Low-temperature thermochronology and vitrinite reflectance data reveal long-wavelength uplift in the Alpine foreland basin

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Introduction

- Previous work [e.g.1,2,3] has shown that the western part of the Molasse basin has been uplifted and eroded in the Neogene.

- The presence of undeformed Upper Marine Molasse (OMM) sediments at altitudes between approx. 300 and 900 m.a.s. visualize the uplift of the entire Molasse basin (*Figure 1*). It is also noticeable that the OMM sediments in the West are at higher elevation than the ones in the East.

- Current data on the timing and spatial distribution of exhumation are insufficient to constrain the processes responsible for the observed amount of exhumation. Little low-temperature thermochronometry and vitrinte reflectance data was published for the German Molasse.

- Here we analyze and discuss existing and new data that cover gaps in the central and eastern part of the basin.

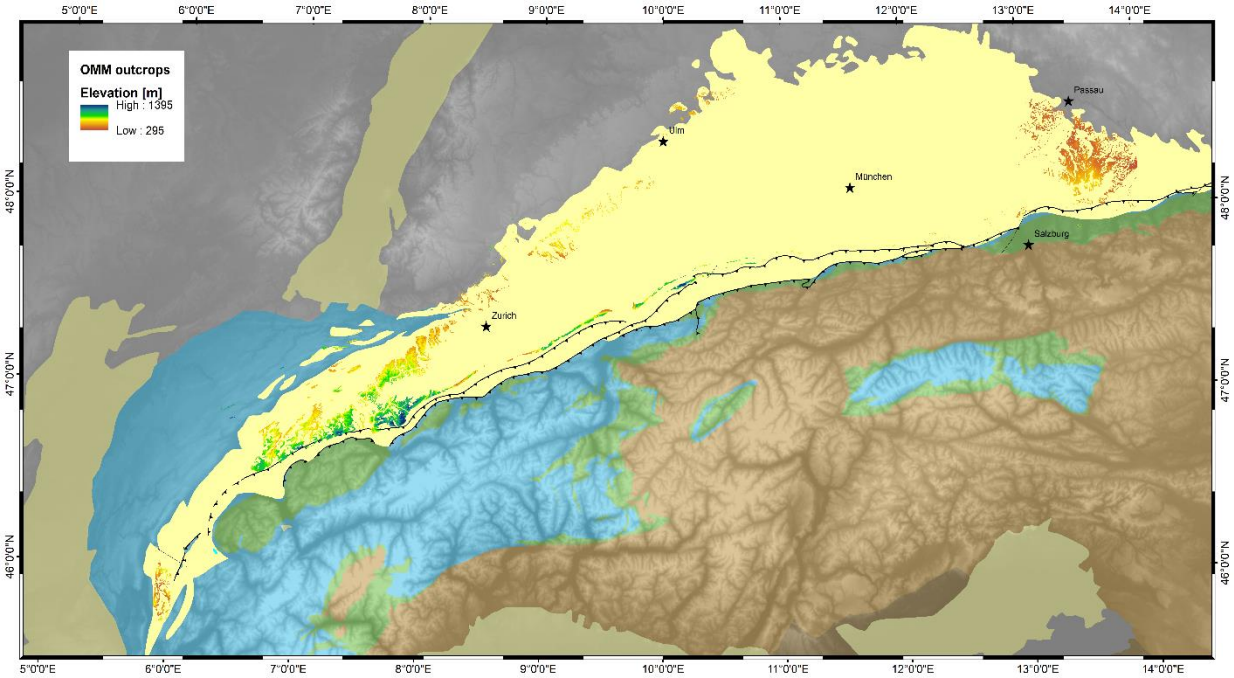


Figure 1: Overview of the Swiss and German Molasse basin and the outcropping Upper Marine Molasse (OMM) sediments. The present day elevation of these outcrops are color coded; yellow marks lower elevation while blue marks higher elevation.

Existing and new data

- Existing data from the Swiss Molasse[2,3] shows 2-3 km of Neogene exhumation of the Molasse basin.
- Tectonic shortening and flexural rebound due to river capture[5] or deglaciation alone cannot explain this amount of exhumation.
- A large dataset of vitrinte reflectance data from the oil and gas industry was provided by the German Geological Survey (BGR)[6] (Figure 2)
- New surface samples were collected in the German Molasse basin for vitrinte reflectance and (U-Th)/He analysis (Figure 2).

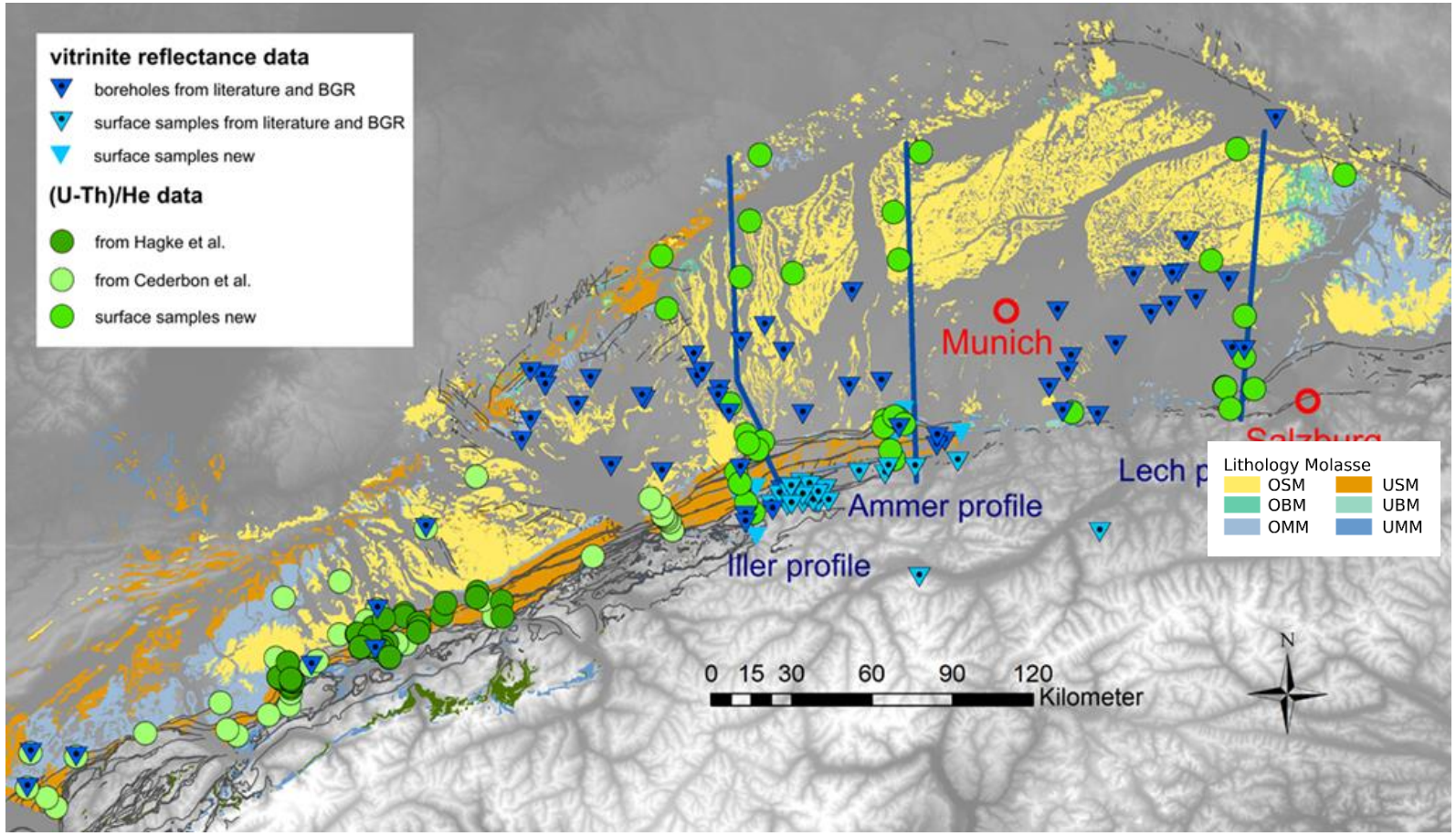


Figure 2: Overview of the Swiss and German Molasse basin and the outcropping Neogen and Paleogen sediments. Compiled and new (U-Th)/He data is shown in green shaded circles and compiled and new vitrinte reflectance data is shown in blue shade triangles. Three cross-sections in the German Molasse basin are used for modelling exhumation. These three cross-sections are shown by dark blue lines.

New thermochronology data

- New (U-Th)/He data of the German Molasse Basin shows that exhumation at this location is below or close to the detection limit (approx. 1.5 km).
- Only 5 samples from the folded and thrusted Molasse (out of 35 measured samples) show partial resetting of their Apatite Helium (AHe) age (red circles).
- None of the flat lying Molasse samples show partial resetting (green and orange circles), although 5 of them show a few single grain ages below their sedimentation age.

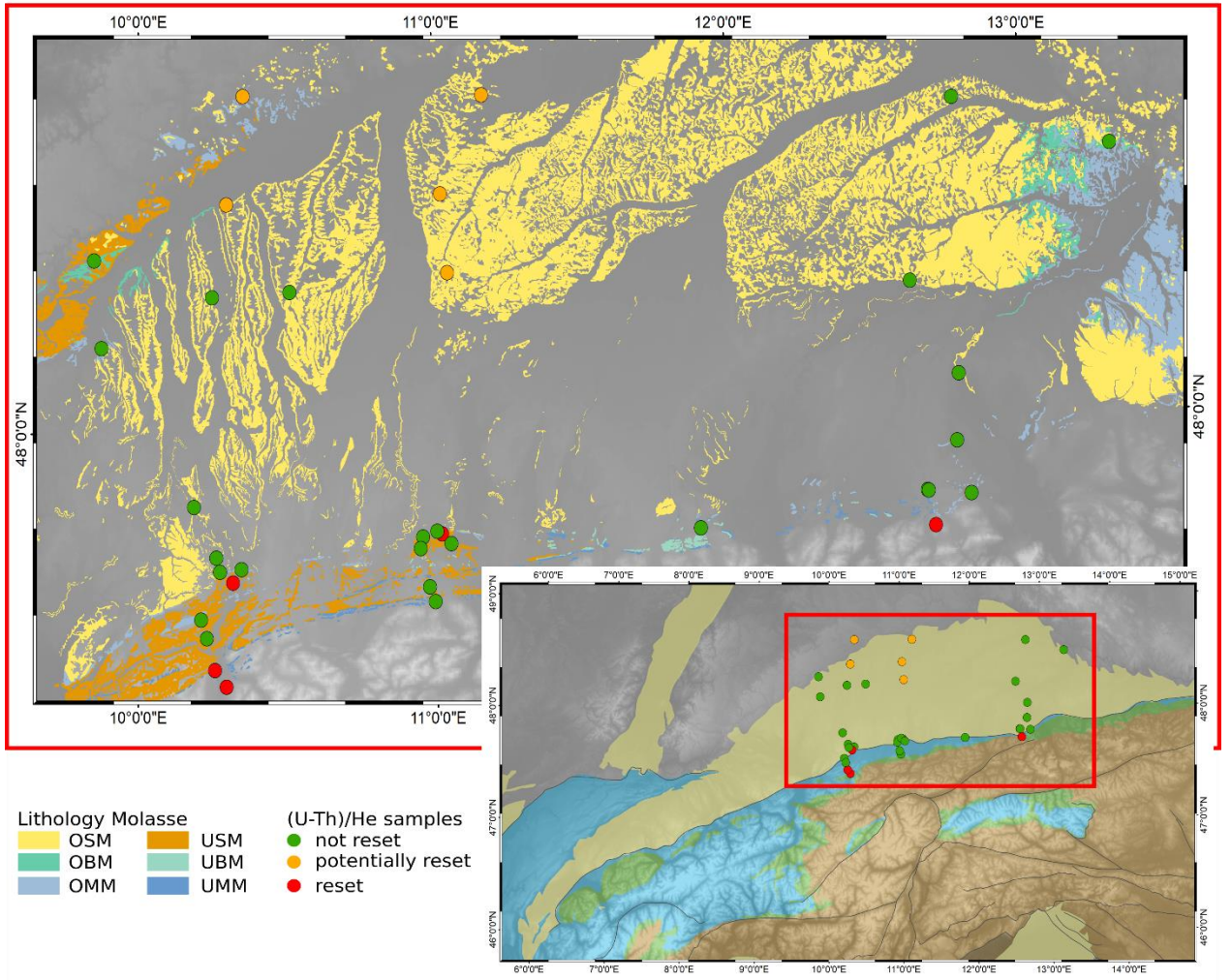
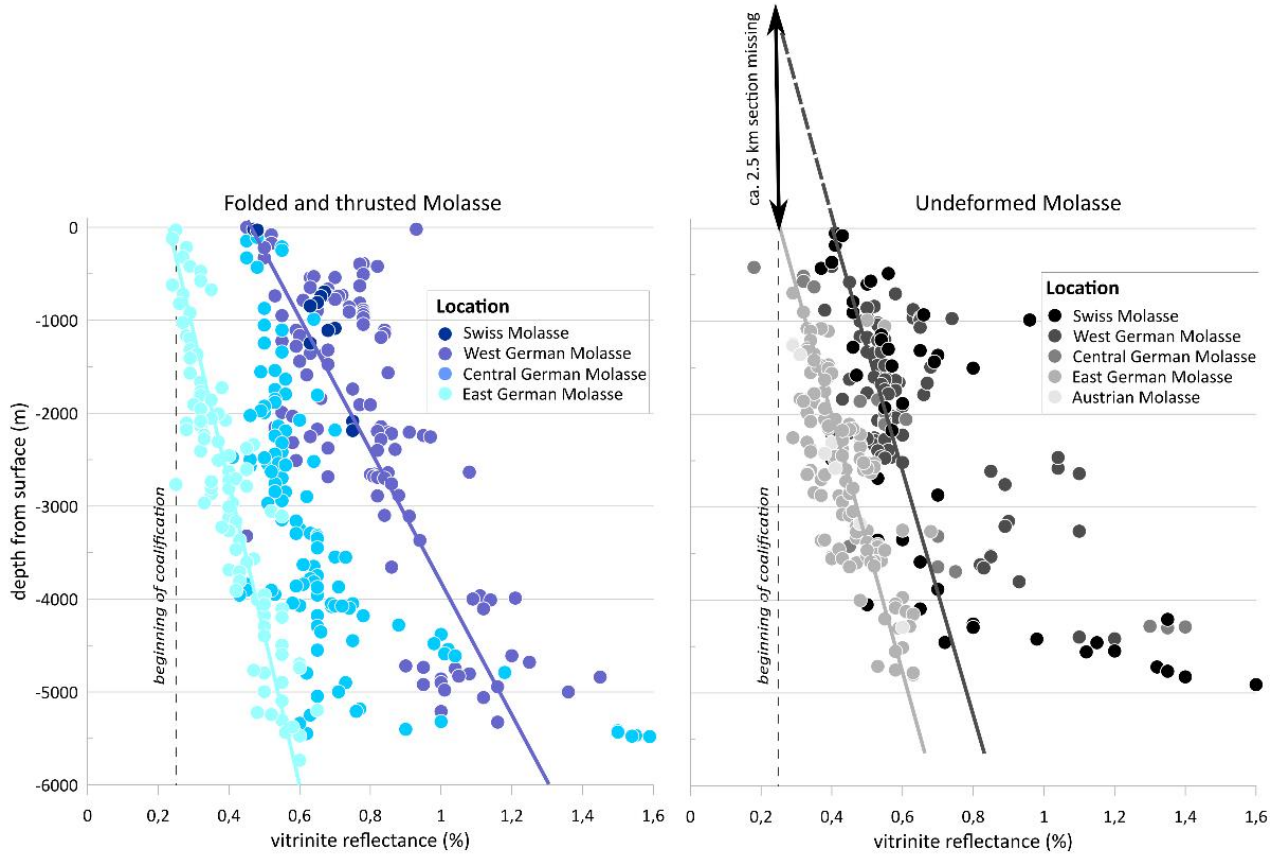


Figure 3: Map is a zoom in of the German Molasse Basin. Green colored circles depict AHe ages that are not reset, orange colored ones show samples that are potentially reset and red circles depict partly reset AHe ages.

New vitrinte reflectance data

- Vitrinte reflectance data[3,6,7] shows a trend of exhumation increasing from East to West.
- Even in the undeformed part of the basin vitrinite data suggests approximately 2.5 km of erosion.



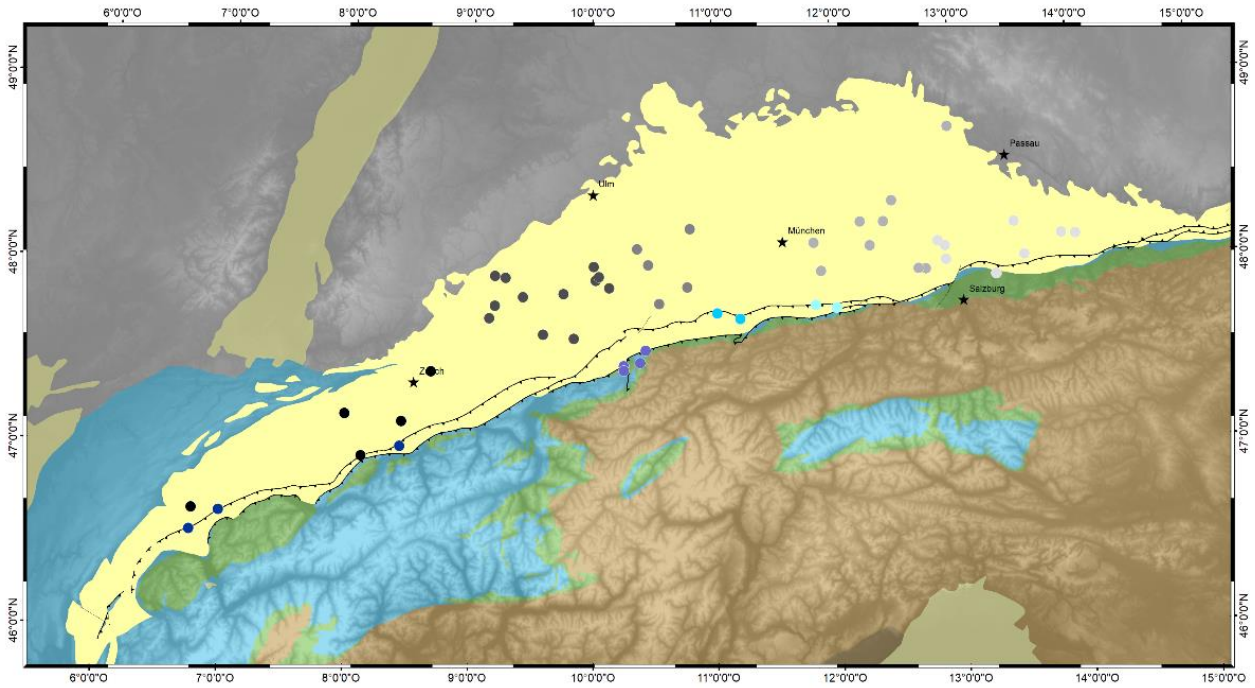


Figure 4: The left panel shows a compilation of vitrinite reflectance data from boreholes in the folded and thrusted Molasse. Light blue colors are samples from the East while dark blue colors are samples from the West. The right panel depicts vitrinte reflectance data from boreholes in the undeformed Molasse. Light grey colors are samples from the East; as they get darker, the samples originate from further West. The maps shows the location of the respective bore holes.

Pybasin – a novel basin model

- To constrain the rate and time of exhumation and account for the sensitivity of thermochronolgical data to time and temperature, we're using the open source model code PyBasin[4].
- This thermal model combines forward and inverse modelling of burial and thermal history of the basin with low-temperature thermochronology and organic maturity data to quantify the exhumation/cooling in sedimentary basins.
- This model is a unique solution towards separating the provenance from the thermal history of a particular basin and improving the interpretation of thermochronological data by setting constraints on the range of potential provenance histories and stratigraphic units.

→ ongoing work with compiled downhole temperature[8] , vitrinte reflectance data[3,6,7] and low-temperature thermochronology data[2] from the Molasse basin.

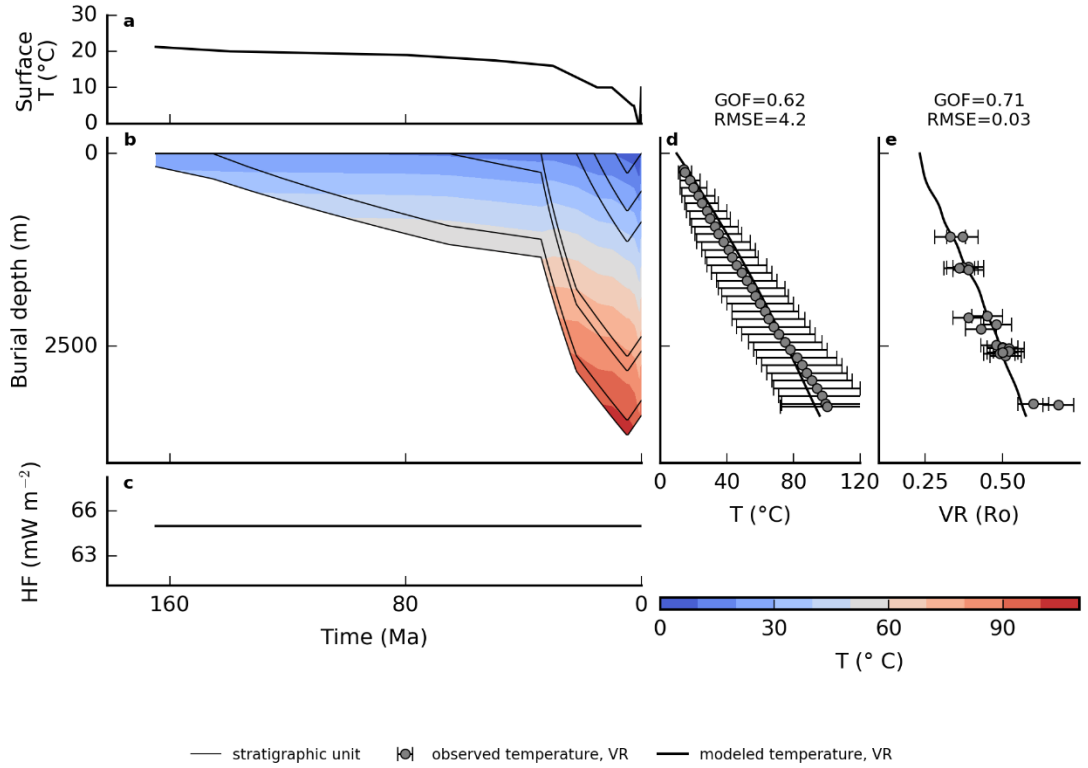


Figure 5: Example of a modeled borehole in the central Molasse basin (east of Munich). The upper left panel shows surface temperature over time. The panels in the middle show, from left to right, burial depth and paleo temperature at depth, present day temperature measurements in boreholes and vitrinite reflectance at depth. The colored area is the entire spectrum of burial path endmembers and sets the limit on possible ages of the grains in a sediment. It also represents the time when burial took place. The colors are coded according to subsurface temperature. For present day temperature and vitrinite reflectance, the modeled values are shown by the black line. The goodness of fit between the modelled and the measured values is calculated and can be seen above the respective graph.

Conclusion

- Estimates from marine units at surface outcrops show 300 to 900 m of net uplift since deposition in undeformed parts of the entire basin.
- While AHe ages in the Swiss Molasse show extensive exhumation (approx.2-3 km), the German Molasse shows AHe ages below or close to the detection limit (approx. 1.5 km).
- Vitrinte reflectance data shows a trend of exhumation increasing from east to west.
- Parts of the central German Molasse basin have been exhumed as well. Therefore, exhumation towards the West cannot only be related to Jura thrusting.
- Although parts of the Molasse basin show evidence of localized exhumation driven by thrusting, on the large scale we can see longwave exhumation patterns in the western part of the basin that affect both the deformed and undeformed parts of the basin.

Ongoing work - Outlook

- Many theories have been established to explain the dynamics of the alps and its foreland basins.
- We will try to quantify and discuss the effects of flexural rebound due to exogenic forces and uplift due to endogenic forces in the alps on the Northern Alpine Foreland Basin.
- Each process expresses a different timing and distribution of the uplift signal within the Molasse basin.
- The wavelength of the uplift signal may also vary: from small wavelengths caused for example by increased erosion due to river capture to large wavelengths caused by mantle processes such as slab break-off.

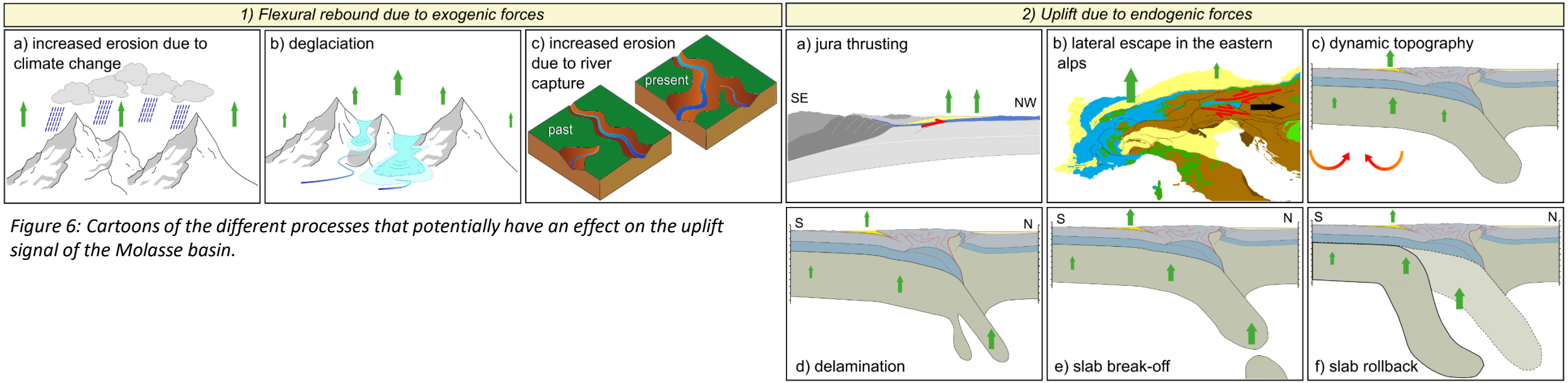


Figure 6: Cartoons of the different processes that potentially have an effect on the uplift signal of the Molasse basin.

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