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Using periodic pumping tests to evaluate the hydraulic changes induced by stimulation experiments in the research mine "Reiche Zeche", Freiberg, Germany

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Hydraulic stimulation tests aim at enhancing hydraulic conductivity by creation of new fractures and shearing pre-existing faults. Stimulation tests were performed in ten sections in a borehole penetrating gneiss, Reiche Zeche, Freiberg, Germany. According to structural analyses from mapping the tunnel faces, retrieved cores, and borehole logs, the gneiss is foliated and the test volume of about 60 x 30 x 30 m^3 is crosscut by two prominent damage zones of 1 to 2 m width as well as numerous joints with a range of orientations. Periodic pumping tests (PPT) were conducted before and after the stimulation sequences to quantify the induced changes in transmissivity and storativity. Interval lengths of 1.75 m and 0.75 m were used before and after the stimulation. Using the relatively long interval before the stimulation intended to include natural fractures surrounding the test interval and thus to characterize the hydraulic environment in which a new fracture is generated. The short interval actually allowed to pressurize fully intact rock sections whose impermeability was documented by pulse tests. Two types of hydraulic analyses were carried out: injectivity analysis (QP) resting on a comparison of the characteristics of the periodic flow and pressure records from the injection interval; interference analysis (PP) using the pressure change in a monitoring well caused by the pumping operation in the injection well. Injectivity testing characterizes hydraulic features in any direction to a distance controlled by the period used; interference testing screens the subsurface in the volume connecting the injection and monitoring well. In this study, periods from 20 s to 900 s were imposed. Furthermore, the injection protocols lead to mean pressures ranging from 0.64 MPa to 7.7 MPa and thus permitting the investigation of the pressure dependence of the hydraulic response. In particular, the newly created fractures were tested below and above jacking pressure, i.e., in closed and open state, respectively. The characteristic values of a test (phase shift and amplitude ratio) were compared to analytical solutions of the pressure-diffusion equation for different boundary conditions. Generally, an enhancement in hydraulic properties is related to an increase in amplitude ratio and a decrease in phase-shift. Results of the injectivity tests document a significant increase in transmissivity by the stimulation; linear, bilinear, or radial flow is consistent with the observations. The interference tests indicate a zoning of hydraulic properties probably reflecting that the untreated rock is unsaturated.