White Paper for DUSEL

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Flow and Storage in Deep Fractured Rock Environments

Exploitation of deep (> 100 m) fractured rock aquifers is becoming commonplace in the United States as more pressure (from both contamination and over extraction) is placed on shallow overburden aquifers. Residence times in the shallow (upper most) flow systems is relatively rapid owing to shallow water table gradients and the strong connection of groundwater and surface water in the most permeable deposits. A few studies have suggested that deeper fractured rock systems have significantly longer residence times (> 100-10,000 years) and are slow to respond to changes in surface hydrological patterns. As fractured bedrock systems are being exploited for water resources, an increased understanding of the nature of flow and storage in these systems is needed in order to properly manage resources. At DUSEL a unique opportunity exists to study a very deep fractured rock system to understand what the role of discrete zones of porosity and permeability (such as fractures or faults) have on the depth of flow systems and their spatial organization. Our group is interested in the following questions.

Key Questions Include:

- What is the typical residence time of the deep fractured rock systems?
- What controls the depth of flow systems in the fractured bedrock?
    - What controls the permeability structure of with depth?
- How do faults and other large scale structural features influence the depth of flow systems?
- What factors are important to the dynamic response of the fractured rock system to perturbations in near surface hydrology?
- What role do climate change and anthropogenic stress play in the storage of these aquifers?
- How will flow systems respond to subsurface modifications of porosity, permeability, and storage?
- Can we use poroelastic responses due to earth tides, earthquakes, etc. to better characterize the subsurface?

Why we need DUSEL to address these questions

- Scale issues, access to a system such as this provides over 6 orders of magnitude of spatial scale for addressing hydrologic systems.
    - Essential for determining the relevance of previously collected data at smaller scales.
- In-situ experiments with lots of boreholes and deep access.

Examples of Possible Experiments and data needed

- Stable and radiogenic isotopic data on subsurface waters to quantify age to determine residence times of water packets

- Distribution of fracture porosity and permeability with depth along mine shafts and boreholes
- Large-scale hydraulic tomography at different depths in the mine
- Long-term monitoring of pore pressure at unique depths in different scale fractures and faults to monitor for earth tides and hydroseismograms

Experiment on the role of anisotropic stress on fracture permeability

Fluid flow in the shallow crust (< 100 meters) is not typically sensitive to the low magnitude crustal stress conditions present. Fractured rocks, unlike porous sedimentary rocks, in this respect are unique since most un-cemented fractures are compliant at lower stress states and fracture apertures can be strongly influenced by the loading. As a result, fracture permeability of the rocks can be strongly dependent on depth and loading conditions (e.g. residual tectonic stresses). This has implications for depth of flow systems and connections between deeper and shallower systems. We have been designing a poly-axial testing apparatus for testing the role of low magnitude (< 2 MPa) anisotropic stress fields on the flow and transport properties of fractured rock on meso-scale samples of fractured rock. We would like to extend these measurements to depth in a heterogeneous rock mass such as DUSEL.