Reconstructing Eastward Propagation of Surface Uplift in the Alps: Integrating Stable Isotope Palaeoaltimetry and Palaeoclimate Modelling (REAL)

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PhDs/Postdocs (one in Frankfurt, one in Tübingen): to be appointed
Start date: early 2021 for three years

Cooperation partners: Katharina Methner (Stanford University), Fritz Schlunegger (Univ. Bern), Oliver Kempf (Swisstopo), Neil Mancktelow (ETH Zurich), Kurt Stüwe (Univ. Graz), Horst Zwingmann (Univ. Kyoto)

Summary

Geodynamic modelling and seismic components of 4DMB suggest west-to-east propagation of slab breakoff and slab tearing under the Western/Central to Eastern Alps. REAL tests whether the observed spatio-temporal variations in mantle processes led to a similar west-to-east propagation in surface uplift, such that the Western/Central Alps reached higher elevations earlier than the Eastern Alps (SPP Themes 1 and 2). REAL combines stable isotope-based palaeoaltimetry and clumped isotope (Δ_{47}) derived temperature reconstructions with isotope-enabled General Circulation Models (GCMs). The proxy data used for δ-δ stable isotope palaeoaltimetry record signals of both surface uplift and climate change. Therefore, GCM simulations for different palaeoenvironmental and topographic conditions are conducted to separate these signals and thus improve the accuracy of palaeoelevation reconstructions.

Our Phase 1 work documented sensitivity of climate and stable isotopes in precipitation to different paleotopographic scenarios (Botsyun et al., 2020), middle Miocene climate change in the foreland region (Methner et al., 2020), and high paleoelevations in the Central Alps (Krsnik et al., 2020). In Phase 2 we extend our interdisciplinary approach to the Western/Eastern Alps to evaluate if surface uplift was diachronous.

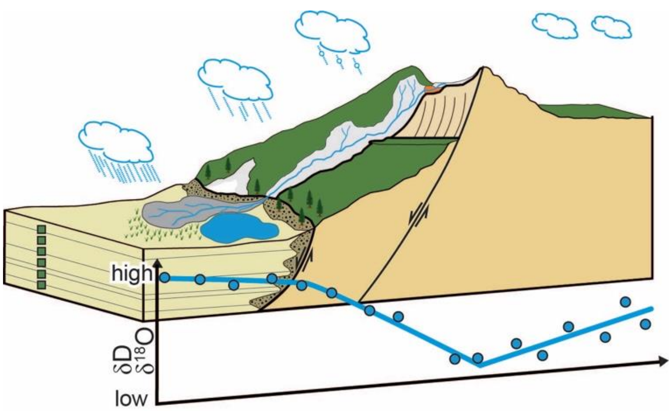

Figure 1, Schematic illustration of orographic rainout across a mountain range and the systematic decrease of $\delta^{18}O$ and δD values in rainfall across a mountain range, which allow for the reconstruction of paleoelevations of mountain ranges in the geological past

Primary research questions

(1) At what time prior to the middle Miocene did the Central Alps reach high elevations?
(2) When did the Western and Eastern Alps reach high elevations with peaks of >3 km?
(3) How does diachronous west-to-east surface uplift of the Alps impact regional climate and in turn affect stable palaeoaltimetry reconstructions?

Research Strategy

(1) Frankfurt PhD or Postdoc: Extend sampling domain for δ - δ palaeoaltimetry, including stable isotope measurements ($\delta^{18}O$, δD, Δ_{47}-Δ_{48}) on Oligocene to Miocene basin deposits (Fig. 1) from the Western and Eastern Alps and along upwind vapor source trajectories (Spain, France, Germany) for comparison to Phase 1 results from the Central Alps.

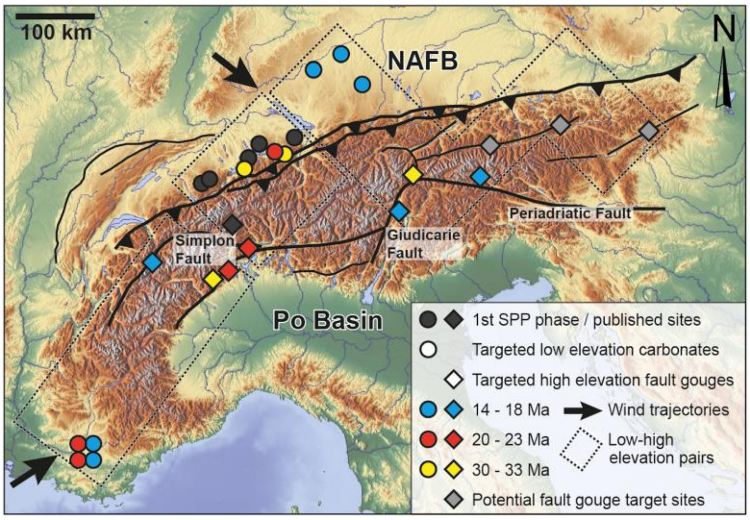

Figure 2, Overview of existing and targeted stable isotope palaeoaltimetry sites. Study areas complement far-field (upwind of the vapor source) sites to distinguish surface uplift from palaeoclimate change in the $\delta^{18}O$ record.

GCM simulations are global, as is required for robust calculation of palaeoclimate. Our analysis of GCM results will focus on Central Europe.

(2) Tübingen PhD or Postdoc: Predict palaeoclimates for critical time periods that overlap with paleoaltimetry proxy records, and quantify the effects of palaeoenvironmental conditions and different west-to-east topographic configurations using an isotope tracking atmospheric General Circulation Model (GCM). Climate modelling aims at isolating surface uplift and paleoclimate change signals in the stable isotope proxy records thereby allowing the reconstruction of Western vs. Eastern Alps surface uplift histories.

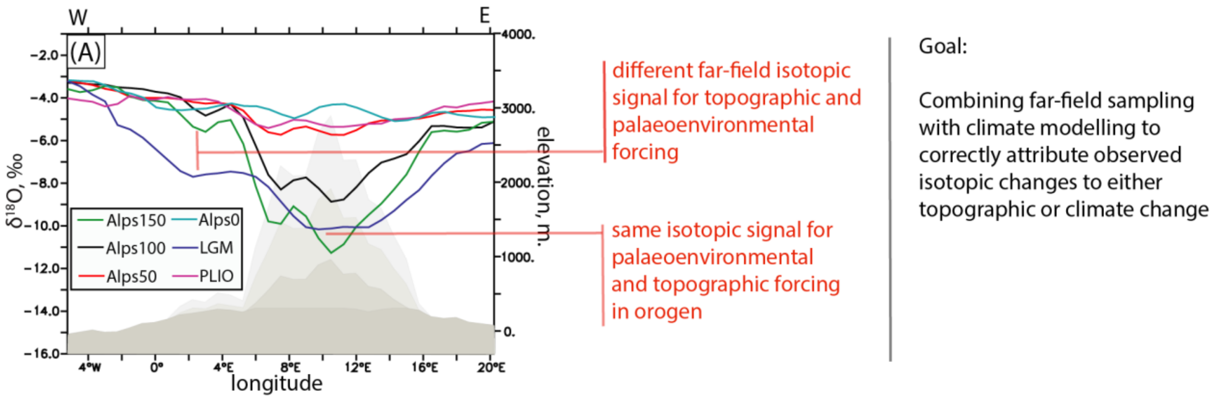

Figure 3, ECHAM5-wiso GCM simulated summer precipitation $\delta^{18}O$ from experiments with 150% (Alps150), 100% (Alps100), and 50% (Alps50) of modern Alps topography (topography shown in grey), using climatic boundary conditions for the Last Glacial Maximum (LGM) and mid-Pliocene (PLIO), for two transects across the Alps (A and B; from Botsyun et al., 2020).

(3) Collectively, approaches (1) and (2) will be used in a modern empirical approach of data-model integration to assess the most realistic topographic scenarios at given times and to determine whether west-to-east propagation of slab breakoff and tearing resulted in diachronous surface uplift of the Western and Eastern Alps.

Publications

Botsyun, S., Ehlers, T.A., Mutz, S.G., Methner, K., Krsnik, E., Mulch, A., (2020). Opportunities and Challenges for Paleoaltimetry in Small Orogens. Geophysical Research Letters 47, https://doi.org/10.1029/2019GL086046

Methner, K., Campani, M., Fiebig, J., Löffler, N., Kempf, O., Mulch, A., (2020). Middle Miocene long-term continental temperature change in and out of pace with marine climate records. Nature Scientific Reports 10: 7989, https://doi.org/10.1038/s41598-020-64743-5

Krsnik, E., Methner, K., Löffler, N., Kempf, O., Fiebig, J., Mulch, A., (2020). New paleoelevation constraints on the Mid-Miocene Central Alps, EGU General Assembly Conference Abstracts, Vienna, 10060