HYDROLOGIC PROPERTY ALTERATIONS DUE TO ELEVATED TEMPERATURES AT YUCCA MOUNTAIN

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ABSTRACT

Drying experiments were conducted on fifty core samples of welded tuff and fifty core samples of zeolitic, nonwelded tuff. Initially, all core samples were vacuum saturated, and weights and volumes were measured. The samples were dried in a relative humidity oven at 60 degrees C and 45 percent relative humidity. Sorptivity was measured to obtain information on flow properties. The samples from each type of tuff were divided into five sets of ten samples with similar mean porosities. Each sample set was subjected to a different drying temperature; 60, 105, 200, 300 or 400 degrees C with the fifth group left as a control. After drying, the samples were resaturated and all the measurements repeated. Calculated porosity, particle density, and sorptivity increased; and bulk density decreased with increasing temperature. Air and water permeability increased on the nonwelded tuff samples, however air permeability was unchanged for the welded tuff. All bulk properties recovered to the original values following drying, while the flow properties (sorptivity and air and water permeability) were permanently altered. At the completion of the flow measurements, one core from each temperature treatment, was cut into small disks. Water retention curves were measured on these disks (subsamples). There were no differences in measured water retention curves due to drying at different temperatures.

INTRODUCTION

Yucca Mountain is currently being evaluated as a potential site for a high level nuclear waste repository[1]. The pre-emplacement hydrologic properties of the rock are important in determining the suitability of the site; however, post emplacement thermal loads and associated drying may permanently alter the character of the rock. A preliminary study was undertaken to determine the effects of elevated temperatures on hydrologic properties of the welded Topopah Spring member of the Paintbrush Tuff and a zeolitic, nonwelded tuff from the Tuffaceous Beds of Calico Hills. Rock outcrop samples were collected and dried in the laboratory at different temperatures (up to 400 degrees C). Hydrologic and physical properties were tested before and after each of the drying cycles.

METHODS

A large block of Topopah Spring welded tuff was collected from a surface outcrop at Busted Butte, 2 km south east of the potential repository block. Another large block of Calico Hills zeolitized tuff was collected from a surface outcrop in Yucca Wash, 3 km north of the potential repository block. Both blocks were brought into the laboratory and 50 cores (2.5 cm diameter by 5 cm high) were collected with a water cooled rock drill from each block. The samples were saturated with CO_2 then vacuum saturated with water for 96 hours. Saturated weights were determined for each sample. Sample volume was determined by water displacement. The samples were then placed in a relative humidity oven and equilibrated at 60 degrees C and 45 percent relative humidity (approximately -123 MPa water potential). This dry weight was used in calculating bulk density, grain density, and porosity. A helium pycnometer was then used to determine solid volume for determining grain density (helium and water determined grain densities were compared).

The samples were then placed on a free water surface and allowed to imbibe water. The samples were periodically weighed to determine the amount of

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water imbibed (I) over time (t). Sorptivity (S) is linear with the square root of time for early time infiltration[2] and can be calculated as $S=I\ t^{-.5}$. Sorptivity is a function of both the hydraulic conductivity and the water characteristic curve and is a useful way of examining any interaction effects. [Sorptivity was originally intended as a replacement for permeability measurements because of the difficulty of measuring permeability on the welded tuff samples.]

The samples were then divided into 5 sets of 10 samples with a statistically similar mean porosity for each group. Each of the 5 groups were dried at a different temperature. The first group was used as a control and dried in the relative humidity oven at 60 degrees C and 45 percent relative humidity. The additional four groups were dried at 105, 200, 300, and 400 degrees C with no humidity control for 24 to 48 hours.

Grain density using helium was first determined on the dried samples; then the measurement sequence to determine bulk density, grain density (using water) and porosity was repeated. The samples were dried again in the relative humidity oven in order to compare preheated conditions to postheated conditions, and assess the recoverability of the flow properties. Measurements of imbibition rate were retaken so that new values of sorptivity could be calculated.

Air permeability was determined for both the welded and nonwelded samples. Because the mean pore pressure was low and air (78 percent nitrogen) was used as the gas, Klinkenberg corrections[3] would be likely to have little effect and were not measured for these core. (Air permeabilities are used in this study for comparative purposes). Water permeabilities could only be run on the nonwelded core.

Ten cores from each temperature treatment formation were cut into small disks (0.5 cm thick). These disks were then saturated and allowed to air dry. During the drying process weights and water potential measurements were periodically made using a chilled mirror psychrometer and used for the determination of the water retention curve.

RESULTS AND DISCUSSION

As expected, increasing the temperature caused an increase in the measured porosity, grain density, and sorptivity, and caused a decrease in the bulk density of all samples (Figure 1a-f and 2a, b). In all cases the measured values for porosity, grain density and bulk density following resaturation returned to their preheated values. The change in sorptivity was determined to be permanent; as the measured values following resaturation and relative humidity drying did not return to the values prior to high temperature drying (Figure 2c, 2d). Air and water permeability increased in the nonwelded tuff but appeared unchanged in the welded tuff (Figure 2c, d). The changes in air and water permeability were determined to be permanent for the same reasons mentioned for sorptivity. [It should be noted that about 50 percent of the nonwelded tuff samples developed microfractures during the permeability measurements, probably as a result of drying and rewetting: these sample were excluded from the calculated mean permeabilities.] No detectable changes were apparent in the water retention curves for any of the heating treatments (Figure 3).

The permanent increase in permeability and sorptivity indicate that some flow pathway damage was done. This effect was much more pronounced in the Calico Hills zeolitized samples and suggests that zeolites occupying flow channels were permanently damaged by the high temperature treatment. Possibly, the zeolites occupying the flow channels, detached from the pore throats and fell into the larger body of the pore; and therefore caused an increase in flow. However, the lack of change in the water retention curves does not support this hypothesis; however, it may only require a small change in the pore throat (unmeasurable with the water activity meter) to change the permeability. If the zeolites are only displaced in the pore they may still be functional to adsorb radionuclides as their structure may still be intact; although they may be less effective since they may be out of the most direct path for water flow through the rock.

The helium pycnometry measurement of grain density was lower following the high temperature treatment than the measurement using water. Even though water (which is polar) was removed from the samples, the helium, being non-polar, could not enter into all of the void spaces. This is an indication that water was removed from clay or zeolitic structures. Water, being polar is able to occupy the newly formed voids in the clay and zeolitic structures, whereas helium, being non-polar cannot. A unique exception for grain density measurements was for the helium measurements on the welded core. Water was removed

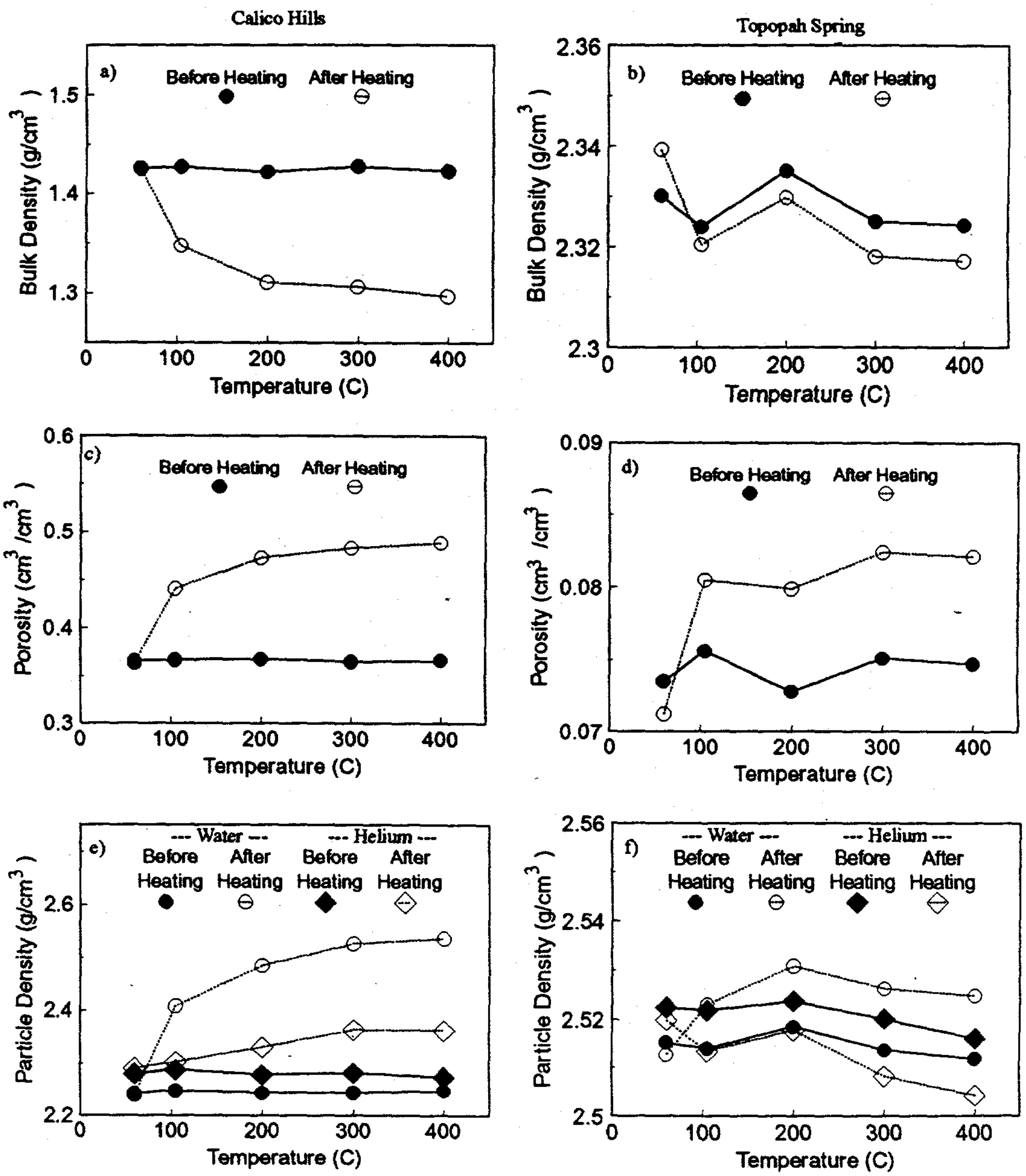

Figure 1. Change in the mean values of bulk rock properties for samples subjected to drying temperature of 60, 105, 200, 300 and 400 C; a) nonwelded bulk density, b) welded bulk density, c) nonwelded porosity, d) welded porosity, e) nonwelded particle density and f) welded particle density.

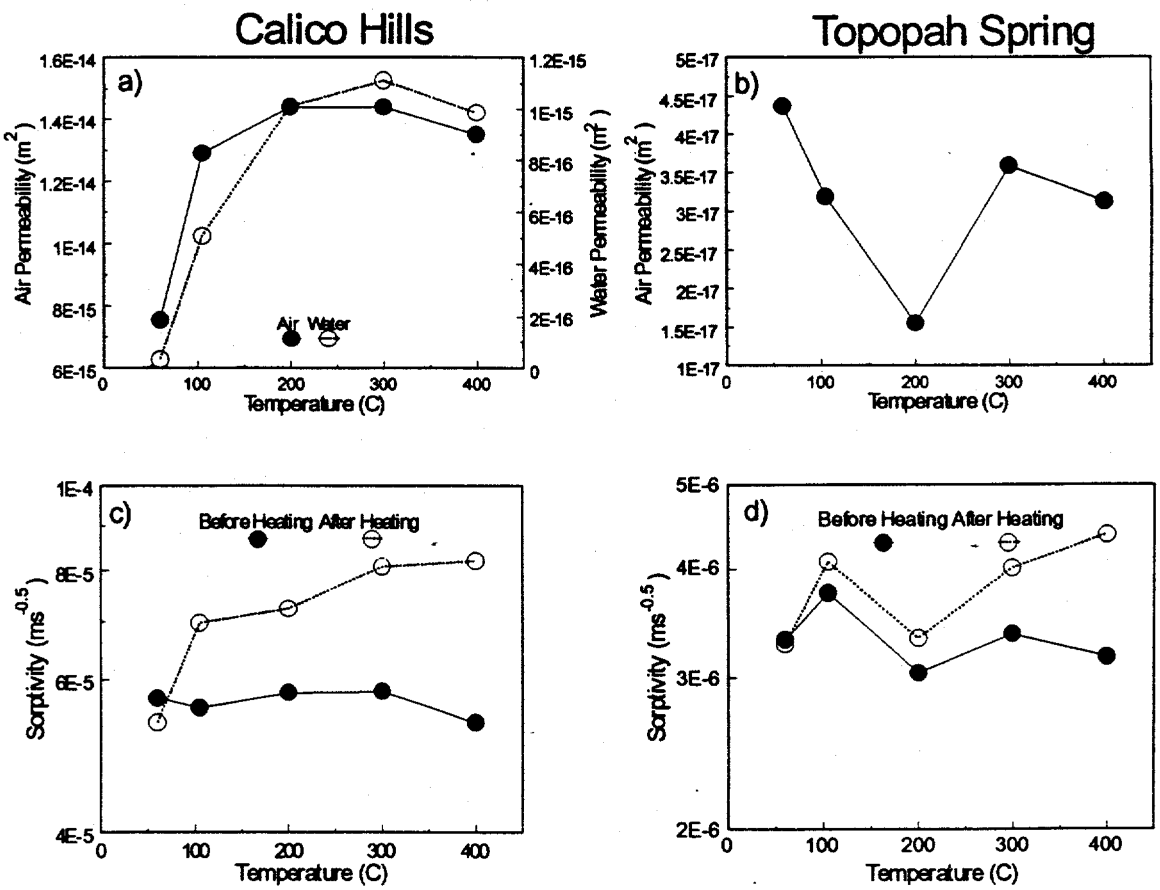

Figure 2. Change in the mean values of flow properties for samples dried at temperatures of 60, 105, 200, 300 and 400 C; a) nonwelded air and water permeability, b) welded air permeability, c) nonwelded sorptivity, and d) welded sorptivity.

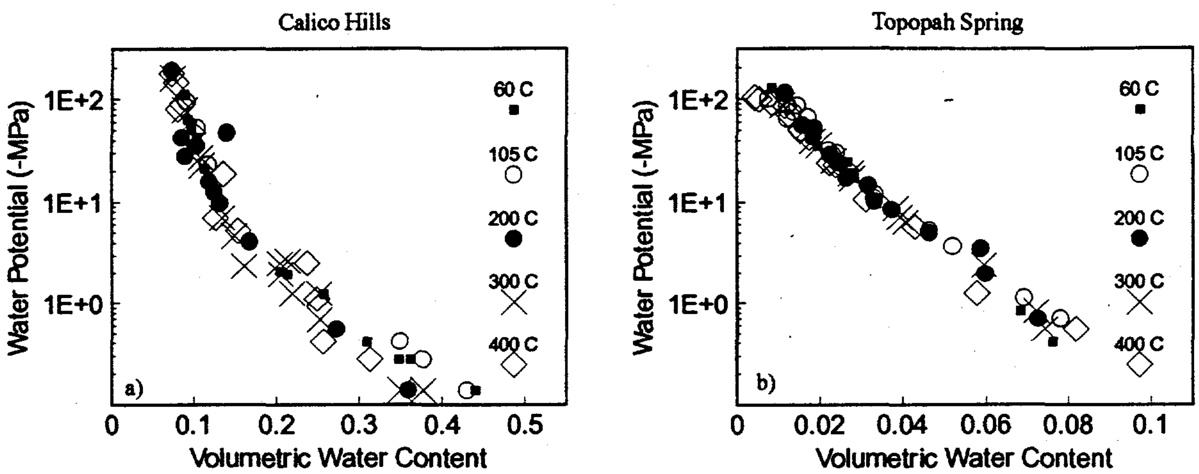

Figure 3. Water retention curves determined for core subsamples dried at 60, 105, 200, 300, and 400 C; a)nonwelded samples and b)welded samples.

from the grains, yet there was little change in measured volume (little to no helium entered into the welded tuff); therefore, the calculated grain density actually decreased. In the nonwelded sample enough helium went into the rock to allow for a measured change in volume to compensate for the loss of weight.

CONCLUSIONS

The hydrologic and physical properties of the volcanic tuff changed with increasing temperature. Even though porosity recovers following the heating treatment, the increase in storage space should be accounted for in flow models after the repository cools and water starts returning to the dry rock. The flow properties changed permanently, with varying magnitudes depending upon degree of heating and rock type, this also needs to be accounted for in flow modeling. The microfracturing that occurred in the nonwelded tuff may have more important implications; but the lack of confining pressure during the heating and drying may enhance the effects. Although this study is only preliminary, it does appear that altered rock properties need to be considered when developing post closure performance assessment models.

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