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Characterization of mudstone, clayey rock and argillite towards stabilisation of boreholes by developing new drilling strategies for geothermal resources exploration

M. Witthaus (1), Ch. Lempp (2), Th. Röckel (3), Ch. Hecht (4), and M. Herold (5)

(1) Martin Witthaus, Martin-Luther-University Halle, Germany, (martin.witthaus@geo.uni-halle.de), (2) Christof Lempp, Martin-Luther-University Halle, Germany, (christof.lempp@geo.uni-halle.de), (3) Thomas Röckel, Piewak & Partner GmbH Bayreuth, Germany, (thomas.roeckel@piewak.de), (4) Christian Hecht, HotRock Engineering Karlsruhe, Germany, (hecht@hotrock.de), (5) Martina Herold, HotRock Karlsruhe, Germany, (herold@hotrock.de)

In this study, relating to the BMU Project „ borehole stabilisation as an important factor for the utilization of deep geothermal resources" (Project No. 0327594), sediment rocks with comparable lithology to the pelite beds of the Upper Rhine zone were investigated by a number of geomechanical tests. The investigation will provide detailed information on the geomechanical behaviour (brittle and ductile deformation) of clay stone formations in order to find out critical reasons for the instability of boreholes at a depth of about 2000 m. The main aspect of the study is to develop improved technical options in order to increase borehole stability. Many geothermal energy projects started near the Upper Rhine Rift in order to produce electricity, as the geothermal gradient rises there to about 150° C at 3 – 4 km depth. For these enhanced geothermal systems it is necessary to drill deep boreholes to install geothermal heat exchangers, so that the injected cold water conducts the high temperature of the rocks (Hot Dry Rock-Technology). The drillings have to be intersected through different rock layers that are influenced by varying regional stress fields respective to their depth. Between depths of 1500 to 2000 m within the Upper Rhine zone some of the drilled boreholes were in some parts very unstable, especially in formations where mud- and clay stones were dominant, as well as in interbedded strata with sandstones. As the maximum load capacity of these clays is very low and due to their ductile as well as brittle deformation behaviour, borehole convergence and borehole breakouts are detected. These changes were also caused by deep injection of drilling fluid into the rock formation, increasing the pore pressure there, so that hydraulic tension cracks were induced (hydraulic fracturing). This occurred mainly during drilling and it is the reason why there is an imminent risk of the stability of geothermal boreholes in geological formations composed of mudstones, clay stones and clayey rocks up to argillite. Important for the manifestation of these instabilities are the differences between mudstones, clays and rocklike pelites. Mudstones and clays with low densities (2,0 – 2,3 g/cm^3) and high moisture content (25 – 40 %) show a ductile and plastic deformation behaviour, so that the whole rock formation weakens and will be squeezed out of the borehole wall during drilling. Convergence of the borehole can be detected and the drilling bit will be forced to stop. On the other hand rocklike clay and argillites with higher densities (2,4 – 2,8 g/cm^3) and lower moisture contents (0,5 – 8%) tend to show brittle behaviour during critical stress conditions around the borehole, indicated by cracks and borehole breakouts, so that the borehole becomes unstable as well. The pore pressure in these formations, increased by the induced drilling fluid, has a fundamental influence on the deformation process of these rocklike clays. Critical changes in the state of stress are caused by the sudden increase of pore pressure in the micro-structure of clays and pelites. As a consequence hydraulic tension cracks can be formed, which weaken the rocks especially when the drilling machine stops and the induced pressure decreases. Pore pressure effects creating hydraulic fracturing are the predominant cause for the instabilities in geothermal boreholes of the Upper Rhine region. In this study, the geomechanical behaviour of mudstone, clay, rocklike clay and argillite were determinated in laboratory tests by stress conditions according to the regional stress field around the borehole at a depth of about 2000 m. Compressive and extensive stress conditions as well as pore pressure could be simulated with the obtained rock samples in order to explain the reasons for borehole instabilities. Based on the experimental results, new drilling strategies will be developed to upgrade the stability of boreholes for enhanced geothermal systems.