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Pore Pressure Cycling and Permeability Evolution of Bentheimer Sandstone: Implications for Underground Hydrogen Storage Operations.

Underground hydrogen storage (UHS) in deep saline aquifers provides a viable approach for large-scale energy storage and mitigates the intermittency of renewable energy sources. The effectiveness of UHS depends on the complex interactions among geomechanical, multiphase fluid flow, and geochemical processes. Cyclic injection and withdrawal operations cause periodic changes in pore pressure, resulting in substantial modifications to reservoir petrophysical properties, including permeability and porosity. To simulate cyclic operation in UHS, a pore-pressure cycling experiment was conducted on a Bentheimer sandstone core under Ketzin reservoir conditions, with a confining pressure of 150 bar, pore pressure between 10 and 120 bar, and a temperature of 37 ℃. Flow behavior and electrical properties as functions of effective stress were evaluated as part of the GeoZeit project. Results demonstrate that porosity decreases as confining stress increases from 0 to 150 bar, and permeability declines with increasing effective stress from 30 to 140 bar. The bulk electrical resistivity of the sample rises with higher effective stress. The permeability-compressibility coefficient *ß* for this pressure range is 8.65 GPa-1 (~0.008 MPa-1), indicating a 0.865% reduction in permeability per additional MPa of effective stress. Compaction-dominated deformation, including grain rearrangement and compression of pore throats, primarily drives the observed reductions in porosity and permeability by decreasing pore volume and connectivity. This effect is most significant during the initial cycles, after which the rock approaches mechanical stability. A comprehensive understanding of these coupled hydro-electrical-mechanical processes is essential for evaluating the integrity and performance of seasonal UHS in saline aquifers

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