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Mapping regional variability of reservoir temperatures for hydrothermal use based on parameter uncertainty

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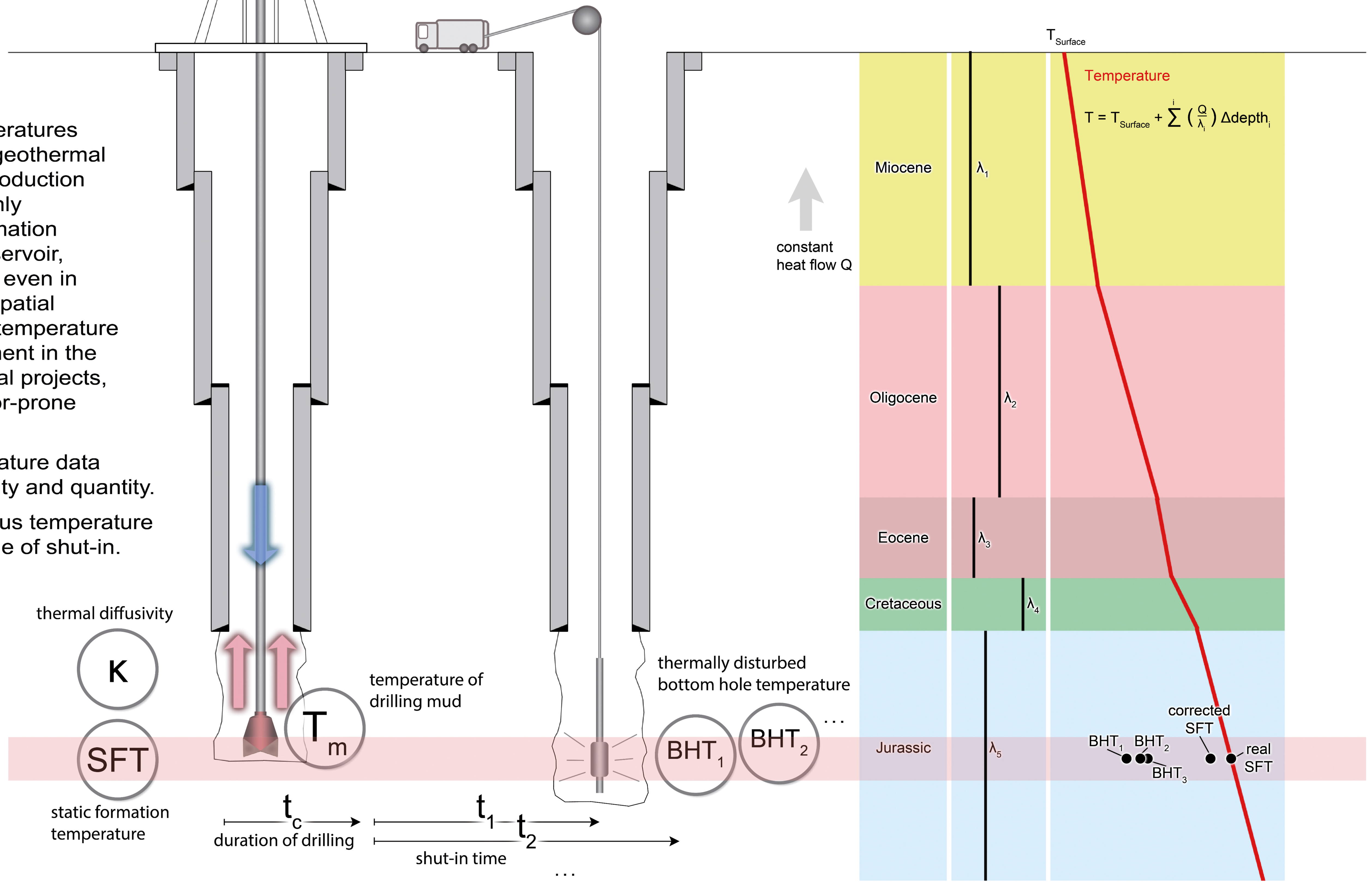
INTRODUCTION

Forecasting downhole temperatures is of great interest for deep geothermal energy development. The production temperature of a well is mainly determined by the static formation temperature (SFT) in the reservoir, which is insufficiently known even in well-developed reservoirs. Spatial representation of downhole temperature is important for risk assessment in the planning phase of geothermal projects, but is highly difficult and error-prone due to low data density.

Generally, downhole temperature data are available in varying quality and quantity.

Of good quality are continuous temperature logs measured after long time of shut-in. Of poor quality, but most available, are bottom hole temperatures (BHTs) obtained from geophysical measurements after drilling a well section. These temperatures are thermally disturbed by the preceding drilling fluid circulation and therefore require correction.



Correction of BHT values using Monte Carlo Techniques

A variety of analytical and numerical BHT correction methods exist, all of which require different input parameters. Those parameters are often documented with **poor quality**, **incompletely**, or **not at all**.

The most commonly used methods require the following input parameters:

- T_m temperature of the drilling mud
- t_c duration of the circulation of the drilling fluid
- t shut-in times (times between drill stop and BHT measurements)
- κ thermal diffusivity of the formation and drilling mud
- a radius of the borehole

BHT correction applied at each well:

- estimation of uncertainty of the available input parameter
- BHT correction with **Sobol** method and **Satelli** sampling
- corrected value is provided as **density distributed value**
- use p10, p50 and p90 values from distribution as **risk scenarios**

➡ The uncertainty range of the results was **up to 30°C**

➡ By comparing with known SFTs, the **p50** values serve well as **expected value**

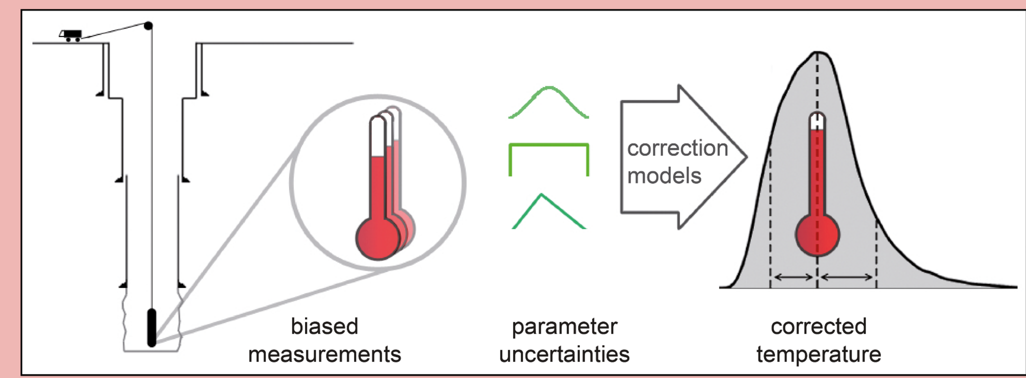


Fig. 2: Concept of risk scenario based BHT correction based on python module SALib (Herman and Usher) (after Schölderle et al.).

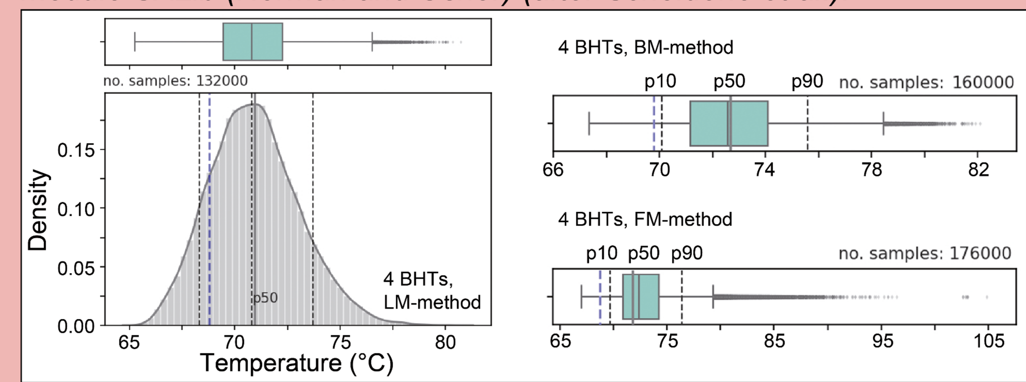


Fig. 3: Exemplary correction of four independent BHT values in a well (modified after Schölderle et al.).

Downhole temperature data in a hydrogeothermal hotspot

Study Area: North Alpine Foreland Basin in Bavaria

Downhole temperature available:

- about 300 BHT values
- 13 undisturbed wireline temperature logs (TLog)

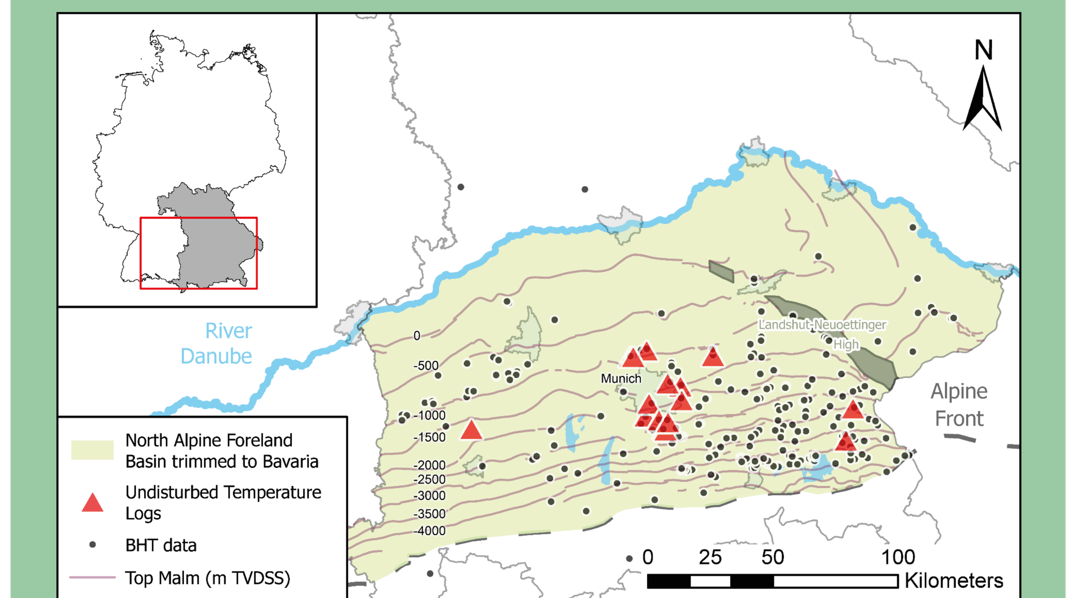


Fig. 1: Temperature data in the Bavarian Molasse Basin.

Approach:

- Study continuous temperature logs with regard to heat flow density and thermal conductivities
- Correct all BHT data with consideration of errors and use them to estimate temperature gradients
- Bring both together into a spatial representation

What temperature logs tell about the geothermal field

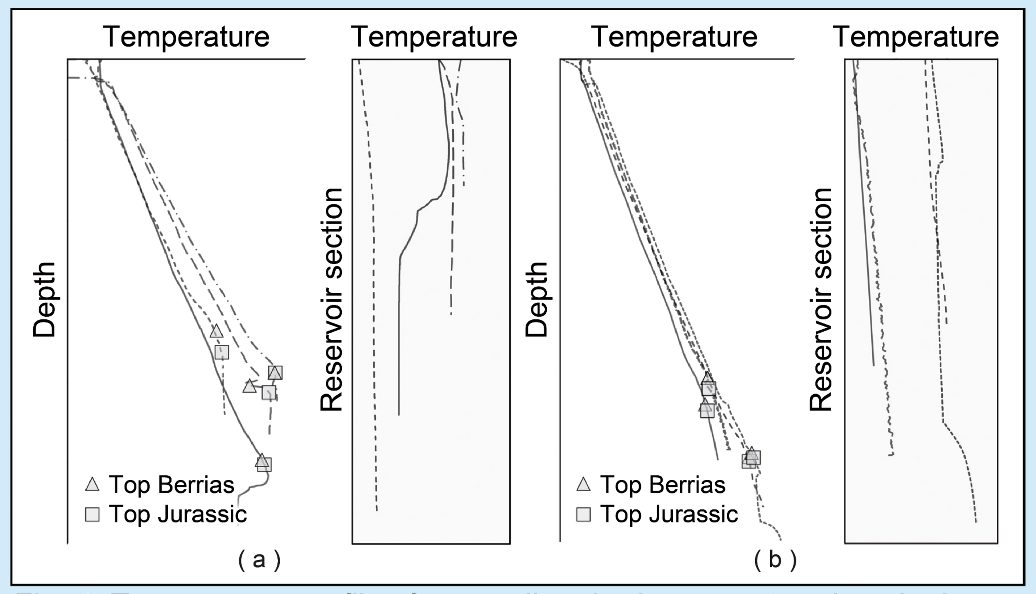


Fig. 4: Temperature profiles from undisturbed temperature logs in the North (a) and South (b) of Munich.

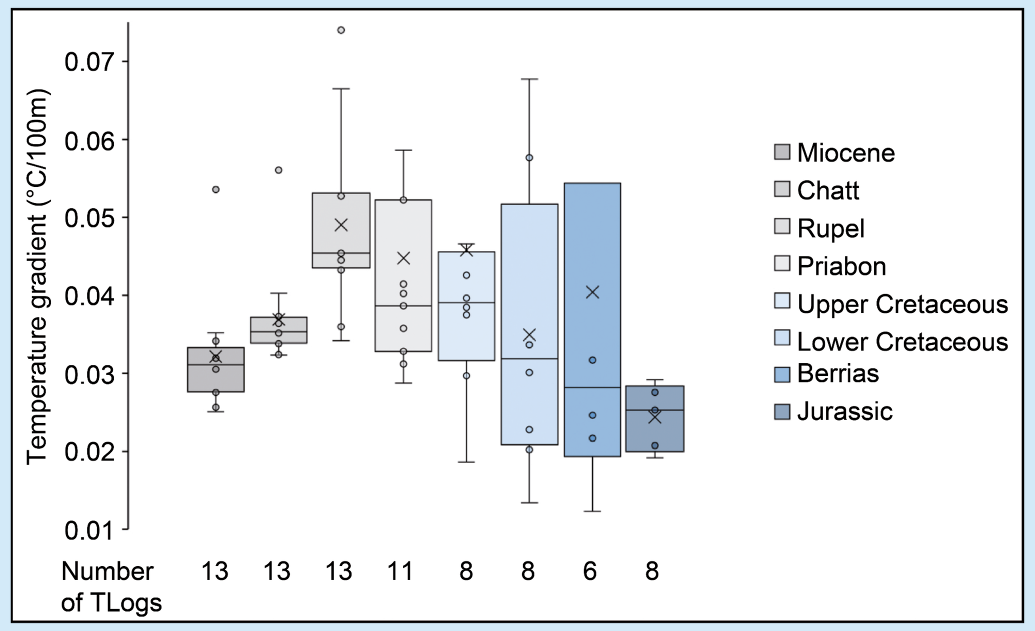


Fig. 5: Thermal gradients obtained from the 13 temperature logs.

8 undisturbed temperature logs reach into the hydrothermal reservoir section.

- reservoir gradients in the **South** of Munich: **0.019 - 0.030°C/m**
- in the **North** of Munich **no or a negative gradient** in the reservoir

➡ Convection probably plays an important role here and thus

➡ BHT correction in the reservoir is not possible with common conductive methods

TLogs show **slope changes** between **stratigraphic units**

- Heat flow density - thermal conductivity (**HFD-λ**) model based on **Fourier law** (e.g., Fuchs et al.) to calculate synthetic geothermal gradients

➡ fitted thermal conductivities lie **inbetween the expected ranges** from sample measurements and literature (e.g., Clauser and Koch et al., Rühaak et al.)

➡ HFD at the 13 locations varies between **86 and 121 mW/m² with a mean of 104 mW/m²**, which is clearly higher than the known mean value for Germany of 78 ± 7 mW/m² (Fuchs et al.)

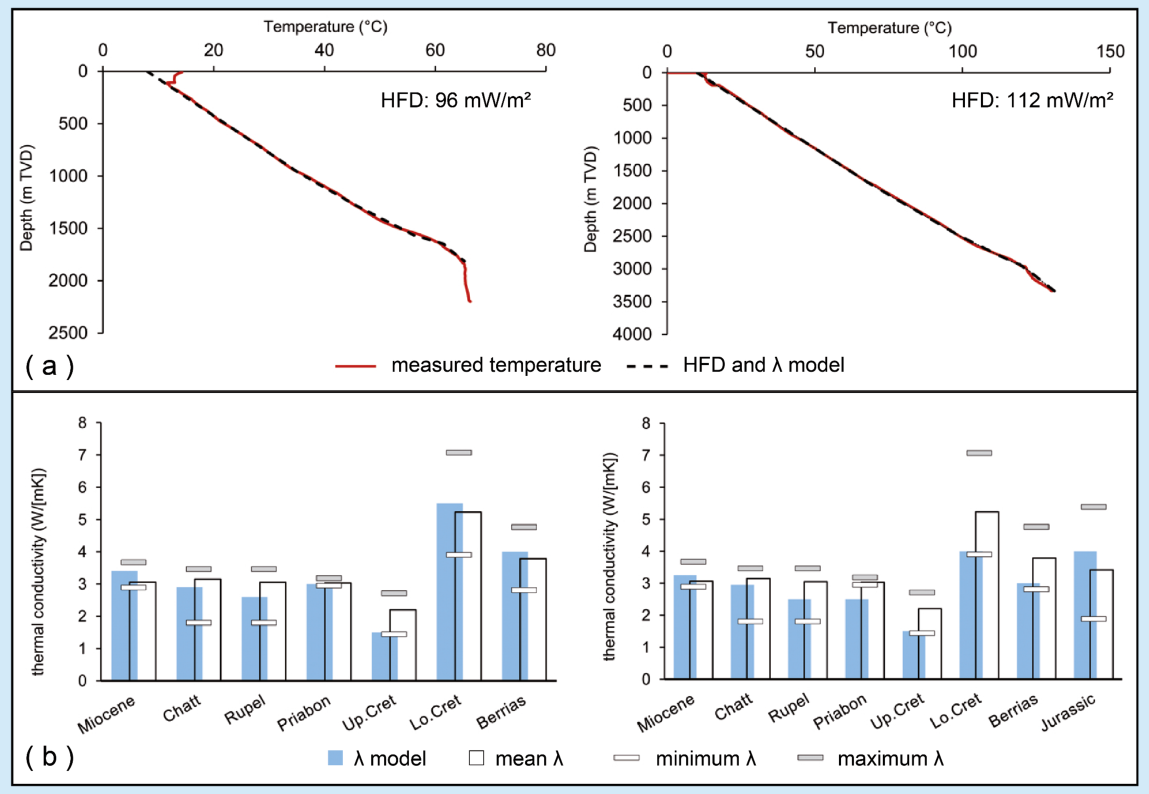


Fig. 6: Two exemplary Tlogs in comparison to HFD and λ model (a) and typical thermal conductivities λ compared to λ from model for each stratigraphic unit (b).

CONCLUSIONS

- The inaccuracy of a corrected BHT value depends to a high degree on the **errors of the input parameters** and not so much on the correction method.
- At the 13 studied undisturbed temperature logs, the **modelled heat flow density** ranges between 86 and 121 mW/m² with a **mean of 104 mW/m²**.
- Gradients indicate a **convectively dominated** reservoir **North of Munich**.

FUNDING

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REFERENCES

Herman and Usher: SALib: An Open-Source Python Library for Sensitivity Analysis. J. Open Source Softw. 2017.
Schölderle et al.: Uncertainty Assessment of Corrected Bottom-Hole Temperatures Based on Monte Carlo Techniques, energies, 2022.
Fuchs et al: Evaluation of the terrestrial heat flow in Germany: A case study for the reassessment of global continental heat-flow data, Earth-Science Reviews, 2022.
Clauser and Koch et al. Erstellung statistisch abgesicherter thermischer und hydraulischer Gesteinseigenschaften für den flachen und tiefen Untergrund in Deutschland : Phase 1 - Westliche Molasse und nördlich angrenzendes Süddeutsches Schichtstufenland, 2007.
Rühaak et al. Detecting thermal anomalies within the Molasse Basin, Southern Germany, Hydrogeol. Journal, 2010.