Multiscale geocharacterization of volcanic tuffs in support of source discrimination modeling

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INTRODUCTION AND MAIN RESULTS

PE1 is a series of multi-physics experiments that includes detonation of underground chemical explosions that will provide key observations relevant to source discrimination models and algorithms. Here we present geologic, hydrologic, and geomechanical properties collected and analyzed from the testbed. This suite of characterization data is synthesized with borehole log data for integration into the testbed's Geologic Framework Model, which directly feeds predictive models of seismic wave propagation, gas transport, and source mechanics.

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Introduction

The PE1 experiment testbed was constructed within the U12p Tunnel complex within Aqueduct Mesa at the Nevada National Security Site (NNSS) (Figure 1). The rocks at P-Tunnel consist of a bedded sequence of nonwelded pyroclastic deposits of generally rhyolitic composition. These beds are designated VNT-1 through VNT-10 and underlying UZNT.

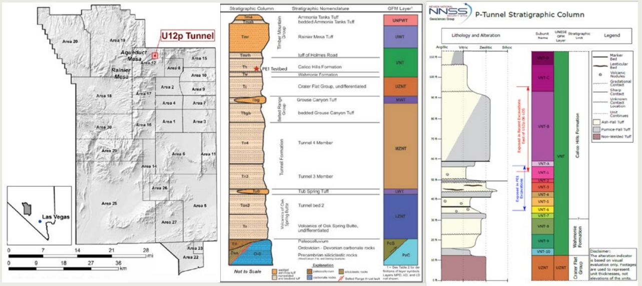

Figure 1. (left) Map of the NNSS with red box covering Aqueduct Mesa, U12p Tunnel. (middle) Full stratigraphic cross section of Aqueduct Mesa with PE1 testbed location marked. (right) Detailed cross section of the pyroclastic deposit subunits that make up the PE1 testbed.

Analysis of geologic samples from underground mining of these units has allowed us to constrain material properties and synthesize this data with borehole log data and geologic mapping for integration into the testbed's Geologic Framework Model (GFM). The GFM ensures that interpretations are grounded in realistic representations of the subsurface, and directly feeds predictive models of seismic wave propagation, gas transport, and source mechanics.

Field Methods

Geologic mapping of VNT and UZNT lithologic contacts within underground drifts include descriptions of textural and alteration variability as well as documenting location and severity of fractures (Figure 2).

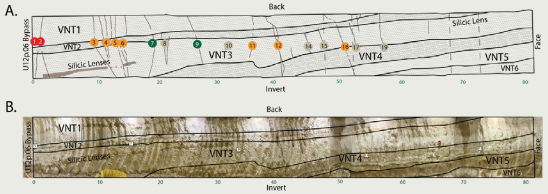

Figure 2. Geologic mapping results for one underground drift. A shows simplified lithologic interpretation along with fracture categorization. Numbered circles are used to uniquely identify fractures and are color coded by their severity. B shows the stitched-together photo mosaics of the drift walls with lithologic interpretations overlain.

A total of 24 boreholes were drilled during PE1 testbed construction. Geophysical data (Figure 3), videos, and core samples (Figure 4) from all boreholes were examined to provide characterization data. Several tabletop measurements were performed on a subset of core, and include ultrasonic velocity, permeability, and surface hardness. Observations of lithologic texture, mineralogy, and fracture occurrence were also recorded.

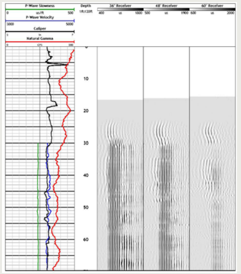

Figure 3. Example of borehole geophysical log.

Figure 4. Example of high-resolution photographs taken for the PE1 core.

Lab Methods

Lab-based material properties determinations from representative lithologic units include ultrasonic velocity, porosity, air permeability, material strength properties, mineral and elemental composition, and water saturation.

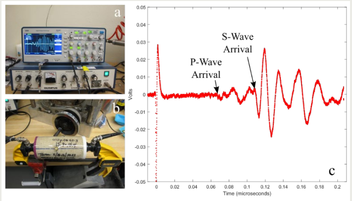

Figure 5. Velocity test setup showing oscilloscope (a), sample being tested (b), and example waveform generated (c).

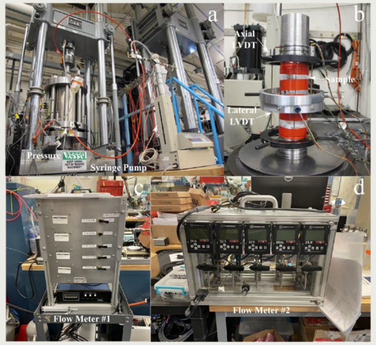

Figure 6. Test setup for conducting permeability and triaxial deformation tests.

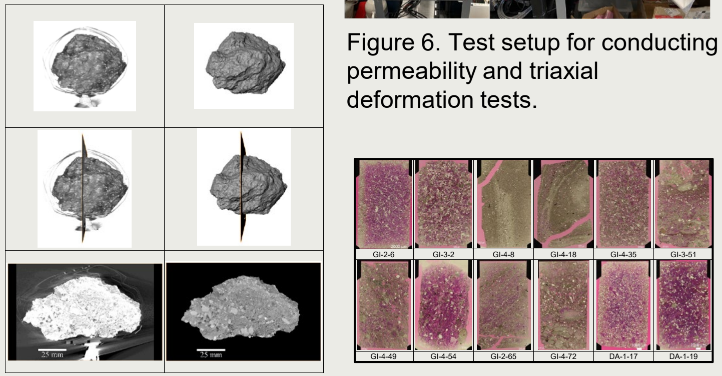

Figure 7. Imaging of core samples through X-ray CT scanning (left) and thin section petrography (right).

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Field Results

VNT layer designations arising from underground mapping and core characterization were quantified through tabletop measurements of ultrasonic velocity (Figure 8), surface hardness, and air permeability (Figure 9).

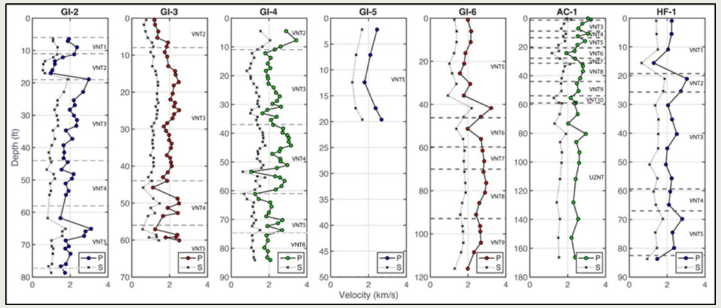

Figure 8. Ultrasonic velocity measurements performed on core from seven boreholes. Large colored symbols indicate P wave velocities while smaller x symbols (and dashed lines) indicate S wave velocities. VNT interfaces are indicated as horizontal dashed lines.

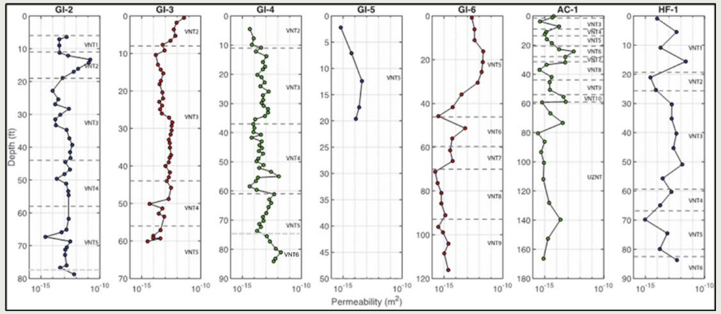

Figure 9. Permeability measurements performed on core from seven boreholes using a TinyPerm air-minipermeameter. VNT interfaces are indicated as horizontal dashed lines.

Lab Results

Higher zeolite and silica content is generally linked to lower porosity, lower permeability, and higher strength. Saturation, especially in samples with pore-lining clays, tends to reduce compressive strength of the tuffs.

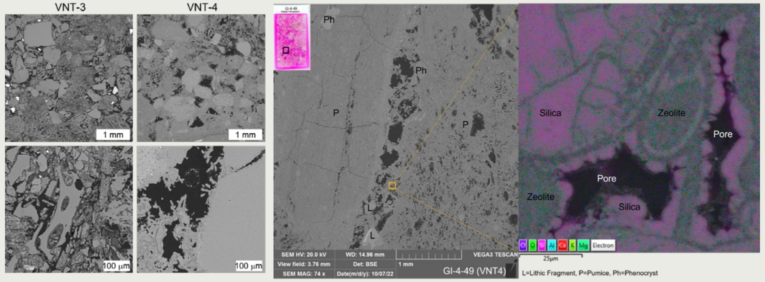

Figure 10. SEM back-scattered electron images of end-member VNT lithologies and energy dispersive spectra (EDS) map of zeolite and post-depositional pore-lining silica.

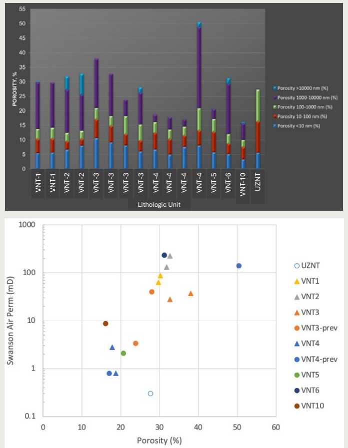

Figure 11. Pore-size distributions (upper) and relationship between porosity and permeability (lower) for UZNT and VNT layers.

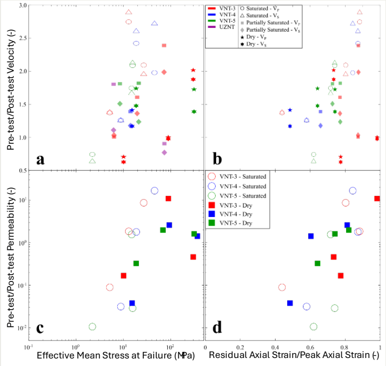

Figure 12. Change in velocities (a/b) and permeability (c/d) with peak effective mean stress at failure and ratio of residual axial strain to peak axial strain experienced during deformation.

Updated PE1 GFM

An updated version of the high-resolution PE1 GFM has been developed, incorporating multiscale and multimodal datasets. Geologic mapping, geophysical logs, fracture characterization, and material properties determinations from core provide high confidence in the stratigraphic and structural characteristics of the testbed, and therefore provide a more accurate representation of the subsurface geology from which modeling of seismic wave propagation, gas transport, and source mechanics can be performed.

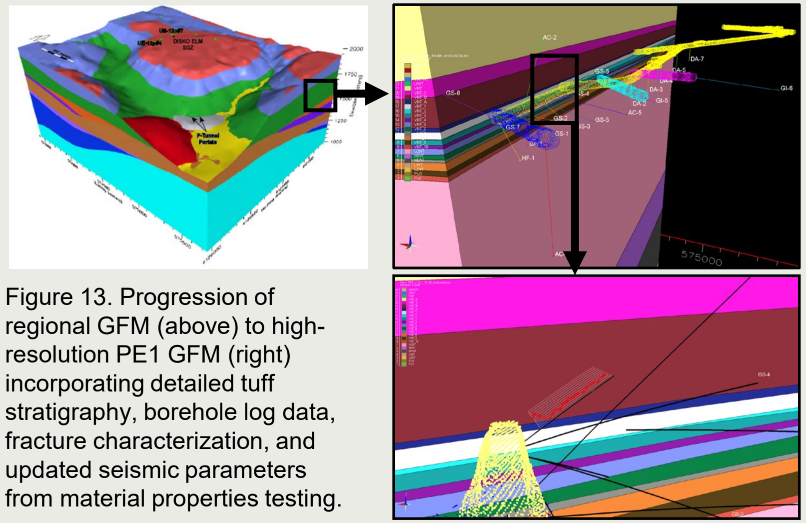

Figure 13. Progression of regional GFM (above) to high-resolution PE1 GFM (right) incorporating detailed tuff stratigraphy, borehole log data, fracture characterization, and updated seismic parameters from material properties testing.

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