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Hydraulic fracturing in sedimentary rocks: In-situ observations, field data, and numerical simulations

T. Weiss (1), R. Jung (2), S.L. Brenner (1), J. Orzol (2) & A. Gudmundsson (1)

(1) University of Göttingen, Geoscience Centre, Goldschmidstr. 3, D-37077 Göttingen, Germany, tweiss@gwdg.de / Phone: +49 551 397983; (2) Leibniz Institute for Applied Geosciences, Stilleweg 2, D-30655 Hannover, Germany

Geothermal energy is environment-friendly, base load capable and accessible almost everywhere. In Germany, high potentials for geothermal energy occur in both crystalline and sedimentary rocks (e.g., in the Rhinegraben and in the North German Basin). The basic principle is that heat at certain depths is extracted by injection and extraction of water in either newly formed or stimulated existing fractures. The geothermal exploration in crystalline rocks is already well developed. In contrast, hydraulic fracturing in sedimentary rocks is still a matter of basic research.

Field experience on the initiation and propagation of hydrofractures in sedimentary rocks was obtained from a pilot drill hole in Northern Germany maintained by the Federal Institute for Geosciences and Natural Resources (Orzol et al. 2004). At this site, concepts for geothermal heat extraction are explored in the Triassic Bunter sandstone. However, in-situ tests reveal that specific tectonic environments and stratigraphic successions with alternating layers of sand-, silt- and claystones may complicate design, evaluation and interpretation of hydraulic fracturing. Therefore, more detailed investigations on typical fracture patterns in sandstones are necessary to understand fracturing of such rocks at 4-5km depths.

Field observations of the Bunter sandstone exposed on the surface show that fracture propagation strongly depends on mechanical contrasts and layering. Lithological variations due to different sedimentary conditions may cause distinct material contrasts, when stiff and homogeneous layers alternate with soft, highly porous rocks. Fine horizontal layering is as common as strong cross bedding. Stratiform lenses with clay or dolomite act as planes of anisotropy. Field observations indicate that even weak layers

of limited size (a few centimeters thick) may arrest the propagation of natural joints. In contrast, fractures in homogenous parts of the Bunter persist over long distances.

In order to constrain stress distributions in heterogeneous rock successions, typical lithological profiles for middle Bunter are analyzed using numerical models. Changes in lithology are constrained by variations in the Youngs modulus and Poissons ratio. Stress calculations are performed as a function of either internal fluid pressure or external tensional stress to investigate the stress influence of the thicknesses and elastic properties of the rock layers. Furthermore, the effects of joint patterns and the local stress fields are considered. The basic question to be addressed is whether the magnitude and orientation of the least maximum principal stress may change as a result of lithological layering, as field observations of fractures suggest. The investigations may help to improve geothermal exploration in sedimentary rocks leading to a wider utilization of geothermal energy in the future.

References

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