Summary Report to NWTRB
The Consequences of Igneous Intrusion at Yucca Mountain
Some Rock Mechanics Aspects of Dike-Repository Interaction

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This report summarizes important mechanical constraints on the anticipated form of dike-repository interaction at the potential repository at Yucca Mountain, Nevada. This summary is supported by the attached annotated presentation, delivered on Thursday 8th November, 2001, at the Arlington office of the NWTRB. Specifically, the primary issues of relevance to the NWTRB, as identified at the meeting, are addressed in this summary report.

How Realistic are the Proposed Models?

The exploratory model[1] is a well-posed and creative approach to simplify the complex fluid dynamic problem of dike-repository interaction. The authors note that they have not considered the effects of *in situ* and drift-local stresses in their analysis. However, these factors exert a strong control in limiting both ascent pressures, and in-drift magma and gas pressures. In the particular case of Yucca Mountain, mechanical constraints appear important. More subtle and complex processes of magma-rock or magma-stress interaction are also neglected in the model. These include effects of the role of field stresses in controlling dike apertures, and the process of pinch-off in the dike as it intersects the drift, and magma overpressure initially drops to atmospheric.

The boundary conditions for the Woods *et al.*[1] model do not currently include important mechanical constraints on the maximum magnitudes of magma overpressures during intersection of the dike with the repository, and of gas and magma overpressures following entry into the drift. Specifically:

1. Magma pressures will be largely limited to the minimum principal field stress during ascent. At repository level, the minimum principal stress is horizontal and is initially of the order of 2-5 MPa. As the repository warms, magma pressures will be limited to the lithostat when the minimum principal stress may rotate to the vertical. Lithostatic stresses are of the order of 7 MPa at the repository horizon. These stresses provide a threshold to the magma pressure in the dike as it approaches the repository.
2. Following potential intersection of the dike with the repository, magma pressures will be limited by the drift-local stress field. For both cold and hot repositories, the minimum drift-wall stresses are of the order of the thermal field stresses and consequently these limit magma overpressures at intersection to between of 2-5 MPa, when cold, and to lithostatic stresses when hot.
3. For a hot repository, the collar of compressive thermal stresses that will develop around individual drifts will resist dike ingress into the drift. However, if this barrier is breached the lesser of the breaching pressure, or the lithostat, will limit the magma or gas overpressures for breakout from the drift.

[1] Woods, A.W., Sparks, S., Bokhove, O., LeJeune, A.-M., Connor, C.B., and Hill, B.E. 2001. Modeling Magma-Drift Interaction at the Proposed High-Level Radioactive Waste Repository at Yucca Mountain, Nevada, USA.

How Do These Assumptions Condition the Model Predictions?

Providing no mechanical limit on field stresses allows in-drift magma pressure predictions to be larger than feasible. This, in turn, elevates predicted shock-wave overpressures beyond the limits of the mechanical strength of the drifts and of the surrounding repository horizon. The mechanical behavior of the repository rocks place limits on these magnitudes that are not honored in the initial calculations. Neglecting these assumptions yields magma and gas pressures that are unreasonably high.

When a dike intersects a drift, the propensity for the full magma flow to be diverted along-drift, and for the external dike-advance to arrest, is greatest for a cool repository. Magma breakout from the drift is conditioned by local stress, and rock structure effects, and will be influenced by the transient thermal regime and other such quantifiable parameters as proximity to the repository periphery. Magma breakout may occur at the location of break-in, or may occur from a weaker location along the drift.

As the repository warms, break-in stresses to the drift increase, and correspondingly so do the required pressures to break-out. In this circumstance the dike would be expected to continue to the surface, and to retain a considerable proportion of the magma flow, with a lesser proportion traveling down-drift. Although it is likely that the drift would fill, up to the location of an appropriate obstruction, a down-drift breakout is relatively less likely, and in-drift containment of the waste is more likely.

In any of these scenarios, the presence of backfill, or of in-drift bulkheads, could substantially limit the potential for through-drift transport of magma, or of egress of the waste from the repository.

What Can be Done to Decrease Uncertainty?

The previous has suggested some limits on magma and gas pressures in bounding the expected response of a repository to dike intrusion. It suggests general characteristics in behavior that may be applied heuristically to any prospective repository design.

The general problem of the mechanical interaction of a dike with multiple drifts is not well understood, and to the author's knowledge has not been previously analyzed. Geological analogs, and physical and mathematical models of varying complexity may be applied to the problem.

The specific controls that drift-local stresses are likely to exert on intrusive behavior make geological analogs difficult to interpret. However, examples such as rifting and dike intrusion at Krafla, or the potential for tunnels to be intercepted in active rifting zones in Hawaii, or in the Canary Islands (where groundwater-drainage tunnels tap the interior of active volcanoes) may present potential examples, among others.

Physical models, comprised of gelatin with an injected fracturing fluid, have been applied to describe the processes of hydraulic fracturing or dike injection where stresses exert some influence. Hydraulic fracture simulators and other coupled hydraulic-mechanical models are also capable of representing many of the important processes previously identified. These methods may be applied to improve the understanding of critical processes involved in dike-repository interaction, and to provide appropriate control on the evolving fluid dynamics models. Large-scale mechanical and thermo-mechanical data derived from the single heater (SHT) and driftscale (DST) tests may be useful in constraining the models, specifically in determining the likely magnitude of thermally-induced in near-drift stresses.

The complexity of the dike-repository interaction problem is sufficiently high that the rapid integration of the complex mechanical, fluid dynamic, thermodynamic, kinetic, geochemical, metallurgical and petrologic behaviors into a single robust and coherent model seems infeasible. Alternatively, expert opinion may be used to condition the expected consequences of an intrusive event, using a diverse group to assemble the important behavioral modes of the relevant processes. These outcomes would then be used to develop a probability distribution of the expected consequences to intrusive events, and combined with probabilities-of-intrusion to define overall risk and projected dose levels.

The Potential to Engineer-Out the Consequences of Dike-Intrusion

In addition to reducing the uncertainty in predicting the consequences of an intrusive event, some of the negative aspects of an intrusive incursion may be removed through the engineered design of the repository. The backfilling of drifts, or the provision of in-drift bulkheads, would be expected to substantially reduce the access of magma and gas overpressures to the waste packages. This, in turn would reduce the anticipated dose rate resulting from igneous intrusion, that currently comprises a significant proportion of the total risk. The extent to which this large reduction in the dose rate from intrusive effects, would be offset by the increase in dose rate from other factors, would be a prime consideration in revising the design. The overriding influence of the intrusive consequences in defining the total risk, above all other potential sources, suggests merit in this approach.

Respectively submitted. Derek Elsworth.

Attachment: Some Aspects of Dike Repository Interaction
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NWTRB Meeting of November 8th, 2001.