Drilling: How do we access subsurface on Mars

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Why Drilling?!
(Short) History of Mars (Shallow) Drilling
It’s feasible to ‘cut’ rocks on Mars (remotely)
Mars rocks have similar strength to terrestrial rocks
2008 Mars Phoenix Rasp [1 cm]

- Ice near the surface
- Perchlorates
2011 MSL Powder Acquisition Drill [5 cm]

- Can drill, acquire and process samples
- ‘Weathered’ layer is very thin
Upcoming: 2018 InSight Mole [5 m]

Target: 5 m in regolith
Upcoming: Mars2020 Coring Drill [6 cm]
Upcoming: 2020 ExoMars Drill [2 m]
Drilling 101
Drilling Steps

1. Drilling

2. Cuttings Removal
Selection of Drilling Method

Drilling Methods

- Thermal
  - Melting
  - Spalling

- Chemical

- Mechanical
  - Percussive
    - Pneumatic
    - U-Sonic
    - Churn
  - R-P

- Rotary
  - Drag Bits
    - Tool Motion: Parallel
    - DI, SSD
  - Roller cone
    - Tool Motion: Normal
    - MT, TCI
    - PDC, TSP
Selection of Cuttings Removal

- Mechanical
  - Auger
  - Bailer

- Fluid
  - Water, Mud

- Gas
  - Continuous
  - Blasts

Dedicated tank
Mars air
Fuel/He pressurant
Generating drilling fluid on Mars

- Drilling power → heat → latent heat → sublimation
- Volumetric expansion of ice → vapor 1000’s x

(Zacny et al., 2004)
But problems can happen in icy soil (even on Mars)!

Drill frozen in the ground...
Recovered (after a lot of work!)
What options do we have?

- Temperature measurement alone not sufficient
- Measure Temperature AND Resistivity
- Look for a large $\Delta R/\Delta T$
  
  - $\Delta R/\Delta T = 700 \text{ k}\Omega/\degree \text{C}$ vs. $75 \text{ k}\Omega/\degree \text{C}$

Zacny et al., 2007

Graph showing bit temperature over drilling time with different resistance measurements at various temperatures.
1 m class drill
Drilling Approaches

SONIC

ULTRA SONIC

PERCUSSIVE

ROTARY

TRL 4 (Rot Perc)

TRL 5 (Rot Perc)

TRL 6 (Rot Perc)
“Bite” Sampling Concept

- Drill in short (~10 cm) “bites”
- Preserve stratigraphy in “bites”
- More accurate strength measurement of subsurface
- Lower power and torque (see next slides)
- Drill in safe place during sample analysis
- Extra time for subsurface to cool down
Advantage of Bite Approach

Continuous Auger

Bite Approach
Implementation of “Bite” Sampling

1. Drill “Bites” into ice-bearing material

2. Retract auger with captured cuttings

3. Inspect cuttings with Infrared Sensor and Camera. If ice bearing material is detected, proceed to next step. Otherwise continue taking “Bites”

4. Rotate and retract auger to deliver ice-bearing material still within sampling system
Rover Architecture: Atacama
Goal: Prospecting for volatiles

- Neutron Spectrometer Subsystem (NSS)
- Near InfraRed Volatiles Spectrometer Subsystem (NIRVSS)
- Oxygen and Volatile Extraction Node (OVEN)
- Lunar Advanced Volatiles Analysis (LAVA)

Rover Architecture: Resource Prospector

Andrews et al., 2014
Lander Architecture: Mars IceBreaker
Sample Delivery using Drill
Sample Delivery using Gas
Testing in Cold Regions

McMurdo and Dry Valleys

ANTARCTICA
AND THE SOUTHERN OCEAN

Polar Stereographic Projection
Scale: 1:35,000,000 at 71°S
Winter station (site is seasonally occupied every winter)
Mars Analog: University Valley, Antarctica
Ice Cemented Ground – Soil Did Not Stick!

**Drilling Data (1-1-100-100):**
- Power: ~ 70 Watt
- Time to 1 m: 54 min
- Weight on Bit: < 70 N
- Drill Energy: 63 Whr
- $T_{\text{Bit}}$: -5°C ($T_{\text{Ground}}$: -19°C)
Antarctic Dry Valleys: Massive Ice

Drilling Data:
- Power ~ 150 Watt (at 2.5 m depth)
- Time to reach 1 m / 2.5 m: 1 hr / 2.5 hr
- Weight on Bit: < 70 Newton
- Energy: 120 Whr for 1 m / 300 Whr for 2.5 m
- T Bit -10 °C ( T Ice -24 °C)

Ice cuttings include many single ice chucks as large as 6 mm long
Test in Mars chamber

- 1 m depth in 3.5 m chamber
- Tests in
  - ice (w and w/out perchlorate)
  - icy-soil
  - rock
- Drilling at 1-1-100-100 level: 1m in 1 hr with 100 Watt and 100 Newton WOB
10 m class drills
MARTE

- 10 m coring drill
- Core processing
- Instruments for core analysis
- ASTEP funded (PI. Carol Stoker)

Honeybee Robotics

MARTE
Limestone Drilling Test
NASA Ames Research Center
May 2005
STEM-Pneumatic Drill
Pneumatic Drill Testing

- Compacted soil simulant (1.9 g/cc)
- Mars pressures
- 2 m in 2 minutes
- Demonstrated Stop-Start

(Zacny et al., 2013)
>100 m class drills
Melt probes

- Developed in 1960s by CRREL
- Simple but slow, power/energy hungry
- Work in ice only (or very limited wt% silt)

Philberth Probe at Century 2
$L = 2.5 \text{ m}, R = 4.6 \text{ cm}, \text{Ice} = -24^\circ \text{C}, P = 3.7 \text{ kW}$
Inchworm/Wireline/Cable Suspended

- Used in Antarctica and Greenland
- In unstable boreholes, need expandable casing and bi-center bit
- Delivers sample and can deploy instrument downhole
AMNH Deep Drill

Drilled two holes
- 10.5 m
- 13.5 m
WATSON – Deep Drill with UV/Raman

PSTAR, Roh Bhartia (PI)
WATSON – next steps

Greenland 2019

Mars (2029 😊 )
SLUSH Drill: Thermo-Mechanical
Search for Life Using Subsurface Heated Drill

Efficiency:
- Mechanical: 1
- SLUSH: 10
- Melt: 100
Drill based water extraction systems
RedWater

- STEM drill with pneumatic cuttings transport makes a hole
- STEM based pumping system deploys and pumps water to the surface
2nd NASA’s Mars Ice Challenge (RASC-AL)

- Dates: June 5-7, 2018
- NASA Langley
Conclusions

• Mars depth record climbed from 5 mm in 2003 to 5 cm in 2012
• Need technology to reach meters and possibly 100s of meters.
• Current Technology Readiness Level (TRL)
  – 1 m class systems are at TRL 6
  – 10 m class systems are at TRL 4
  – 100 m class systems are at TRL 4
• Drills can bring sample to an instrument AND can bring an instrument to a sample:
  – Temperature profile and k, (heat flow probe)
  – Resistivity, LIBS, UV, Raman, Microscope
  – Strength/density (comes “free” from drill telemetry)
• There is no substitute for tests in analogs on Earth (e.g. Dry Valleys)
• Numerous ISRU options exist for mining water on Mars
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Thank You!

http://utcjonesobservatory.tumblr.com/