The Alps Paleoelevation and Paleoclimate Experiment (APE): Neogene Paleoelevation and Paleoclimate of the Central Alps

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Stable isotope paleoaltimetry takes advantage of the relationship between orogen elevation and the stable isotope ratios in meteoric water, which are ultimately recorded in geological archives like foreland basins or orogen-internal shear zones. The δ-δ approach relies on contrasting time-equivalent δ18O and δD records from high- and low-elevation sites to constrain the height of the orogen at the time these geologic archives were formed. However, at the same time, different boundary conditions such as changing paleogeography, atmospheric CO2 concentrations or sea surface temperatures result in complex paleoclimate model outputs, which predict significant changes in the isotopic composition of meteoric water. These changes may be recorded in geological archives and thus complicate the reconstruction of past elevations. The 4DMB Phase 1 project APE aimed at generating a first quantitative estimate for the paleoclimatic signal in Alpine stable isotope records, so that these records may be corrected for and ultimately yield more accurate paleoelevation estimates. We addressed this challenge by integrating isotope-tracking climate model (ECHAM5-wiso) simulations with stable isotope and clumped isotope data from the foreland basin and high-elevation regions of the central Alps.

ECHAM5-wiso simulations have been conducted with 1) boundary conditions based on paleogeographic reconstructions of the Last Glacial Maximum (LGM) and the mid-Pliocene (PLIO), and 2) different topographic scenarios for the Alps. The simulations show that modifying environmental conditions can produce similar magnitudes of δ18O change as changes in alpine topography. For example, the climatically induced δ18O changes in the PLIO and LGM experiments correspond to the magnitude of changes created by setting the entire orogen to 50% and 150% of its modern height, respectively (Botsyun et al., 2020). Our modelling results stress the need for the paleoaltimetry community to correct isotopic signals in geologic archives for climate-induced changes in isotope ratios.

Pedogenic carbonate proxy data from alluvial megafans of the Swiss Molasse Basin revealed that 1) low-elevation, distal δ18O values are higher than previously assumed and thus, more adequately reflect low-elevation δ18O values required for paleoelevation estimates; 2) Mid-Miocene megafans had considerable topography and an internal elevation gradient; 3) clumped isotope-derived carbonate formation temperatures yield low-elevation paleoclimate estimates and help to embed δ18O data into global climate models. Under consideration of previous work and our modelling results, we conclude that the Central Alps, more specifically the region surrounding the Simplon Fault Zone, attained surface elevations of >4000 m no later than the mid-Miocene (Krsnik et al., 2021).

In summary, our approach represents an important methodological advance that allows the disentangling of climatic and surface uplift signals in the geologic stable isotope record. Furthermore, new insights into the Alps elevation history can help to constrain the timing of slab inversion and/or break-off in the Western/Central Alps.

Phase 1 publications:

Botsyun et al., 2020, GRL, doi:10.1029/2019GL086046

Botsyun et al, 2022, Paleoceanography and Paleoclimatology, doi:10.1029/2022PA004442

Krsnik et al., 2021, Solid Earth, doi:10.5194/se-12-2615-2021

Methner et al., 2020, Scientific Reports, doi:10.1038/s41598-020-64743-5

Mutz et al., 2019, ESurfD, doi:10.5194/esurf-7-663-2019