Geophysical Research Abstracts,
Vol. 11, EGU2009-13441, 2009
EGU General Assembly 2009

The relation between storage capacity and the scale dependence of hydraulic properties

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Non-steady state fluid pressure evolution in the subsurface is governed by the hydraulic diffusivity that combines transport (e.g., permeability, transmissivity, transmissibility) and storage (e.g., specific storage capacity, storage factor) characteristics of a rock-fluid system. Traditionally, storage capacity is considered the less important/varying hydraulic parameter and focus has been put on spatial variability of transport characteristics. Based on simple conceptual models and observations in field tests and laboratory experiments we show that this strategy may be an undue oversimplification, particularly for jointed rocks and rocks with high and pressure-dependent pore compressibility, and that realistic variability in storage parameters causes a dependence of hydraulic processes on time and space scales. For example, storage capacity is strongly time-dependent in pore spaces that exhibit a hierarchy of fluid conduits (pores, cracks, fractures, joints, faults) such that transmissive conduits are intersected by less transmissive conduits that in turn are connected to even less transmissive conduits and so on. In contrast in such a rock the most transmissive conduits will dominate flow and pressure evolution rather independent of the time scale of the pressure perturbation. In combination, hydraulic diffusivity rather reflects the variability of storage parameters than the constancy for transport parameters. We show examples for such behavior from an analysis of periodic pumping tests at a range of pumping periods in a jointed rock. In addition laboratory experiments on rock samples and simple analogue systems show that pressure-dependent storage characteristics cause apparent spatial heterogeneity in hydraulic properties in conjunction with the geometry of the source of the pressure perturbation. Finally, storage capacity as a representation of the bulk deformability is also related to propagation of elastic waves.

We show examples where fast propagating waves are induced in jointed rocks by pressurization that in turn alter the storage capacity and therefore cause fluid pressure perturbations on time scales and at distances from the source that are in stark contrast with the standard scaling relation for hydraulic diffusivity. The latter observation has significant consequences for the interpretation of fluid-injection induced seismicity.