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Deep learning and geochemical modelling as tools for solute geothermometry

L. H. Ystroem, M. Vollmer, F. Nitschke, T. Kohl
lars.ystroem@kit.edu

Motivation

- Solute geothermometry is an economical green field exploration tool to estimate reservoir temperatures from fluid composition
- Geochemical modelling is able to reconstruct *in-situ* conditions of the reservoir resulting in more precise temperature estimations
- Artificial neural networks are able to learn complex chemical coherences for reservoir temperature estimation

Conclusion

- **Geochemical modelling**: Statistically robust and precise temperature estimations via interdependent optimisation processes
- **Artificial neural network**: Computational efficient geothermometer, capable of handling large amount of data
- **High accuracy**: Calculated temperatures of both methods match measured in-situ temperatures very well

Solute geothermometry

- Solute geothermometry is able to predict the reservoir temperature using the chemical composition of a geothermal fluid
- Basic assumption:
  - Reservoir mineral composition and the geothermal fluid are in chemical equilibrium
  - Temperature-driven rock – water interaction saturates the fluid with elements of the reservoir rock
  - The chemical equilibrium is mostly preserved while the fluid ascends to the surface
- Method:
  - Element ratios as well as saturation state of mineral phases contain information about the temperature of the reservoir
- Input:
  - Standard geochemical water analysis of major cations and anions (Na, K, Ca, Mg, Cl, S, C, Si) as well as trace elements (Al, Fe)
  - Sampling parameters of the fluid (temperature, pressure, pH)

Statistical evaluation

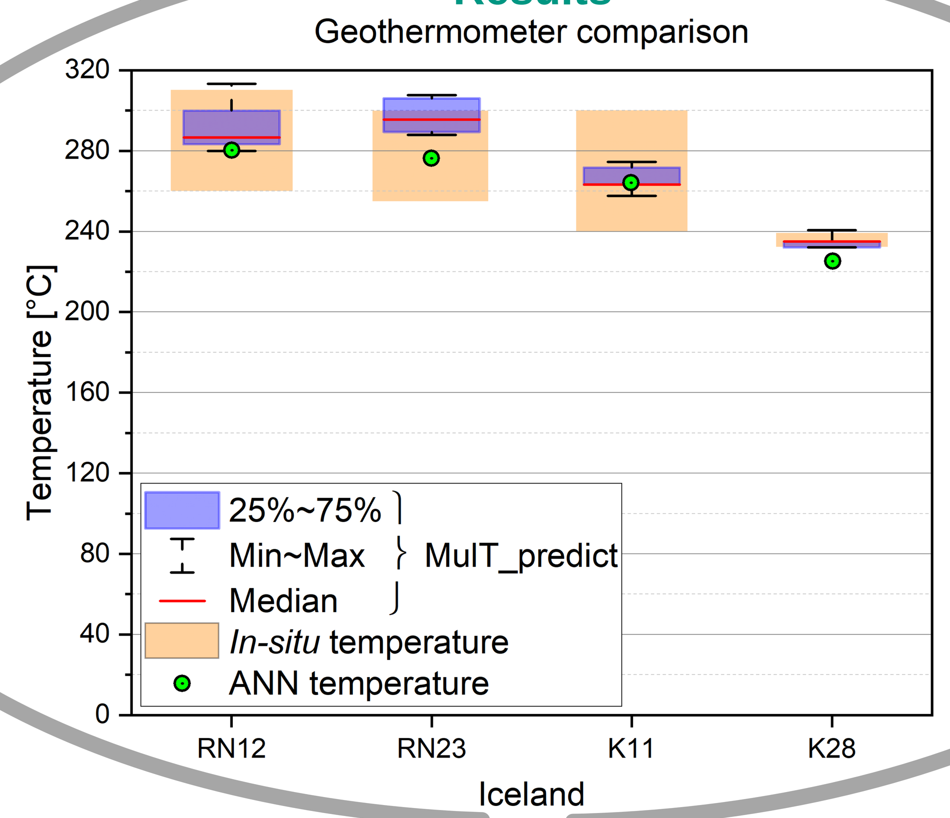
- **MulT_predict:**
  - Multicomponent geothermometer with integrated optimisation process
  - Using saturation indices of multiple mineral phases to estimate the reservoir temperature
  - Interdependent parameter adjustment reconstructing equilibrium state of reservoir conditions
  - Converging equilibrium temperatures until a global minimum is reached

$$SI(T) = \log \frac{IAP}{K_s(T)}$$

- Equilibrium state for SI = 0
- IAP: measured ion activity product
- K_S: mineral solubility product

- **Artificial neural network:**
  - Minimising cross-entropy losses by adjusting weights within neurons fitting input parameters to the target value
  - Performance metrics of the neural network are depending on various model parameters
    - Network architecture
    - Activation functions
    - Hyperparameter selection

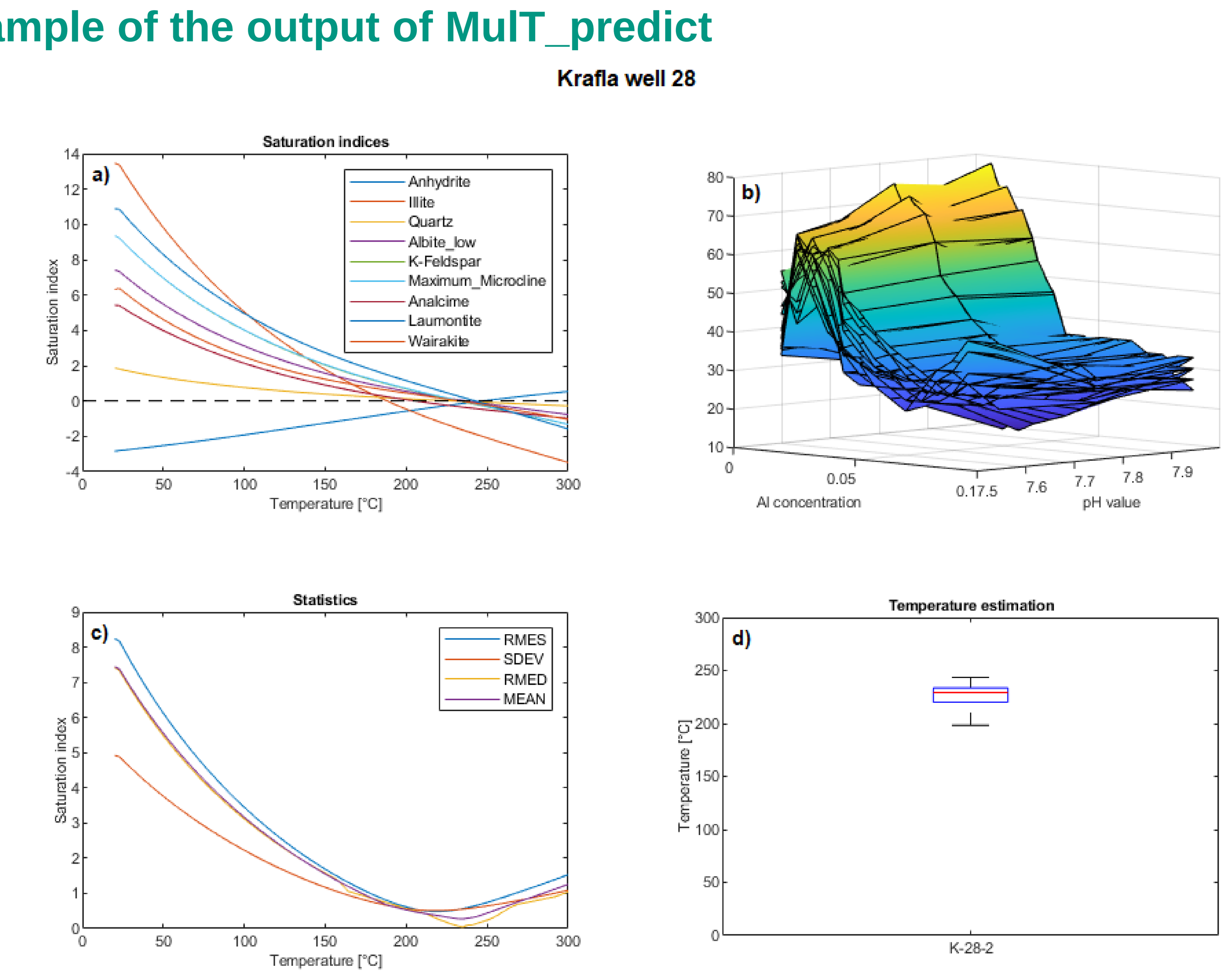
Results



MulT_predict

- Minimisation of equilibrium temperature distribution using interdependent optimisation processes

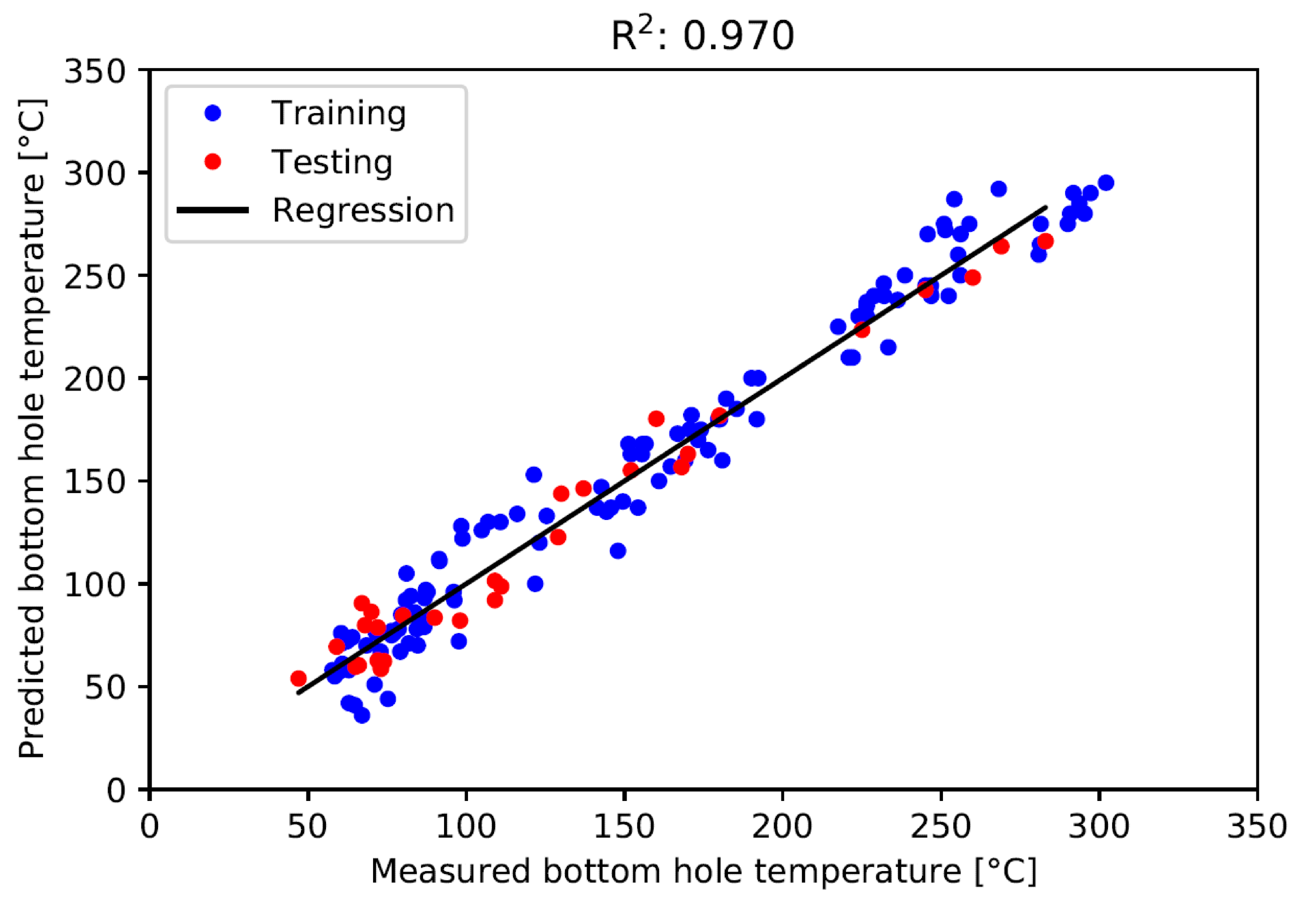
Example of the output of MulT_predict



Artificial neural network

- A supervised multilayer perceptron is trained with high-quality data
- Validation and testing of the network minimising the error without overfitting the neural network

Artificial neural geothermometer



Publications

Ystroem LH, Nitschke F, Held S, Kohl T (2020) A multicomponent geothermometer for high-temperature basalt settings. Geothermal Energy 8:13
Ystroem LH, Nitschke F, Kohl T (2022) MulT_predict - An optimised comprehensive multicomponent geothermometer. Geothermics 105:102548