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SURFACE-DISCHARGING HYDROTHERMAL SYSTEMS AT YUCCA MOUNTAIN -- EXAMINING THE EVIDENCE

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ABSTRACT

Exposures of altered rock that have been thought to form by recent discharge of water from depth were examined to address a concern that hydrothermal processes could compromise the isolation capability of a potential high-level nuclear waste repository at Yucca Mountain. The suspected hot-spring and hydrothermal-vent deposits are more likely the products of infiltration of meteoric water into newly deposited and still-hot pyroclastic flows >12 Myr ago.

INTRODUCTION

The possibility of radionuclide release by surface-discharging hydrothermal systems has become an issue for the potential high-level nuclear waste repository site at Yucca Mountain, Nevada (Yucca Mountain Site Characterization Project (YMP), managed by the U.S. Department of Energy). Rising water, moving through a repository and emerging at the surface, could provide transport of radionuclides to the accessible environment. For this reason, an effort has been made to identify and study surficial features characteristic of hydrothermal deposits or hydrothermally altered rocks.

Systematic investigations of rock alteration at Yucca Mountain, in progress for more than ten years, are building a comprehensive history of alteration. Since the 1980's, a variety of individuals and organizations have raised concerns about surface or trench exposures that they believe to be products of recent hydrothermal activity [1,2,3]. The common characteristic of suspected hydrothermal sites is an alteration that distinguishes them from the surrounding rock. Many sites are within fault zones where the rock may be brecciated or discolored, raising the concern that faults could act as conduits for fluids from depth. There are outcrops thought to be silica spring mounds, and examples of possible breccia dikes consisting of rock fragments that could have been transported from depth by a high-pressure fluidized system.

Because Yucca Mountain lies within a long-active (15 Myr) volcanic area, evidence of past hydrothermal activity is to be expected. Recent hydrothermal deposits, if present, must be distinguished on the basis of field relations and other applicable criteria. Characterization of the deposits involves determining their distribution, association with particular rock units, structural features, or syngenetic zones (zonation formed during the cooling of a pyroclastic deposit), as well as where they are in place, reworked, or truncated. Aspects of the deposits specifically relevant to the issue of surface discharge include evidence of constructional features, fluid outlets or feeders, and relationships to past or present topography.

The approach used in addressing the issue of recent hydrothermal surface discharge has been to examine three areas with exposures of altered rock judged most likely to be of hydrothermal origin, based on current understanding. Studies of possible hydrothermal deposits have been concentrated on the east side of Yucca Mountain and its immediate vicinity. Additional studies are in progress.

FIELD AND ANALYTICAL METHODS

This investigation emphasizes surface exposures of possible hydrothermal deposits, but also incorporates information from drill cores. The labeled drill holes in Fig. 1 are the sources of samples included in this study. Surface study sites are the informally named "Harper Valley" of SE Yucca Mountain and Busted Butte, east of the mountain (Fig.1).

Field samples and their derivatives were examined by optical and scanning-electron microscopy. X-ray diffraction and electron microprobe analysis were used to determine the identities and chemical compositions of secondary minerals in altered rocks.

GEOLOGIC SETTING

The predominant rock unit exposed at the surface around Yucca Mountain is the Paintbrush Tuff, consisting of two thick ash-flow sequences and an intervening sequence variably composed of thinner ash flows and bedded tuffs. The two main ash-flow tuffs are the 12.8-Myr Topopah Spring Member and the overlying 12.7-Myr Tiva Canyon Member [4]. All examples of hydrothermal alteration in this study are located within the Paintbrush Tuff.

The Topopah Spring and Tiva Canyon tuffs were each erupted at temperatures around 700°C and required about 10^2 years or more to cool [5,6]. Early in the cooling period, the hot interior of a tuff was densely welded by viscous flow and compaction of the glass particles. 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. Subsidiary syngenetic features include lithophysal zones -- concentrations of former gas cavities -- and zones of vapor-phase crystallization. The tuffs were also subject to fracturing, faulting, and brecciation during cooling, forming potential pathways for fluids.

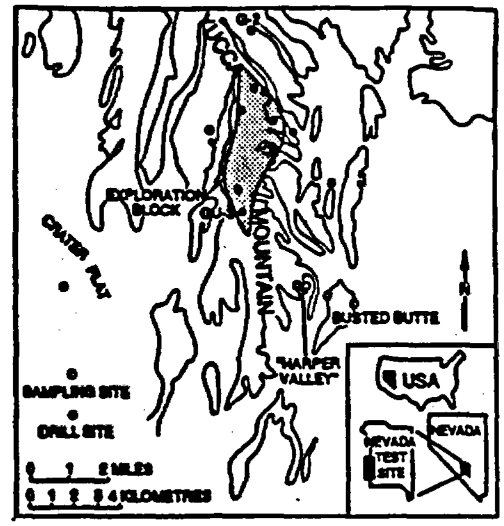

Fig. 1. Location map.

HYDROTHERMAL ALTERATION IN THE LOWER TOPOPAH SPRING MEMBER

The devitrified-vitric transition zone in the lower part of the Topopah Spring Member is characterized by distinctive hydrothermal alteration [7,8]. Within this zone, devitrification is incomplete and is localized around fractures. Examples of devitrified fracture borders as much as 0.1 m wide are exposed at eastern Busted Butte. The major mineralogic constituents of the devitrified rock are alkali feldspar and cristobalite, with hydrous smectite, zeolites, and opal in the outermost margins of the fracture borders and adjacent glassy rock (usually vitrophyre). The hydrous minerals 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 devitrification cavities filled with quartz crystals, chalcedony, and horizontally layered silica, testimony to an abundance of liquid water.

The consistent association of the alteration with the transition zone ties the timing of hydrothermal activity to the cooling of the pyroclastic unit ~12.8 Myr ago, when meteoric water infiltrated into 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. This was 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 fluid feeders from depth.

Alteration in the upper Topopah Spring transition zone is uncommon and inconsistent. This difference is due in part to faster cooling in the upper part of an ash flow [6]. The results of this study have provided some unexpected information about alteration in the upper transition zone, described below.

The hydrothermal alteration in the lower Topopah Spring devitrified-vitric transition zone, restricted to the vicinity of a 12.8 Myr-old syngenetic boundary, provides a basis of comparison for proposed examples of recent surficial hydrothermal deposits. Recent deposits must not only contain evidence of hydrothermal processes but must also show a significantly different distribution pattern from the Topopah Spring hydrothermal deposits.

THE SEARCH FOR CONSTRUCTIONAL FEATURES

Constructional features -- mineral mounds or other deposits built up by repeated localized discharge of solute-laden fluids -- are among the most distinctive expressions of hydrothermal systems that reach the surface. Two types of rock exposure have been identified as possible constructional features of hydrothermal origin.

Possible Silica Spring Mounds

Scattered exposures of mostly white, dense, fine-grained rocks at Busted Butte and near Harper Valley have been cited as possible hydrothermal spring mounds. Individual outcrops of broken rock have less than one metre of residual relief and lateral extent. The white color of the outcrops contrasts with the mostly gray and brown colors of surrounding rock. Irregular, millimetre-scale banding resembles a common feature of hydrothermal mounds [9]. Although they occur at different elevations, all outcrops are stratigraphically located in the uppermost part of the Topopah Spring tuff.

Microscopic studies have shown that the rocks are moderately welded and nonwelded tuffs modified by brecciation and secondary-mineral crystallization. Tight cementation of the altered rocks by secondary minerals accounts for the enhanced resistance to weathering. The existence of relict pyroclasts is a conclusive indication that the outcrops are not constructional features. The banding evident in outcrop is a product of pyroclastic welding or alignment of pyroclasts, enhanced by secondary-mineral crystallization along clast margins.

The principal secondary minerals, formed after the rocks were brecciated, are alkali feldspar, tridymite, and cristobalite. This mineral assemblage is identical to the minerals formed by devitrification (including vapor-phase crystallization) of densely welded tuff farther down in the interior of the ash flow [10]. The feldspars crystallized from breccia clasts have grown beyond the original clast boundaries to form fringes radiating from the relict clasts. These textures closely resemble vapor-phase feldspar textures within pumice lapilli in the densely welded tuffs.

Most of the feldspar compositions (Fig. 2) are similar to data for vapor-phase alkali feldspar from the devitrified Topopah Spring tuff, but some of the feldspars from the altered rock on eastern Busted Butte are much more potassic. For comparison, Fig. 2 shows compositional fields for two other distinctive occurrences of secondary alkali feldspar at Yucca Mountain. First, authigenic feldspars interpreted as products of ground-water hydrothermal alteration at about 200 to 275°C [11], related to Timber Mountain caldera activity (~11 Myr), have nearly end-member sodic or potassic compositions [12]. Second, normative alkali feldspar compositions for the cryptocrystalline devitrified fracture borders in the lower Topopah Spring transition zone cover a range similar to the feldspars from the altered rock, including more potassic compositions than the vapor-phase feldspars.

In the Yucca Mountain area, the alkali feldspar-tridymite-cristobalite assemblage has not been identified in any genetic context other than early post-depositional devitrification and vapor-phase crystallization of ash flows. The restricted occurrence of this mineral assemblage, plus the proximity of the altered tuffs to the top of the devitrified zone, suggest that the altered tuffs represent local variations of normal devitrification. This interpretation is compatible with the

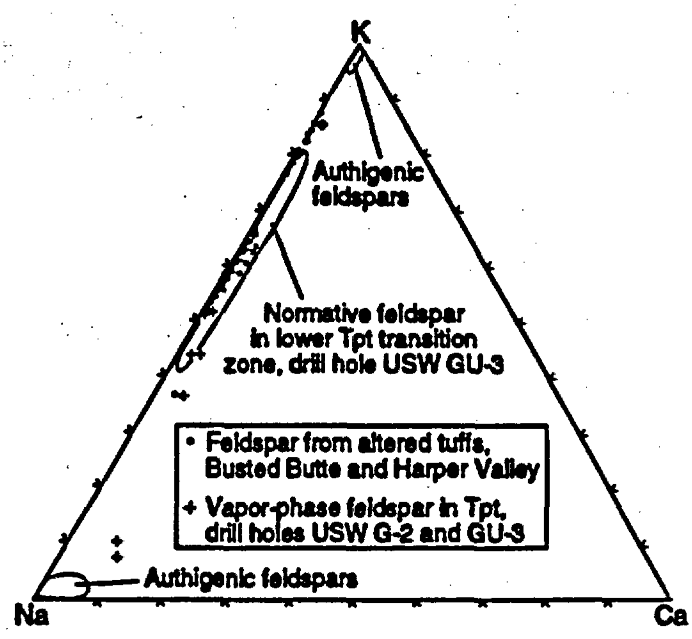

Fig. 2. Normalized molecular proportions of K, Na, and Ca in secondary alkali feldspars.

similarity of feldspar compositions among altered and devitrified rocks. Early brecciation at the alteration sites may have provided pathways for both the upward escape of hot vapor from the interior of the ash flow and the downward infiltration of meteoric water. High-pressure escaping vapor might have contributed to the brecciation, but breccia zones in the devitrified rocks below some of the white outcrops contain no associated vapor-phase crystallization and no evidence of clast transport. Brecciation may have resulted from compaction of the ash flow over uneven terrain [13]. The altered rocks do not include any textural features, like the layered silica void fillings in the lower Topopah Spring tuff, that are unequivocal indications of the presence of water during mineral deposition. However, the dense cristobalite-tridymite cementation of some sample may reflect increased mass transport in the presence of more abundant water.

Concretionary Structures

The upper part of Harper Valley and the upper slopes of southwestern Busted Butte contain extensive exposures of resistant concretions standing in relief as much as 15 cm above the ground surface. Free-standing concretions occur as scattered groupings of as many as twenty or thirty individual conical or finger-shaped structures and expanses of continuous honeycomb-like structures. The long axes of elongate concretions and the walls of honeycomb concretions are predominantly vertical in undisturbed exposures. The concretions initially appear to be scattered randomly along the slopes, but are restricted to specific layers of bedded tuff in a 10-m interval immediately below the Tiva Canyon Member of the Paintbrush Tuff. One interpretation, based on the belief that the concretions are distributed independent of stratigraphic interval, cites the structures as products of hydrothermal solutions, including boiling liquids, discharged at the contemporary land surface [3].

The concretions are composed of the same glassy nonwelded tuff as the bedded tuffs in which they are anchored. Opal cementation is the distinguishing mineralogic characteristic of the concretions. Excavation of less-eroded portions of the bedded tuffs has revealed localized opal cementation in patterns that are generally consistent with the shapes of the free-standing concretions. Preferential erosion of noncemented tuff surrounding the concretions is probably responsible for the free-standing structures, which are therefore residual rather than constructional features.

The opal cement in the concretions is part of a distribution pattern for secondary silica observed at both the Harper Valley and Busted Butte sites, described in additional detail below. In the lower moderately welded Tiva Canyon tuff, fractures are commonly coated with opal with minor chalcedony. The opal fracture fillings in the moderately welded tuff and the void-filling opal cement in the concretions both display a distinctive dripstone texture in which 1- to 2-mm aggregates are built from layers of opal draped upon each other. There is a consistent sense of downward transport in the draped structures of the opal aggregates.

Glass pyroclasts within the cemented concretions are among the least altered glassy materials in Harper Valley. Pyroclasts in uncemented tuff adjacent to the concretions have slightly etched surfaces. Glass particles exposed to boiling liquids would not remain in such pristine condition. The amount of glass dissolution and alteration increases upward from the base of the Tiva Canyon tuff to the transition between vitric and devitrified tuff, making the transition zone the interval of most intense alteration and a likely source of dissolved silica. The distribution and morphology of the opal aggregates in the moderately welded tuffs and the concretions also support downward movement of silica-bearing fluids from the Tiva Canyon tuff into the underlying bedded tuffs.

BRECCIA DIKES

The upper reaches of Harper Valley contain many exposures of rock fractures, with wall separations of as much as a few decimetres, filled with rock fragments. Breccia-filled fractures are traceable vertically for as much as several metres through the densely welded, devitrified tuff and underlying moderately to slightly welded, vitric portion of the Tiva Canyon Member of the Paintbrush Tuff. A distinctive aspect of the breccias, as they appear in the field, is that rock fragments, predominantly larger than one millimetre, are well sorted and the deposits contain very little fine-grained matrix. It has been suggested that the breccia deposits are fossil fumarole pipes in which upward discharge of steam winnowed out the fine-grained rock fragments [14] or hydroclastic injection dikes of recent age [3].

One example of a breccia-filled fracture on the northeast flank of Harper Valley has been examined in detail. The host rock is moderately to slightly welded, vitric basal Tiva Canyon tuff. All breccia clasts are densely welded, devitrified Tiva Canyon tuff, transported downward at least several metres. The common occurrence of sphene in the clasts distinguishes the Tiva Canyon from the Topopah Spring tuff [15], and precludes the possibility of the clasts having been transported upward from the lower Paintbrush section. Botryoidal chalcedony and cristobalite are the cementing agents in the central part of the breccia deposit, whereas the finer-grained outer zones are cemented by the zeolite heulandite-clinoptilolite.

The downward movement of breccia clasts and the complete absence of material from lower stratigraphic levels are incompatible with any mechanism for upward transport of particulates. The observed clast size sorting may have occurred, not by gas winnowing, but by the sieving effect of fracture blockages as material moved downward. Breccia was deposited in increments as the fracture opened episodically. After an initial batch of clastic material was deposited and cemented by silica, small gaps between the cemented breccia deposit and the fracture walls were filled by finer-grained material.

As described above, there is a general pattern to the distribution of secondary minerals in fractures. Chalcedony, cristobalite, and heulandite-clinoptilolite cements in the breccia are more similar to the chalcedony/zeolite fracture fillings in the overlying densely welded tuff than to the opal fracture fillings in the moderately welded tuff adjacent to the dike and in the bedded tuffs below. In effect, the zone of more highly crystalline silica fracture coatings is extended downward a few metres within the breccias. The breccia-filled fractures acted as preferential pathways for mineral-bearing fluids when chalcedony and zeolites were being deposited. The probable source of the silica and zeolites was residual glass in the partially devitrified pumice clasts and groundmass of the otherwise devitrified tuffs.

This alteration shows many similarities to the lower Topopah Spring devitrified-vitric transition zone and may also have resulted from infiltration of meteoric water into cooling tuff. The restriction of this particular kind of breccia-filled fracture to the Tiva Canyon tuff also suggests that the breccias are about the same age as the tuff itself. Surface exposures of the breccias would therefore be the results of erosion, and do not mark the locations of recently active hydrothermal vents.

CONCLUSIONS

Genuine hydrothermal deposits have been identified in surface exposures around Yucca Mountain. Preliminary studies suggest that none of the exposures described here represent surface expressions of hydrothermal systems originating at depth. The deposits are most likely the products of hydrothermal processes engendered by infiltration of meteoric water into newly deposited and still-hot pyroclastic flows >12 Myr ago, as shown by the geometry, spatial distribution, and mineralogy of the deposits. These transient hydrothermal systems, linked as they were to the cooling tuffs as heat sources, have never been reactivated.

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REFERENCES

1. R. Loux (State of Nevada Nuclear Waste Project Office), letter to D. Vieth, U.S. DOE, Nevada Operations Office, September 19, 1985.

2. Hanson, G., V. Baker, P. Bethke, P. Hudleston, and G. Roquemore, U.S. DOE, Waste Management Project Office Action Item #87-2022 (1987).

3. J. Szymanski, U.S. DOE report, 1992 (unpublished).

4. D. Sawyer, R. Fleck, M. Lanphere, R. Warren, and D. Broxton, EOS Transactions 71, 1296 (1990).

5. P. Lipman, Jour. Geol. 79, 438 (1971).

6. J. Riehle, Geol. Soc. Amer. Bull. 84, 2193 (1973).

7. S. Levy, in Scientific Basis for Nuclear Waste Management II, edited by G. McVay (Elsevier Science Publishers, New York, 1984), pp. 959-966.

8. S. Levy and J. O'Neil, Chem. Geol. 76, 321 (1989).

9. N. White, D. Wood, and M. Lee, Geology 17, 718 (1989).

10. D. Bish and S. Chipera, Los Alamos National Laboratory Report LA-11497-MS, 68 pp. (1989).

11. D. Bish, Los Alamos National Laboratory Report LA-10667-MS, 40 pp. (1989).

12. D. Boxton, R. Warren, R. Hagan, and G. Luedemann, Los Alamos National Laboratory Report LA-10802-MS, 160 pp. (1986).

13. S. Levy and C. Naeser, U.S. Geol. Surv. Bull., in press.

14. C. B. Raleigh, G. Thompson, W. Brace, B. Brady, J. Bredehoeft, R. Burke, R. Fournier, S. Gary, G. Hornberger, R. McGuire, A. Nur, H. Ramey, E. Roedder, D. Rumble, W. Spaulding, B. Wernicke, and M. Zoback, Ground Water at Yucca Mountain: How High Can It Rise? (National Academy Press, Washington, DC, 1992).

15. F. Byers, Jr., W. Carr, P. Orkild, W. Quinlivan, and K. Sargent, U.S. Geol. Surv. Prof. Pap. 919, 70 pp. (1976).