

Part 1: Geological and hydraulic evaluation of the geothermal reservoir Basel 1.

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Drilling data, cutting analysis, downhole logging and hydraulic tests have been interpreted in order to evaluate the geological and hydraulic conditions in the first deep well of the Basel geothermal project (Häring et al., 2007). The well Basel 1 was drilled to 5 km depth and penetrated a 2.4 km thick sequence of Tertiary, Mesozoic and Permian sediments. The basement top consists of an approximately 100m thick *mélange* of weathered pieces of granite and red siltstone. The underlying crystalline basement comprises exclusively plutonic rocks. No high-grade metamorphic rocks are present. The primary rock types include granitoid plutonic rocks (> 99%), aplite and lamprophyre. The granitoid plutonic rocks are mainly hornblende-bearing biotite granite, hornblende-biotite monzogranite and monzonite. Major rock-forming minerals are plagioclase, K-feldspar, quartz, hornblende, biotite and titanite. Accessory minerals are apatite, zircon, allanite and magnetite. Geochemical parameters indicate that the Basel 1 monzogranite are I-type granitoids meaning that their parental magma formed by melting of older igneous rocks (Kaeser et al., 2007)

According to temperature logs, which were obtained shortly after reaching the final depth, the reservoir temperature was still disturbed due to the cooling effects of the drilling mud. Various extrapolation methods provided an estimate of the reservoir temperature of 195°C at 5km depth.

In order to determine the principal horizontal stress directions and to detect fractures and fault zones an Ultrasonic Borehole Imager (UBI) log was run in the basement section from 2'600 – 5'000 m below surface. Analysis of the UBI indicated a maximum horizontal stress direction of $144 \pm 14^\circ$ (Valley & Evans, 2006). The dominant structural feature in the crystalline basement consists of conjugate fractures striking 163° and dipping at $> 60^\circ$ preferentially to the southwest. The open hole section (4'629 – 5'000m below surface) contains two major fractures zones. A several meter thick cataclastic fracture zone at 4'691m and a further zone at 4'826m below surface. Both zones are affected by argillic alteration. In the fracture zone at 4'826m cataclastically deformed anhydrite was observed with argillic altered plagioclase.

Prior to the hydraulic stimulation a low rate injection test was conducted in order to characterize the hydraulic properties of the undisturbed reservoir. The results show an average transmissibility of $\sim 5 \cdot 10^{-15} \text{ m}^3$ and an intrinsic permeability of $\sim 1 \cdot 10^{-17} \text{ m}^2$ for the open hole section. Further analysis indicates a bilinear flow suggesting that the flow regime is dominated by single fractures. The natural reservoir overpressure was estimated around 15 bars.

During the hydraulic stimulation a total water volume of $11'500 \text{ m}^3$ was injected. The injection started on December 2 until December 8, 2006 when a maximum wellhead pressure of 296 bars was reached. The hydraulic stimulation process

was stopped when high seismic activity built up with magnitudes up to M_l 2.7. Four hours after the well was shut in a seismic event of M_l 3.4 occurred, following which the well was bled off to hydrostatic pressure conditions. Since then no further technical operations have been undertaken. Final flow tests and production logging runs are outstanding. Conclusive statement of the effect and efficiency of the hydraulic stimulation are therefore not yet available. Analysis of the existing data sets allow for a preliminary evaluation only. The hydraulic stimulation was planned over a injection period of 20 days. Due to the unacceptable seismic activity the stimulation was stopped 14 days before completion. The estimated volume containing stimulated, or at least seismically active fractures is $35 \times 10^6 \text{ m}^3$, which is of the order of 10% of the target volume, that should have been reached after a full injection programme. The hydraulic stimulation process resulted in an increase of fracture transmissibility by a factor of about 400.

The integration of all available data supports the hypothesis that the stress field around Basel 1 is dominated by a distinctive strike-slip regime with relatively high deviatoric stresses satisfying the hierarchy $S_{Hmax} > S_V > S_{hmin}$.

REFERENCES

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