Mapping Moisture Distribution in Yucca Mountain

Using Electrical Resistance Tomography

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Introduction:

The Single Heater Test (SHT) is being conducted as an integral part of the testing and studies by the U. S. Department of Energy to evaluate the suitability of Yucca Mountain in Nevada as a potential site for a deep geologic repository for the permanent disposal of spent nuclear fuel and high level nuclear waste. The objective of the SHT is to study the thermo-hydrologic, thermo-mechanical, and thermo-chemical responses of the Topopah Springs tuff in Yucca Mountain. This paper describes electrical resistance tomography (ERT) surveys made during the SHT to map changes in electrical resistivity caused by temperature and moisture changes in the rock mass. The subsequent interpretation of this data to produce images of moisture distribution in the rock mass is also presented. Of particular interest, are the formation and movement of condensate within the fractured rock.

Work Description:

Figure 1 shows the boreholes used to conduct the ERT surveys. Electrical resistance tomography is a geophysical imaging technique used to map subsurface resistivity. Rock mass heating creates temperature and water content changes which result in electrical resistivity changes that are readily measured. These measurements are inverted using a 2D or 3D algorithm to generate a map of rockmass resistivity (LaBrecque *et al.*, 1996).

To generate a map of changes in moisture distribution from ERT images, a model is used based on Waxman and Thomas (1974 a, b) to convert from changes in electrical resistivity to changes in moisture content. This model requires and is therefore limited by (1) our knowledge of the thermal field (independently measured in the rock) and (2) assumptions about electrical current flow through the pore water.

Results:

Electrical resistivity changes measured at the SHT are shown in Figure 2. In this image plane which is centered on and perpendicular to the heater axis, early heating produces a small axisymmetric zone of decreasing resistivity (i.e., ratio < 1.0) or increasing conductivity around the heater which grows larger with time. The rest of the images in Figure 2 also show a clear trend of overall increase in electrical conductivity in the rockmass (decreasing resistivity or a ratio less than 1.0). The first 59 days of heating show a pattern of change which

is different from the pattern observed in subsequent images. Up to the day 59 images, the conductive anomaly is mostly circular in section (although not centered on the heater). However, between day 59 and day 100, the pattern is more irregular and "fingers" of decreased resistivity begin to appear below and to the sides of the heater; the largest changes are near the heater but there is no clear pattern from which one could locate the heater. We believe that this is due to the fact that moisture re-distribution is being influenced by fractures.

During the cooling phase, the region around the heater shows resistivity increases as the temperature drops to near ambient conditions. We believe that these resistivity increases are due to the decreases in moisture content which developed during the heating phase and to temperature decrease during the cooling phase.

Conclusions and Discussion

Using ERT and a simple model relating the electrical conductivity, temperature, and moisture content of the rockmass, we have estimated the moisture distribution as a function of time at the SHT. The temperature field was constructed by interpolating and extrapolating temperature measurements made near the heater within the RTD boreholes shown in Figure 1. The accuracy of the constructed temperature field is good near the heater but poor away from the heater. The accuracy of the saturation estimates discussed below depend on the accuracy of the temperature field.

In Figure 3, a region of drying surrounds the heater. This region increases in size and magnitude as heating progressed. The shape of the dry zone is irregular and appears to be controlled by heterogeneities (probably fractures) in the formation. The drying appears to propagate upwards and sideways and the rock appears to be dryer overall above the heater than below it. . Regions of increased moisture can also be observed, primarily below and to the sides of the heater borehole. These wetter regions may indicate drainage pathways for condensate through fractures. After heating ceased, the dry region around the heater appears to be rewetting; wetter rock regions observed below the heater are also becoming smaller in size.

With the demonstration that ERT may be used to estimate moisture content changes, we have new capabilities for study of rockmass hydrology. ERT can be used for either 2 or 3D imaging and on scales between laboratory (centimeter) and regional (kilometer). The method is minimally invasive, excellent for long term monitoring and requires minimal field personnel. ERT is to be deployed at the upcoming Drift Scale Test at Yucca Mountain to study hydrology at a larger scale than the SHT. It may be worthwhile to use ERT to monitor the early thermo-hydrologic response of the proposed repository.

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Figure 1. ERT at the SHT. The borehole layout relative to the drifts and the RTD boreholes is shown.

Figure 2. ERT sequence of resistivity changes during the heating and cooling phases of the test.

Figure 3. Estimated saturations during the heating and cooling phases of the test. The estimates are based on the resistivity changes shown in Figure 2.