Petrographic evidence of past seismicity from secondary mineral deposits in the unsaturated zone at Yucca Mountain, Nevada

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INTRODUCTION

Performance objectives for the proposed high-level radioactive waste repository at Yucca Mountain, Nevada, require waste containment for a minimum of 10,000 years. However, modeling studies of long–term drift stability, based on Probabilistic Seismic Hazard Analysis, predict that some drifts, especially in the lower lithophysal unit of the Topopah Spring Tuff, are likely to collapse. In apparent contradiction, however, deposits of secondary calcite and silica on fracture footwalls and lithophysal cavity floors in the tuffs, although commonly fragile, are well preserved and undamaged. On fractures the coatings may be loosely attached and easily dislodged and in lithophysal cavities they often contain delicate calcite blades several centimeters tall with bulky overgrowths of calcite and opal. Modeling or physical testing of the ground motions required to disrupt these textures might provide an upper bound on past ground motions in the repository units.

During the course of USGS studies of these deposits since 1995, approximately 450 samples have been collected, most with one or more thin sections made for petrographic examination. Evidence of damage to fracture coatings has been observed in several samples, but is rare; lithophysal cavity deposits are typically undamaged. These observations are, however, preliminary and anecdotal; neither the samples nor the thin sections were systematically examined for evidence of seismic damage.

SECONDARY MINERAL DEPOSITS

Calcite and silica (quartz, chalcedony, and opal) with minor amounts of fluorite, zeolites, and manganese oxides are found in some open fractures and lithophysal cavities in the Topopah Spring and Tiva Canyon Tuffs in the UZ (Whelan and others, 1994; Paces and others, 2001; Whelan and others, 2002). Published studies of these deposits have concluded that the secondary minerals formed in the UZ during the past 10+ million years from meteoric waters percolating along fractures to the water table (Szabo and Kyser, 1990; Whelan and others, 1994; Paces and others, 2001). Underground exposures in the ESF and ECRB Cross Drift tunnels show the deposits to be sparsely and heterogeneously distributed in less than 10 percent of potential fracture and cavity depositional sites and generally restricted to the floors of lithophysal cavities and the footwalls of fractures in the welded tuffs (Paces and others, 2001; Whelan and others, 2002), evidence that is consistent with UZ depositional conditions.

The secondary mineral deposits range in thickness from a fraction of a millimeter (mm) to as much as 5 centimeters (cm). Typical coatings are 5 to 10 mm thick in cavities and 1 to 5 mm thick on fractures. Secondary mineral deposits on fracture footwalls tend to form coatings of relatively uniform thickness or masses of calcite-cemented fracture (or fault) breccia. On the floors of lithophysal cavities, the deposits are coarser grained and commonly contain tall, thin blades of calcite. A generalized paragenetic sequence of secondary mineral deposition in the UZ divides them into early, intermediate, and late stages (Whelan and others, 2002).

The early stage consists of calcite, followed by calcite that is locally admixed with fluorite and commonly capped by deposition of botryoidal chalcedony and (or) drusy quartz. The intermediate and late stages are mineralogically similar, both consisting largely of calcite and opal, but texturally different. Intermediate-stage calcite typically displays an elongate, thin-bladed habit, whereas late-stage calcite typically forms overgrowths on older calcite, often as distinctive knobby or corniced masses on the tips of intermediate-stage blades. Intermediate- and late-stage opal forms botryoidal masses and laminar sheets on or interlayered with calcite (Whelan and others, 2002).

TEXTURAL EVIDENCE OF PAST SEISMICITY

Field and thin section relations suggest three possible records of past seismicity: (1) incorporation of tuff fragments into the coatings; (2) preservation of delicate bladed crystals; and (3) preservation weakly attached or detached coatings on fracture walls.

<u>Incorporation of tuff fragments</u>. Many deposits, in lithophysal settings in particular, contain fragments of tuff that have been incorporated into the deposit during deposition (Fig. 1). This relationship is relatively common in the early stage but rare to absent in the intermediate and late stages.

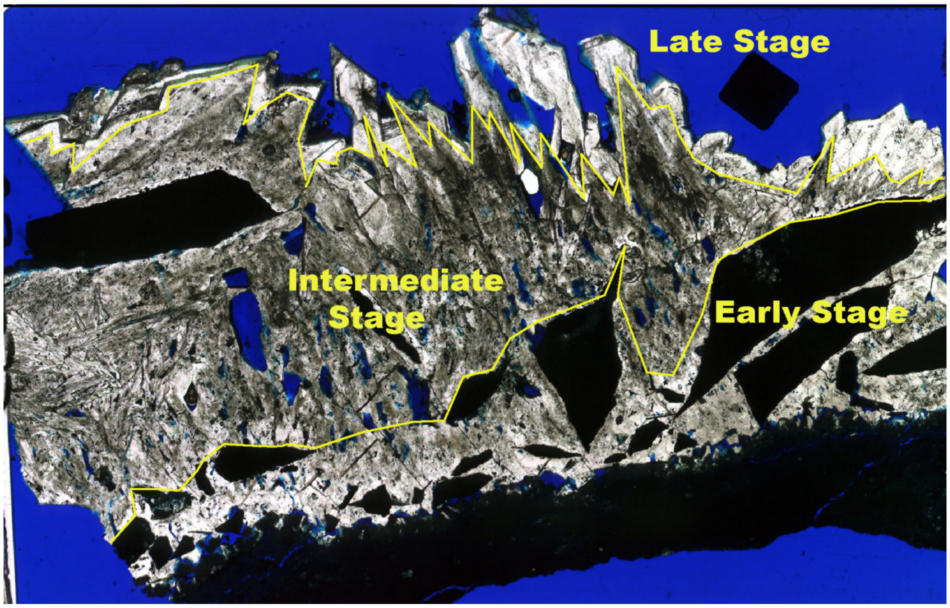

Figure 1. Photomicrograph of calcite-cementing tuff fragments from a lithophysal cavity deposit at ECRB 10+10. The paragenetic stages are labeled and the small square has ~2.3 mm sides.

Preservation of bladed crystals. The characteristic calcite habits of the intermediate stage bladed crystals and the late stage overgrowths consisting of calcite and opal have resulted in blade-form crystals with large bulbous tops. These "sceptered" crystals are common in lithophysal cavity settings and in at least one instance, a cavity at ESF 30+18, resulted in extremely delicate free-standing crystals. These fragile crystals may rest on thin blades less than 0.6x0.2 millimeters in cross section (Fig. 2) and their preservation indicates that ground motions during the late stage have not been strong enough to break them. In spite of their fragile appearance, however, modeling studies by McCallen (this report) indicate that the seismic intensities necessary to break them are extremely unlikely.

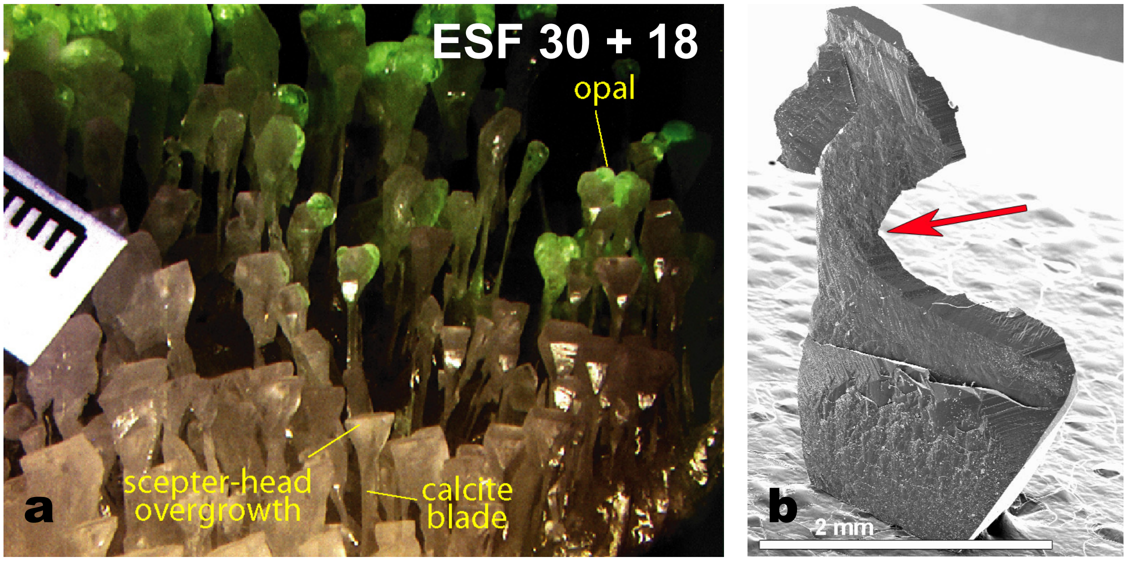

Figure 2. Scepter head crystals from ESF 30+18 consisting of late-stage overgrowths of calcite and opal on intermediate-stage blades. (a) is a photograph in mixed white and short-wave ultraviolet illumination; the green color is from the ultraviolet fluorescence of the opal. The scale is marked in millimeters and shows that the crystal cross sections are often <<1 millimeter. (b) is an SEM image of a broken blade allowing a more precise estimate of the minimum blade dimensions indicated by the red arrow. The scale bar is 2 millimeters.

Preservation of weakly attached coatings. During sample collection it was noted that the coatings on some fracture surfaces were not securely attached. Indeed, some could be, and were, removed by hand. Furthermore, in several other deposits, thin section examination showed that, locally, similar coatings had become detached in the past, accumulated within the fracture, and subsequently cemented together by later calcite (Fig. 3). Although the preservation of weakly attached coatings places some constraints on the intensity of past ground motions, converting that observation to an estimate of those ground motions is probably not feasible. Nonetheless, such fragment accumulations do suggest that past ground motions were sufficient to dislodge those coatings.

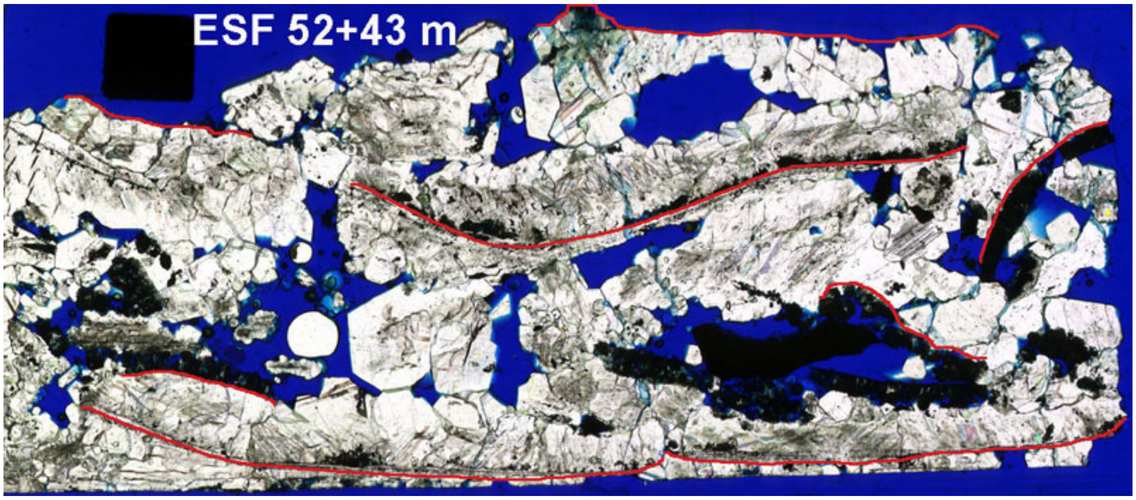

Figure 6. Photomicrograph of a petrographic section of a secondary mineral deposit at Exploratory Studies Facility (ESF) station 52+43, a steeply dipping fracture in the Topopah Spring Tuff. The sample consists of accumulated coating fragments that have been cemented together by later, probably late-stage, calcite deposition. The initial tuff attachment surfaces of several coating fragments are traced in red (dashed where uncertain). The sample was impregnated with blue-dyed epoxy to label primary porosity. The black square ~2.3 millimeters on a side.

SUMMARY

Secondary minerals, largely calcite and silica, deposited on fractures and in cavities in the 12.7 to 12.8 Ma Topopah Spring and Tiva Canyon Tuffs of Yucca Mountain record evidence, both positive and negative, of past seismic shaking. In the early paragenetic stage, the deposits commonly incorporated tuff fragments that fell into them; however, tuff fragments are rare to non-existent in the intermediate and late stages. The preservation of delicate textures and presence of weakly attached fracture coatings indicate that ground motions during the late stage were inadequate to disturb those coating features.

These observations are anecdotal and not systematic. Systematic examination of archived samples and thin sections could provide insights into the timing and distribution of tuff fragmentation and document the distribution of damaged textures in the deposits. Laboratory experiments to directly measure the motions required to damage the delicate blades or to dislodge the weakly attached coatings may be possible but would require further underground study of the deposits to identify and collect suitable samples of the secondary mineral deposits.

REFERENCES

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