The Alps Paleoelevation and Paleoclimate Experiment: Reconstructing Eastward Propagation of Surface Uplift in the ALps (REAL)

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Geological observations, geodynamic models, and seismic studies suggest Neogene eastward propagating surface uplift of the European Alps. Whereas 4DMB Phase I project APE focused on reconstructing surface uplift of the Central Alps, 4DMB Phase II project REAL aims at testing the predicted west-to-east surface uplift of the Alps by combining stable isotope paleoaltimetry and paleoclimate modeling. Stable isotope paleoaltimetry is based on the inverse relationship between elevation and the stable isotopic composition of meteoric water and provides a tool to reconstruct the elevation of mountain belts in the geological past.

First, REAL explores applications of the δ-δ method (see Poster Phase I APE), which requires that various recorders of past rainfall are available in the rock record: soil carbonates from low-elevation (foreland) basins and hydrous minerals from high-elevation fault gouges/shear zones. Paleoelevation estimates are obtained by contrasting time-equivalent low- and high-elevation proxy data sets, provided that the isotopic composition of the fluids during mineral formation is estimated accurately. Whereas formation temperatures of fault gouge minerals (such as illite and syntectonic micas) can be readily estimated, we apply clumped isotope paleothermometry to provide robust estimates of meteoric water $\delta^{18}O$ from the low-elevation foreland basin carbonate record.

Second, meteoric water $\delta^{18}O$ values are not only sensitive to local elevation, but also to the complex climatic changes resulting from different paleoenvironmental boundary conditions and regional topographic configuration. To isolate the contribution of each of these components δ-δ stable isotope paleoaltimetry is applied in combination with ECHAM5-wiso paleoclimate simulations for a number of topographic scenarios of diachronous surface uplift. This unique combination allows for the removal of climate change effects on the stable isotope data, and therefore improves the accuracy of paleoelevation reconstructions.

Results from our ongoing Phase II project (spring 2021 - spring 2024):

1. Reveal that diachronous surface uplift would produce patterns of climate, $\delta^{18}O$ in precipitation values, and isotopic lapse rates that are distinctly different from those of today and those produced by bulk surface uplift scenarios. Importantly, this signal would be detectable in stable isotope paleoaltimetry results (Boateng et al., in revision).
2. Present a Miocene (23–13 Ma) continental paleotemperature record from the northern Mediterranean region (Digne-Valensole basin, SE France), which indicates near-constant temperatures from 23.0-18.8 Ma, followed by a highly variable and warm climate during the Middle Miocene and rapid cooling after 14 Ma (Ballian et al., 2023).
3. Together with new and existing paleotemperature records, preliminary results of the δ-δ method show for the first time that (a) the Central Alps were already high during the Early Miocene and (b) the Eastern Alps were appreciably lower than the Central Alps during the Middle Miocene (Ballian et al., 2022).

Phase 2 publications:

Ballian et al., 2022, EGU General Assembly, doi:10.5194/egusphere-egu22-2346

Ballian et al., 2023, EGU General Assembly, doi:0.5194/egusphere-egu23-14517

Boateng et al., in revision, Earth System Dynamics discussions, doi:10.5194/esd-2022-48