Leibniz Institute for Applied Geophysics

Supported by: Federal Ministry for Economic Affairs and Energy

Geothermal reservoir modelling and production optimization of smart multi-well patterns in the fractured and karstified Upper Jurassic aquifer in the Bavarian Molasse Basin: Case study: Greater Munich geothermal field

Ernesto Meneses Rioseco

Leibniz-Institut für Angewandte Geophysik, 30655 Hannover

Introduction

Coupled flow and thermal modelling in fairly heterogeneous and anisotropic geothermal reservoirs under optimized multiple sources and sinks requires the use of new mathematical models. Aim and available data have a significant influence on the model architecture (e.g., mesh refinement with large permeability gradients – up to which level of detail must/can permeability heterogeneities and anisotropies be implemented?).

Example: permeability structure of a fault zone

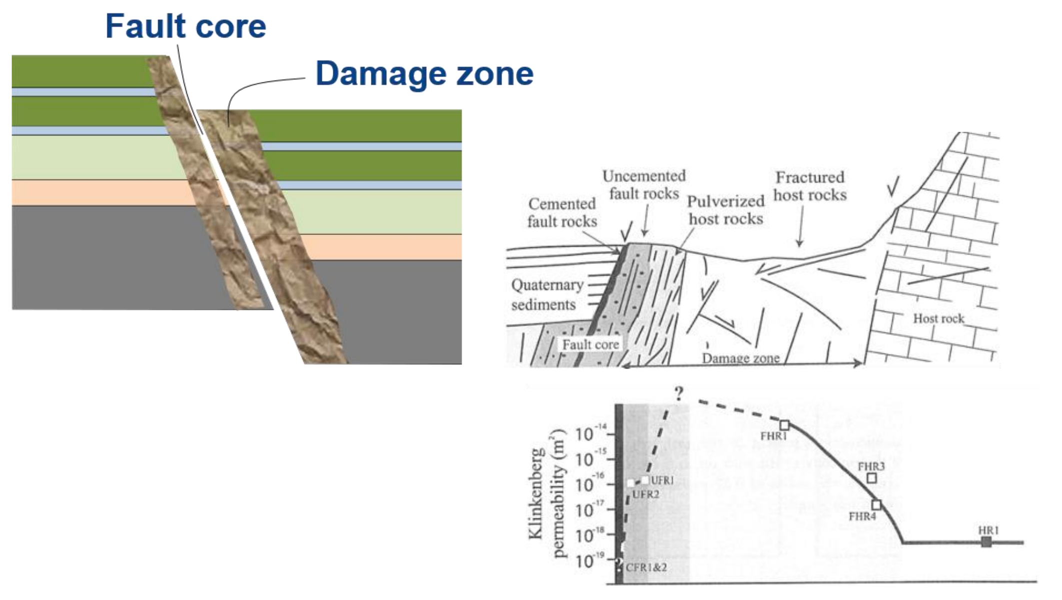


Fig. 1: On the left-hand side a schematic representation of a fault zone is shown. On the right-hand side a real example of the permeability structure around a normal fault in the Fucino Basin (Central Italy) is displayed after [1].

The present work lies within the scope of the GeoParaMoL-project, which is part of the GRAME-project and focusses on the estimation of geophysical parameters to determine facies of the Upper Jurassic (Malm), structural and stratigraphic geological features and the modeling of the thermal-hydraulic long-term behavior of the Malm affected by geothermal multi-well arrays.

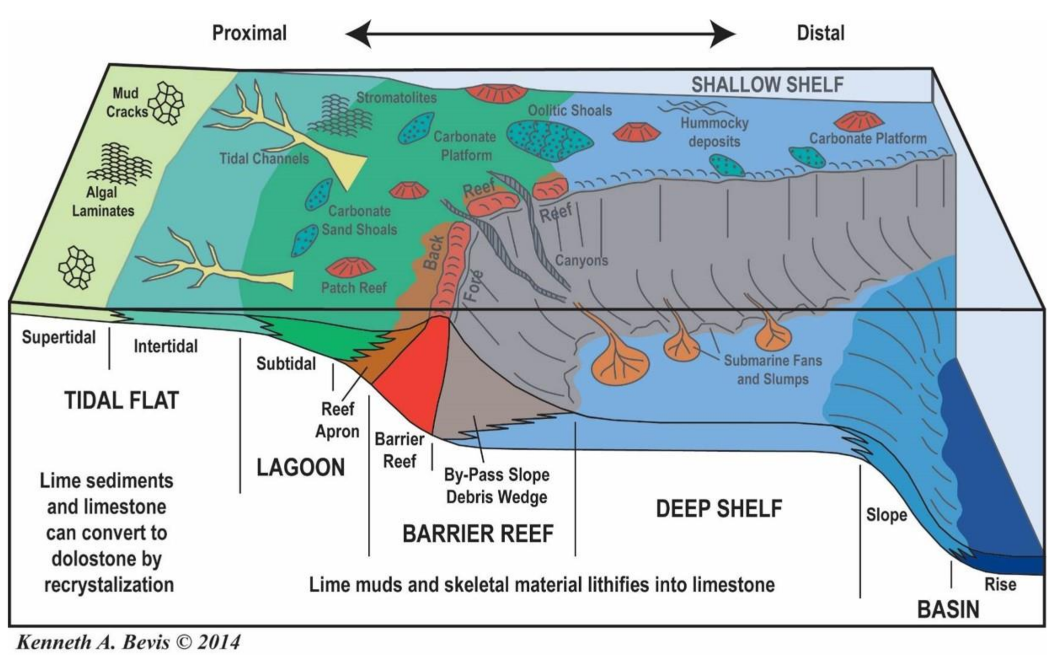


Fig. 2: Carbonates are extremely heterogeneous right from the beginning.

Building a 3D geothermal reservoir model

Implementing the geological controlling factors to an appropriate resolution remains a challenging task. In addition, inserting the study region as a subdomain of a larger model further requires matching approaches.

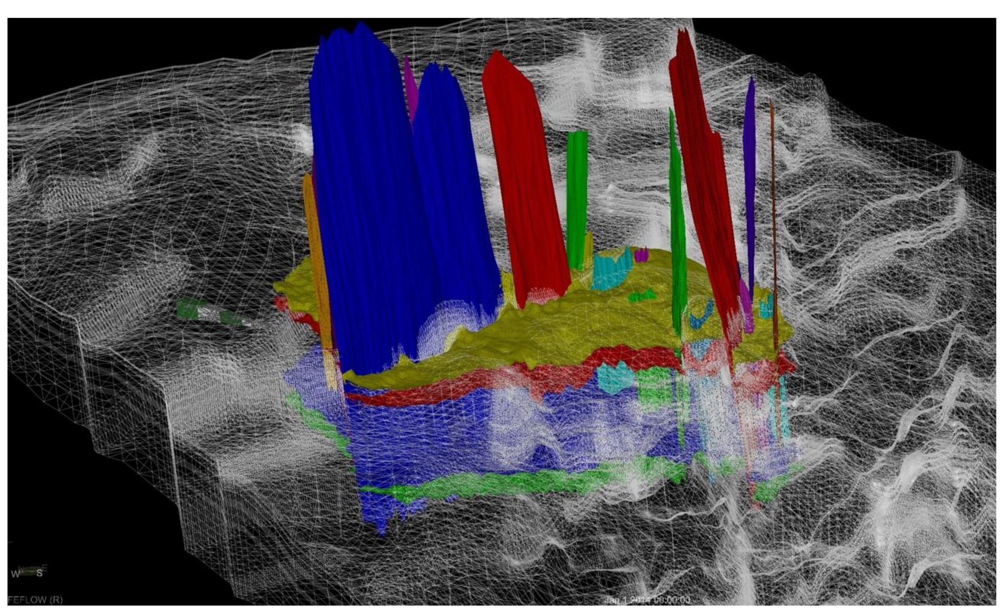


Fig.3: Implementation of the updated geological model in the reservoir model of Greater Munich.

Reservoir engineering: multi-well systems

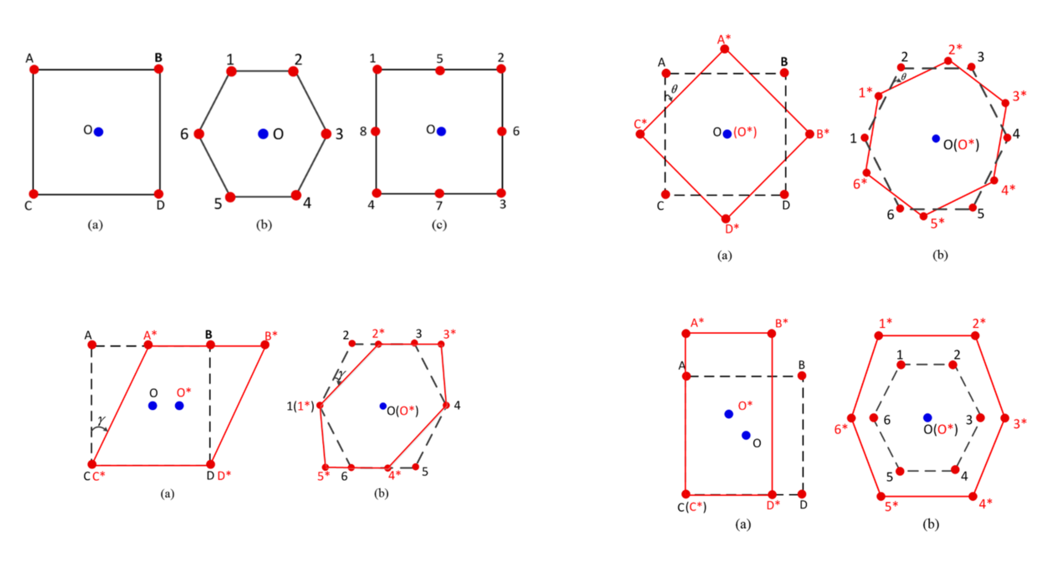


Fig.3: Different multi-well arrangements extensively used in the hydrocarbon industry (Fig. after [2]). Similar multi-well arrays can be readapted to geothermal purposes.

Multi-variable optimization problem

Choosing an appropriate geothermal recovery concept related to complex geometrical well patterns constitutes a multi-variable optimization problem. A series of irreconcilable technical and economic issues has to be weighted up. In particular, the separation between the production and injection wells together with the geometrical architecture of the geothermal well-field configuration is crucial when it comes to optimizing the exploitation concept. In addition to minimizing pressure difference between injection and production wells, temperature drop of the thermal fluid in the production well should be minimized.

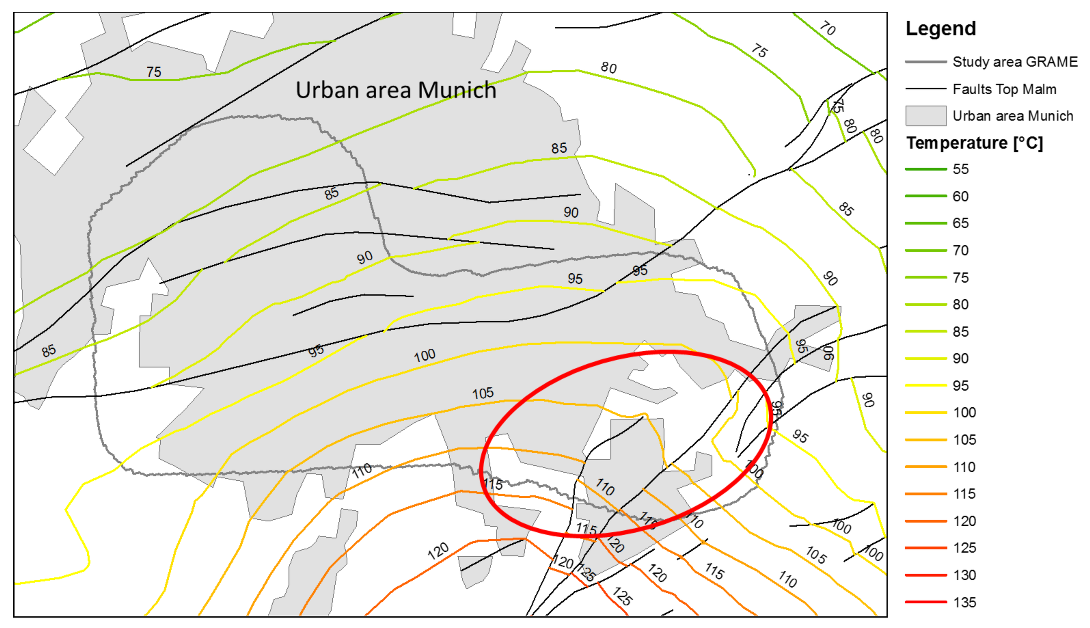
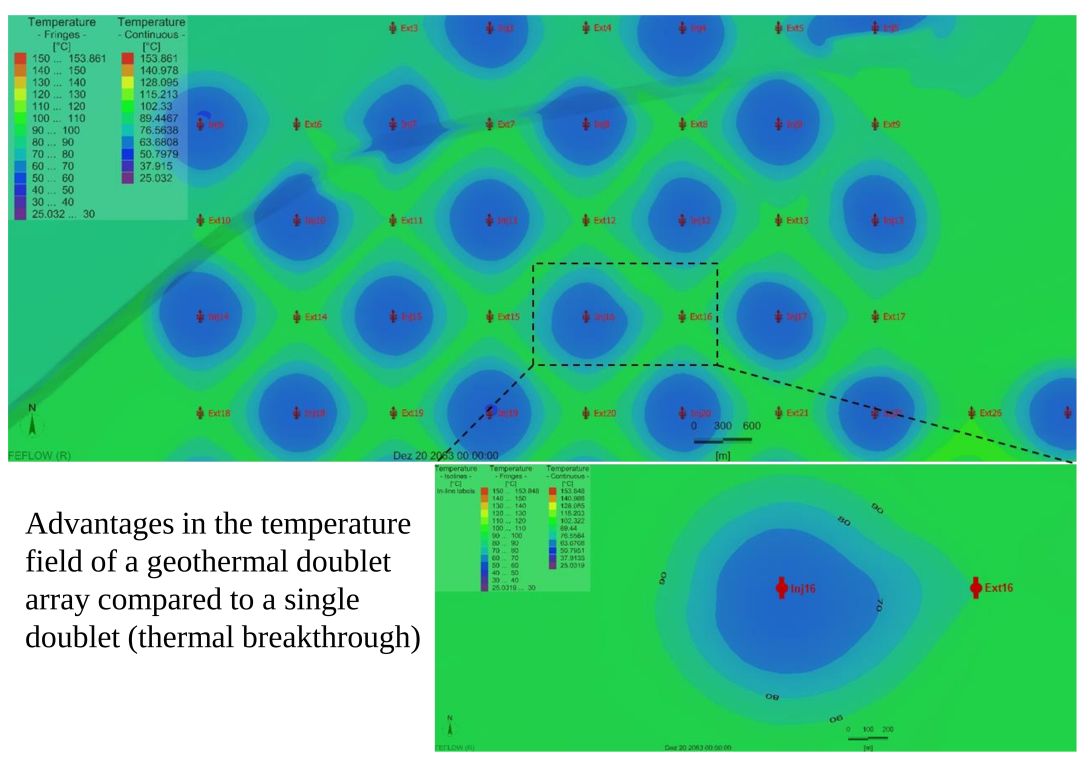


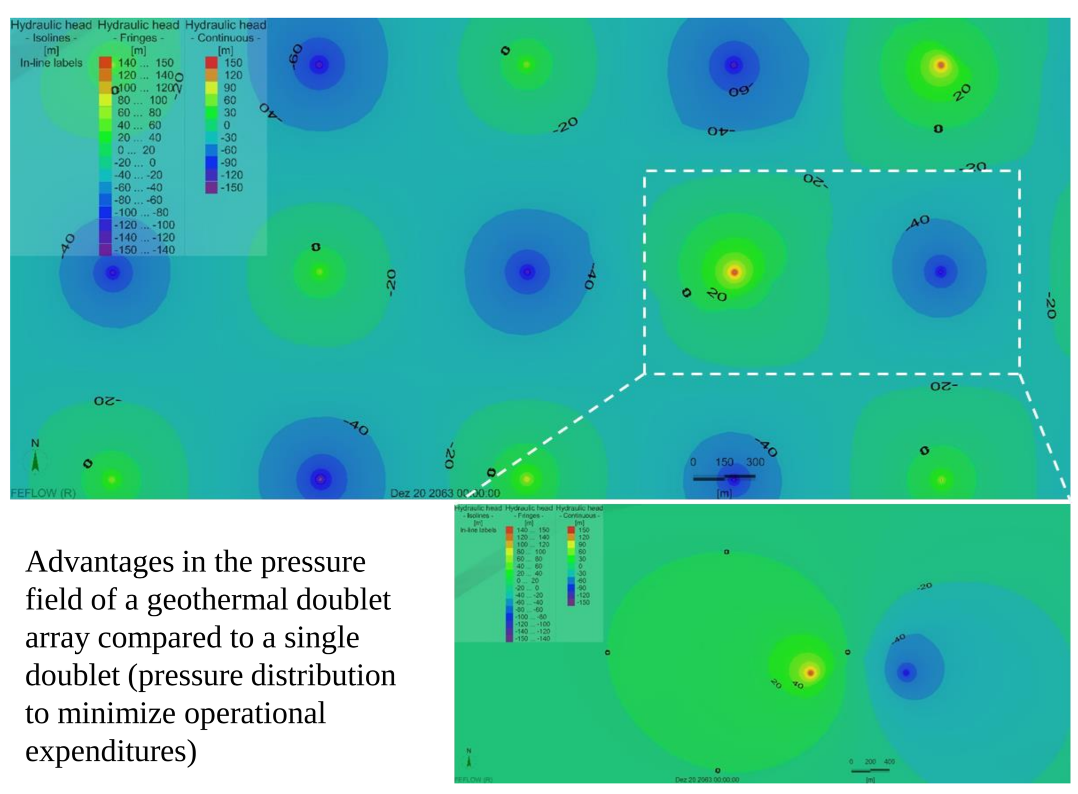
Fig. 5: Temperature distribution in Top Malm from GeotIS (status 10/2017). The area marked with thick red line indicates the domain in the study area of highest temperature.

Preliminary modelling results with FEFLOW

The optimization of geothermal energy production as well as reservoir management of multi-well patterns involve the study of possible positive and negative thermal-hydraulic interferences that such multi-well systems may have within the array and with neighbouring geothermal wells already in operation in the immediate surroundings of the study region [3, 4].



Advantages in the temperature field of a geothermal doublet array compared to a single doublet (thermal breakthrough)



Advantages in the pressure field of a geothermal doublet array compared to a single doublet (pressure distribution to minimize operational expenditures)

Fig. 6: Temperature distribution (upper figure) and pressure field (lower picture) in the first main influx zone after 50 years modelling time for a geothermal doublet array of 1 km lattice spacing, 80 l/s permanent injection and production rates and 60 °C water injection temperature. Note that in case of a doublet array the thermal breakthrough is slowed compared to a single doublet (upper picture). The pressure field shows also advantages in case of a doublet array compared to a single doublet (lower picture).

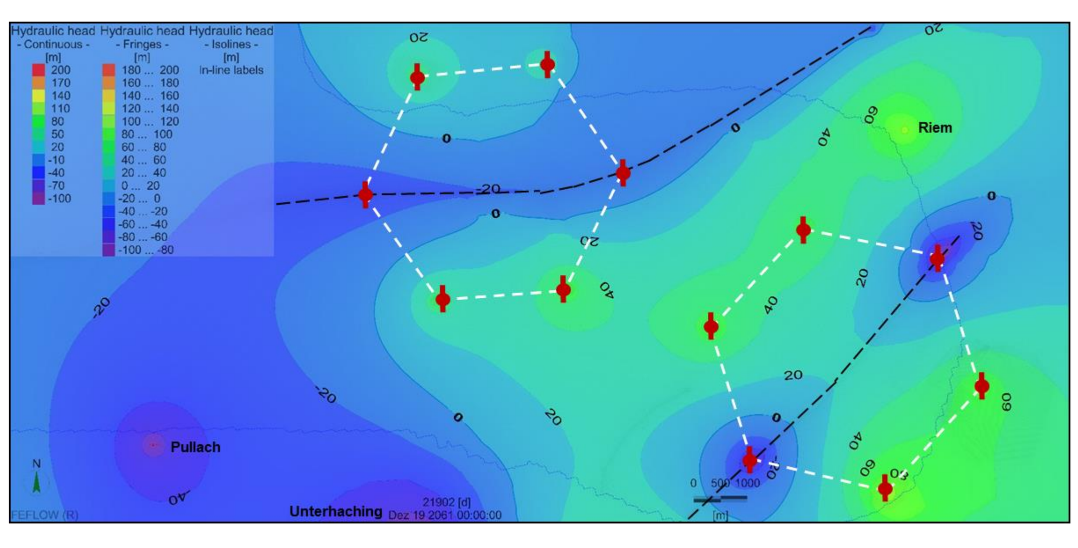


Fig. 7: Pressure field in the first main influx zone for multi-well configurations (hexagon-configuration of 6 geothermal wells) after 50 years simulation time. Red symbols display injection and production wells. Different hydraulically active faults are shown with black dashed lines. Note that production wells are placed in the faults while injection wells are placed around the faults. 150 l/s of thermal water has been constantly produced in each production well and 75 l/s of cooled thermal water has been permanently injected in the injection wells.

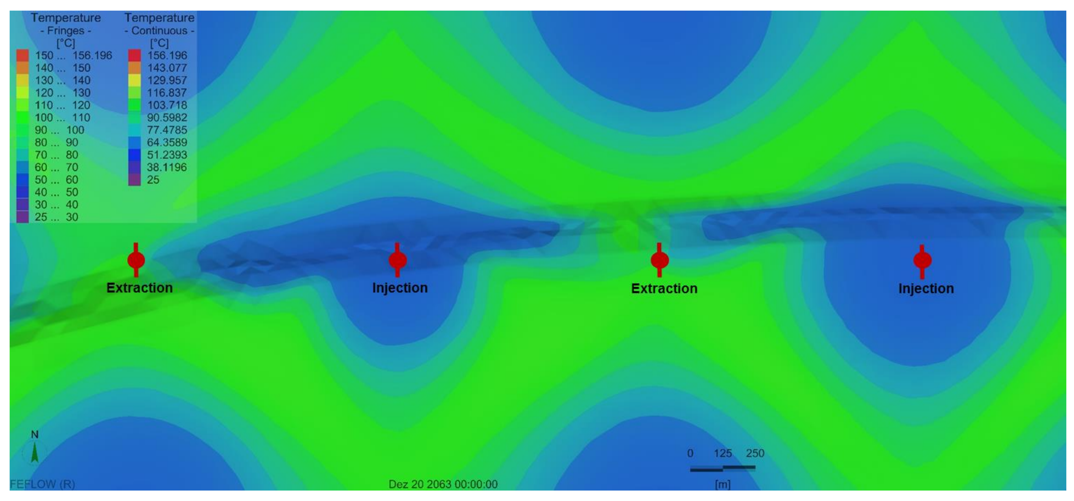


Fig. 8: Temperature distribution along and across a major hydraulically active fault after 50 years of simulation time. 80 l/s of injection and production rate has been circulated for a geothermal doublet array of 1 km lattice spacing.

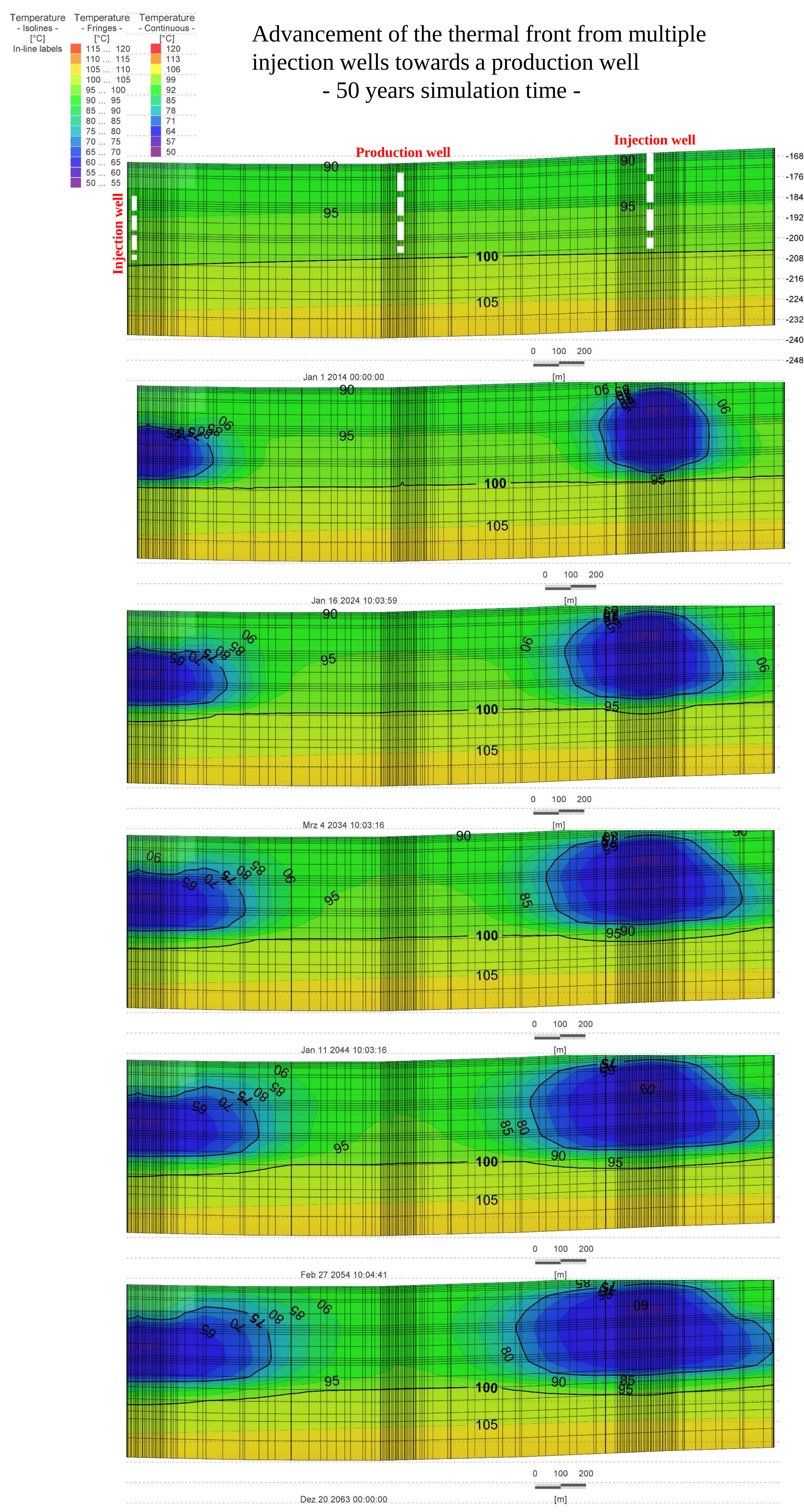


Fig. 9: Vertical cross-section of the spatio-temporal evolution of the thermal front at multiple injection wells towards a production well. The subsurface temperature disturbance due to the injection of 60 °C cooled water and hot water extraction is shown in 6 snapshots starting from 2014 (upper picture) up to 2063 (lower picture). As can be seen from the images, after 50 years of 80 l/s permanent water injection and extraction, the thermal breakthrough has not been reached for 1 km distance between injection and extraction wells.

Concluding remarks

Several scenarios with varying geometrical and operational conditions were implemented and numerically simulated. Preliminary thermal-hydraulic modelling results show that, for the simulation time considered, geothermal doublet-arrays with a lattice spacing between 1 and 2 km and flowrates between 80 and 120 l/s are promising scenarios. In addition, model results indicate that geothermal multi-well configurations of 4 to 6 wells are under particular geothermal and hydrogeological conditions more appropriate. This later model result relates to hydraulically active faults. Modeling results suggest thermal and hydraulic advantages and disadvantages of geothermal doublet-arrays over a single doublet. For instance, the use of geothermal doublet-arrays leads to a significantly slower advancing thermal front but once the thermal breakthrough is reached the temperature in the production well drops more rapidly.

References

[1] F. Agosta, M. Prasad and A. Aydin. Physical properties of carbonate fault rocks, fucino basin (Central Italy): implications for fault seal in platform carbonates. *Geofluids*, 2007.

[2] L. Zhang, K. Zhang, Y. Chen, M. Li, J. Yao, L. Li and J. Lee. Smart well pattern optimization using gradient algorithm. *J. Energy Resour.* Technol., 2015.

[3] M. Dussel, E. Lüschen, R. Thomas, T. Agemar, T. Fritzer, S. Sieblitz, B. Huber, J. Birner and R. Schulz. Forecast for thermal water use from Upper Jurassic carbonates in the Munic region (South German Molasse Basin). *Geothermics*, 2016.

[4] M. Jobmann, & R. Schulz. Hydrogeothermische Energiebilanz und Grundwasserhaushalt des Malmkarstes im Süddeutschen Molassebecken. –GGA-Abschlussbericht. Archiv Nr. 105 040. Niedersächsisches Landesamt für Bodenforschung Hannover, 1989.

Acknowledgement

The project "GeoParaMoL" wouldn't have been possible without the financial support of the German Federal Ministry for Economic Affairs and Energy (BMWi).