Neogene Paleoelevation and Paleoclimate of the Central Alps – Linking Earth Surface Processes to Lithospheric Dynamics

PIs: Prof. Andreas Mulch and Dr. Katharina Methner, Frankfurt; Prof. Todd Ehlers and Dr. Sebastian Mutz, Tübingen; Postdoc: Dr. Svetlana Botsyun, Tübingen; PhD: Emilija Krsnik, Frankfurt

This project integrates stable isotope altimetry records ($\delta^{18}O/\delta D$) of the Central Alps with a high-resolution, global, isotope tracking paleoclimate model. We envisage testing between different Miocene to present surface uplift scenarios driven by lithospheric scale geodynamic processes inferred from AlpArray seismic imaging. For instance, if true that accretion of crustal material to the overriding plate results in short-wavelength orogen uplift and foreland basin subsidence, we would expect to see a steady increase in the change of oxygen isotopes in precipitation as a function of elevation, $\Delta(\delta^{18}O)$, or Δz between high Alpine regions and the foreland over time. In contrast, if the opening of slab gaps, slab breakoff, and subduction polarity reversals produce long-wavelength uplift signals affecting both the orogen and its foreland, the resulting changes in surface elevation might be more variable in time and result in a $\Delta(\delta^{18}O) \approx 0$ (if foreland and high-alpine elevations increased in a similar manner). However, in the latter case absolute changes in $\delta^{18}O$ can be expected. Testing these hypotheses requires a multidisciplinary approach involving tools that go beyond the methods commonly employed in stable isotope paleoaltimetry. We address this challenge through an integration of isotope-enabled paleoclimate models (ECHAM5-wiso) with new paleoclimate proxies (stable isotope and clumped isotope studies) collected from the foreland basin and high-elevation regions of the Alps (Fig. 1).

These experiments will bridge spatial and temporal scales of environmental change over the Alps, thereby forming a baseline for evaluating past climate influences on paleoaltimetry, erosion and exhumation studies across the AlpArray study area. Furthermore, establishing a surface elevation record will inform the debate about the timing of slab inversion and/or tearing in the Western Alps, and serve as a point of reference for thermochronology and geo-dynamic modelling studies that investigate the coupling between tectonics and erosion, and the crust-mantle processes responsible for shaping the European Alps.

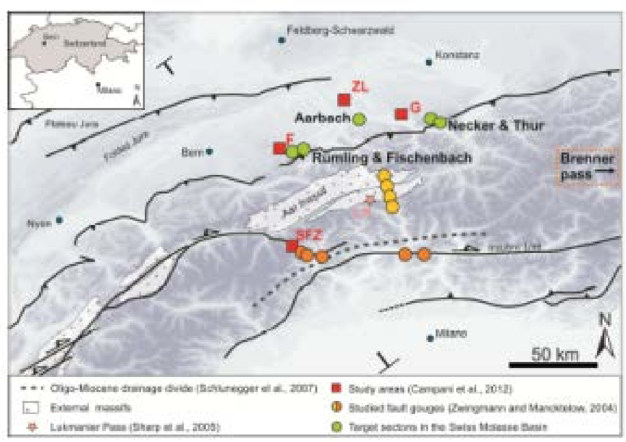

Figure 1: *Map of the central Alps showing previous sampling locations of Campani et al. (2012) (red squares) and Sharp et al. (2005) (star). Target localities for sampling clayey fault gouges (Zwingmann & Mancktelow, 2004) and soil carbonates are marked in orange and green, respectively.*

Objectives: 1) Determine stable isotope patterns of clay minerals (δD) in high-elevation fault zones and pedogenic carbonates ($\delta^{18}O$) of their age-equivalent low-elevation counterpart (North Alpine Foreland Basin) – The δ-δ paleoaltimetry approach (Frankfurt; Fig. 2).

2) Apply the global atmospheric GCM ECHAM5-wiso to quantify the mechanisms for observed spatial and temporal variations in precipitation using high-resolution global atmospheric circulation models, and test different Alpine surface elevation scenarios (Tübingen; Fig. 3).

3) Identify and quantify Miocene-to-Pliocene Alpine paleoelevation and test hypotheses about surface elevation change as a response to slab tearing - Integration of results with AlpArray erosion/exhumation studies (Frankfurt, Tübingen).

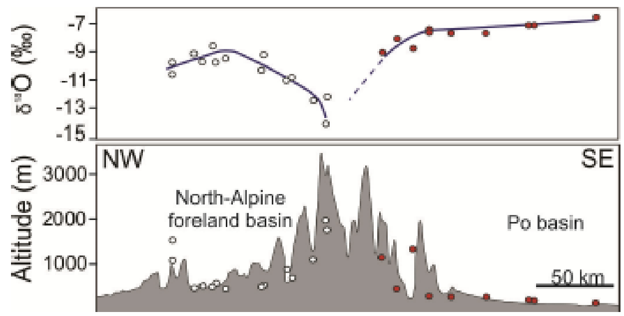

Figure 2: *Modern isotope gradients of surface waters on the northern and southern alpine flanks, caused by topography and distillation of moisture from air masses rising orographically from foreland regions, resulting in highly ^{18}O- and ^{2}H-depleted rainfall in the high Alps. Location of cross section shown in Fig. 1 (taken from Campani et al., 2012).*

The paleoclimate modelling results will significantly improve our ability to correctly interpret the stable isotope paleoaltimetry data and a test for presence or absence of surface elevation response during slap geometry changes. Our proxy reconstruction and GCM simulations will provide an integrated picture of the climate and the topographic evolution of the Alps over the last ~24 million years.

This integration will provide: (a) identification of the tectonic, topographic, and atmospheric controls on Alpine climate, and (b) a baseline comparison of climate and surface elevation variability over the Alps - a requisite element for understanding past geodynamic changes.

This study directly contributes to Research Themes 1, 2, 3 and Activity Fields E, F of the 4D-MB priority research program.

We envisage collaboration with other investigators of the AlpArray framework and maximize the range of observations in our analysis. Our paleoelevation estimate can serve as important constraint for exhumation/erosion studies or numerical modeling studies within 4D-MB.

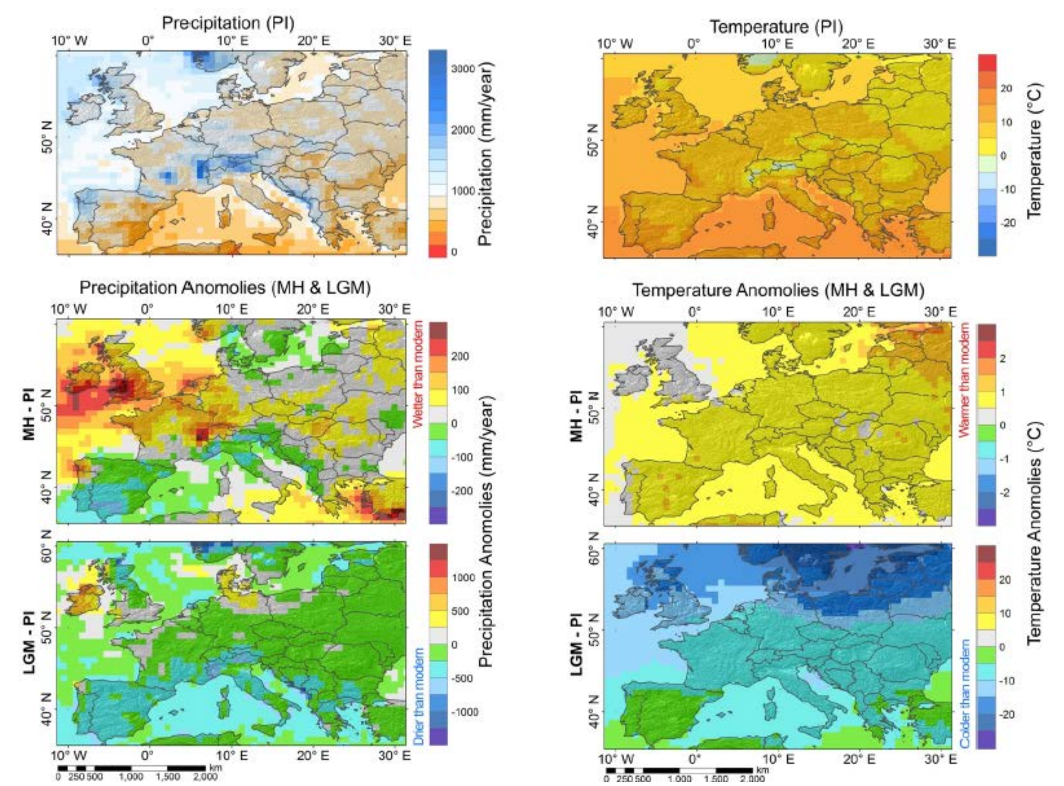

Figure 3: *Example pilot study calculation of precipitation and surface temperature changes from a low-resolution (T63) simulation using the ECHAM5 atmospheric model. PI predicted precipitation and temperature (Top row), Precipitation and temperature differences between MH and PI (middle row) and LGM and PI (bottom row).*

Simulations are from Li et al. (2016b), conducted for Tibet, and replotted for Europe. In this proposal higher resolution (T159, ~80x80 km) simulations with water isotope tracking capabilities will be used to better resolve the topography of the Alps. Furthermore, additional time slices going back to the Middle Miocene, and topographic sensitivity experiments (e.g. removal of the Alps) will be conducted to quantify potential climate drivers for Alpine erosion/exhumation and signals of climate change preserved in the isotope proxy data collected.