The Scientific Rationale and Technical Approach of Drilling on the Moon and Mars

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Drilling and sample analysis is a key science activity for robotic precursor missions and human explorations on both the Moon and Mars. Regolith core samples are among the most valuable science products of Apollo. Drilling is required on the Moon to determine regolith properties, to access unweathered samples to characterize volcanism and impact processes, and to characterize volatiles in the polar regions.
<table>
<thead>
<tr>
<th>Objective</th>
<th>Type of drilled Sample</th>
<th>Depth Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determine intrinsic heat flow and study past variation in solar flux</td>
<td>Emplacement of heat flow sensors</td>
<td>At least 3m</td>
</tr>
<tr>
<td>Study regolith formation and weathering processes on anhydrous airless bodies</td>
<td>Regolith Cores</td>
<td>1-10 m</td>
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<tr>
<td>Sample a variety of Lunar volcanic deposits to determine the origin and variability of basalts, how old is the youngest basalt, what are the range of lunar pyroclastic deposits, what is the flux of lunar volcanoes and how did it evolve through time.</td>
<td>Bedrock samples from strategically selected sites</td>
<td>20 m</td>
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<tr>
<td>Characterize the regolith at the lunar poles particularly lateral and vertical distribution of volatiles</td>
<td>Shallow core samples at many locations, deep core samples at a few locations</td>
<td>2m shallow, 50 m deep</td>
</tr>
<tr>
<td>Study impact processes on Planetary Scales</td>
<td>Core samples from impact melt sheet</td>
<td>100m</td>
</tr>
<tr>
<td>Determine the environment of the Earth during the Hadean. Search for samples of the Hadean Earth</td>
<td>Ancient Regolith samples buried by subsequent lava flows</td>
<td>100m or more</td>
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Follow the Water - A Unifying theme for Drilling

Why drill on the Moon?

Crux rover and drill
## Objectives for Drilling on Mars

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<tr>
<td>Determine depth of oxidized layer and extent of organic destroying oxidizing conditions</td>
<td>Dry soils, any mid-low latitude location</td>
<td>5m</td>
</tr>
<tr>
<td>Search for biomarkers and organics in shallow subsurface</td>
<td>N. Plains ice deposits, exposed aqueous sediments (e.g. Sinus Meridiani)</td>
<td>10m</td>
</tr>
<tr>
<td>Assess layering in polar layered terrains for links to climate change</td>
<td>Polar layered deposits</td>
<td>20m</td>
</tr>
<tr>
<td>Characterize the stratigraphy of sedimentary evaporite deposits to understand the chemical conditions of past standing bodies of water</td>
<td>Layered deposits-e.g Valles Marineris interior deposits, phyllosilicate deposits</td>
<td>50-100 m</td>
</tr>
<tr>
<td>Search for extant life in liquid water aquifers</td>
<td>Aquifer zone upstream of Gullies,</td>
<td>200-500m</td>
</tr>
<tr>
<td>Extract (through pumping) liquid water as enabling resource</td>
<td>Shallowest accessible liquid water</td>
<td>500m – 5 km</td>
</tr>
</tbody>
</table>
Why Drill on Mars?

Near Surface water in the Martian Polar regions - cm below the ground

Martian Gullies suggest aquifer at 100-500 m depth
Phoenix lander is exploring ice in Martian Subsurface
The Robotic Arm

- RAC
- TECP
- Scoop (shown in extended position)
- Rasp
- Digging Blades

Allows sampling hard, icy soils
Samples stuck on the surface of instruments
Ice Breaker Mission - A follow on to Phoenix

Science Objectives:

Search for signatures of habitable environments associated with periodic warmer climates occurring in the geologically recent past in the Northern Plains of Mars.

Solar insolation history at landing site over 10 MY. High insolation (>300) produces melting.
2005 MARTE Drilling Mission Simulation

• Coring drill 10 m depth capability

• Borehole Inspection Downhole Instrumentation

• SOLID life detection instrument

• Fully automated drilling, sample handling, science inspection, subsampling, and life detection

MARTE drilling lander in the field
MARTE Drill
- Drill and core retrieval system built by Honeybee Robotics.
- 10 m depth capability
- Power consumption 150 watts
- Each core bite is 25 cm long, 2.7 cm diameter
- Dry rotary cutting using carbide drag cutters and diamond bits
- Core hand off to a core clamp
- Automated drilling, core removal, and string replacement
Subsampling Tool
V-NIR Spectrometer (350nm – 1000nm)
Hyperspectral Imager
Panoramic & Microscopic Imagers
Rock Crusher
BHIS
Drill System
Faced core goes under Remote Sensing instrument package

RS instruments examining core

Subsample saw

Sample acquired
Down Hole Instrumentation

- The Bore Hole Inspection System inspects hole after removal of the drill.

- Instruments in the BHIS include a panoramic microscopic imager and Raman spectrometer.

- The BHIS can position the inspection tool from depths ranging from 0 to 25m.
Ice-Ax payload development integrates two downhole instruments and a drill together on a carousel that can be carried on a small rover.
Drill

Drill Mechanical Design
- Rotary drill w/ DC motor and 91:1 planetary gear reducer
- Pneumatic actuation for weight-on-bit and side wall anchor
- Pneumatic cutting removal

Drill Performance
- Rotary Bit Torque: 0 – 200 in-lbs
- Rotary Bit Speed: 0 – 275 rpm
- Weight-On-Bit: 0 – 150 lbs
- WOB Actuator Travel: 3 in
- Anchor Force: 0 – 700 lbs
IceAx wireline drill

Bit and gas jet cuttings removal

Force on bit actuator

Side wall anchor
This is a picture of a small rover carrying a device with a similar tether management system. The bracket pivots down to deploy the launch tube, and up to allow the rover to drive.
miniBiospectral Logger (N. Bramall NASA Ames)

Purpose: a borehole logger for sensing bacteria down an ice borehole
- Emission source is 224 nm HeAg laser
- Fluorescence is detected by a chain of bandpass-filtered PMTs
- Current prototype is 5.1 cm diameter, 1.3 m long, Uses 12 W of power
mBSL is a UV fluorimeter designed to detect fluorescence associated with common amino acid compounds associated with all life, notably tryptophan. It is sensitive to a single bacteria in the field of view.
Subsurface Access/Assessment

- **Borehole Neutron Probe**
  - Log hydrogen with depth
  - Icy layers/aquifers
  - Evaporite sequences

These instruments detect hydrogen:

**Surface Neutron Probe (SNeuP)** rides on rover, ‘dowses’ for subsurface ice.

**Borehole Neutron Probe (BNeuP)** is integrated in drill string, detects layers of buried water ice.
Borehole Neutron Log

- Borehole Test Data

100-sec running averages
- thermal+epithermal
- epithermal

Layered column
- 10 wt% 3 wt%
- ~1 m

HeSn, HeCd count rate
- Depth (cm)
Drilling should be a cornerstone activity for both Moon and Mars exploration.

**ROADMAP**

- Drill on Moon for science investigations, to explore and characterize resources, and to advance technology for future human exploration-enabling missions to Mars. Robotic precursor missions conduct shallow drilling. Astronaut supervised deep drilling as cornerstone science capability at lunar base.

- Begin Mars robotic precursor program to characterize the global distribution of subsurface liquid water on Mars (combination of orbital, airborne, and landed instrumentation including orbital ground penetrating radar, low frequency electromagnetic sounding, and other geophysical techniques)

- Robotic shallow (5-20 m) drilling on Mars to address key science questions, followed by deeper astronaut assisted drilling (100 m or deeper) to access liquid water aquifer).

**Recommendation**

Develop a lightweight and highly automated drilling system expandable from shallow to deep drilling.