Conf-9309228--5

LA-UR-93-3691

Title: NATURAL ALTERATION IN THE COOLING TOPOPAH SPRING TUFF, YUCCA MOUNTAIN, NEVADA, AS AN ALALOG TO A WASTE-REPOSITORY HYDROTHERMAL REGIME

Author(s): S. Levy, and G. Valentine

Submitted to: FOCUS '93
Las Vegas, NV
September 27-29, 1993

MASTER

Los Alamos
NATIONAL LABORATORY

NATURAL ALTERATION IN THE COOLING TOPOPAH SPRING TUFF, YUCCA MOUNTAIN, NEVADA, AS AN ANALOG TO A WASTE-REPOSITORY HYDROTHERMAL REGIME

Schon Levy
Los Alamos National Laboratory
Mail Stop D462
Los Alamos, NM 87545
(505) 667-9504

Greg Valentine
Los Alamos National Laboratory
Mail Stop F665
Los Alamos, NM 87545
(505) 665-0259

ABSTRACT

Studies of natural hydrothermal alteration in the cooling Topopah Spring tuff suggest a useful "self-analog" predictor of fluid-rock interactions within the thermal regime imposed by a potential nuclear waste repository at Yucca Mountain. This tuff has the advantages of representative rock types and appropriate spatial distribution of lithologic features. The cooling history of the tuff spanned the temperature range for any proposed repository thermal load, and the unsaturated-zone hydrologic conditions of the natural alteration would have been similar to existing conditions. A site at northeastern Yucca Mountain, with a prominent vertical fracture zone, has been selected for natural analog studies. The cooling of the tuff and the movement of water in the fracture zone and adjacent matrix will be modeled with the finite element code FEHNM, capable of simulating flow through porous and fractured media using a dual porosity-dual permeability continuum model, with heat transfer and two-phase (vapor and liquid) processes fully accounted for.

INTRODUCTION

Yucca Mountain, Nevada, is being studied as a site for a potential high-level nuclear waste repository. Two major components of the Yucca Mountain Site Characterization Project are site characterization and performance assessment. Site characterization activities will provide the basic information and conceptual understanding to support performance assessment calculations. The ultimate purpose of numerical models used in performance assessment is to predict whether radionuclide releases from a potential repository will meet regulatory requirements. Efforts to model a repository thermal regime, including the mechanical, hydrologic, and geochemical effects, are an important part of performance assessment.

Model validation is a process used to determine whether numerical models can adequately represent the complex systems they were designed to simulate. One way to accomplish validation involves the use of so-called natural analogs. For the purposes of Yucca Mountain researchers, natural analogs are usually geologic sites affected by active or formerly active processes having something in common with expected processes in a potential repository. Common choices include active geothermal areas, areas affected by uranium mineralization, and small igneous intrusions. No single analog site is optimal for all validation purposes, but a useful analog study should include a conceptual model that identifies the significant processes affecting the site and as quantitative a description as possible of the resultant changes.

This information provides the basis against which numerical model predictions are tested.

There may also be a need within the project for interactive studies involving site-specific characterization activities and numerical models that are not directly applied to performance assessment. Such studies would be distinguished from formal model validation by a higher amount of feedback between modeling and site-characterization activities. For example, investigations of secondary-mineral textures might focus on evidence indicative of pore water content based on the results of models that incorporate capillarity in heat transfer.

The candidate host rock for repository construction at Yucca Mountain is densely welded devitrified tuff in the lower part of the Topopah Spring Member of the Paintbrush Tuff. Studies of hydrothermal alteration during the cooling of ash-flow deposits comprising the Topopah Spring Member suggest that the altered tuff could be a valuable natural analog predictor of fluid-rock interactions within the thermal regime imposed by a potential nuclear waste repository at Yucca Mountain. As a self-analog for a repository, the Topopah Spring tuff has the advantages of precisely representative rock types and appropriate spatial distribution of lithologic features. The cooling history of the tuff, particularly in the later stages, spanned the temperature range to be expected under any proposed repository thermal load.

COOLING AND HYDROTHERMAL HISTORY

About 12.8 million years ago,[1] the pyroclastic material comprising the Topopah Spring tuff was erupted and deposited as a thick sequence of ash flows covering the existing land surface. Exact eruption temperatures are not known, but may have been within the 600 to 800°C range of Fe-Ti oxide crystallization temperatures.[2] The time required for the deposit to cool is also not known; it could have been in the range of tens to hundreds of years.[3] The cooling pyroclastic deposit provided an internal heat source for a variety of common syngenetic processes. Early in the cooling period, the hot interior of the tuff was densely welded by viscous flow and compaction of the glass particles comprising the bulk of the pyroclastic material. The more quickly cooled upper and lower margins of the deposit were moderately welded to nonwelded. Also in the hot interior, the tuff devitrified -- crystallized to an assemblage of feldspars and silica minerals -- while the outer margins remained glassy. Paleomagnetic data indicate that welding or rheomorphic flow of densely welded glassy tuff (vitrophyre) below the devitrified interior may have continued to temperatures as low as 475°C.[4] Additional syngenetic features generally associated with devitrification include lithophysal zones -- concentrations of former gas cavities -- and zones of vapor-phase crystallization. The tuff was also subject to fracturing, faulting, and brecciation during cooling, forming potential pathways for fluids.

The syngenetic processes described above mostly occurred at temperatures higher than expected repository conditions, but later stages of cooling also involved rock alteration. A distinctive example of such alteration is in the devitrified-vitric transition zone between the candidate host rock and underlying vitrophyre in the lower part of the Topopah Spring Member. This interval is characterized by hydrothermal alteration that is present wherever this syngenetic boundary has been examined, both in outcrop and in drill holes.[5,6,7] Within this zone, devitrification is incomplete and is localized around fractures. Examples of devitrified fracture borders are as much as 0.1 m wide. The main mineralogic constituents of the devitrified rock are alkali feldspar and cristobalite,[8] but the outermost margins of the fracture borders and the adjacent glassy rock also contain hydrous minerals (smectite clay and zeolites) and silica minerals. The hydrous minerals and silica are also present as fracture fillings and replacements of pumice lapilli within the transition zone. Quartz and chalcedony are common constituents of the hydrothermal assemblages and locally predominate, as in a geode-bearing variant of the transition zone at northeast Yucca Mountain. The geodes are devitrification cavities connected by fractures. The cavities have outer rinds of hydrous minerals and are filled with 1-cm quartz crystals, chalcedony, and horizontally layered silica (Figure 1).

The layered silica, present also as fracture fillings, is of special interest because it is testimony to at least a local abundance of liquid water during this episode of hydrothermal alteration that certainly occurred in the unsaturated zone. Textural evidence indicates that the silica aggregates probably are the last abundant secondary minerals deposited in fractures and voids during the alteration. Deposition temperatures for the quartz and chalcedony, estimated by oxygen isotope geothermometry,[6] were above present-day ambient temperatures but below 100°C.

Fluid transport and alteration took place within a hierarchy of fracture systems carrying heated water into the vitrophyre. Many of the earliest formed fractures -- those with devitrified borders -- are highly planar and may extend several metres or more downward into the vitrophyre. The fracture apertures may have been mostly less than 1 to 2 mm. Subsidiary fractures cutting across the main fractures developed faint incipient devitrified borders. This set of fractures in turn intersected the perlitic fracture system that extends throughout the vitrophyre. Perlitic structure, formed by contraction during cooling, is a system of small, convolute, spheroidal cracks typical of silicic vitrophyres. The cracks had original apertures of a few micrometres. Examination of individual perlitic cracks within a few centimetres of larger fractures reveals substantial glass dissolution along the crack surfaces. In one example, a zeolite-smectite mixture was deposited in the fracture adjacent to the dissolved perlitic crack surface. The local volumetric ratio of glass dissolved to secondary minerals deposited is estimated to be at least 10:1, with the extra solutes presumably transported out of the perlitic cracks back into the larger fractures.

The consistent association of the alteration with the transition zone ties the timing of hydrothermal activity to the cooling of the pyroclastic unit, when water interacted with the still-hot tuff. Alteration was localized in the boundary between devitrified and glassy tuff because it was a region in which chemically reactive volcanic glass still existed at a relatively high temperature. If the source of water was either meteoric recharge infiltrating downward into the tuff from the ground surface or downward-refluxing condensed water vapor from within the tuff itself, this boundary region would have been the first glassy rock encountered by water heated during downward flow through the hot, devitrified interior of the tuff. The characteristic alteration diminishes and disappears below the transition zone, with no evidence of major fluid feeders from depth. This type of hydrothermal regime is referred to as a rootless hydrothermal system, indicating that fluid was not supplied from deep ground-water sources. It is an excellent hydrologic analog for a waste repository in the unsaturated zone.

ANALOG ISSUES

In developing the Topopah Spring tuff as a repository analog, a number of information needs have been identified. Detailed field and mineralogic studies will refine our knowledge of the temperatures at which alteration occurred and the nature of the water-rock interactions. A model of the cooling history would provide temperature-depth profiles for the entire cooling period to help understand the distribution and timing of alteration. This will also make it possible to estimate the total duration of the alteration period and faciliate comparison with expected repository conditions. The evidence for water-filled fractures recalls a key challenge of repository performance: to determine under what thermal conditions water from a reflux zone above a dried-out repository or surface recharge water could flow downward along fractures through the waste storage level. The question will be addressed by geothermometry studies of secondary minerals, mostly silica, for comparison with the results of modeling the interactions of water introduced into a vertical fracture in cooling tuff.

Another concern is the dissolution, transport, and deposition of silica or other secondary minerals by water driven away from the repository. Hydrologic properties of both fractures and rock matrix in a zone around the repository could be affected, with consequences for the thermal behavior of the rock as well.[9] Figure 2 illustrates the results of scoping calculations for the dissolution of volcanic glass and precipitation of smectite, zeolite (heulandite-clinoptilolite), and silica (cristobalite). This approximates natural hydrothermal reactions that occurred in the devitrified-vitric transition zone immediately below the candidate host rock. Because aluminum is the limiting constituent in determining how much of the reaction products can be made from a given amount of glass, the reaction is balanced only on a constant-Al basis for variable proportions of smectite and zeolite reaction products, with leftover silica represented as cristobalite. The possible volumetric increase for the product assemblage versus the dissolved glass varies from 13 to 24%. These values are an order of magnitude higher than the bulk porosity of unaltered vitrophyre,[10] indicating that secondary mineral deposition could have a significant effect on rock hydrologic properties.

A surface exposure at NE Yucca Mountain has been tentatively chosen as a self-analog study site to augment our existing knowledge of hydrothermal alteration in the Topopah Spring tuff. The area is distinguished by a higher than usual abundance of secondary quartz and chalcedony in cavities and fractures; this is the site where the layered silica fillings in cavities are located. There is a prominent vertical fracture zone, about 1 to 2 m wide, that extends from the top of the Topopah Spring tuff into the devitrified-vitric transition zone below the candidate host rock, and the abundant silica may be associated with the fracture zone. The apparent nonpersistence of the fracture zone in the underlying vitrophyre indicates that the fractures formed while the vitrophyre was still sufficiently plastic to discourage fracture propagation or to heal newly formed fractures. Establishing the approximate age of the fracture zone is important because it enhances confidence that the alteration in and around the fractures was also associated with the cooling of the pyroclastic deposit. The abundance of alteration features and secondary minerals in the fracture zone increases the likelihood of success in tracing fluid movement and mass transport.

MODELING OF NATURAL ANALOG SYSTEMS

A variety of combinations of physical parameters may produce a given set of observations at an analog site; numerical simulations will be carried out to find the most important of these parameters and the combination of parameters most likely to produce the observed features. Some of these parameters are: fracture and matrix components of the water infiltration rate, maximum temperture of the tuff, spatial variability in hydrologic properties (e.g., varying degrees of welding in the tuff), and overall thermal evolution of the tuff. In order to model these parameters we will use the finite element code FEHMN, developed at Los Alamos National Laboratory.[11] FEHMN is capable of simulating flow through porous and fractured media using a dual porosity-dual permeability (DPDP) continuum model, with heat transfer and two-phase (vapor and liquid) processes fully accounted for. The DPDP approach is ideally suited for the studies described in this paper because it is likely that there is a complex interplay between water penetrating fractures, being imbibed into adjacent matrix, and boiling as it penetrates into hot regions of tuff. A capability to simulate fracturing in response to thermal and fluid stresses is in the process of being added to the code, and may also prove useful for these analog studies (e.g., [12]).

Previous modeling of cooling of thick ignimbrites has suggested that with initial emplacement temperatures of 700 to 800°C the deposits may take many tens to hundreds of years to cool to the point that the entire deposit is cooler than the boiling temperature of water.[3] Those model calculations assume that heat flow within ignimbrites is only by conduction, and thus should be regarded as maximum cooling times. We will use these calculations for initial analysis of penetration depths of slugs of water flowing down fractures, with negligible matrix imbibition, at various stages in the thermal history of the analog site. The next step in our modeling will supplement the original calculations by accounting for infiltration of water through coupled matrix and fractures. Convective flow, with phase change, will likely occur under some conditions, especially those that are in the same thermal regime as proposed "hot repository" scenarios.

ACKNOWLEDGMENTS

This work was suppported by the Yucca Mountain Site Characterization Project Office as part of the Civilian Radioactive Waste Management Program. This Project is managed by the U.S. Department of Energy. Technical review by David Vaniman is greatly appreciated.

REFERENCES

1. D. SAWYER, R. FLECK, M. LANPHERE, R. WARREN, and D. BROXTON, "Episodic Volcanism in the Southwest Nevada Volcanic Field: New $^{40}Ar/^{39}Ar$ Geochronologic Results," EOS Transactions, 71, 1296 (1990).

2. P. LIPMAN, "Iron-titanium oxide phenocrysts in compositionally zoned ash-flow sheets from southern Nevada," Jour. Geol., 79, 438 (1971).

3. J. RIEHLE, "Calculated Compaction Profiles of Rhyolitic Ash-Flow Tuffs," Geol. Soc. Amer. Bull., 84, 2193 (1973).

4. J. ROSENBAUM, "Paleomagnetic Directional Dispersion Produced by Plastic Deformation in a Thick Miocene Welded Tuff, Southern Nevada: Implications for Welding Temperatures," J. Geophys. Res., 91, 12,817 (1986).

5. S. LEVY, "Studies of Altered Vitrophyre for the Prediction of Nuclear Waste Repository-Induced Thermal Alteration at Yucca Mountain, Nevada," Scientific Basis for Nuclear Waste Management VII, Elsevier Science Publishers, New York (1984).

6. S. LEVY and J. O'NEIL, "Moderate-temperature zeolitic alteration in a cooling pyroclastic deposit," Chem. Geol., 76, 321 (1989).

7. Z. PETERMAN, R. SPENGLER, K. FUTA, B. MARSHALL, and S. MAHAN, "Assessing the Natural Performance of Felsic Tuffs Using the Rb-Sr and Sm-Nd Systems -- A Study of the Altered Zone in the Topopah Spring Member, Paintbrush Tuff, Yucca Mountain, Nevada," Scientific Basis for Nuclear Waste Management XIV, Elsevier Science Publishers, New York (1991).

8. D. BISH and S. CHIPERA, "Revised Mineralogic Summary of Yucca Mountain, Nevada," LA-11497-MS, Los Alamos National Laboratory (1989).

9. N. BIXLER and C. CARRIGAN, "Enhanced Heat Transfer in Partially-Saturated Hydrothermal Systems," Geophys. Res. Lett., 13, 42 (1986).

10. J. BLACIC, J. CARTER, P. HALLECK, P. JOHNSON, T. SHANKLAND, R. ANDERSEN, K. SPICOCHI, and A. HELLER, "Effects of Long-Term Exposure of Tuffs to High-Level Nuclear Waste-Repository Conditions: Preliminary Report," LA-9174-PR, Los Alamos National Laboratory (1982).

11. G. ZYVOLOSKI, Z. DASH, and S. KELKAR, "FEHMN1.0: Finite Element Heat and Mass Transfer Code," LA-12062-MS, Los Alamos National Laboratory (1991).

12. C. CARRIGAN, "A Two-Phase Hydrothermal Cooling Model for Shallow Intrusions," J. Volcanol. Geotherm. Res., 28, 175 (1986).

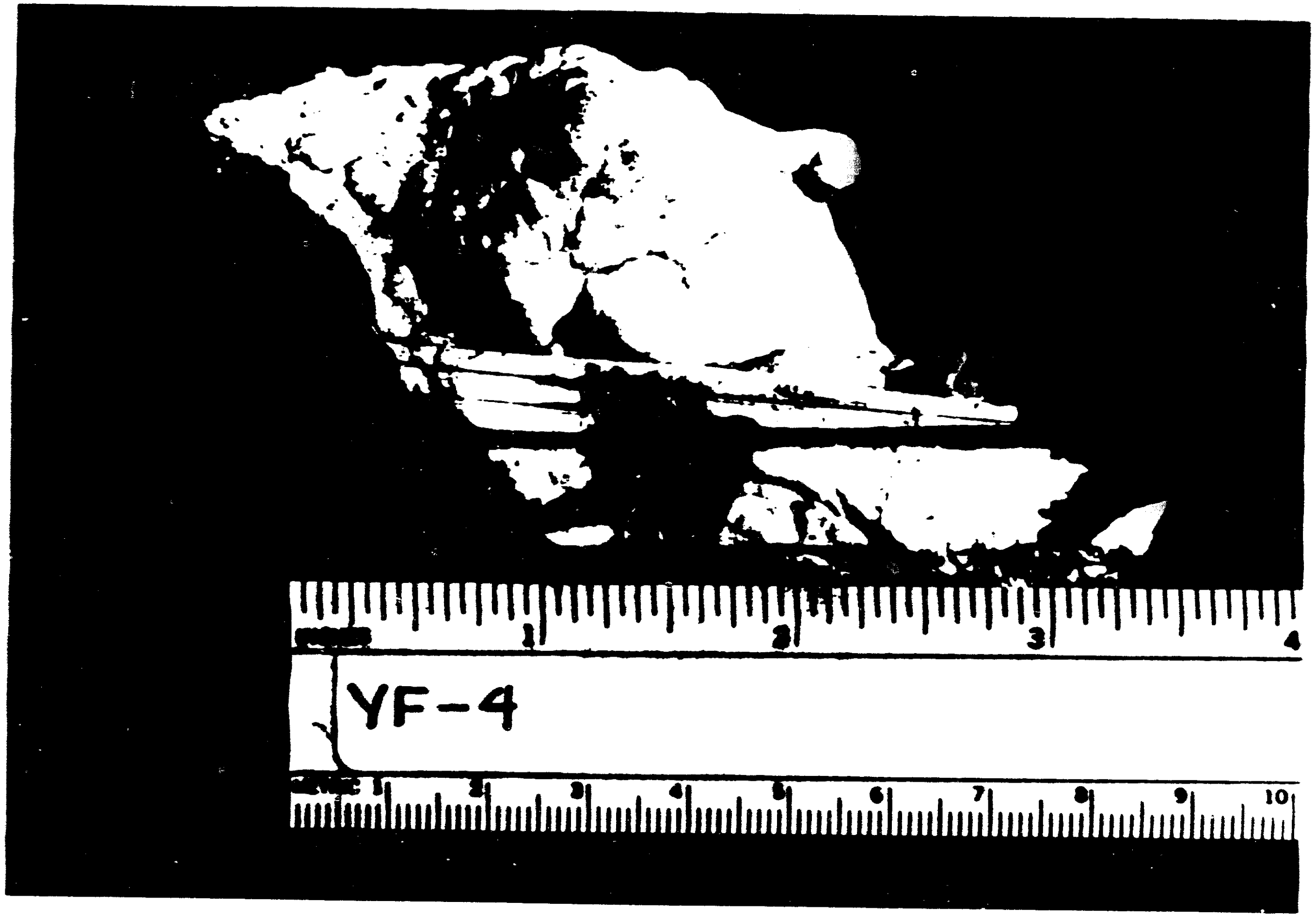

FIGURE 1 - Devitrification cavity with layered silica fillings. The angled layers attest to tilting or faulting of enclosing rock during period of silica deposition.

	MOLES CATION/cm 3			
	GLASS	SMECTITE	HEUL-CLINOPT.	CRISTOBALITE
Si	0.029	0.014	0.024	0.038
Al	0.006	0.008	0.006	0

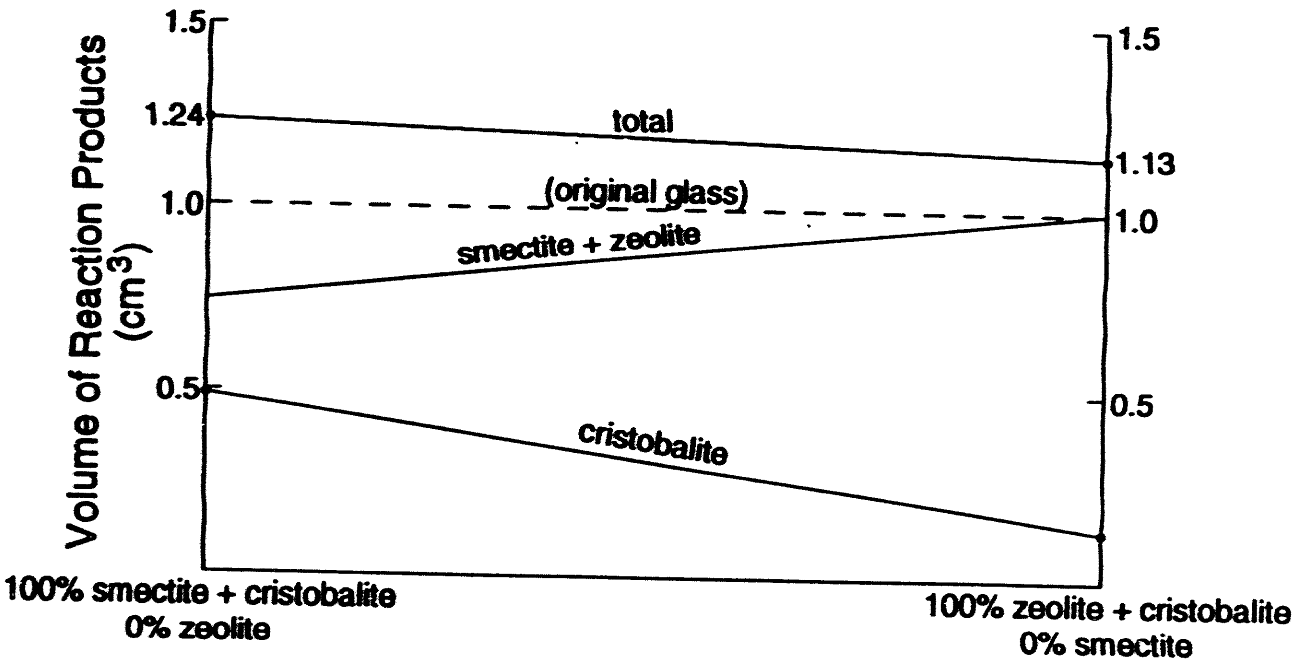

FIGURE 2 - Volumetric changes associated with the alteration of vitrophyre glass to a smectite-zeolite-cristobalite assemblage.

DATE FILMED

5/20/94

END