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Fault evolution and retrodeformation of the GRAME study area around Munich, Bavarian Molasse Basin

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1. Introduction

The southern German Molasse Basin is one of the most promising areas for geothermal exploration in Germany (Fig. 1). We aim to optimize exploration for deep geothermal reservoirs in the Bavarian realm. The prediction of potential fluid pathways, such as faults, plays an essential role in geothermal exploration. To this aim, we interpret the GRAME*[1] 3D seismic survey (170 km²) that was acquired in 2015/2016 in the western and southern part in the city of Munich (Germany). The hydrothermal Malm carbonate reservoir at a depth of ~3 km is overlain by Tertiary Molasse sediments.

Within the research project GeoParaMoL*[2], we focus on structural interpretation and retro-deformation to detect sub-seismic structures within the reservoir and overburden.

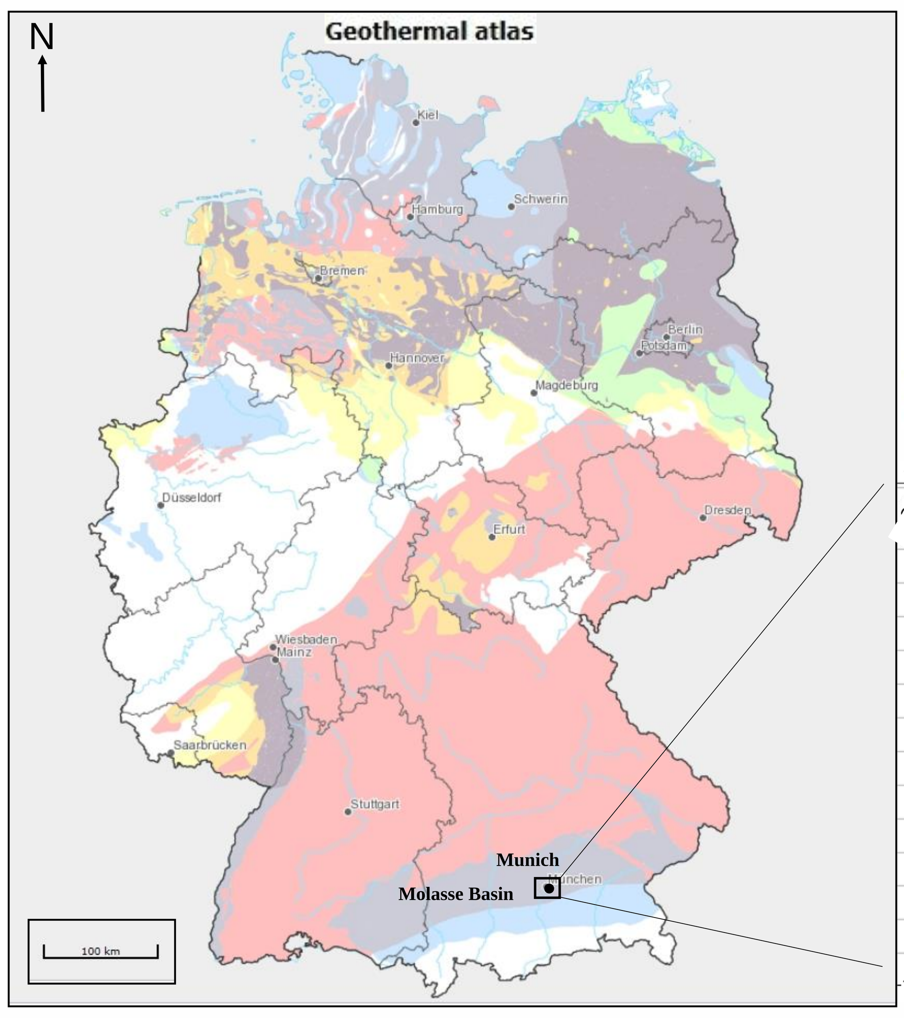
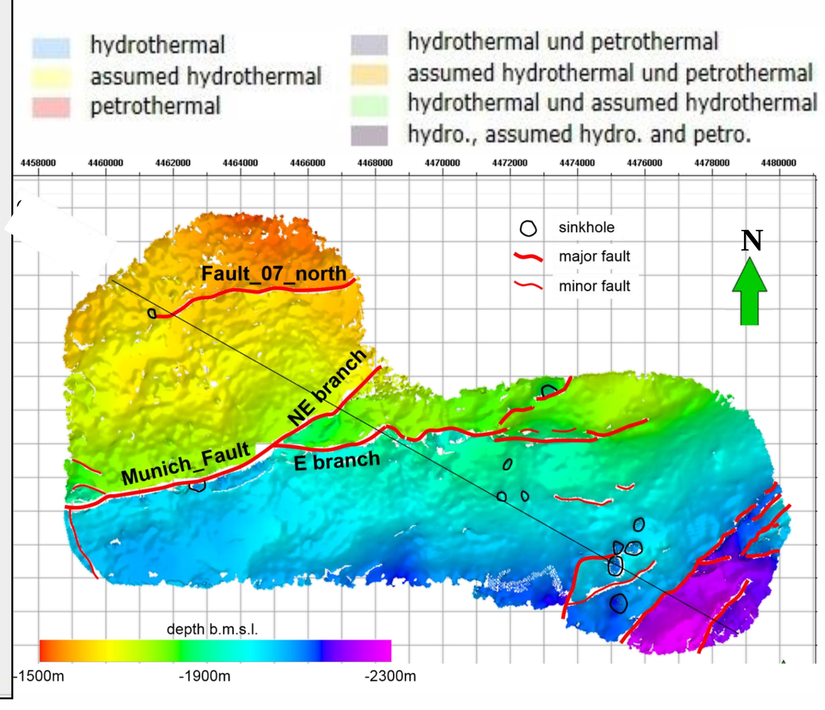


Figure 1: Left: Map of Germany and study area. Colours refer to different geothermal regimes (http://www.geotis.de, LIAG), Below: Depth map of Top Priabonian (Lithothamnien limestone).



2. Interpretation

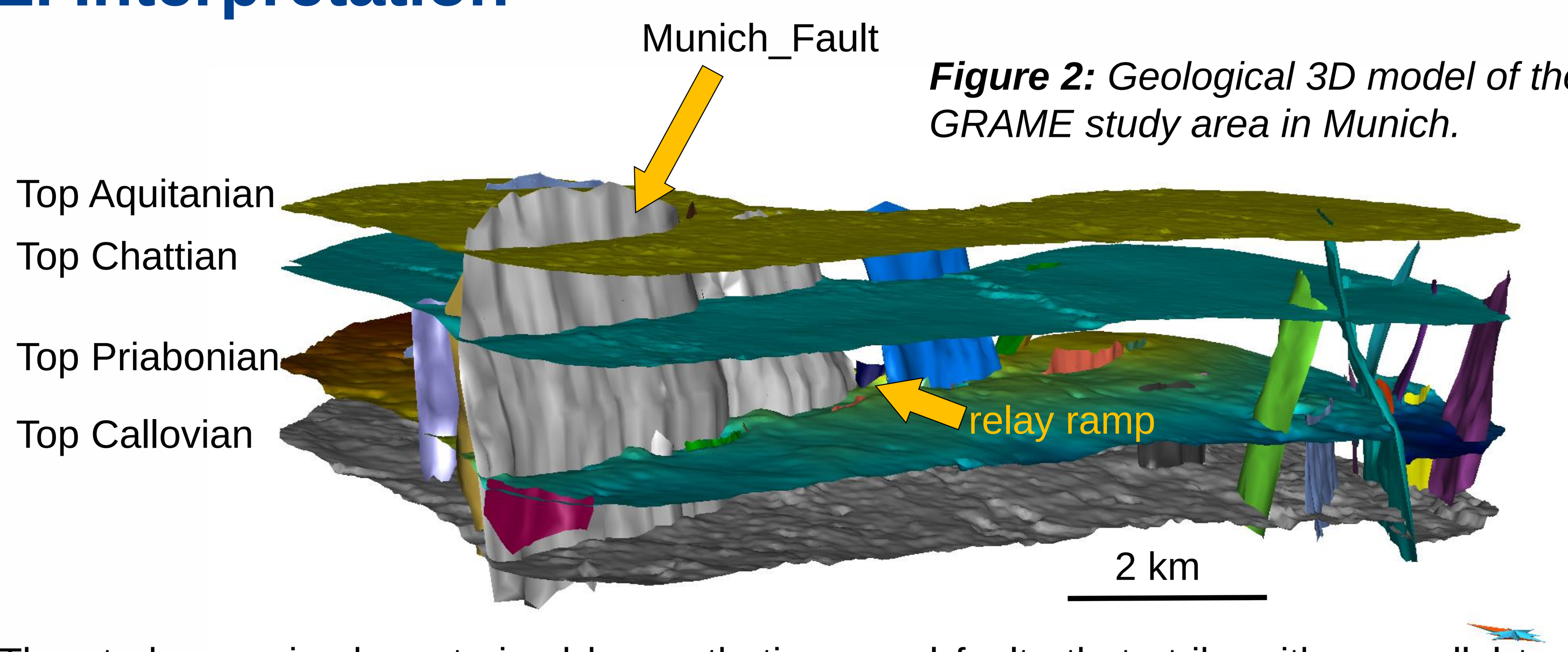


Figure 2: Geological 3D model of the GRAME study area in Munich.

The study area is characterised by synthetic normal faults that strike either parallel to the alpine front or SW-NE. Most major faults were active from Jurassic up to at least Miocene. The Munich_Fault (Fig. 3), which has a maximum vertical offset of 350 m in the central part, dies out in the eastern part of the area.

3. Allan maps

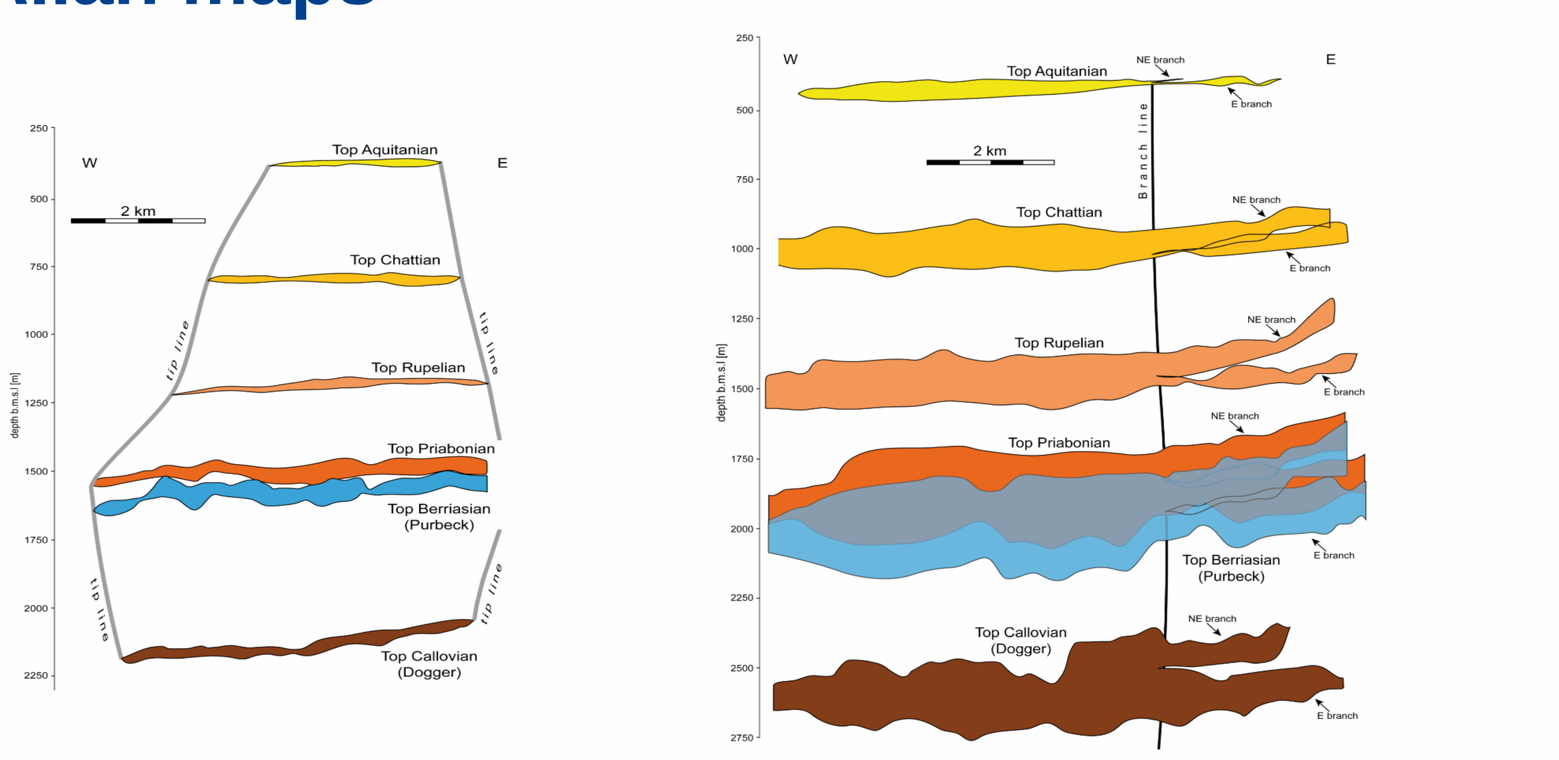


Figure 3: Juxtaposition diagram of two faults (07_north and Munich faults, for location, see Fig. 1). The upper and lower lines of each strata polygon represent the footwall and hanging-wall cutoffs, respectively.

The Allan diagrams show that the maximum offset is between Upper Jurassic and Eocene strata and fault throw decreases both towards younger and older strata. The throw profiles of the Upper Jurassic (Top Malm) and Eocene (Top Lithothamnian limestone) strata are significantly different. Therefore, we surmise that the main activity was during Cretaceous. However, Cretaceous sediments pinch out within the study area, excluding the possibility to further investigate this aspect. We postulate that most of the major faults below Munich do not continue into the crystalline basement.

4. Retro-Deformation

A significant amount of strain is due to decompaction. Although data about porosity of the Molasse sediments is sparse, we succeeded in building a model using exponential functions for each stratigraphic layer. Porosity of the carbonates could only be descry-bed as a constant value. The values for strain due to decompaction range from 5% at Top Aquitanian and up to > 40 % for several deeper Molasse layers.

We retro-deformed all hanging-wall volumes at the Munich Fault tracking the incre-mental (sub-seismic) strain within the restored volumes (Fig. 4). Strain is a proxy for sub-seismic faults. The highest strain does not occur near to the fault, but at more than 1 km distance from it. There are also lateral differences: while the western part is characterized by smaller strain values of 0-20%, in the east the strain values increase up to 85%. We conclude that an increased amount of sub-seismic faults is more likely to occur in the area where the Munich fault splits in the east.

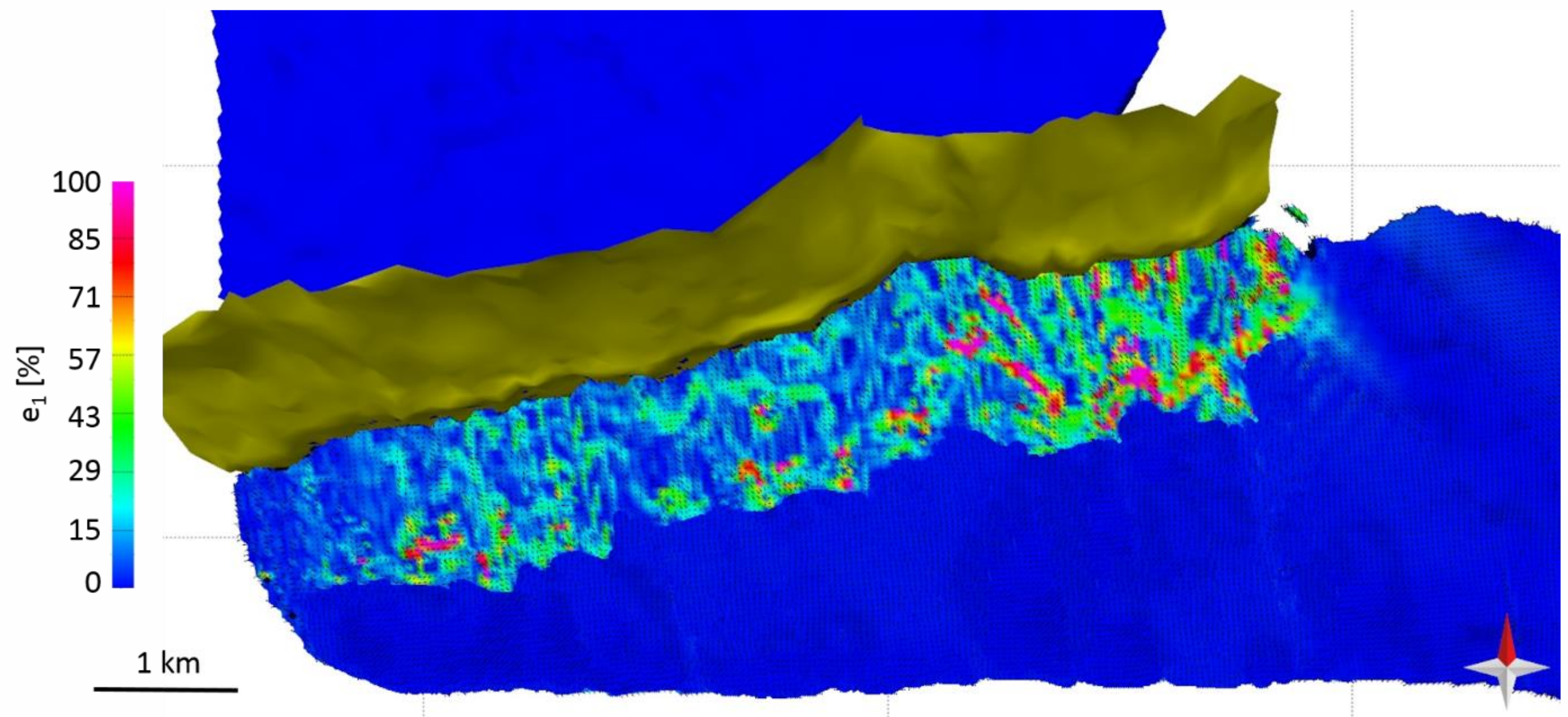


Figure 4: Maximum strain magnitude e_1 at Top Purbeck after retro-deformation of all strati-graphic layers in the hanging wall of the Munich Fault. Strain increases from west to east.

The orientation of the strain tensors describes the orientation of the sub-seismic faulting (Fig. 5). Fractures strike predominantly perpendicular to the Munich fault, at least in the eastern part. This implies enhanced permeability parallel to the faults, provided this happened in an extensional regime.

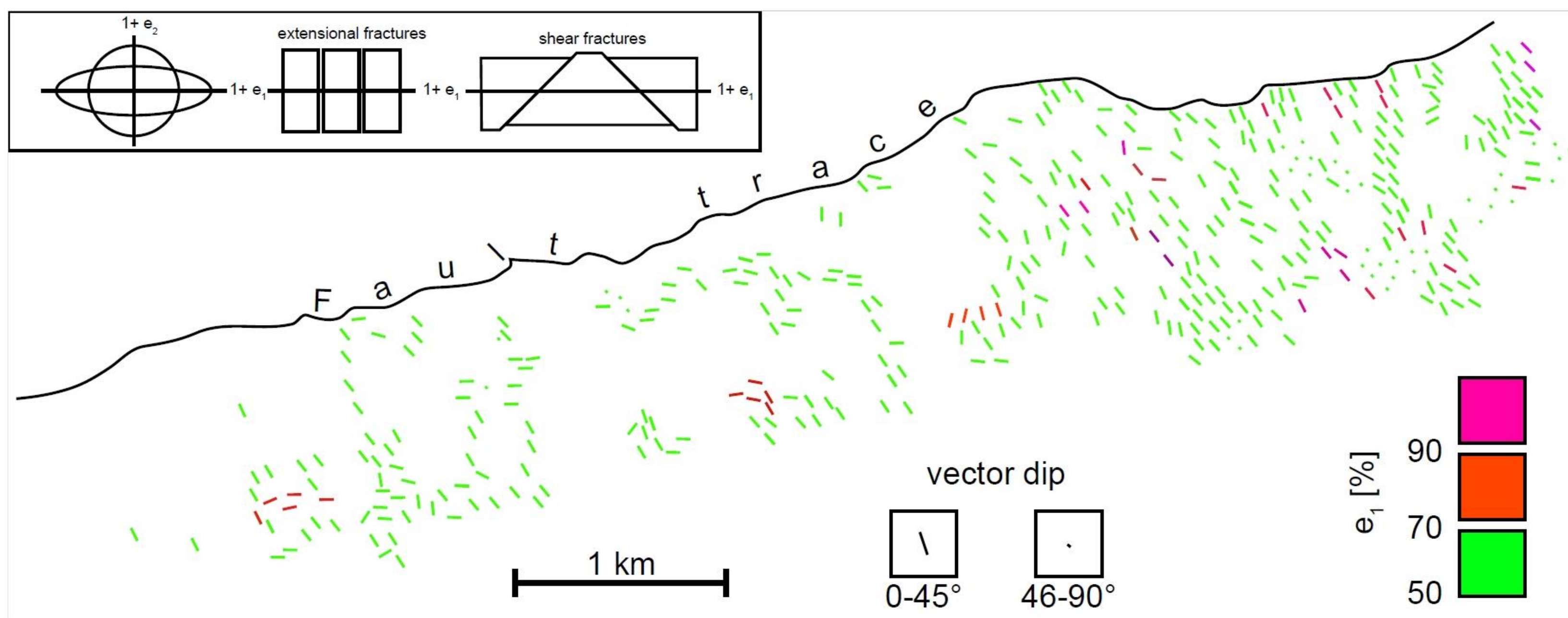


Figure 5: Orientation of the e_1-axis of strain tensors at Top Purbeck. The magnitude of e_1 is colour-coded.

5. Conclusions & Outlook

Structural analysis shows that most of the main faults visible at the carbonate platform level continue to the uppermost Molasse sediments. Since the 3D seismic illumination ends approx. 400 m below surface, high resolution near-surface seismic is required for the timing of the last tectonic activity.

Retro-deformation depends on reliable porosity values. Borehole geophysics should comprise a complete data acquisition, e.g. porosity value sampling along the entire well path.

The results indicate regions of enhanced sub-seismic deformation that are promising targets for geothermal exploration. As new boreholes are presently underway, a comparison with, e.g., FMI logs could verify the results of the retro-deformation. On the other hand, our results may influence well path planning in the future.

Acknowledgements

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1) **G**anzheitlich optimierte und nachhaltige **R**eservoirerschließung für tiefengeothermische **A**nlagen im bayerischen **M**olassebecken – **E**ntwicklung eines 50 MWel Kraftwerkes und von 400 MWth für die Fernwärme in München.
2) **Geo**physical **para**meter to determine facies of the Malm und **mo**delling of the thermal-hydraulic **l**ong time behaviour

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