PS The Application of Borehole Image Interpretations for Geothermal Well Stimulation: A Case Study from Two Deep Geothermal Boreholes in Late Jurassic Carbonates in Southeast Bavaria*

Bastian Roters[1], Mario Habermuller[1], Lars Matthes[2], Ulrike Miersemann[3], and Hans-Gert Linzer[3]

Search and Discovery Article #42381 (2019)**
Posted July 1, 2019

*Adapted from poster presentation given at 2019 AAPG European Region, 3rd Hydrocarbon Geothermal Cross Over Technology Workshop, Geneva, Switzerland April 9-10, 2019

[1]NiMBUC Geoscience OG - Vienna, Austria (roters@nimbuc.com)
[2]Silenos Energy Geothermie, Augsburg, Germany
[3]RAG Exploration & Production GmbH, Vienna, Austria

Abstract

In 2018 Silenos Energy GmbH started a project in southeast Bavaria to produce electricity from a deep geothermal doublet system. Two highly deviated wells targeted the Mesozoic cover units of the Alpine Foreland Basin beneath the Bavarian Molasse. The Late Jurassic (Malm) is recognized as the main geothermal reservoir in this area. Exploration activities in other areas of the Bavarian Molasse proved the high complexity of the Malm reservoir due to the interaction of matrix porosity with karstification and fractures (Steiner et al., 2014). Seithel et al. (2015) highlighted the importance of critically stressed fractures for the hydraulic conductivity of the Malm in the Bavarian Molasse Basin as a reservoir.

Borehole Image Logs (BHI) were acquired in both wells in order to reduce the risk arising from this complexity. More than 1200 m of images were logged around the target interval in each borehole together with standard open hole logs. A quick- look interpretation of the BHI data was performed with short turnaround time of less than 12 hours for fast decision-making before starting the well stimulation processes.

After reception of the BHI data from the logging company, the logs were carefully quality controlled and processed to guarantee the completeness and accuracy of the data as well as the correct orientation of the logs. The subsequent analysis was focused on bedding orientation, fracture classification and orientations, fault zones, karstified intervals as well as drilling-induced borehole failures. The analyses were performed by two geologists working simultaneously within the tight time schedule in order to ensure the quality of the interpretation. The whole analysis was performed manually, without using any automatic picking algorithms, thus increasing the quality of the analysis.

Our interpretation revealed a triple porosity system driven by strong karstification as well as fractured zones in both wells. The boreholes penetrated Late Jurassic limestones and dolostones that contain highly fractured intervals as well as local karst phenomena, i.e. vugs and

breccias. The karst features appear to be bound both to certain stratigraphic intervals as well as to the fracture-fault system, thus indicating a strong interaction of the karst system with fractures. Fracture sets strike preferably in E-W/ENE-WSW directions and around N-S direction, where the sets in E-W/ENE-WSW directions show preferably higher apertures. Natural tensile enhanced fractures were encountered in both wells and align with the tensile regions of the boreholes. The fracture density was calculated to identify highly fractured intervals, whereas karst intervals were identified by visual inspection. Small vugs occur along fracture surfaces; bigger vugs and karst holes are seen dispersed in the rocks but are confined to certain intervals in the dolomitic Malm. The BHI analyses suggest that karstified zones have the strongest impact on reservoir flow, even though the reservoir is highly fractured.

Well stimulation was performed through acidization of open fractures and vugs in order to increase the producible volume around the borehole. It is not possible to acidize the entire borehole, as the volume of the stimulation fluid is limited. Hence, the most prospective intervals for stimulation were defined based on the results of the BHI analysis. Pump tests before and after the stimulation from both wells indicate increased flow rates of thermal waters, which proves the success of the stimulation and highlights the value of BHI interpretations for geothermal projects.

The Application of Borehole Image Interpretations for Geothermal Well Stimulation

A case study from two deep geothermal boreholes in Late Jurassic carbonates in Southeast Bavaria

Bastian Roters[1], Mario Habermüller[1], Lars Matthes[2], Ulrike Miersemann[3] & Hans-Gert Linzer[3]

[1]NiMBUC Geoscience OG, Vienna, Austria - roters@nimbuc.com; [2]Silenos Energy Geothermie, Augsburg, Germany; [3]RAG Exploration & Production GmbH, Vienna, Austria

1 Project Overview

The deep geothermal project is performed by Silenos Energy Geothermie, which is a joint venture of STRABAG SE and RAG Rohöl Aufsuchungs AG.

The project started in June 2017 and and it consists of a geothermal doublet penetrating Late Jurassic (Malm) carbonates.

Drilling activities commenced in spring 2018 and finished in December 2018. The two boreholes are highly deviated each with a length of more than 5,000m. Both wells are successful, the temperatures and flow rates in the doublet system are high enough to operate a power plant. A further use of the water for a local district heating network is under consideration.

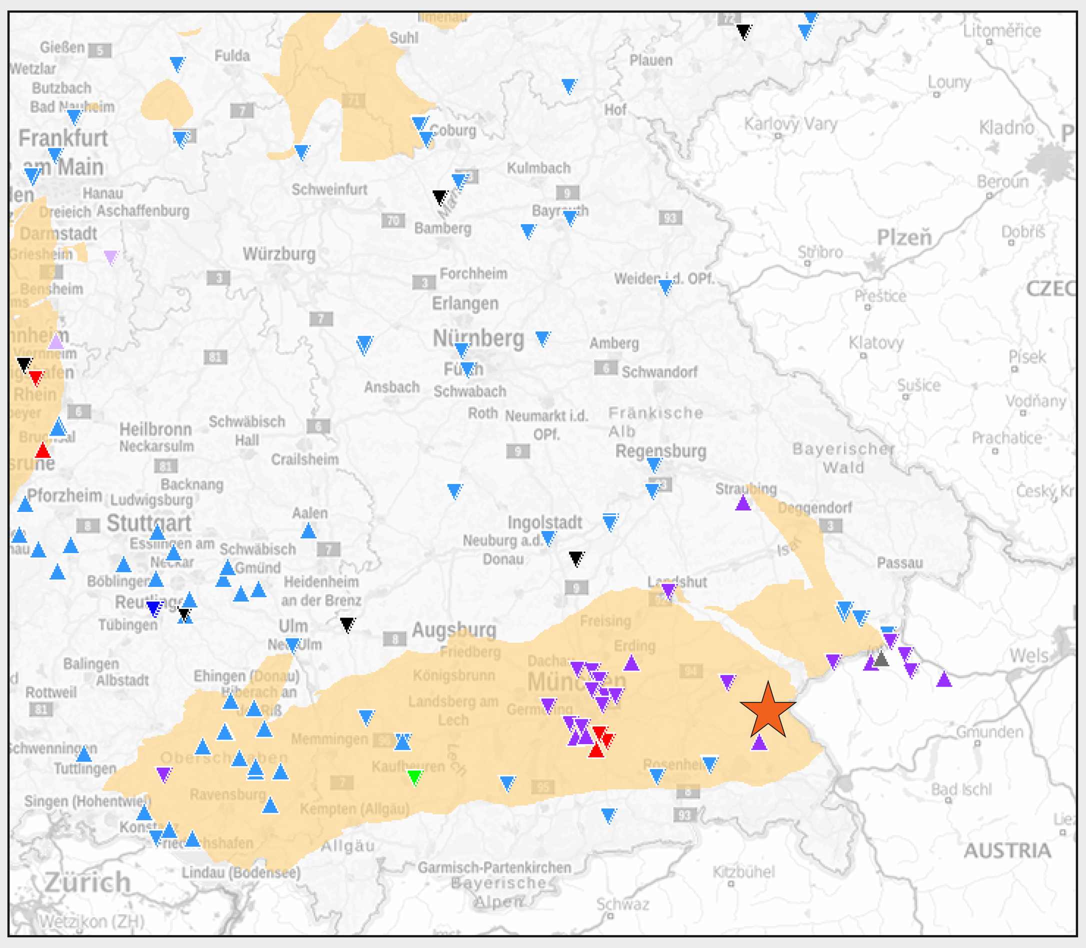


Figure 1: Map of South Germany and adjacent areas showing the position of geothermal wells. Areas with large hydrogeothermal potential are highlighted in orange. Approx. wellsite position is marked with orange asterisk. Source: Geoportal.de, accessed Feb. 18, 2019.

2

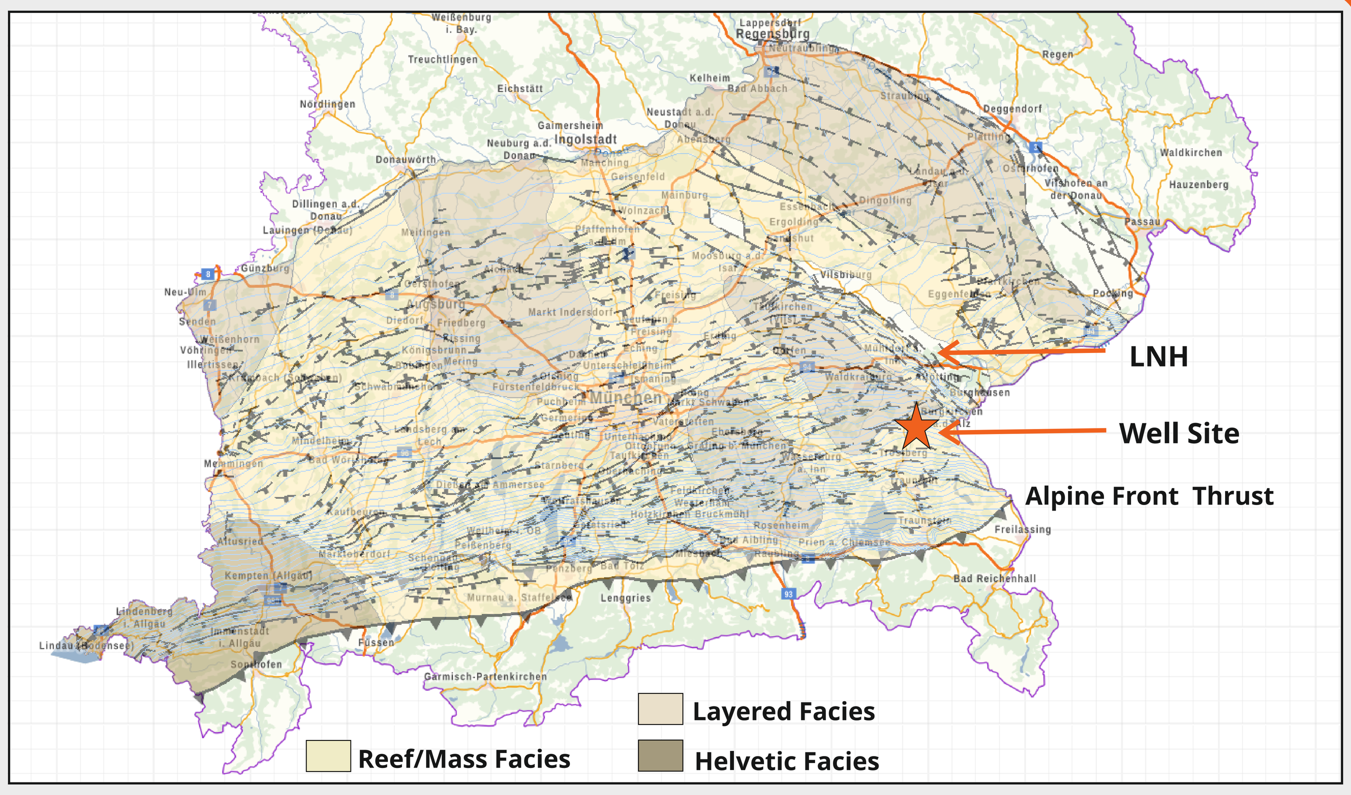


Figure 2: Map of southern Bavaria showing the subsurface extension of the Upper Jurassic and its facies distribution. Also faults crossing the Upper Jurassic surface are shown. LNH: Landshut-Neuötting Crystalline High. Source: Umweltatlas Bayern – umweltatlas.bayern.de, accessed: February 4, 2019, modified.

The Upper Jurassic in southern Bavaria is made up of reef and layered facies and of Helvetic facies carbonates in the SW. Faults strike parallel to the alpine front approx. WSW-ENE. NE of the Landshut-Neuötting Crystalline High (LNH) faults strike in NW-SE direction. The LNH is situated ca. 15 km northeast of the drill site. The drill site is located near the boundary between reef/un-bedded facies and layered facies. Due to the interaction of fractures and matrix porosity the Upper Jurassic reservoir in South-East Bavaria is highly complex (Steiner et al., 2014).

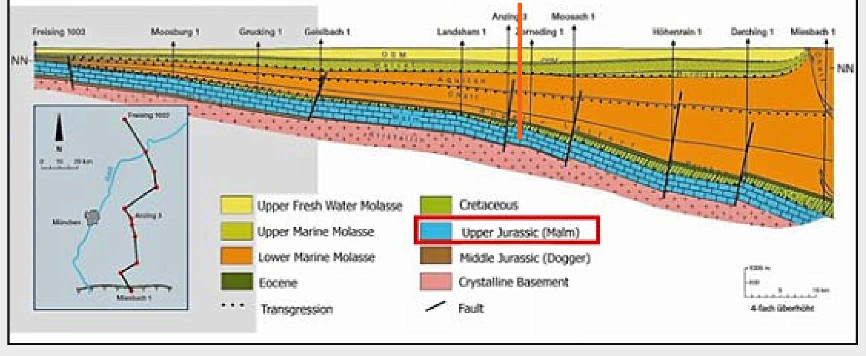


Figure 3: N-S cross-section through the Bavian Alpine Foreland basin. The Upper Jurassic is marked in blue. From Hedtmann & Alber (2017), modified.

Critically stressed fractures are crucial elements for its hydraulic conductivity (Seithel et al., 2015).

3 Methodology

Borehole Images (BHI) were acquired in both wells over a length of >1200m each in order to reduce the subsurface risk.

A quick-look interpretation (in less then 12 hours) was then performed for fast decision-making before starting the well stimulation processes.

Borehole image tools measure a certain petrophysical property, i.e. resistivity, sonic travel time/impedance, GR, etc. Logging-while-drilling tools (LWD) tools are mounted on the drill string behind the drill bit and allow logging and data transfer to the surface while drilling is in progress.

Resistivity-based LWD images were acquired for this project. However, logging was performed after the drilling process for better image resolution. While the logging operations, the drill string was removed (reaming-up) to save time. In general, the quality of LWDs is reduced, depending on tool speed, memory and data transmission

Different vendors were used in Well A and B. Image examples are shown in figure 4. Both deployed tools spin during logging and generate 360° degree (circumferential) images of the borehole, with different depths of investigation (DOI). The principle is shown in figure 5. Maintaining constant tool rotation and ROP during logging was crucial for image quality.

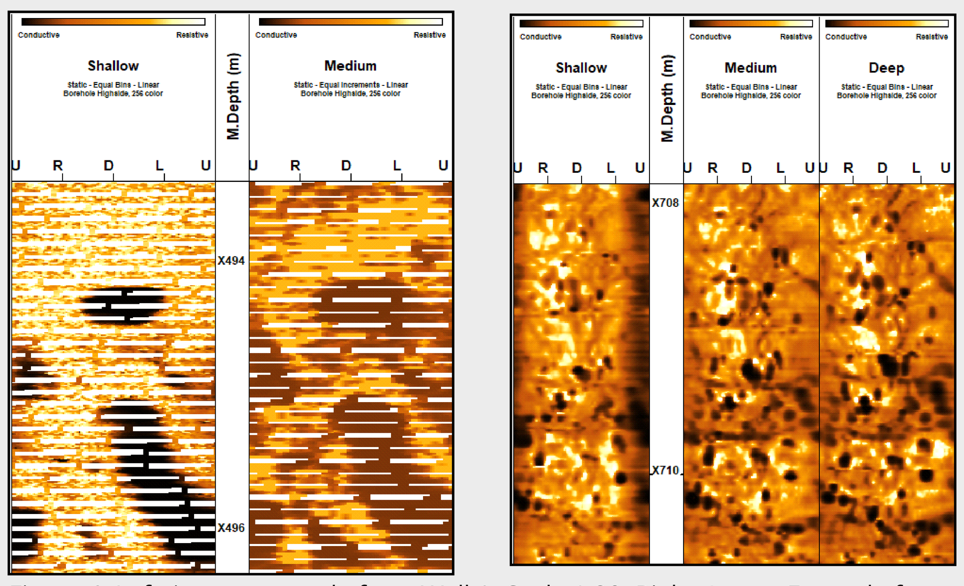


Figure 4: Left: image example from Well A. Scale 1:20. Right: Image Example from Well B. Scale 1:20

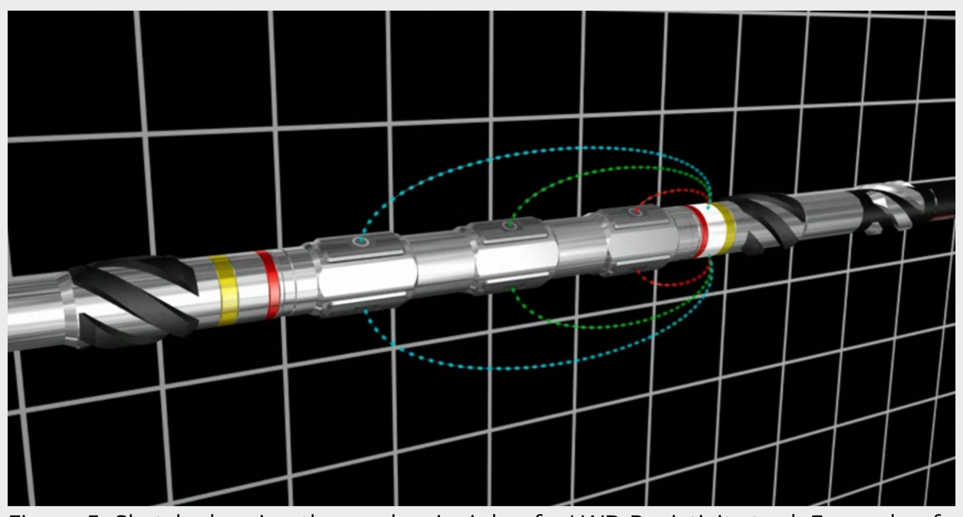


Figure 5: Sketch showing the work principle of a LWD Resistivity tool. Example of the Halliburton AFR tool. Courtesy of Halliburton Inc.

4 BHI Workflow

1. Quality control and processing of the image data:

- Checking data completeness
- QC tool orientation
- Checking for accuracy
- Image Normalization

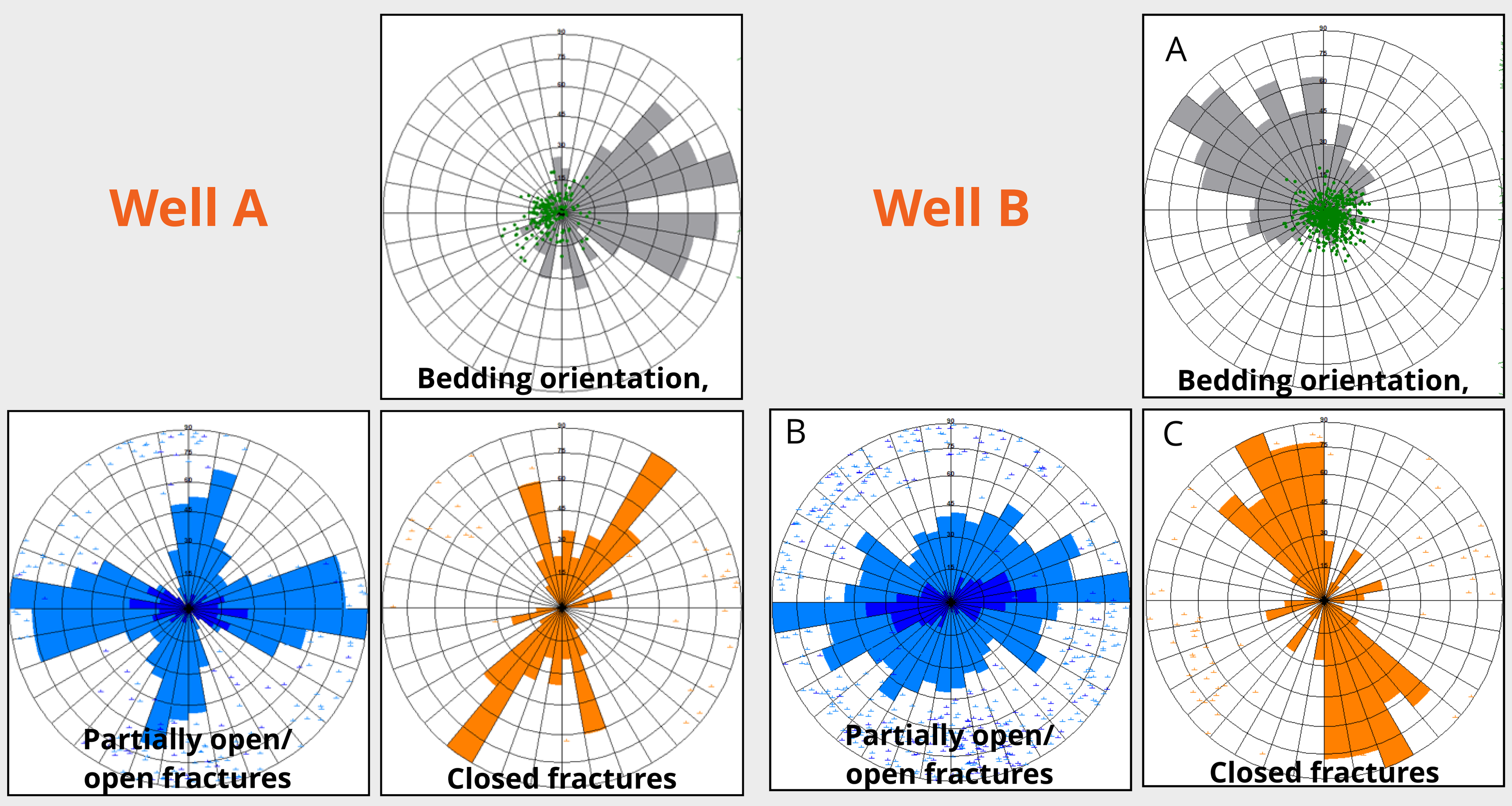
2. The whole analyses are performed manually. No auto-analysis was applied.

3. Analysis of the image data:

- Bedding orientation
- Fracture classification and orientation
- Fault zones
- Drilling-induced borehole failures
- Karstified intervals

5 Interpretation Results

Geological Features



Bedding dips near-horizontal in both wells. The orientation difference probably reflects a structural feature, i.e. a fold. The overall number of identified features in Well B is higher than in Well A due to the borehole image quality.

Highly fractured intervals are identified with fracture density curves.

In both wells no structural compartmentalization has been encountered.

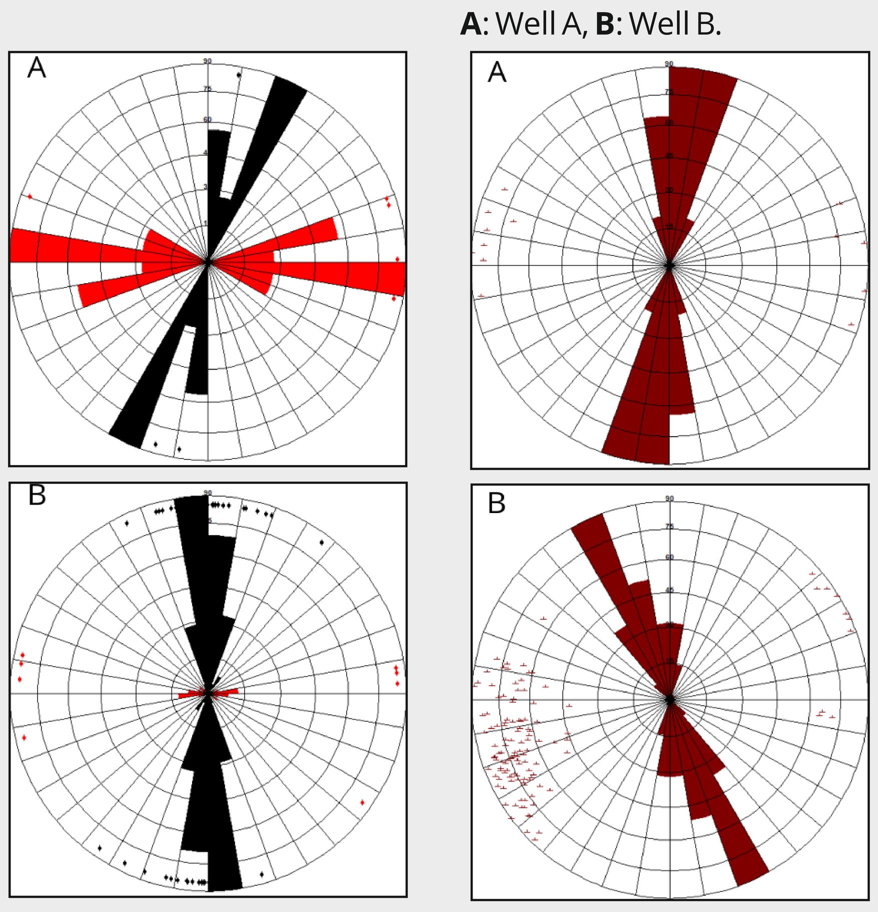
Drilling-Induced Features

DITF & Borehole Breakout

DITF (black) and Borehole Breakout (red) orientation plots. Projection Borehole lowside azimuth. **A**: Well A, **B**: Well B

Tensile Enhanced Fractures

Tensile Enhanced Fractures strike plots. The features are seen in the upper, less inclined part of the wells. Projection: True North. **A**: Well A, **B**: Well B.

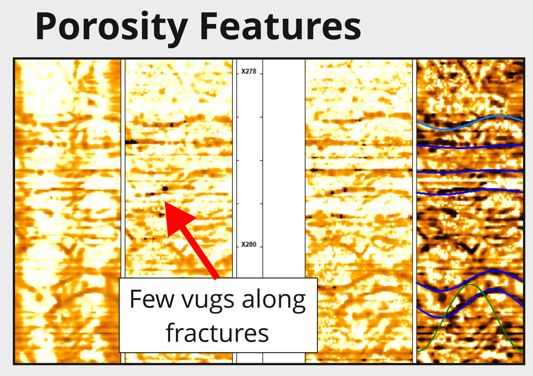


Both wells show centerline fractures and borehole breakouts in their highly inclined sections. However, due to the inclinations of >60° they do not reflect the present day stress field orientation.

Tensile enhanced natural fractures are encountered in both wells in the less inclined sections near the tops. They align with the tensile regions of the boreholes. Their orientations are similar to the regional present-day stress field (figure 6).

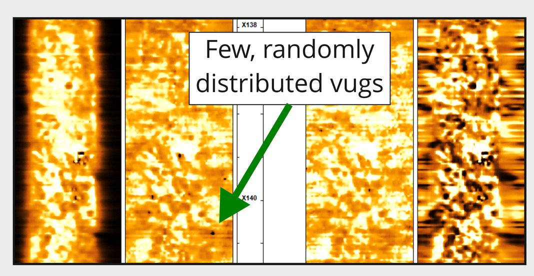
Figure 6: Snapshot from Google Earth with SHmax data from Heidbach et al. (2016) indicates, that the regional stress pattern shows SHmax in N-S direction (orange circles). The orientation of the Tensile Enhanced Fractures in both wells ± show a similar orientation. Asterisk marks drilling site.

Porosity Features



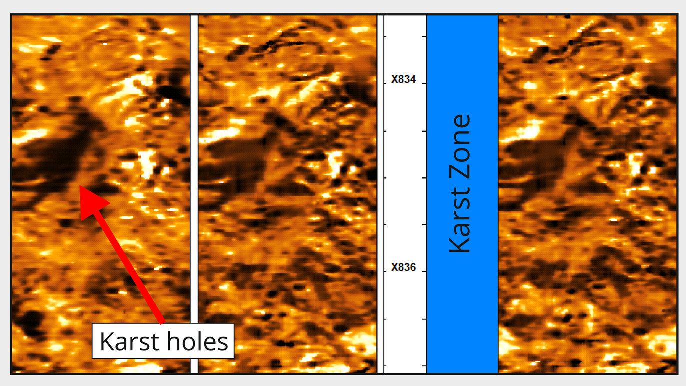
Example of a highly fractured interval showing possible open fractures. Very few and small vugs are visible along the fractures.

⇨ **Predominantly fracture porosity**

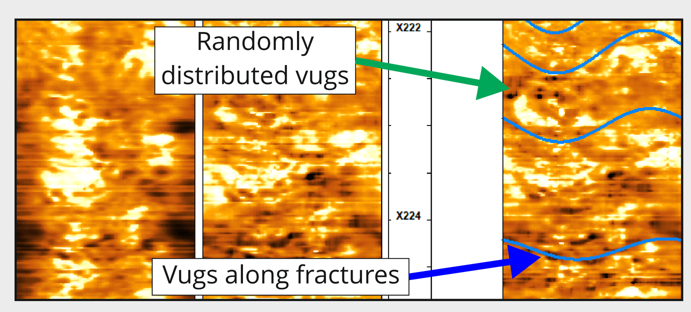


Example of un-bedded / reef facies carbonates containing very few, small and randomly distributed vugs.

⇨ **Predominantly matrix porosity**



Borehole Image Examples from Well B



Both wells contain intervals with karst phenomena, i.e. vugs and breccias. These are identified by visual inspection and are of high interest as they provide porosity. The karst features are bound to certain stratigraphic intervals as well as to the fracture/fault system. Small vugs are seen along fracture surfaces. Big vugs/karst holes are dispersed in the dolomitic rocks.

⇨ **Karstified zones have the strongest impact on the reservoir flow.**

6 Well Stimulation

- **The stimulation was performed by acidization of open fractures and vugs**
  ⇨ Increase of producible volume/ permeability
- **The available volume of stimulation fluid is limited**
  ⇨ Most prospective intervals for stimulation are defined by borehole image analysis
- **Pump tests before and after the stimulation indicated increased flow rates**
  ⇨ Successful stimulation proves the value of Borehole Image Interpretation

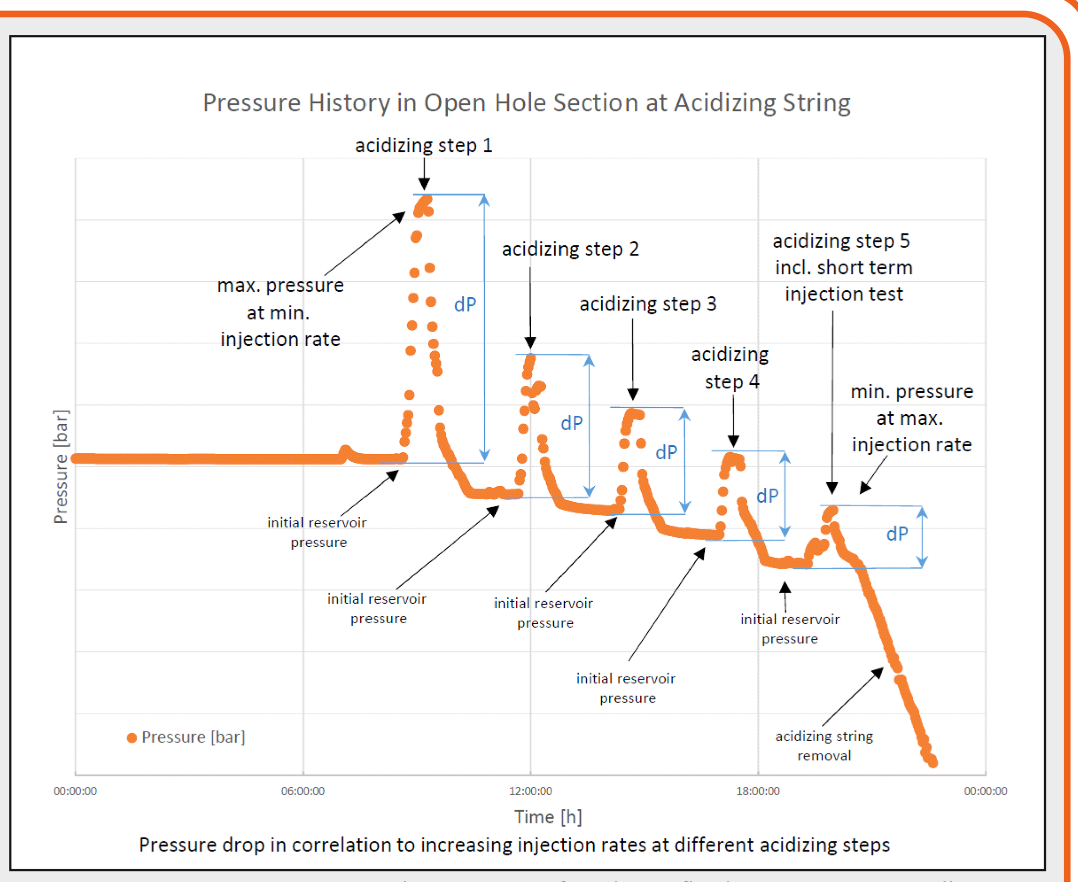


Figure 7: Injection pressure at acidizing string of acidizing fluid versus time in well A.

References:

Heidbach, O., Rajabi, M., Reiter, K., and Ziegler, M. [2016] World Stress Map 2016, GFZ Data Services, http://doi.org/10.5880/WSM.2016.002.

Seithel, R., Steiner, U., Müller, B., Hecht, C. and Kohl, T. [2015] Local stress anomaly in the Bavarian Molasse Basin. Geothermal Energy, **3(4)**.

Steiner, U., Savvatis, A., Boehm, F. and Schubert, A. Explorationsstrategie tiefer Ressourcen am Beispiel des süddeutschen Oberjuras (Malm). In: Bauer, M., Freeden, W. and Jacobi, H. (ed.) [2014] Handbuch tiefe Geothermie. Berlin Heidelberg: Springer Spektrum Verlag; 429p.

Hedtmann, N. and Alber, M. [2017] Investigation of Water-Permeability and Ultrasolnis Wave Velocities of German Malm Aquifer Rocks for Hydro-Geothermal Energy. Procedia Engineering, **191**: 127-133.