Foreland dynamics as a measure of mountain building processes

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Forelands record the uplift and exhumation history of mountain belts. The alpine foreland basin is particularly exciting, as is shows late-orogenic exhumation, possibly as a reaction to mantle-driven, plate convergence, or climatic forcings. However, inferring the contribution of the individual drivers to exhumation from stratigraphic or thermochronological data is challenging. The reason for this are along strike variability basin of stratigraphy, different degree of exhumation, as well as structural style of the Subalpine Molasse (i.e., the fold-thrust belt at the southern fringe of the basin). Furthermore, the influence of fluid flow on the thermochronological ages is unknown.

Exhumation estimates in the central part of the basin are mostly based on stratigraphic arguments. Thermochronological data is scarce and limited to local studies. As the Molasse has also been uplifted in the central part of the basin since the Miocene, it is probable that it also responds to deep-seated processes, but to a lesser extent than the western part of the basin. This may be a result of different slab dynamics along strike the orogen. To test this, we used detrital and in situ low-temperature thermochronological age dating to shed light on the surface expression of the underlying geodynamic process (Figure 1). Data shows that most ages in the central part of the basin are unreset, while resetting occurs in the southernmost tectonic slices of the Subalpine Molasse. Generally, Miocene shortening in the Subalpine Molasse progressively decreases from west to east. The pattern coincides with slab geometries at depth (Mock et al., 2020). A general trend of lesser erosion from west to east is also visible in the flat lying Molasse based on vitrinite reflectance data. This suggests that a geodynamic driver is required for explaining basin exhumation on basin scale.

Locally, the pattern is more complex. Particularly in the Subalpine Molasse, exhumation may be associated with plate convergence. To test the influence of faulting on exhumation, we constrained the geometries of the fold-thrust belt. Using a new compilation of stratigraphy and structures along the entire Alpine deformation front (Ortner et al., 2023), we identified two key regions: the Bregenzerach south of the eastward termination of the Jura Mountains, and the Hausham Syncline southeast of Munich. The Bregenzerach region lies at the surface boundary between Eastern and Western Alps. Furthermore, previously published thermochronological data indicate thrust activity in the mid-Miocene. Structures at depth are reasonably well-constrained due to good outcrop conditions and seismic data. The Hausham Syncline represents the region where structures at depth are less well constrained, and additionally the frontal triangle zone of the Subalpine Molasse tapers out. Structural modeling shows that it is possible to quantify the uncertainty of structures at depth, paving towards thermo-kinematic modeling including structural uncertainty (Brisson et al., 2023; Frings et al., 2023).

The extensive thermochronological dataset offers the opportunity to identify local particularities not in line with the general trends observed in the data. Using thermal springs as proxy for heat flow (Luijendijk et al., 2020), we show that fluid flow may at least locally influence the cooling pattern. This is important for translating cooling into exhumation, particularly in regions where less data is available and thus outliers may be overlooked.

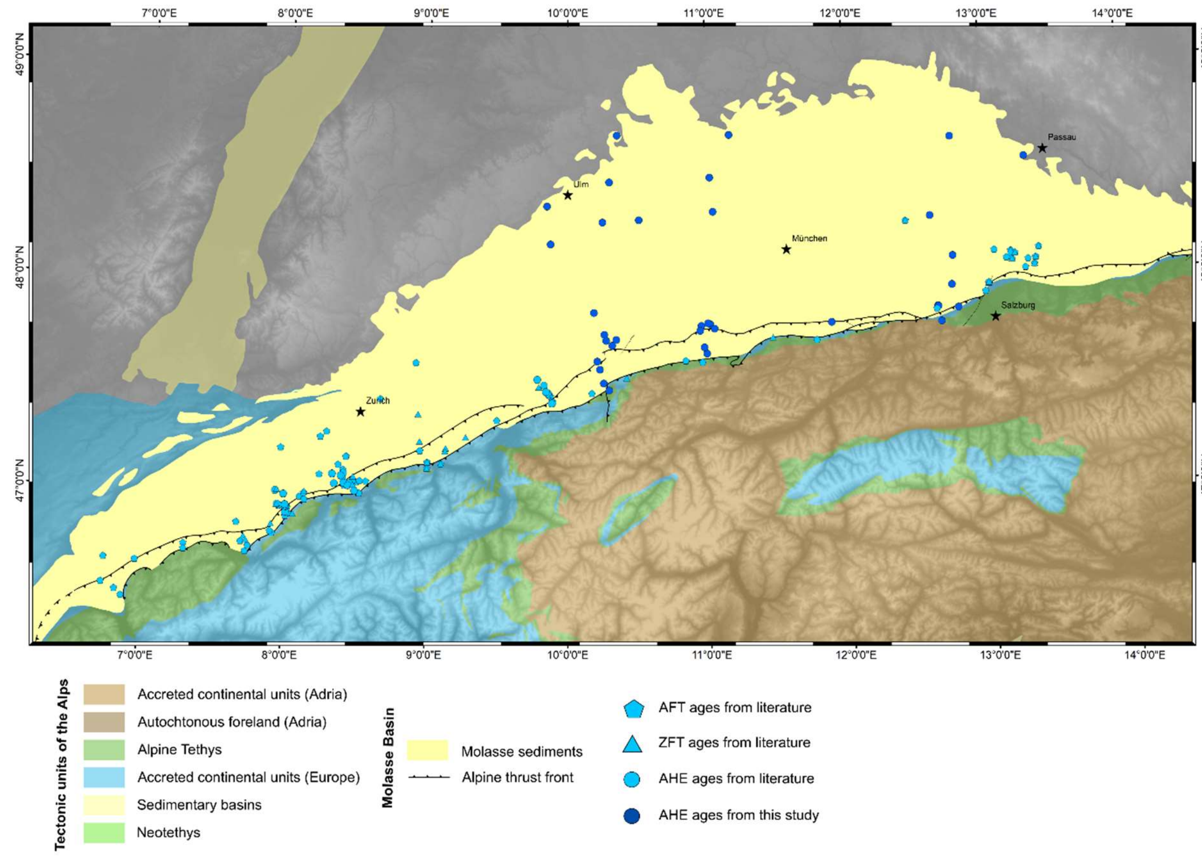

Figure 1: Thermochronological data from the Molasse Basin collected at the surface and from borehole data (western Molasse).

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