Permeability of Fractured Tuff as Functions of Temperature and Confining Pressure

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Permeability of Fractured Tuff as Functions of Temperature and Confining Pressure

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Summary

1). Introduction. Understanding the transport properties of water through fractured rock is critical to predicting and modeling the hydrothermal performance of a geologic nuclear waste repository. Previous studies indicate that intact Topopah Spring tuff from Yucca Mountain, Nevada has a low permeability, \(-1 \times 10^{-18} \text{ m}^2\) (\(-1 \text{ microDarcy}\)).\(^1\)\(^2\) A single fracture in the tuff increases the permeability to \(-100 \times 10^{-15} \text{ m}^2\) (hundreds of milliDarcies).\(^3\) However, fracture healing may occur when high temperature water flows through the fracture lowering the permeability by one or more orders of magnitude.\(^3\) We report progress on laboratory experiments on permeability of fractured Topopah Spring tuff as functions of confining pressure, temperature, and water/rock ratio.

2. Description of work. A sample containing a single open fracture was machined from USW-G4 core, sample ID 17351.1, 342 m depth. The sample dimensions are 5.085 cm diameter and 6.335 cm length. The matrix porosity is \(-10.3\%\).

The sample was placed in a pressure vessel heated externally by an electrical resistance heater. Confining pressure was maintained with a Haskel pump using Dow Corning 200 Si fluid as the pressurizing medium. A separator with a series of metering and shut-off valves controlled the upstream and downstream pressures. A differential pressure transducer accurate to within +/- 0.1\% was used to measure the differential pressure (\(\Delta P\)). Pore water pressure throughout the experiment was kept at \(-0.48\) to 0.58 MPa. The permeability was found to be independent of pore pressure over this range. J-
13 water doped with 1 g/l sodium azide to inhibit bacterial growth was used as the pore fluid. The sample was kept saturated at all times. Periodic inspections of fluid passing through the sample using ICP and scanning electron microscopy indicated no abnormal Si levels or bacterial growth that could affect the permeability measurements. The steady state flow-through method and Darcy's law were used to determine permeability under the conditions discussed below.

3). Results. A general overview of the experiment is shown in Figure 1 which shows permeability and temperature as functions of time. Figure 2 shows permeability and confining pressure (Pc) as functions of time. During the first portion of the experiment the temperature was held constant (23°C) and Pc was increased stepwise to 5 MPa and then decreased to the starting point of 1 MPa. The permeability decreased with increasing Pc and recovered to near the starting value of ~18x10^-15 m² upon returning to 1 MPa Pc. This indicates that confining pressure alone might not irreversibly affect the permeability.

The next portion of the experiment was a cycling of temperature from 23 to 155°C and back as the Pc was kept at constant values of 1, 2, and 3 MPa. The temperature cycle at Pc=1 MPa resulted in a decrease in permeability from ~18 to 8x10^-15 m². At the peak temperature of each cycle a period of steam flow was generated by lowering the pore pressure. Steam flow had little effect on the permeability of the fractured sample.

The temperature cycle at Pc=2 MPa resulted in a further lowering of the permeability to ~4x10^-15 m². The last temperature cycle at Pc=3 MPa resulted in only a small change in the permeability. The lowest permeability value reached during any portion of the experiment was ~3.2x10^-15 m² at ~4000 hours. Small increases in permeability occurred following the cooling portion of the temperature cycles for 2 and 3 MPa confining pressures. One possibility is that cooling was rapid enough to create thermal gradient fracturing that temporarily increased the permeability. These fractures were then subsequently healed or closed.
Figure 1. Permeability and temperature (°C) as functions of elapsed time (hours) since the beginning of the experiment. Error bars for permeability are approximately the size of the symbols. Each temperature cycle results in a decrease in permeability of about 50%. Note the slight recovery in permeability following rapid cooling at ~2900 and 4200 hours.

Figure 2. Permeability and confining pressure as functions of elapsed time since the beginning of the experiment. The first portion of this experiment shows the inverse relationship between confining pressure and permeability.
Pore fluid was collected as the experiment progressed. Water samples were chemically analyzed using inductively-coupled plasma atomic emission spectrometry for K, Na, Ca, B, Si, Al, and Fe. No Fe or Al was detected above the detectability limits of 0.02 and 0.06 ppm, respectively. Potassium concentration [K] strongly correlates with temperature, [Na] concentration increases with $P_c$. [Ca] displays a strong inverse temperature correlation. Boron and silicon correlate with temperature and generally increase with increasing cumulative water flow. The pH of the fluid was also measured and was found to vary between 7.9 and 8.7. No systematic variation of pH with time, temperature, or confining pressure is apparent.

4). Conclusions. Permeability of tuff containing a single fracture decreases following fluid flow at high temperature. Changes in permeability are not strictly a result of any one parameter change, such as temperature, $P_c$, and water/rock ratio, but are caused by some or all of these in a complex manner. Thus, the history of the sample is important. These experiments were conducted in such a way to study the changes in permeability in a systematic manner. The results will be examined in the framework of existing models with regard to fracture aperture and geochemistry. Future experiments will be designed to isolate, to the extent possible, the separate effects of confining pressure changes, temperature excursions, and steam flow.

5). References.


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