

FIELD TESTS WITH TRIDENT DRILL IN BISHOP TUFF HELP PREPARE FOR FUTURE MISSIONS TO MOON AND MARS. C.R.Stoker¹, B.J. Glass¹, C. Walter², H.D. Smith¹, E. Eshelman³, and A. Aksay⁴, ¹NASA Ames Research Center, carol.stoker@nasa.gov, ²NASA Ames Research Center and USGS, ³Montanna State Univ. Bozern, ⁴Cornell University

Introduction: We performed drilling in volcanic deposits near Bishop California using an engineering model of the Honeybee Robotics TRIDENT (The Regolith and Ice Drill for Exploration of New Terrains) drill [1] a rotary percussive 1-meter class drill that is carried on the PRIME1 and VIPER (Volatiles Investigating Polar Exploration Rover)[2] missions that launch in 2024. A similar drilling system was planned for the proposed Icebreaker Discovery class mission to Mars [3] and the Mars Life Explorer mission recommended by the 2020 Decadal Survey of planetary science [4].

The objectives of the project were (1) to use data collected by the drill for operational purposes as a probe of subsurface material properties in formations that are analogous to those that may be encountered on planetary surfaces; (2) correlate subsurface structures with those deduced from Ground Penetrating Radar (GPR); and (3) inspect the boreholes after they were drilled to test PERISCOPE (Probe for Exploring Regolith and Ice by Subsurface Classification of Organics, polycyclic aromatic hydrocarbons (PAHs), and Elements), a newly developed downhole UV fluorescence spectrometer [5].

Methods: In September 2023 two holes were drilled with TRIDENT at each of three sites (Figure 1). 1B and 1C were in Bishop Tuff, a pyroclastic deposit consisting of dense welded tuff resulting from the eruption that formed the Long Valley Caldera 0.76 Ma ago. The third drill site was a nearby porous pumice deposited as airfall ash in that eruption. Drilling was performed using an engineering model of the TRIDENT drill previously used in the ARADS field experiment [6,7]. GPR measurements were made using a USRadar Quantum 4 GPR that operates simultaneously in 3 frequencies (1000Mhz, 500 Mhz, and 250 Mhz). The instrument is pushed over the ground while included software provides a real time display and records radargram profiles as an image along the track. PERISCOPE uses an optical relay to obtain UV-VIS-NIR hyperspectral maps of the borehole wall *in situ*. The relay was sized to fit in boreholes generated by the TRIDENT drill. The instrument is sensitive to organics and rare earth elements.

Results: Plots of the drill data (Figure 2) clearly show the interface between the overlying unconsolidated sediments and bedrock in the tuff drill site. The densely welded tuff bedrock was difficult to drill and the auger motor limits were exceeded several times causing the auger to stop turning requiring operator intervention. The pumice drilled quickly and

easily, as expected for soft highly porous material. Fine scale layering was observed in the drill data for the pumice site but no layering was observed in the tuff.

Drilling in densely welded tuff showed the drill can quickly stop rotating when currents in the torque motor exceed operational limits. This behavior was also observed in lab tests that drilled lunar simulant cements [8]. Prior to the binding fault the auger torque quickly increased (Figure 2). The drill uses bite sampling where it returns to the surface after drilling an operator specified depth interval. We found that binding was prevented by reducing the size of the drill bites, ultimately to 2 cm in the deepest part of tuff holes. The smaller bites effectively reduce downhole friction by moving fine cuttings to the surface more frequently.

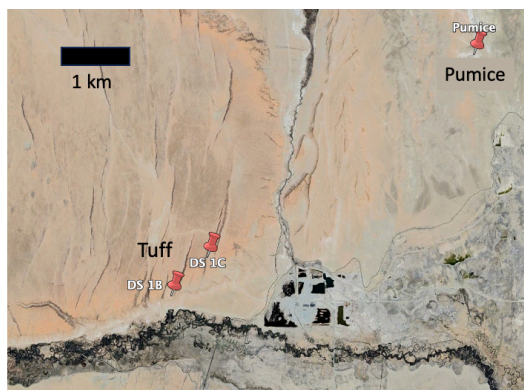


Figure 1. Drill Locations. The image center is at 37.443° latitude, -118.404° longitude.

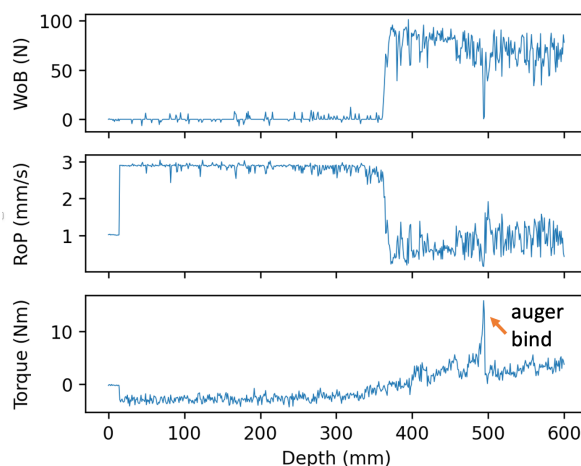


Figure 2. Drill data recorded for hole 1C. The 3 panels are WOB, rate of penetration (ROP) and auger torque. The spike in torque at 48 cm occurred when the auger froze.

The specific energy of drilling was computed for each of the boreholes drilled. We had previously prepared and drilled a set of cements made from lunar simulants and measured their unconfined compressive strengths (UCS) and computed the specific energy of drilling (SE) then determined a function relating UCS to SE as in [9]. From this we estimate the UCS of the Bishop Tuff where we drilled was between 40 to 80 Mpa, while the Pumice showed a layered structure with UCS values between 2 to 5 Mpa.

GPR data was used to select exact drilling sites and to estimate bedrock depth prior to drilling. GPR data response was primarily impacted by liquid water content (high dielectric constant) in the sediments overlying the bedrock that experienced recent rainfall. This moisture was concentrated at the base of the sediment layer and above the less permeable bedrock. The bedrock location can be inferred in the radargrams as lying directly below the high amplitude radar reflections (high liquid water content). Radar derived depth estimates are consistent with bedrock locations identified from the drill data (Figure 3).

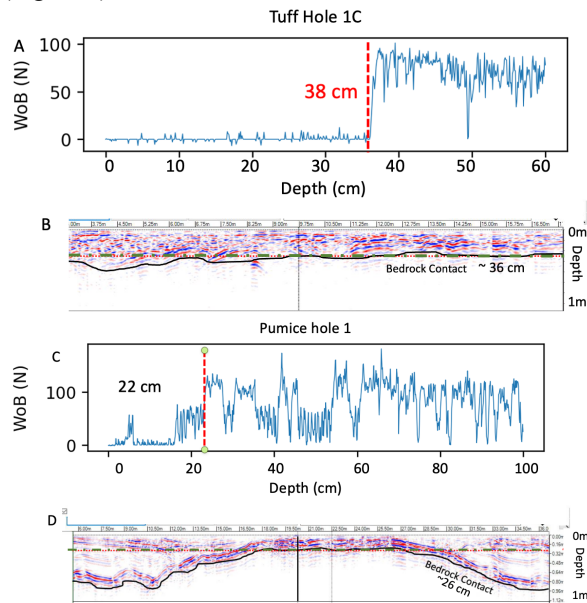


Figure 3. A. drill weight on bit (WOB) from borehole 1C. The bedrock boundary (red line) is inferred from the sharp rise in this parameter at 38 cm. B. Plot of GPR radargram in 1000 Mhz channel. The green dashed line is the inferred bedrock boundary at 36 cm. The vertical black line denotes the borehole. C. Same as A for the Pumice site. Bedrock depth estimated at 22 cm. D. Radar scan crossing the boreholes (vertical black lines), and estimated bedrock depth is 26 cm.

PERISCOPE obtained scans down to a depth of 42 cm in the boreholes. From the hyperspectral dataset, visible maps were generated that contained morphological information about the borehole,

including the transition from the surface layer to bedrock. Several ultraviolet hotspots were detected around 380 nm following excitation with PERISCOPE's ultraviolet LED. Additional lab work is required to interpret their origin.

Discussion: This field experiment shows the value of drilling in lunar analog materials in actual field situations to prepare for the operation of drills in upcoming missions. The episodes of drill jams observed in the tuff holes show that it is important to prepare for and prevent this from occurring on a planetary mission where it will be difficult to recover [7] and may be mission ending. These faults happen too fast for a human in the loop to take action even on a teleoperated lunar mission like VIPER so it is important for onboard software to monitor drill data and take action to prevent the drill from getting stuck.

The USRadar GPR system worked well for this application. The GPR data allowed for targeting of subsurface structure (bedrock depth) prior to conducting drilling operations. GPR in a planetary drill mission would similarly help to determine subsurface structure prior to the more resource consuming process of drilling. In this case, the high soil moisture attenuated the signal of the GPR instrument. While the data provided limited structural information at depths below the moisture layer, the data still allow a good estimate of the bedrock depth. The objective of drilling on the moon is to access subsurface water ice. Crystalline ice would not block/attenuate the radar signal as we saw in this experiment due to its much lower dielectric constant. We plan to conduct a follow on study in a permafrost region to better assess radar and drill synergy in icy environments.

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References:[1] Zacny, K. *et al.* Earth and Space 465, 2022. [2] Colaprete, A. *et al.* LPSC 2022 #2241. [3] McKay, C.P. *et al.* Astrobiology 2013. Doi:10.1089/ast.2012.0878 [4] Origins Worlds and Life, Natl. Acad. Sci., 2022. [5] Eshelman, E. *et al.* IEEE Aerospace 2024. [6] Stoker, C.R. *et al.* Astrobiology 2023. Doi: 0.1089/ast.2022.0055 [7] Glass, B.J. *et al.* Astrobiology 2023. Doi:10.1089/ast.2022.0126 [8] Stoker, C.R. *et al.* NASA Exploration Science Forum, 2023. [9] Peters, G.H. *et al.* Geophys. Res. Lett. 2018. Doi:10.1002/2017GL075965