

TRIDENT Drill for VIPER and PRIME1 Missions to the Moon – 2023 Update. K. Zacny¹, P. Chu¹, V. Vendio-la¹, K. Bywaters¹, S. Goldman¹, P. Creekmore¹, P. Ng¹, E. P. Seto¹, J. Quinn², A. Eichenbaum², J. Captain², J. Kleinhenz³, A. Colaprete⁴, R. Elphic⁴ and TRIDENT team, ¹Honeybee Robotics, Altadena, CA, KA-Zacny@HoneybeeRobotics.com, ²NASA Kennedy Space Center, FL, ³NASA Johnson Space Center, TX, ⁴NASA Ames Research Center, CA

Introduction: The Regolith and Ice Drill for Exploration of New Terrains (TRIDENT) is an ice mining drill under development for two exploration/ISRU missions to the Moon: Volatiles Investigating Polar Exploration Rover (VIPER) – see Figure 1, and PRIME1 (Polar Resources Ice Mining Experiment) – see Figure 2 [1]. PRIME1 is scheduled to fly to the Moon in 2023 and explore the area outside of Shackleton crater, while VIPER is targeting 2024 launch year, with a goal of exploring terrain near Nobile crater. Both missions are targeting volatile rich deposits.

The primary goal of TRIDENT is to deliver volatile-rich samples from up 1 m depth to the lunar surface [2]. Once on surface, the material would be analyzed by Mass Spectrometer Observing Lunar Operations (MSolo) and the Near InfraRed Volatiles. Spectrometer System (NIRVSS) to determine volatile composition and mineralogy of the material. MSolo will fly on both missions while NIRVSS will fly on VIPER.



Figure 1. VIPER mission. TRIDENT is placed in vertical position in the middle of the rover.



Figure 2. PRIME1 mission. TRIDENT is vertically mounted on the lander.

TRIDENT is a rotary-percussive drill which enables it to cut into icy material that could be as hard as rock. The drill consists of the following subsystems: rotary-percussive drill head for providing percussion and rotation to the drill string, deployment stage for deploying the drill to the ground, feed stage for advancing the drill string 1 m into subsurface, drill string

for drilling and sampling, brushing station for depositing material onto the surface (Figure 3). Table 1 details specifications of the drill. The stowed volume of the drill is 20.6 cm x 33.3 cm x 168 cm.

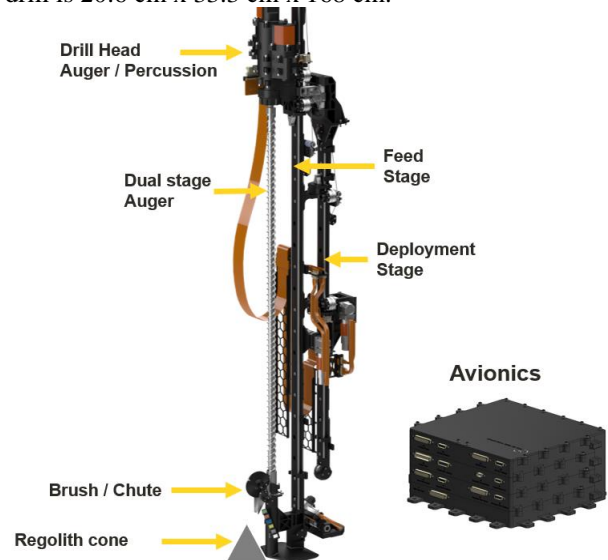


Figure 3. TRIDENT subsystems.

Table 1. TRIDENT specifications.

Parameter	Value
Bit Diam. (mm)	25.4
Nominal Auger Spin (RPM)	120
Auger Average Output Torque (N-m)	5.5
Auger Average Power Consumption (W)	87
Percussion Impact Energy (Joules/Blow)	2
Nominal Percussion Rate (BPM)	972
Feed Stage Stroke (mm)	1240
Maximum Drill Depth (mm)	1020
Deployment Stage Stroke (mm)	380
Z Stage Force Cont. (N)	500
CBE Drill + Launch Locks Mass (kg)	~22
CBE Avionics + Harness Mass (kg)	~7

TRIDENT drill is designed to capture and deliver samples in so-called bites (Figure 4). That is, the drill

penetrates 10 cm into subsurface, and then it is pulled out and deposits the 10 cm worth of material onto the surface for analysis by MSolo and NIRVSS instruments. Once the analysis period is complete, the drill penetrates another 10 cm (i.e., from 10 cm to 20 cm depth), and brings up fresh material for the analysis. The 10 cm bite is a nominal drilling depth, however, the drill could also use shorter bites, if requested.

To achieve bite sampling approach, the auger is split into two sections. The lower section has flutes designed for sample retention: the flutes are deep and have low pitch. The upper section is designed for efficient conveyance of material to the surface: the flutes are shallow, and the pitch is steep. This combination allows efficient sampling but inefficient conveyance – the drill should not be used to drill to 1 m depth in a single run as this will lead to increase in drilling power and ultimately heat input into formation.

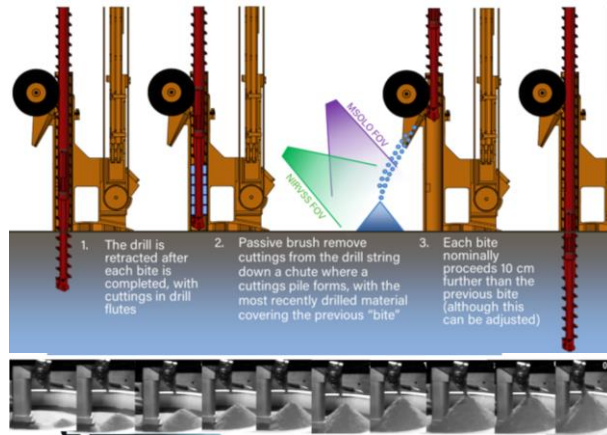


Figure 4. Bite sampling approach. Shown below are cuttings cones every 10 cm bite.

The bite operation allows for stratigraphy to be preserved in at least the 10 cm bites. In addition, drilling in 10 cm bites, has a major advantage of keeping drilling power to minimum.

TRIDENT is the only system that interacts with the subsurface regolith. As such, it offers additional information that otherwise would not be possible (Figure 5).

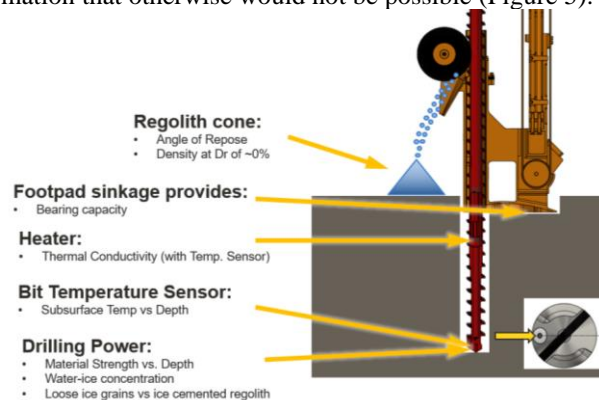


Figure 5. TRIDENT drill will provide additional information about subsurface.

TRIDENT will be able to provide in-situ density by measuring the size of the cuttings cone on the surface. The bearing capacity of the top lunar surface could be determined by measuring the sinkage of the drill's footpad into the surface.

Integrated heater with co-located temperature sensor could be used to determine subsurface temperature and thermal conductivity. When measurement is used at different depths, this could provide the heat flow properties of the Moon at the location.

The temperature sensor at the drill bit, will be directly exposed to the regolith. As such, this sensor will be able to determine more accurate subsurface temperature. It should be noted that measuring subsurface temperature and thermal conductivity in highly insulating material (lunar regolith) is very difficult and requires highly complex thermal modelling, backed by test data.

TRIDENT drilling power and penetration rate would be used to determine regolith strength and together with data from MSolo, NIRVSS and Neutron Spectrometer System (NSS), we would be able to determine structure of ice – whether it's mixed with regolith or cemented with regolith grains.

TRIDENT drills and associated avionics have undergone vibration testing and will be undergoing Thermal Vacuum and EMI tests in January and February of 2023 (Figure 6).

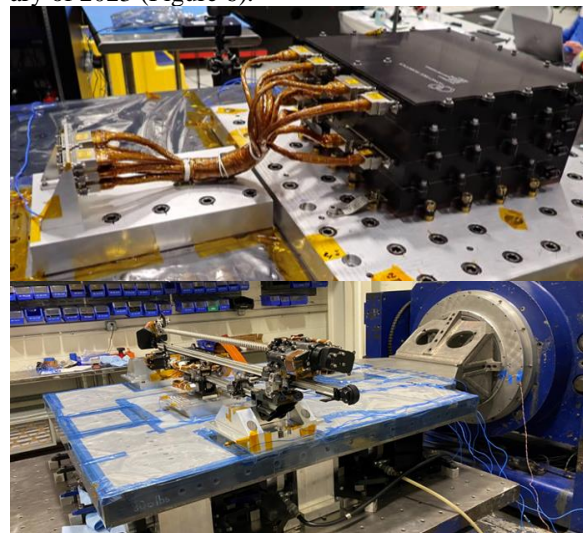


Figure 6. TRIDENT avionics and drill vibration tests.

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References: [1] Colaprete et al., (2020), LPSC, [2] Zacny et al., (2018), LPSC, [3] Paulsen et al., (2018), Aerospace Mechanisms Symposium.