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Thermal modeling of heating of the vadose zone at Yucca Mountain, Nevada, by a shallow crustal silicic magma chamber

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Thick, 600 to 900 m, vadose zone of Yucca Mountain in southern Nevada is being studied as a potential host formation for the disposal of the high-level nuclear waste. The vadose zone is thought to have persisted during the last 11 million years *circa*, and the safety case of the disposal facility critically relies on the long-term stability of the zone. Fractures and cavities in the Miocene rhyolitic tuffs of Yucca Mountain host secondary calcite, quartz, chalcedony, opal, and fluorite which represent "footprints" left behind by waters that circulated through the vadose zone in the past. Fluid inclusion studies demonstrated that the minerals were deposited from waters whose temperature decreased over time from 70-90^{o}C to >35-50^{o}C [1]. According to U-Pb dating of opals, the cooling occurred over a 5 to 8 million year-period [2]. Interpretation presently accepted by the U.S. Department of Energy calls for deposition of minerals from meteoric precipitation waters percolating through the rocks while the latter were conductively heated by a large magma chamber, emplaced beneath the Timber Mountain caldera some 7 km to the north. The heating is believed to have been primarily by solid-state conductance with possible contribution from the thermal waters circulating beneath the vadose zone.

Simulations for the conduction-only heating were carried out using HEAT3D code [3] and simulations in which lateral movement of thermal waters was considered – using HYDROTHERM code [4]. The crustal stratigraphy was approximated by a layer-cake sequence including, from top to bottom: (1) vadose-zone silicic tuffs; (2) phreatic-zone (water-saturated) tuffs; (3) carbonate rocks; (4) quartzite; (5) igneous mafic rocks; and (6) metamorphic rocks. The magma body was assigned initial T = 900^{o}C and vertical

cross-section of 30x7 km. The depth of emplacement varied in different simulations from 7 km to 2.5 km. The temperature was monitored at a reference point (depth 0.25 km, lateral distance from the edge of the magma body 7 km; approximating the spatial relationships between the Timber Mountain caldera and the exploratory tunnel ESF at Yucca Mountain. The temperature-time (T-τ) trajectory constructed on the basis of fluid inclusion temperatures and U-Pb ages for secondary minerals served as the "target" for calibration of the numeric models.

Results. In conduction-only simulations, we were unable to match the target T-τ trajectory at reference point by varying the depth of emplacement of magma body and/or the duration of the crustal pre-heating. The thermal perturbations at the reference point were virtually imperceptible ($<4^o$C). The target temperatures could only be reached by "placing" the model magma body underneath or immediately adjacent to the reference point; even in this case, however, the conductive cooling occurred much too fast to reproduce the target T-τ trajectory. In addition, there is no geological evidence consistent with the presence of shallow magma body underneath Yucca Mountain.

Simulations involving lateral movement of waters from cooling magma body underneath the vadose zone resulted in complex and variable (sensitive to even slight changes in model parameters) patterns of groundwater movement, reflecting the interplay of topography-driven and buoyancy-driven flows. The lateral movement of hot waters produces somewhat higher temperatures at the reference point. The rate of the heat loss by magma increases, resulting in mismatch between modeled and empirical cooling times even greater than in the conduction-only model.

Conclusions. Thermal simulations employing two different numeric codes and considering both pure conductance and coupled conductance-plus-advection heat transfer, failed to reproduce the target temperature-time cooling trajectory established from secondary minerals at Yucca Mountain. We conclude that the "hydrothermal" temperatures of formation of the Yucca Mountain minerals cannot be rationally explained by heat transfer from shallow crustal silicic magma chamber(s). Other phenomenological model must be proposed to explain the presence of thermal waters in the vadose zone of Yucca Mountain in the past.

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References. [1]. Dublyansky et al., 2001, Chem. Geol. 173, 125-149; [2]. Neymark et al., 2002, Appl. Geochem. 17, 709–734. [3]. K. Wohletz; Copyright © 1998-2001, The Regents of the University of California. [4]. USGS, 1997, Water Resources Applications Software.