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Anisotropic Behavior in 0.5M Scale Blocks of Topopah Spring Tuff

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ABSTRACT

Laboratory tests on 0.5-meter-scale blocks of Topopah Spring tuff were performed to determine fluid flow and mechanical behavior of samples containing fractures. Results include data for a comprehensive set of flow measurements through a rock sample containing a horizontally oriented fracture at uniaxial stress conditions up to 8 MPa at room temperature. Directional channeling, rather than mean fracture aperture, controls the flow. On the time scale of these experiments, imbibition is negligible.

1. INTRODUCTION

Laboratory tests on 0.5-meter-scale blocks of Topopah Spring tuff were performed to determine fluid flow and mechanical behavior of samples containing fractures. The purpose of these tests is to investigate the effect of coupled thermal-mechanical-hydrologic (TMH) processes on the properties and behavior of a fractured rock mass at conditions that simulate those expected in the Near-Field Environment (NFE) of a potential geologic repository for nuclear waste at Yucca Mountain. A major objective is to provide a phenomenological understanding of coupled TMH properties of the tuff for use in computer modeling of the NFE. Laboratory experiments on 0.5-m-scale samples of Topopah Spring tuff containing multiple natural fractures will provide data on changes in fracture permeability, mechanical properties, and geochemical reactions as a function of temperature, uniaxial stress, and time. These data also will permit development of scaling relations between properties measured in laboratory and field environments.

Displacement measurements across 14 baselines provide information on rock matrix and fracture deformation at axial stresses to 8 MPa. Water flow measurements from a point source through a horizontally oriented, artificial fracture at uniaxial stress conditions at room temperature provide estimates of hydrologic conductance. These spatially resolved measurements indicate no dependence of flow rate on fracture aperture changes of 0.04 cm, and a strong channeling of the flow in selected directions. Models of flow from a point source through an idealized flat fracture, based on cubic dependence of flow on aperture, are not adequate to describe these results.

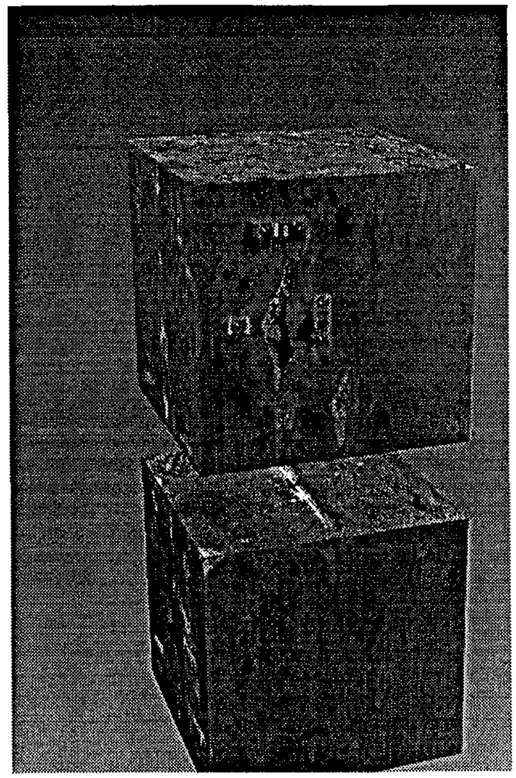

Figure 1. Digital rendering of the sample prepared from photographs of each face. The ash flow texture is oriented parallel to the vertical direction and an artificial fracture is normal to the texture.

II. WORK DESCRIPTION

A laboratory sample containing an artificial horizontal fracture was prepared using two right-prism blocks of Topopah Spring tuff having typical edge dimensions of 25 cm (Figure 1). This sample has prominent ash flow textures in the rock fabric consisting of pores, vugs and inclusions that occur generally in the shape of oblate spheroids. These range in typical dimension from a few tens of microns to several centimeters, and have a subplanar orientation. The sample was prepared so that compressive stress could be applied in the plane of the texture. This is illustrated in Figure 1, which shows that the ash flow texture is oriented parallel to the vertical direction and that the artificial fracture was introduced in the direction normal to the plane of the texture. Prior to testing, a portion of the fracture surface measuring 120 mm x 260 mm was profiled to provide quantitative information on the surface roughness of the artificial fracture.

Uniaxial stresses to 8 MPa were applied normal to the fracture plane. Fluid flow was generated by a point source in the plane of the fracture at its center, connected to a pressurized fluid reservoir using a small-diameter tubing. A grid of fluid collection ports, spaced at 2.5 cm intervals around the perimeter of the fracture, was used to provide spatial resolution of the flow in the plane of the fracture. This grid was constructed so that flow could be sampled with spatial resolution greater than the typical hydrologic network path, permitting quasi-quantitative analysis of flow at the sample boundary. Flow data were analyzed in terms of flow rate vs. time and uniaxial stress. Deformation data were analyzed in terms of stress-strain behavior.

III. RESULTS AND DISCUSSION

Our results show that flow in the plane of the fracture is anisotropic, dominated by channeling, primarily along the direction of elongation in the ash flow texture (Figure 2). More than 50 liters of water were flowed through the sample at ambient temperature at average fracture interface stresses up to 8 MPa. The mass balance of water into and out of the fracture showed negligible imbibition into porosity. Using an average porosity of 11%, water storage in the rock could be accounted for in a zone 0.5 cm thick on either side of the fracture. This imbibition appears to be much lower than previously observed[1], supporting the recent calculations of Buscheck[2] that show that current simulations of fluid flow in the Topopah Spring tuff may overestimate the effect of imbibition.

Increasing normal stress across the fracture from 0.1 to 8 MPa, with a decrease in the fracture aperture of up to 0.04 cm, did not reduce the flow rate, indicating that flow in the plane of the fracture owes primarily to flow in channels that are unaffected by the normal stress applied across the fracture. Fracture surface profiles show topographic features up to a few millimeters in width and depth, corresponding to macroscopic pores and vugs. The connectivity of this network is the likely source of channeling for the flow. While the distribution of porosity in the fracture plane may not be significant for directional flow in an isotropic

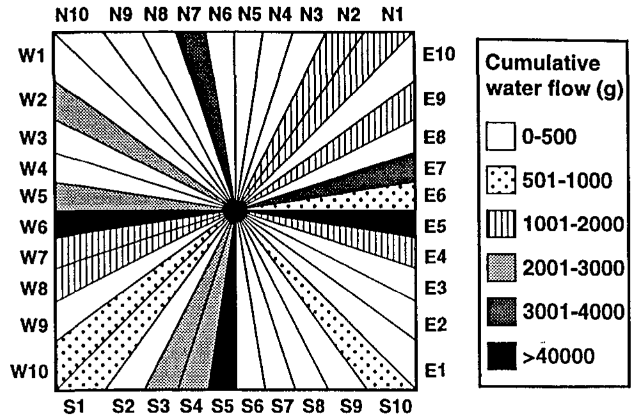

Figure 2. Spatial resolution of total flow in the plane of the fracture, assuming linear flow paths between the injection point at the center of the fracture plane and each collection port. Texture direction is generally East-West. Nominal edge dimension is 25 cm.

material, it may result in enhanced channeling in an anisotropic material, where shear fractures preferentially follow the fabric of the porosity. This results in a network of connected porosity in the fracture plane. Further, the evident independence of the flow on fracture aperture (Figures 3 and 4) indicates flow is dominated by paths outside the nominal "aperture" of the fracture. This is significant for simulation of the TMH behavior of the potential repository, as it indicates that fracture permeability in the host rock may not decrease significantly as the overall state of compression increases due to heating. It further supports the conclusion that application of effective aperture models for fluid flow to real fracture networks requires *in situ* measurement of fracture permeability.

The rock was loaded in compression in the plane of the ash flow texture, and exhibited a Young's modulus of 40±10 GPa for compressive stress in the range 4–8 MPa. This value is much higher than the 15±10 GPa observed in a similar sample of tuff tested in a direction perpendicular to the plane of the texture[3]. This result indicates that, at the 0.5-m scale, the mechanical properties of the tuff may have significant anisotropy correlated with the ash flow texture.

IV. CONCLUSIONS

Our results show anisotropy in both flow and mechanical properties of 0.5-m-scale blocks of Topopah Spring tuff. This anisotropy is associated with the ash flow texture found in the rock fabric. We also note negligible imbibition, and no dependence in the flow properties of the fracture with increasing normal stress across the fracture.

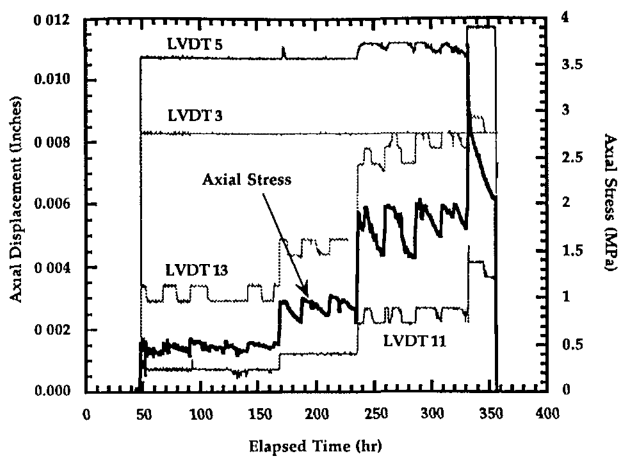

Figure 3. Displacement and normal stress. Transducers 3, 5, 11, and 13 have short baselines across the fracture.

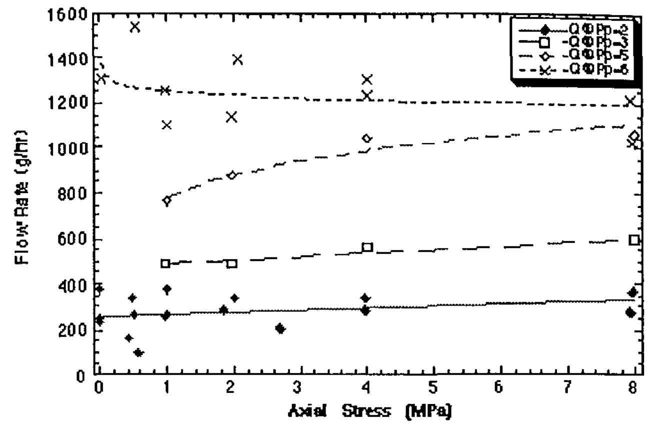

Figure 4. Flow rate at four different fluid inlet pressures, plotted as a function of axial stress. Flow rates are independent of axial stress and, from Figure 3, of fracture aperture.

Additional tests are planned that include flow in similar samples with fractures oriented both horizontally and vertically, at conditions of elevated temperature, and with compressive stress applied normal to the plane of the fracture. These tests are designed to characterize coupled thermal – hydrological – mechanical – chemical (THMC) processes in fractures under stress, and to assess their effect on fluid flow and mechanical properties of the rock.

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