TRIDENT Drill for VIPER and PRIME1 Missions to the Moon. K. Zacny[1], P. Chu[1], V. Vendiola[1], K. Bywaters[1], S. Goldman[1], P. Creekmore[1], P. Ng[1], E. P. Seto[1], J. Quinn[2], A. Eichenbaum[2], J. Captain[2], J. Kleinhenz[3], A. Colaprete[4], R. Elphic[4] and TRIDENT team, [1]Honeybee Robotics, Altadena, CA, KA-Zacny@HoneybeeRobotics.com, [2]NASA Kennedy Space Center, FL, [3]NASA Johnson Space Center, TX, [4]NASA 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 2022 and explore the area outside of Shackleton crater, while VIPER is targeting 2023 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.

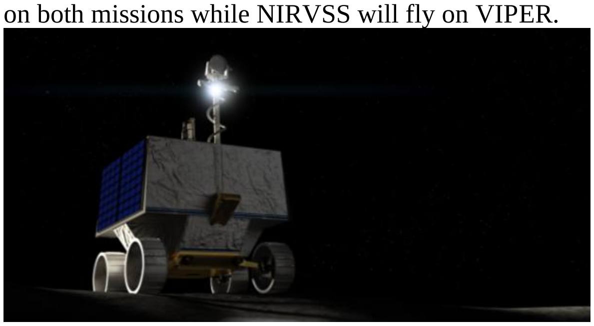

Figure 1. VIPER mission. TRIDENT is placed in vertical position in the middle of the rover.

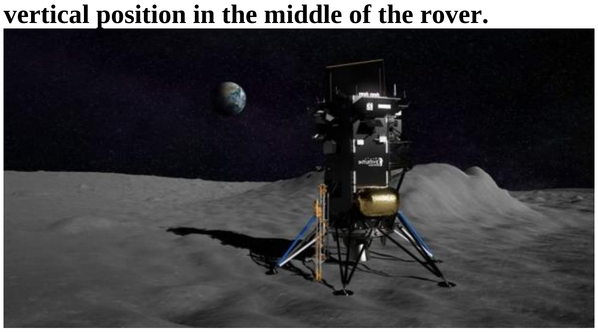

Figure 2. PRIME1 mission. TRIDENT is vertically mounted on the lander.

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.

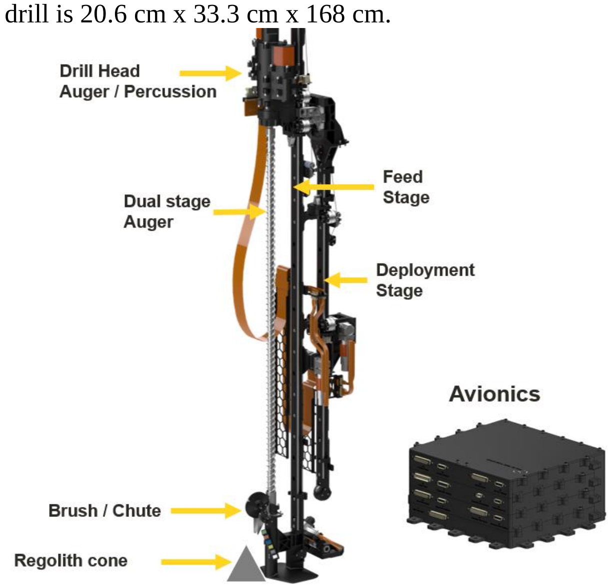

Figure 3. TRIDENT subsystems.

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.

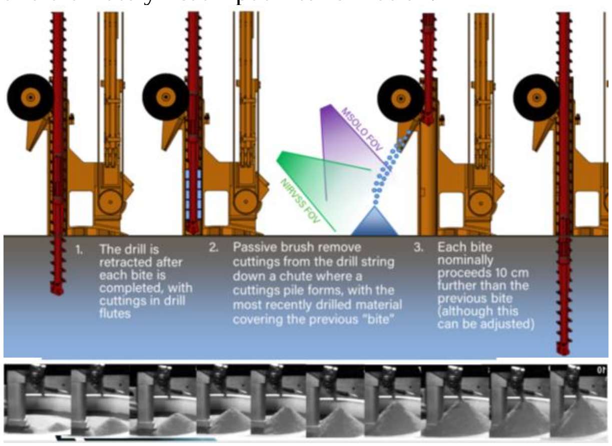

Figure 4. Bite sampling approach. Shown below are cuttings cones every 10 cm bite.

The bite operation allows for stratigraphy to be preserved in at least the 10 cm bites, though, it is highly probably that MSolo and NIRVSS will be able to provide information at a much higher depth resolution, provided the subsurface material is cohesive and dense. If subsurface material is highly porous, it is likely that some of the material, instead of being captured, will be pushed sideways into the borehole wall.

Drilling power comes from two major sources: power needed drill and power needed to remove cuttings. As the drill penetrates deeper, the power required to remove cuttings can be significantly higher than the power required to drill. As such, drilling in 10 cm bites, has a major advantage of keeping drilling power to minimum. This in turn, reduces the need for more powerful drive electronics and simplifies power distribution.

As illustrated during Apollo drilling, the biggest problem during drilling was chips transport to the surface. In fact, the drill got stuck because of poor chips flow – this eventually was overcome by the perseverance of Apollo astronauts, who after significant effort, managed to pull the drill out. TRIDENT, via bite sampling approach, reduces the risk of the drill getting stuck.

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).

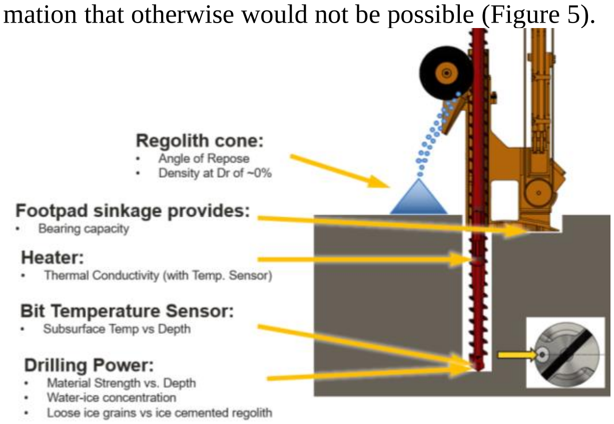

Figure 5. TRIDENT drill will provide additional information about subsurface.

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.

Conclusions: TRIDENT is currently being assembled. A significant test effort, that includes 50 drilling operation inside TVAC is planned for early 2022

Acknowledgments: TRIDENT drill has been developed thanks to funding from various NASA programs including (but not limited to) SBIR, ASTID, and ASTEP.

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