track thermochronology. Tectonics, 36, 207–228, doi:10.1002/2016TC004133.
Dixon, J.L., von Blanckenburg, F., Stüwe, K., and Christl, M., 2016. Glaciation´s topographic control on Holocene erosion at the eastern edge of the Alps. Earth Surf. Dyn., 4, 895– 909, doi:10.5194/esurf-4-895-2016.
Dunkl, I., Frisch, W., and Grundmann, G., 2003. Zircon fission track thermochronology of the southeastern part of the Tauern Window and the adjacent Austroalpine margin, Eastern Alps. Eclogae Geol. Helv., 96, 209–2017.
Dunkl, I., Kuhlemann, J., Reinecker, J., and Frisch, W., 2005. Cenozoic relief evolution of the Eastern Alps – constraints from apatite fission track age-provenance of Neogene intramontane sediments. Austrian J. Earth Sci., 98, 92–105.
Foeken, J.P.T., Persano, C., Stuart, F.M., Voorde, T.M., 2007. Role of topography in isotherm perturbation: apatite (U-Th)/He and fission track results from the Malta Tunnel, Tauern Window, Austria. Tectonics, 26, TC3006.doi:10.1029/2006TC002049.
Hejl, E., 1997. "Cold Spots" during Cenozoic evolution of the Eastern Alps: thermochronological interpretation of apatite fission track data. Tectonophysics, 272, 313 159–173.
Reinecker, J., 2000. Stress and deformation. Miocene to present-day tectonics in the Eastern Alps. Tübinger Geowiss. Arb., 55, 78pp.
Wölfler, A., Kurz, W., Fritz, H., Glotzbach, C., and Danišík, M., 2016. Late Miocene increasing exhumation rates in the eastern part of the Alps – implications from low temperature thermochronology. Terra Nova, 28, 297–305, doi:10.111/ter.12221.
Wölfler, A., Dekant, C., Danišík, M., Kurz, W., Dunkl, I., Putiš, M., Frisch, W., 2008. Late stage differential exhumation of crustal blocks in the central Eastern Alps: evidence from fission track and (U-Th)/He thermochronology. Terra Nova, 20, 378–384.