Lunar Drill Development

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Spacecraft Mechanisms Corporation

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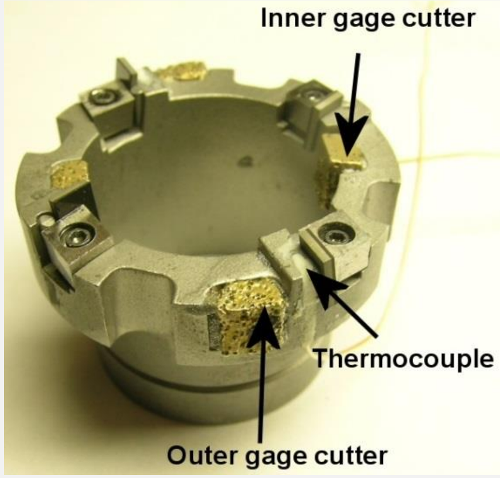
Drilling 101

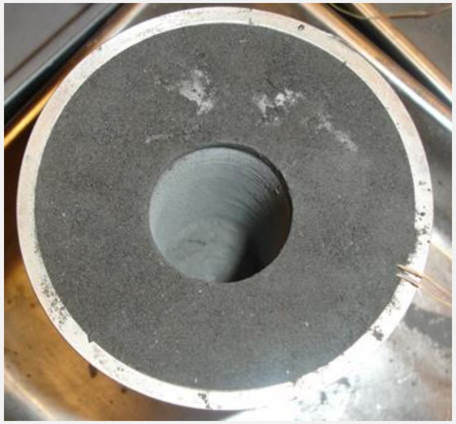
Drilling 2 Steps

1. Drilling

Coring Bit



Full Faced Bit

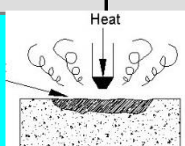


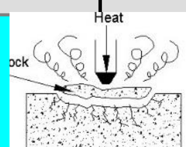
2. Cuttings Removal

This is what got Apollo drill stuck

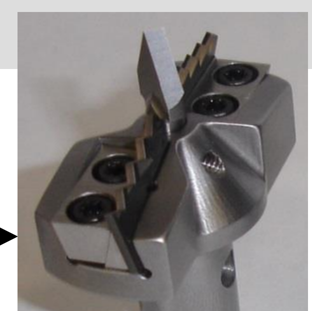
Selection of Drilling Method

Drilling Methods

- Thermal
  - 

  - 

- Chemical
- Mechanical
  - Rotary
    - Drag Bits
      Tool Motion: Parallel
      - DI, SSD
      - PDC, TSP
    - Roller cone
      Tool Motion: Normal
      MT, TCI
  - Percussive
    Pneumatic,
    U-Sonic,
    Churn
  - R-P



Methods of Cuttings Removal

- **Cuttings Removal**
  - **Mechanical**
    - Auger
    - Bailer
  - **Liquid**
    - Water, Mud
  - **Gas**
    - Continuous
    - Blasts

sublimation

Exploration and Sampling Approaches

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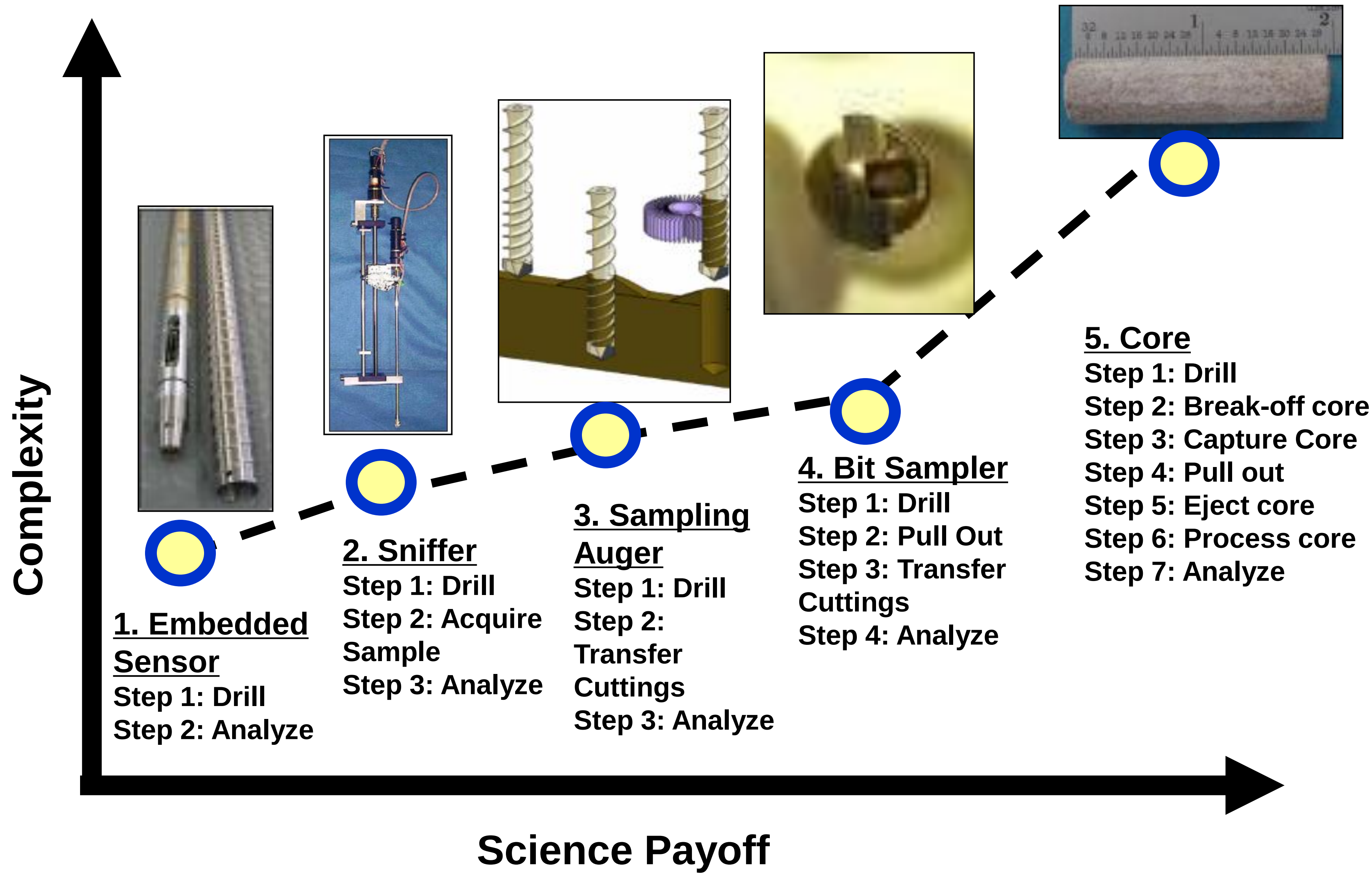

Drill Integrated Neutron Spectrometer

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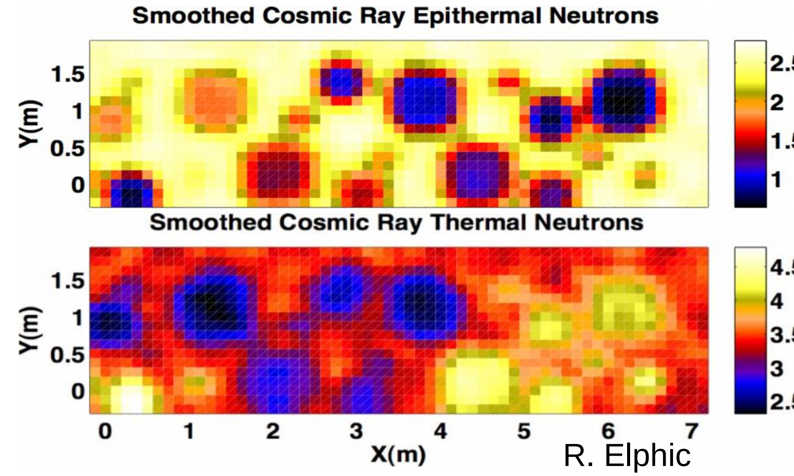
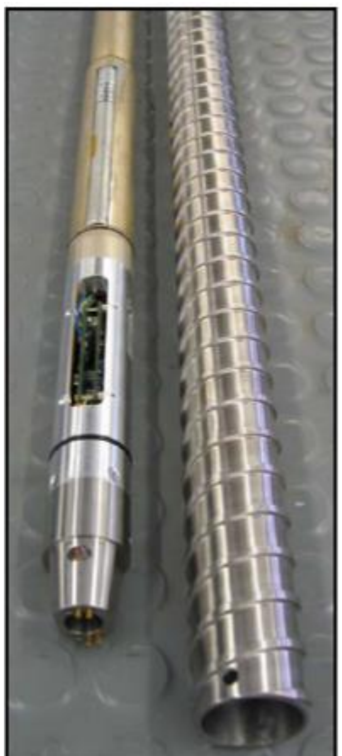
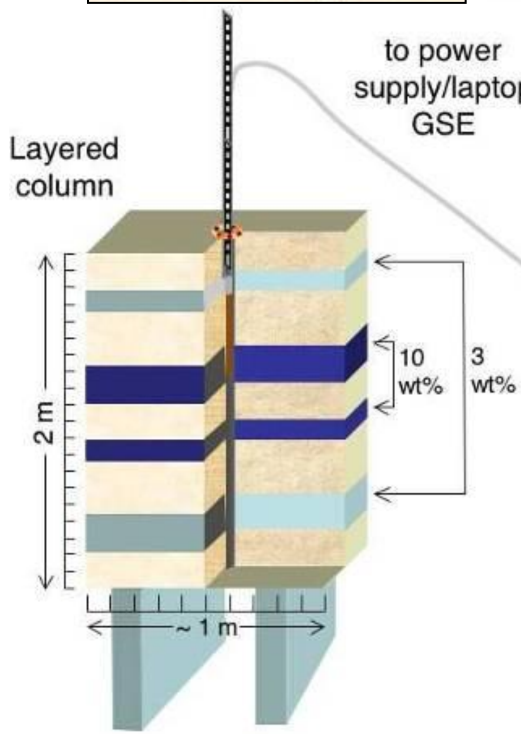
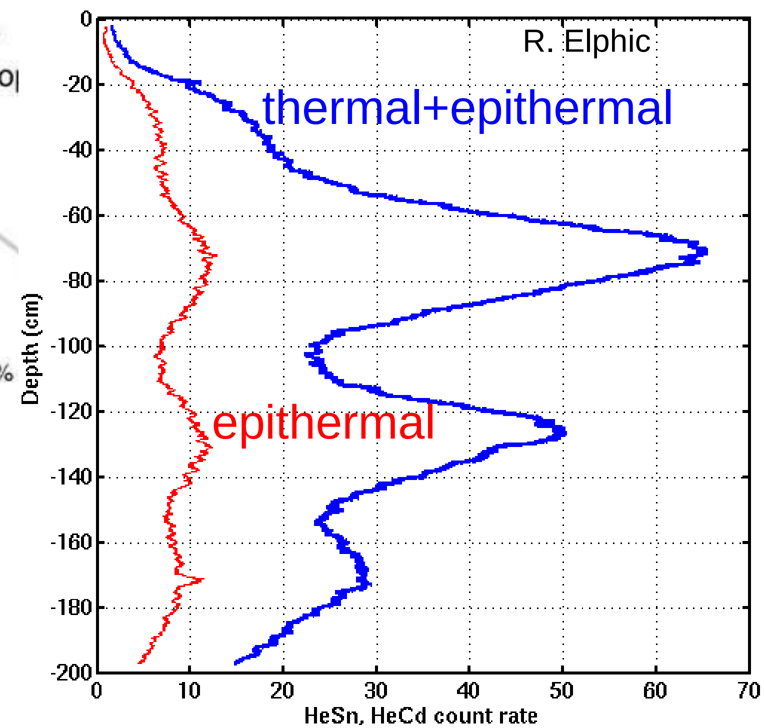
Neutron Spectrometer

- Hydrogen → Water
- Rover Based: H2-rich regions
- Drill based: exact depth and concentration









1 meter Drill Down Select

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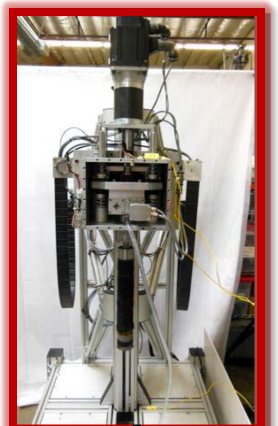
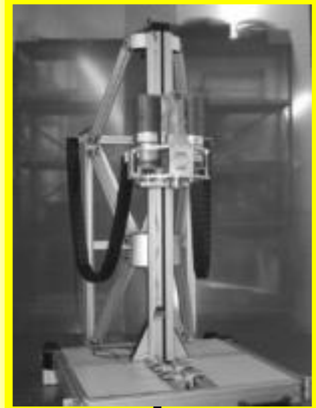
SONIC

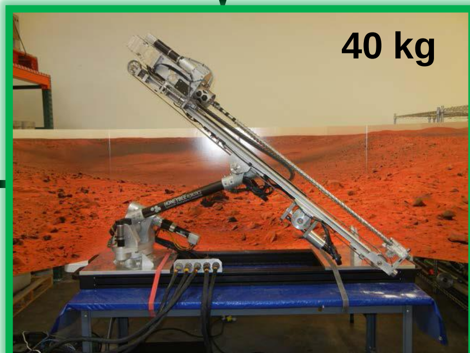


ULTRA SONIC

PERCUSSIVE



ROTARY



Final Selection:
ROTARY-PERCUSSIVE

Lander

Rover

Core vs. Cuttings for 1 m class drill system

Core Capture vs. Cuttings Capture Trade

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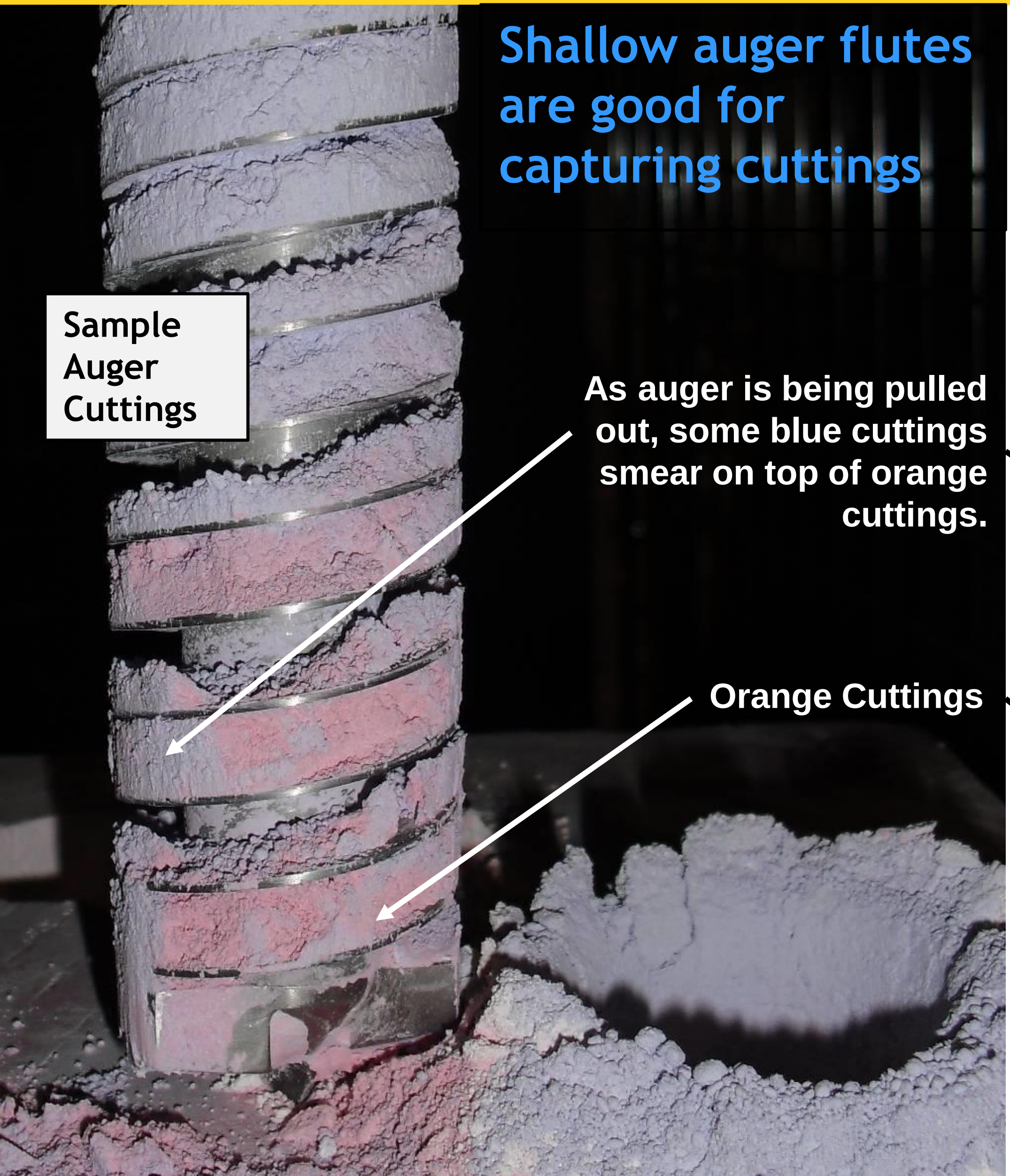
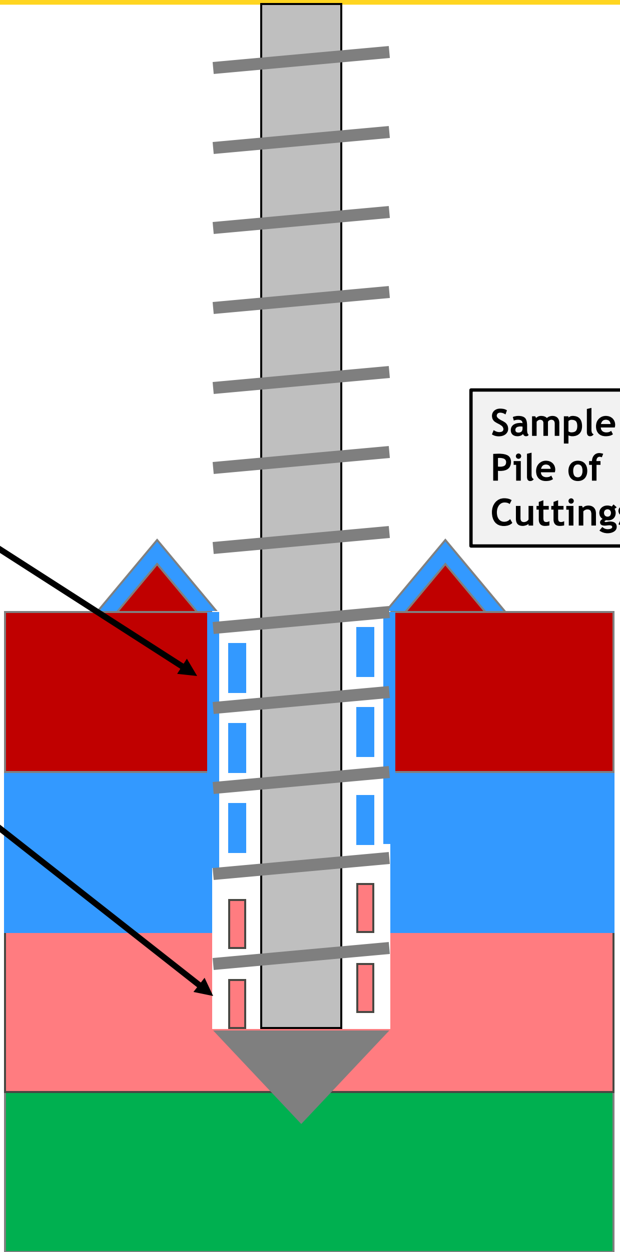
	Cuttings		Core	
	Pros	**Cons**	**Pros**	**Cons**
Drill Diameter	Small			Large Need to house actuators, breakoff system, pushrod.
Drilling power/energy	Low			High – because diameter is high.
Volatiles loss	Function of formation strength and water content.		Function of core diameter, water wt%, and temperature	
Complexity	Low			High. Need to package mechanisms inside a drill string. Reliable core capture and ejection is difficult. Need large slipring for downhole actuators. Need small flight qualified actuators
Dust	Not an issue			Mechanisms need to work many times.
Possible failure modes		• Drill freezes in • Cuttings freeze onto flutes		Same as with “Cuttings”, PLUS: • One or both actuators within drill auger fail • Mechanism fails or freezes in • Core freezers in or gets stuck

Capturing Cuttings: Auger Flutes or Pile of Cuttings

Shallow auger flutes are good for capturing cuttings





Sample Auger Cuttings

	A	B	C	D

Cohesive materials works for all auger shapes.

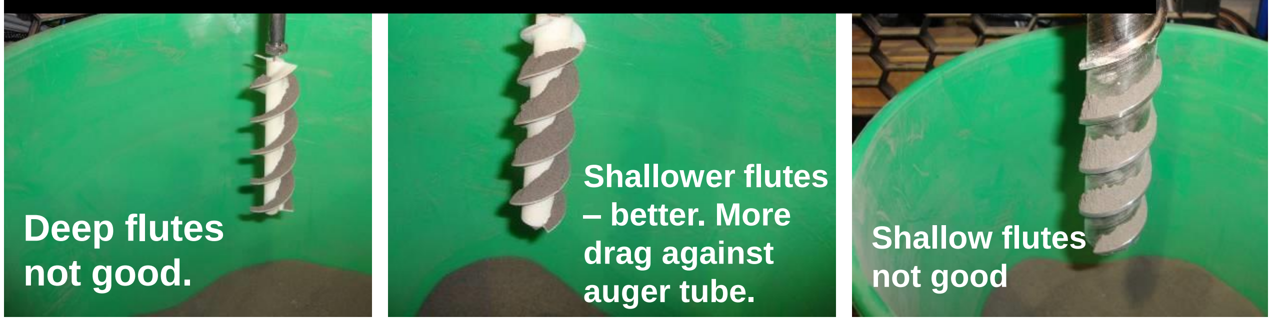
Limestone Cuttings

(cohesive)

Optimum flute width exists for 25° pitch

JSC-1a

(somewhat cohesive)

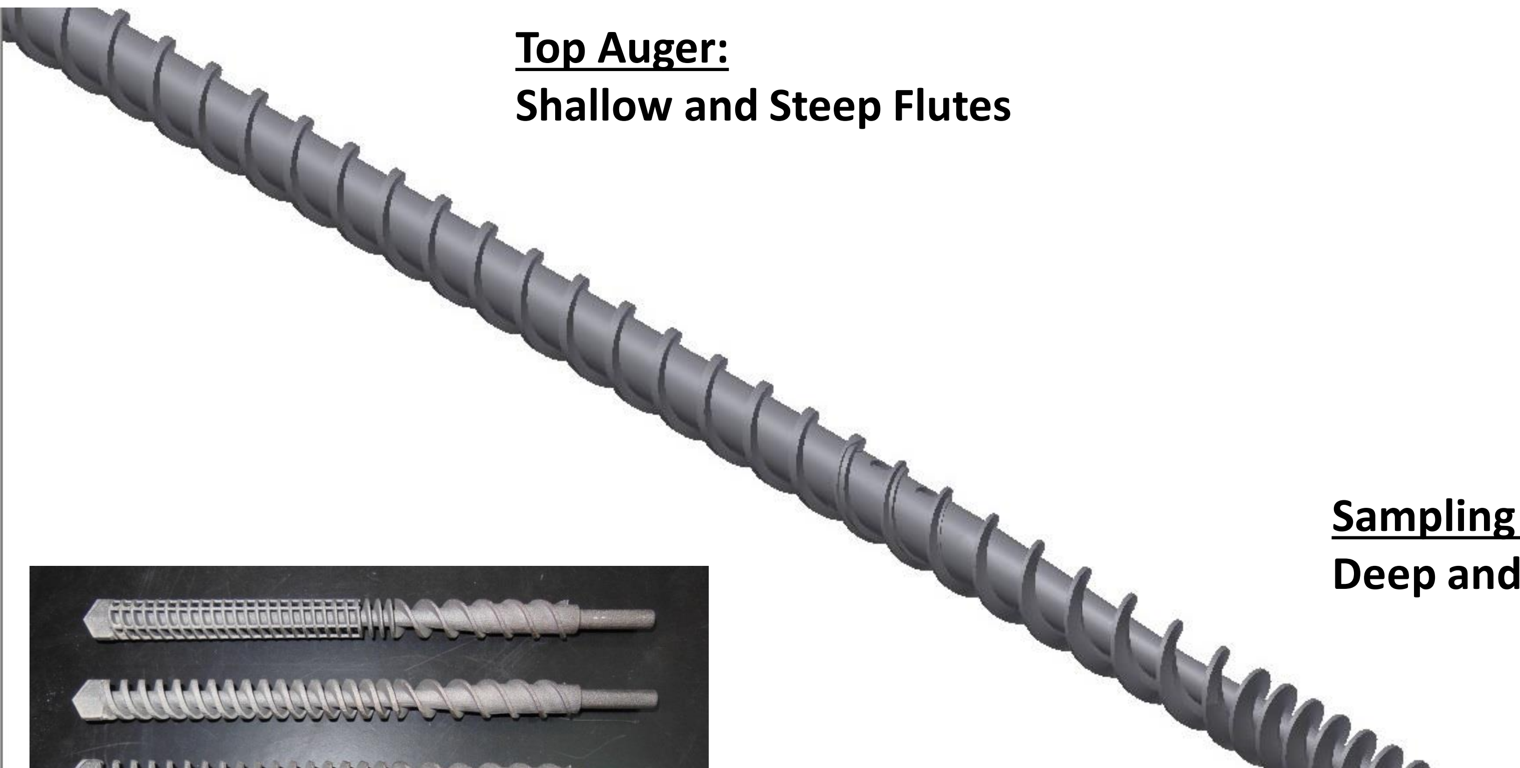


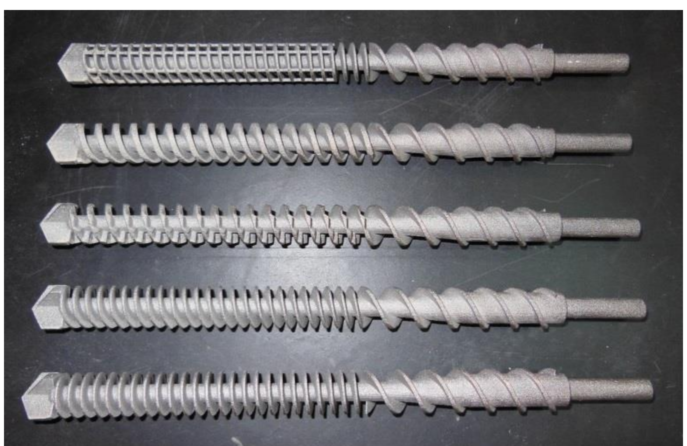
Only low pitch auger works in non-cohesive material (larger contact area).

Sand

(non-cohesive)

Result: Dual Auger





“Bite” Sampling Concept

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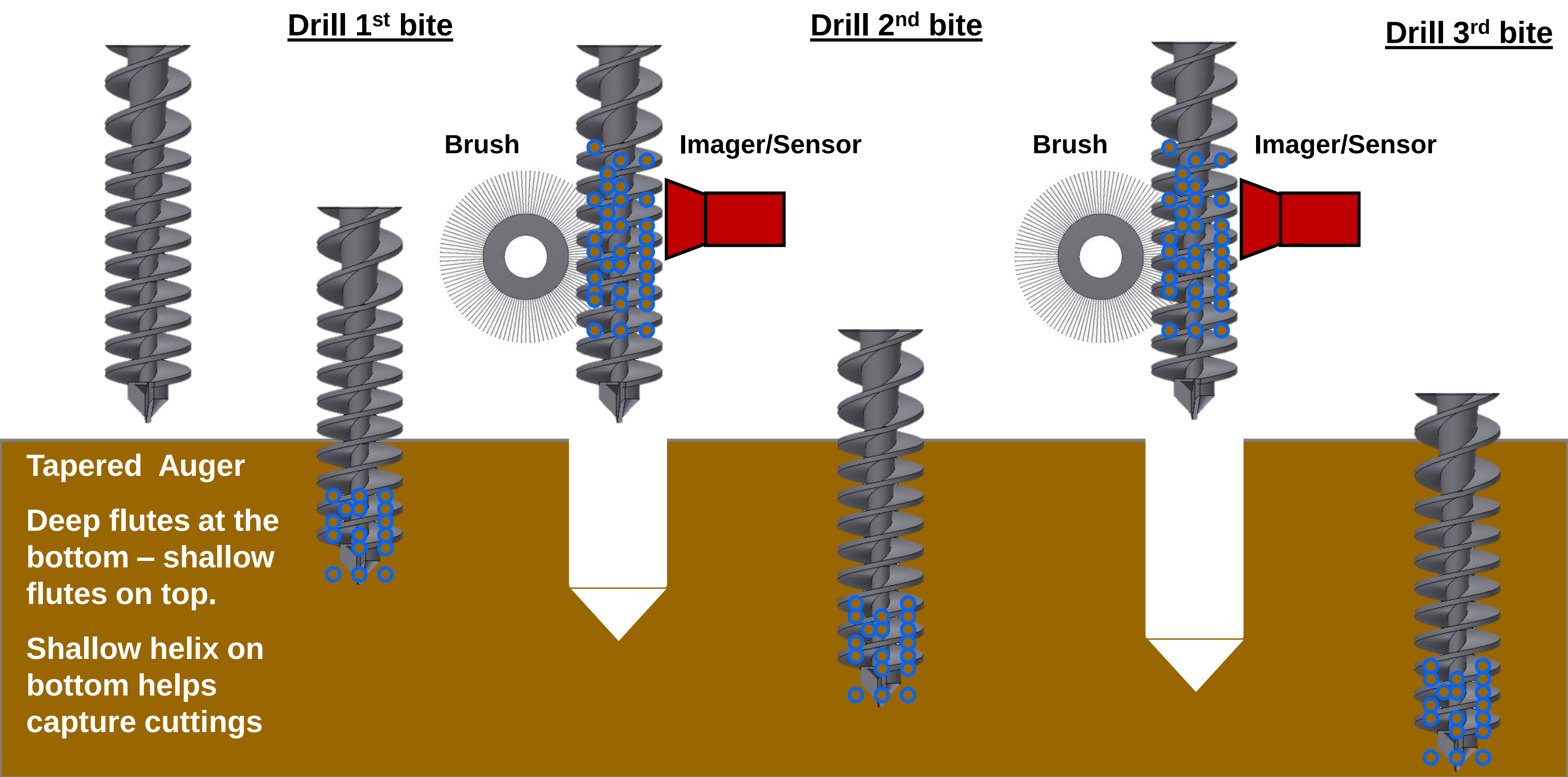
- Progressively drill to 1 meter with short (~ 10 cm) “bites”
- Preserves stratigraphy in “bites”
- Risk reduced (“graceful failure”) – e.g. drill stuck at 60 cm, 5 “bites” analyzed
- Allows time for sample analysis while the drill is in ‘safe’ location (above the hole)
- Allows subsurface to cool down



Thermal Considerations

Distribution of Heat

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Background

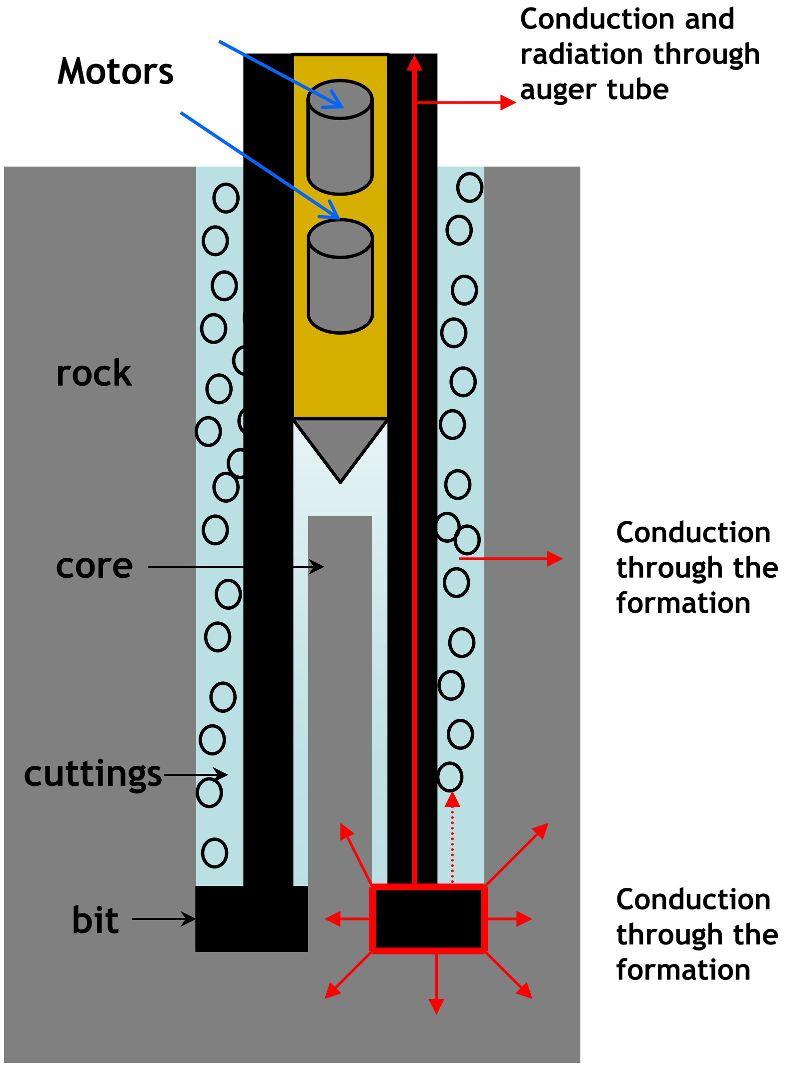
- ❑ Significant heat generation during dry drilling:
  - No fluid or gas to clear cutting and to cool/lubricate
  - Dry drilling is less efficient due to regrinding
- ❑ Heat dissipation:
  - Vacuum on the Moon
  - Radiation into space, conduction into formation, liquefaction and sublimation (if volatiles present)

Core and Cuttings

- ❑ The core is surrounded by "hot" auger and is underneath 'hot' actuators (actuators need to be kept warm)
- ❑ Cuttings conduct heat into formation as they move up the auger

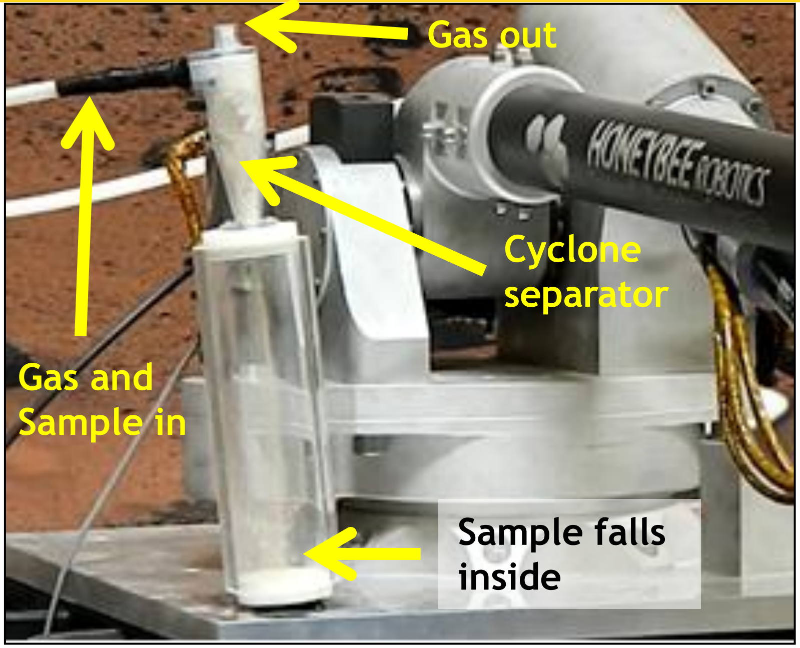
Table from Szwarc (2013)

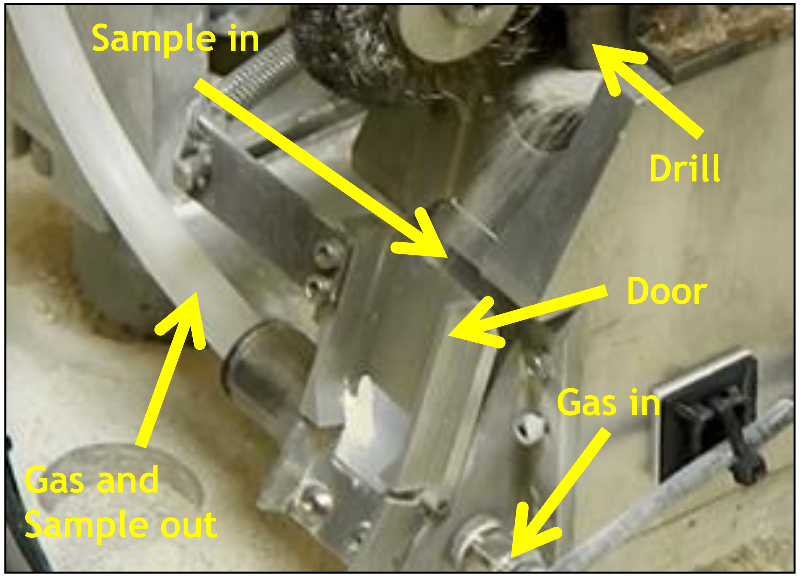
		Location			
		Core	Rock	Bit	Cuttings
Final Heat [%]	Mean	2.5	79.5	11.3	6.6
	Min	1.1	59.8	5.5	1.5
	Max	6.0	94.6	19.4	16.6
	Std Dev	1.5	11.4	4.7	5.0

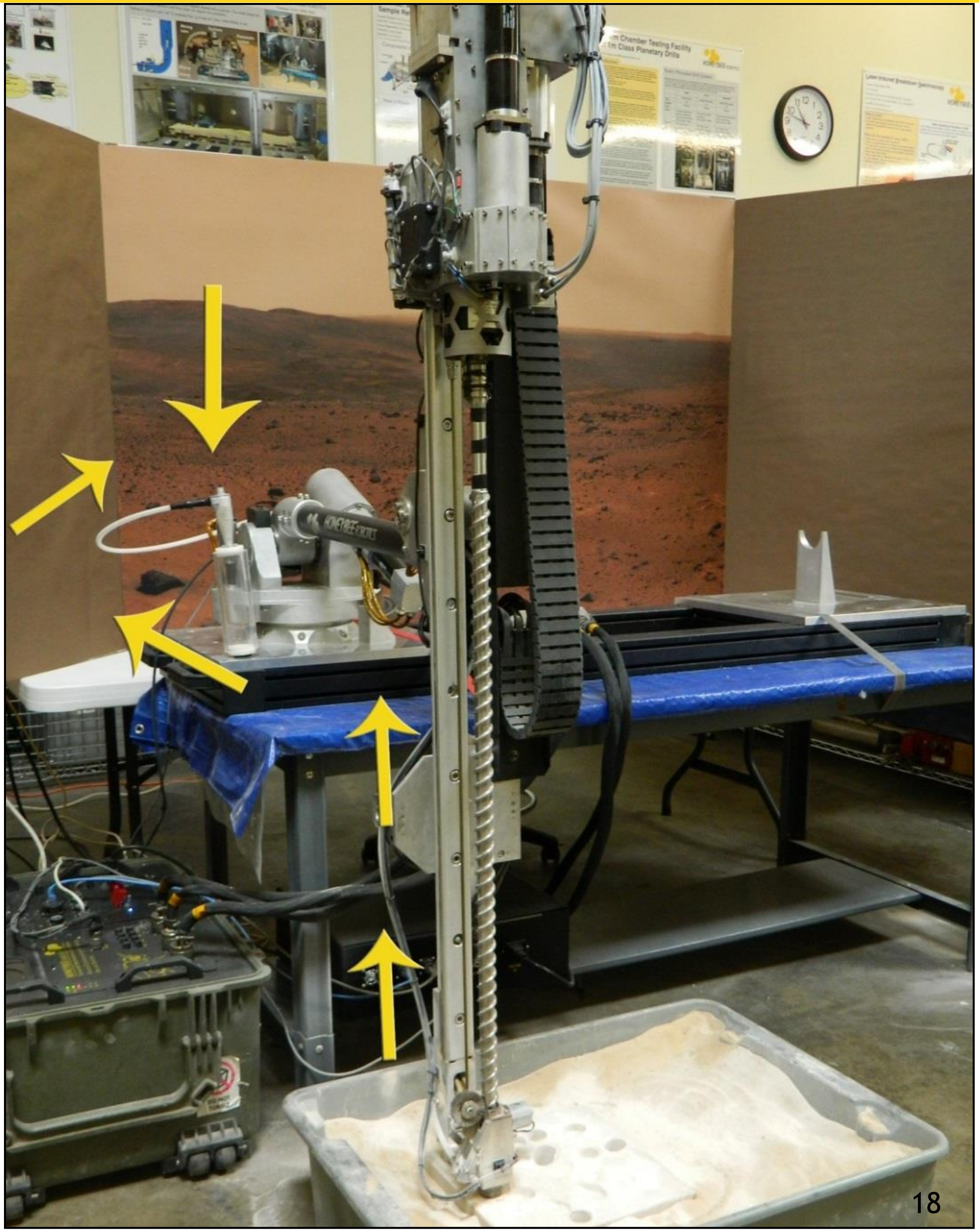


Sample Transfer

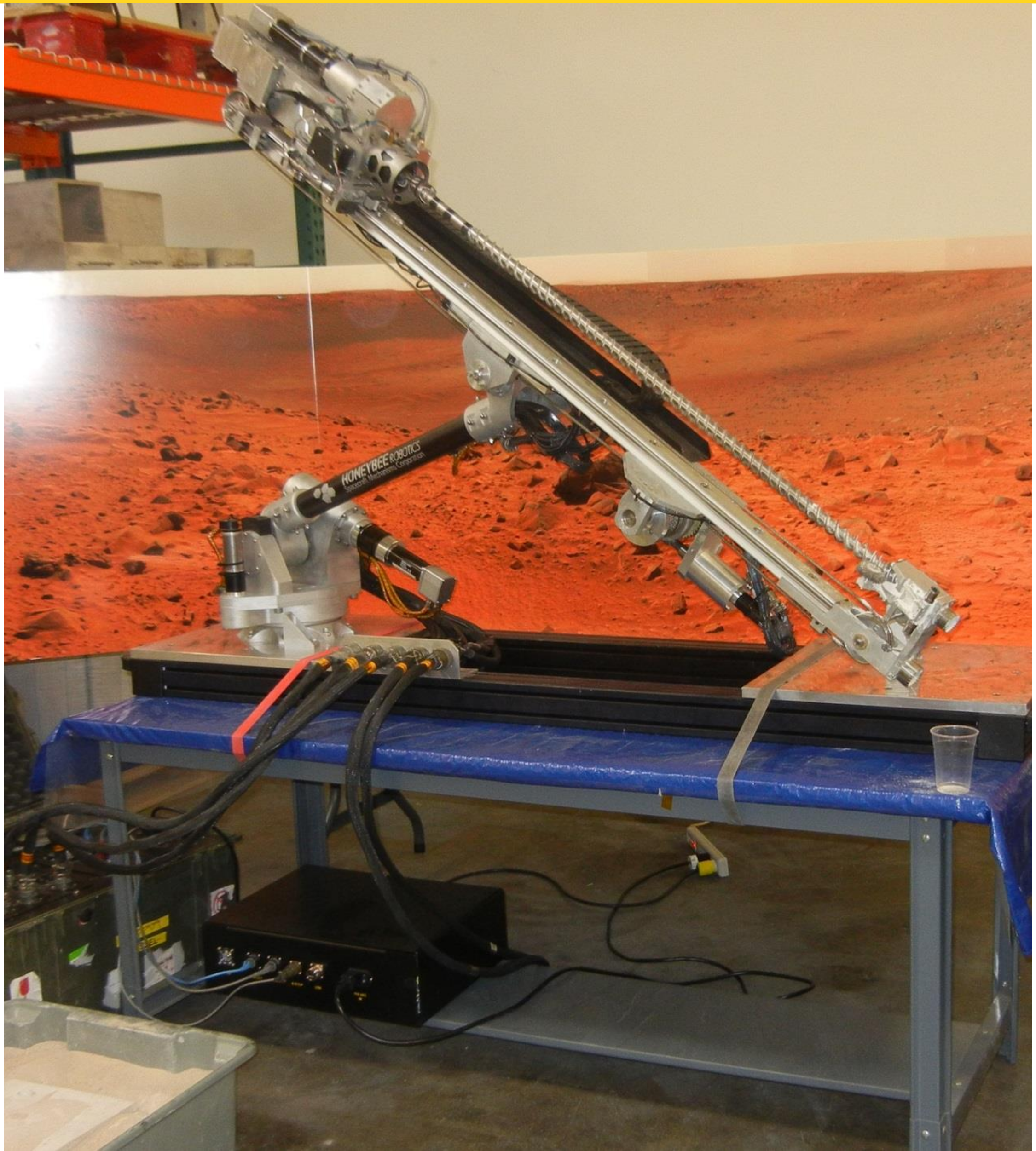
Option 1: Pneumatic







Option 2. Drill Drop off



IceBreaker

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https://www.youtube.com/watch?v=fTNPokiXa0E

Option 3. Cuttings Capture and Delivery to a Carousel

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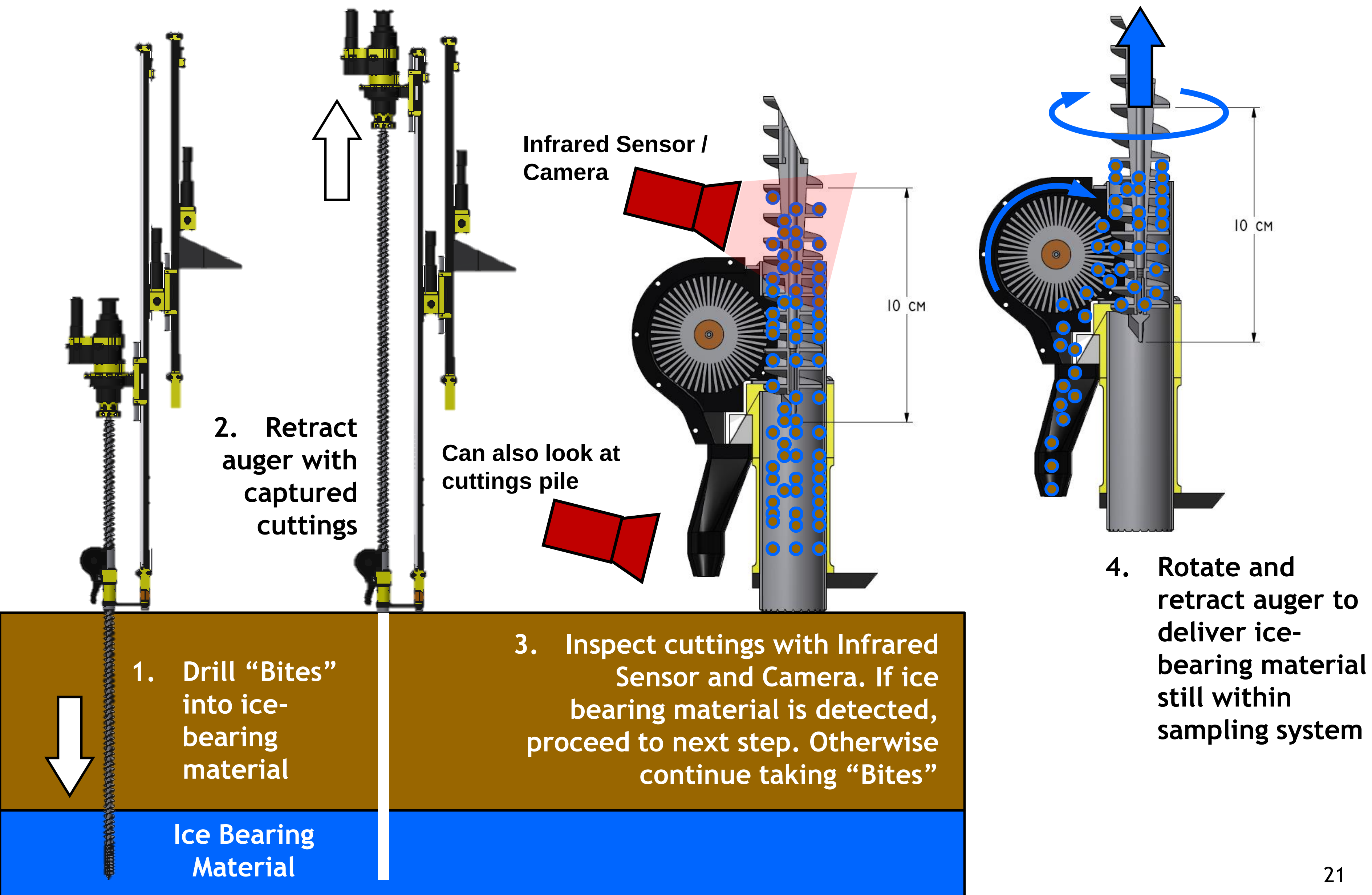
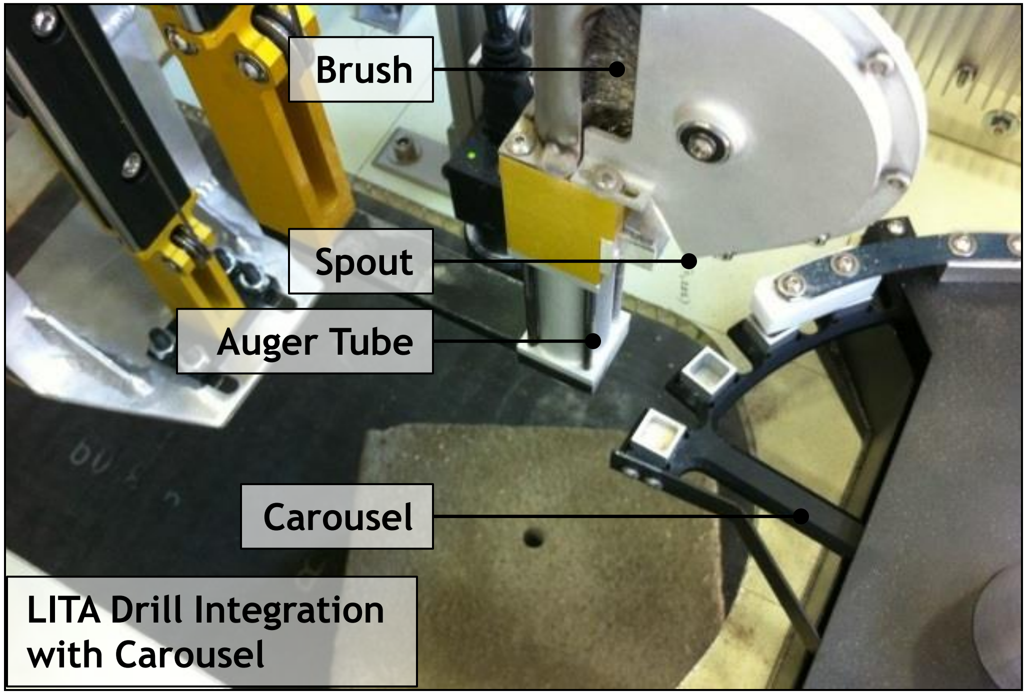


Option 3. Cuttings Capture and Delivery to a Carousel

- Implemented in ASTEP funded Life in the Atacama project
- Sample is stored on Auger Flutes and protected within Auger Tube
- When ready to deposit, Auger rotates and moves up, Brush scrapes sample into delivery “spout”



LITA Drill Integration with Carousel


Testing Powder Delivery in Atacama Field Test

LITA drill

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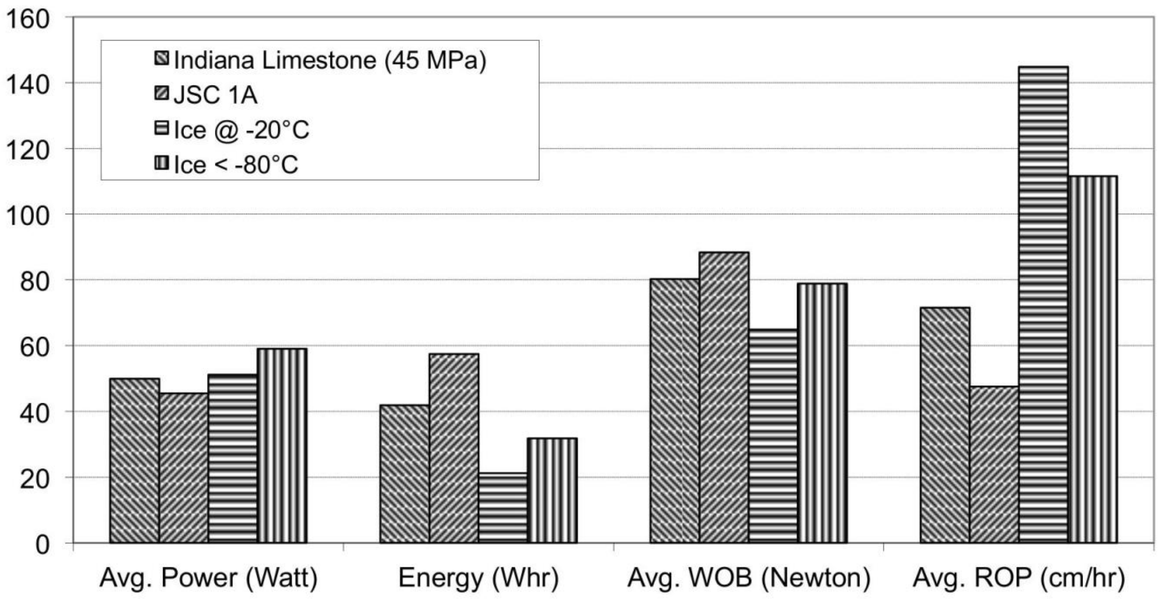
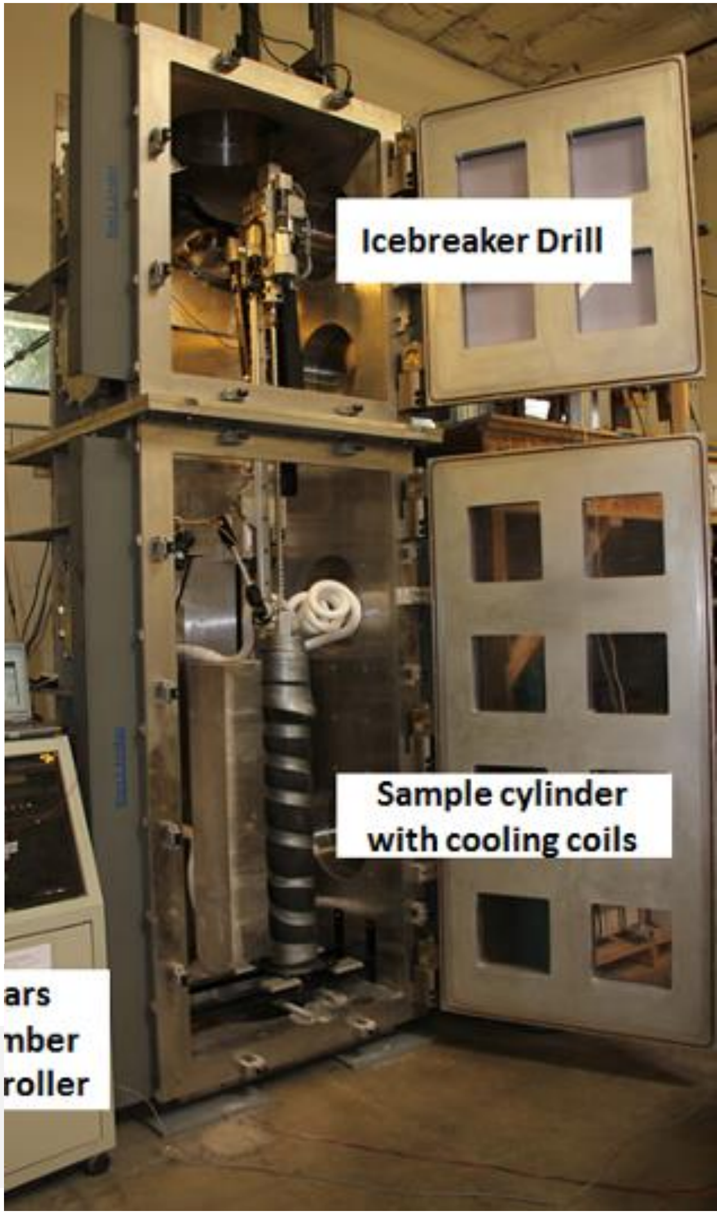
https://www.youtube.com/watch?v=QE7aYUnAA9o

Testing

Vacuum Chamber Test Results

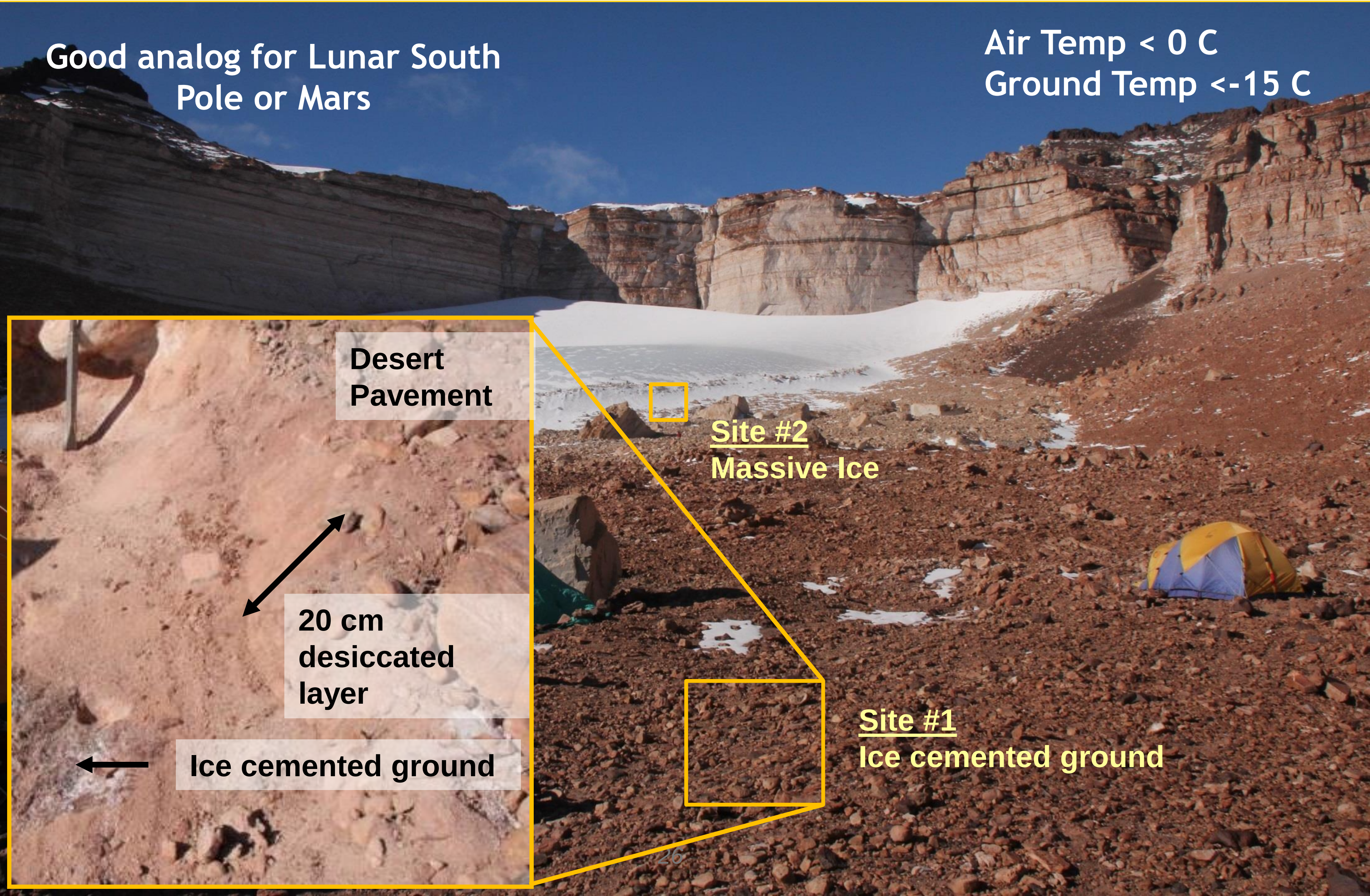
Power < 100 Watt (net)
Energy to 1 m < 100 Whr (net)
WOB < 100 N
Time to 1 m: 1-2 hr



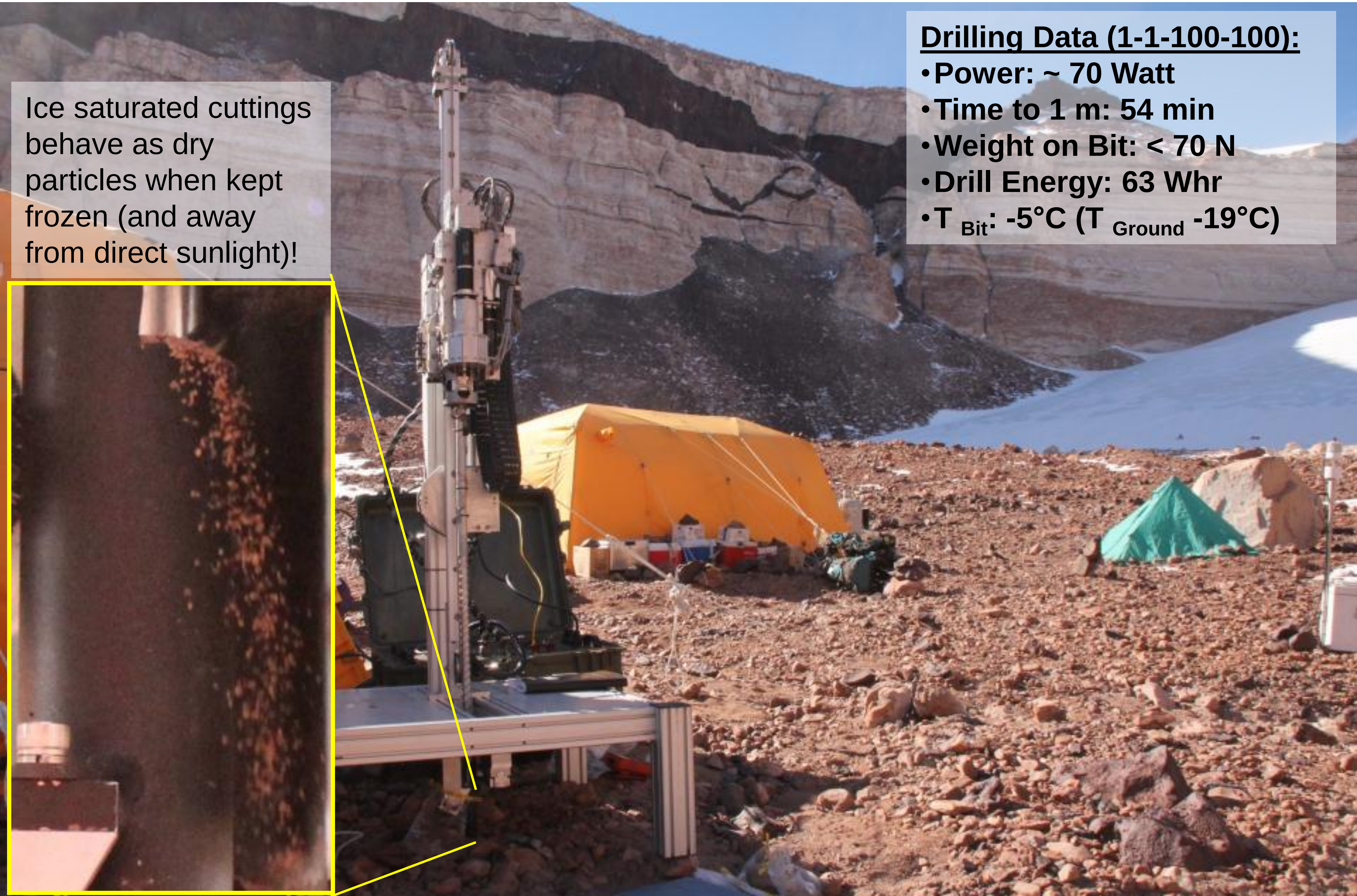


Bit diameter: 25.4 mm; Speed: 100rpm; Percussive energy: 2.6 J/blow; Percussive frequency: 810 bpm. Ambient temperature: 25°C.
Material: 45 MPa Indiana Limestone rock; water-ice at -20C, water-ice at -80C, water-saturated JSC-1A at -20C (saturated and compacted prior to freezing).

Tests in Antarctica, Dry Valleys



Site 1: Ice Cemented Ground



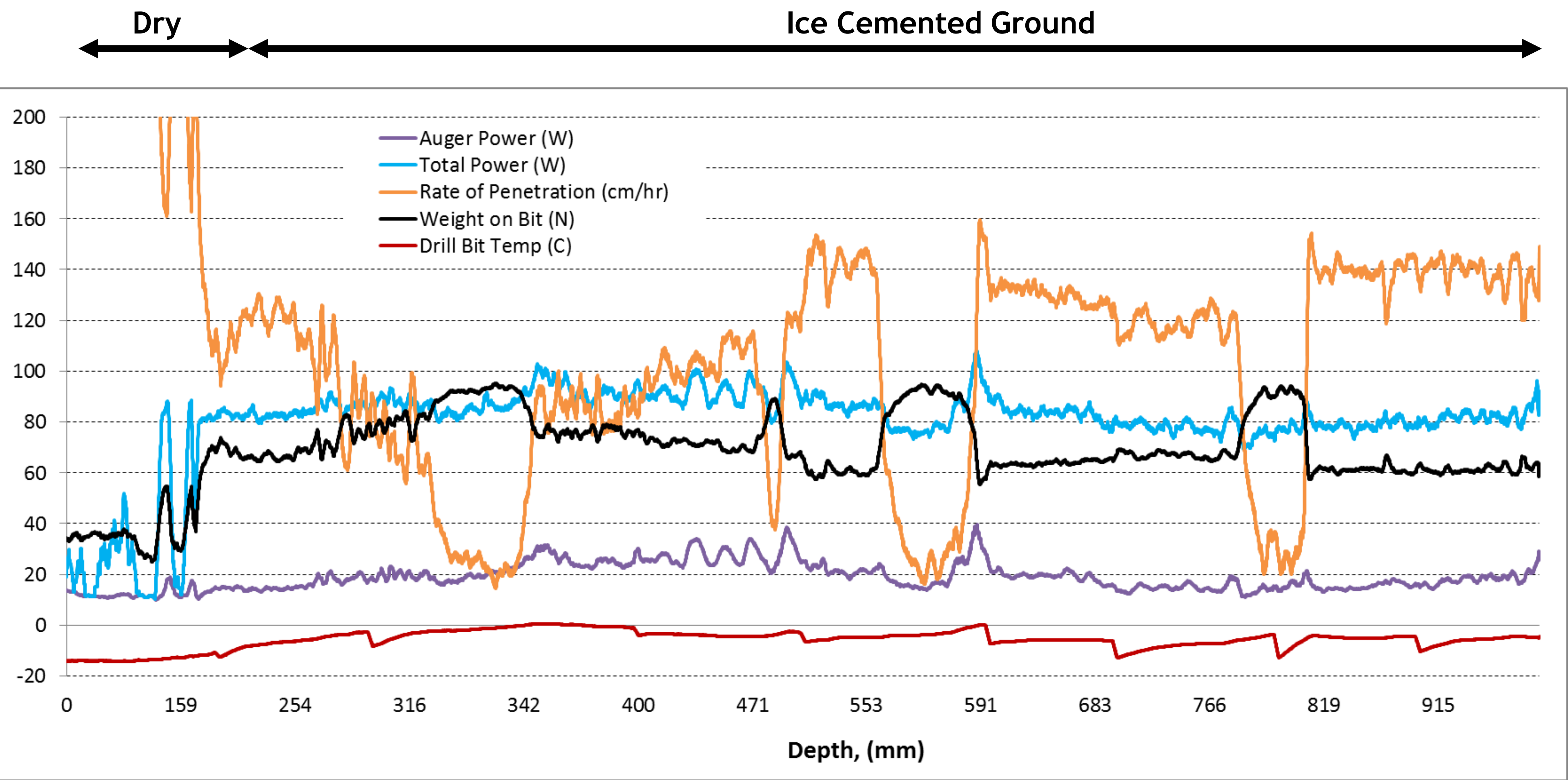
Ice saturated cuttings behave as dry particles when kept frozen (and away from direct sunlight)!

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_{Bit}: -5°C (T_{Ground} -19°C)**

Site 1: Test Results for Bite Sampling

- Bite approach: drill pulled out every 10 cm to deposit sample
- Time to reach 1 m: <1 hr; Net Power: 100 Watt, WOB: <100 N; Net Energy: 100 Whr
- Percussion kicked in at 160 mm - depth to ice-cemented ground. WOB/Energy algorithm worked.
- Bit T < 0 C. Thermal algorithm worked.
- Frequent pulling out allowed both the auger and the formation to cool down.



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Additional Science

Strength of Material from Drilling SE

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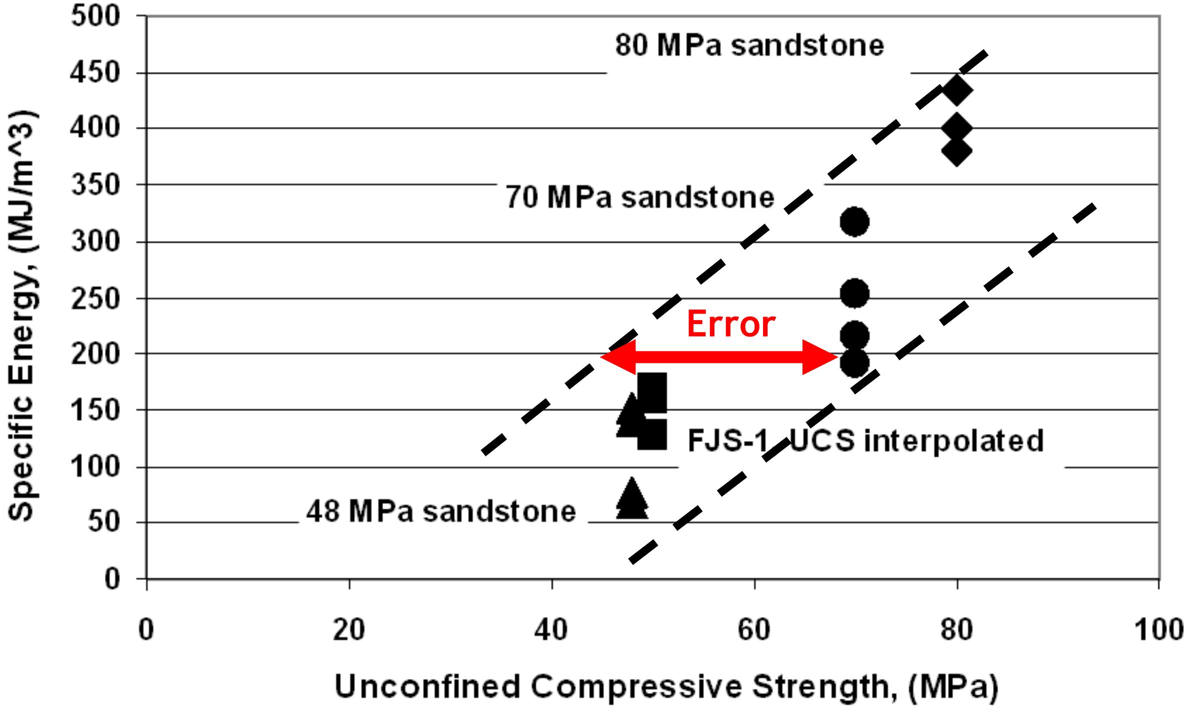
Strength value from drilling telemetry

- Drilling in three known sandstones and FJS-1
- Extrapolating UCS of FJS-1 based on SE of FJS1 and the three sandstones
- UCS ~ 48 MPa

Strength value from UCS tests

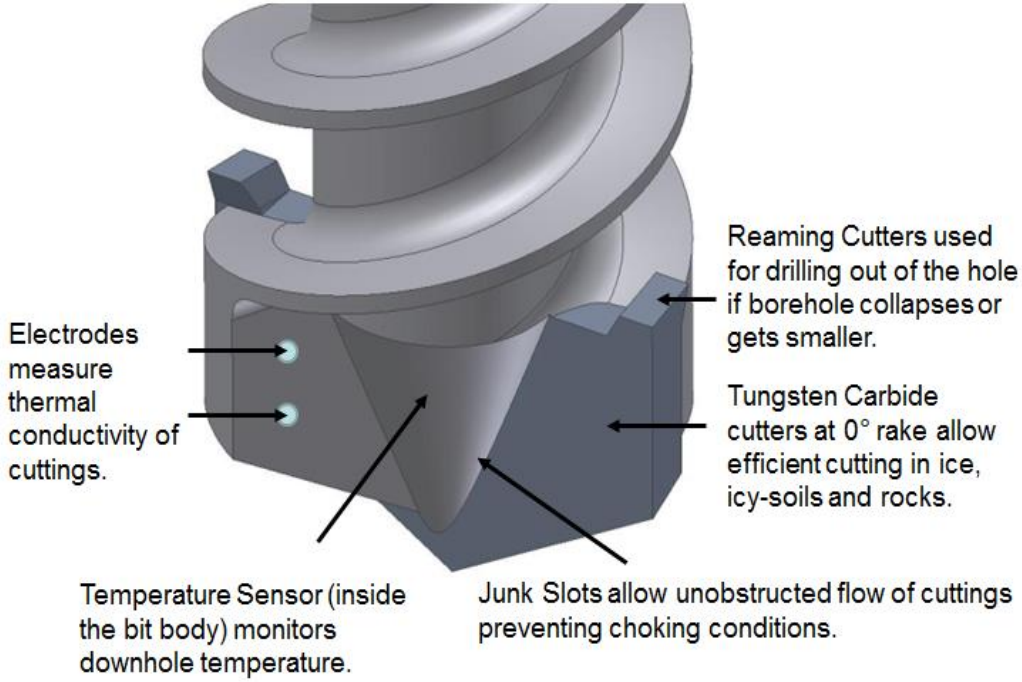
- UCS=43 MPa,
- std=11 MPa

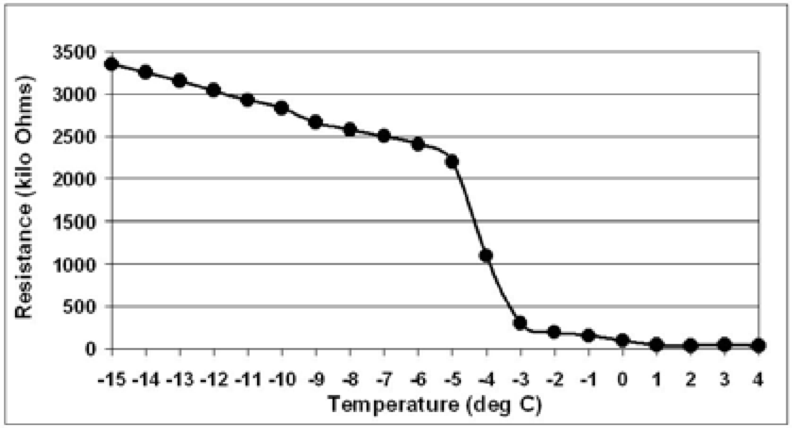


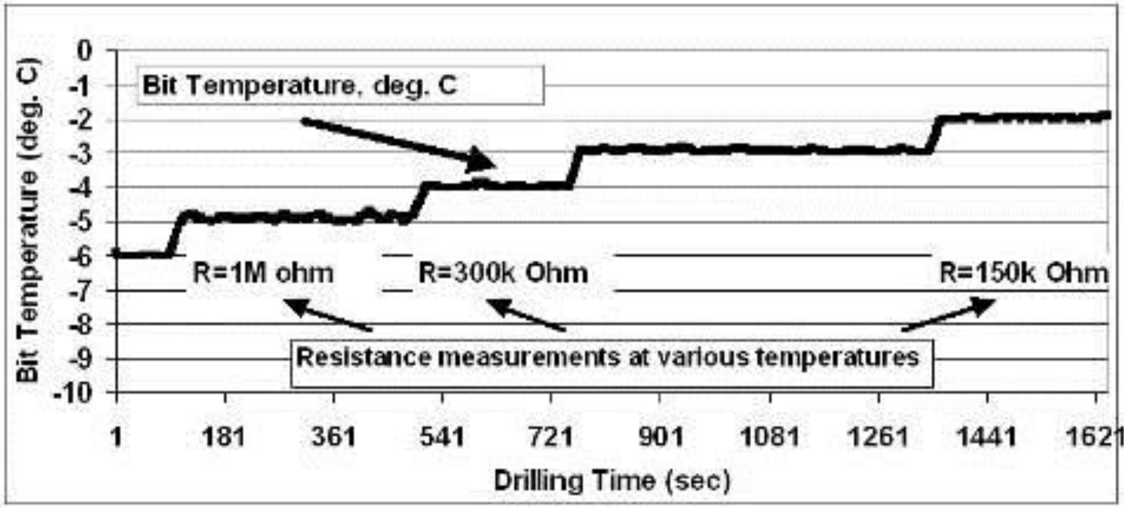
Dave Cole, CRREL

Temperature and Conductivity

- Thermal gradient
- Thermal conductivity (based on drilling power)
- Electrical Resistivity (onset of melting)







Acknowledgements

- NASA ASTEP and ASTID
- NASA PIDDP
- NASA SBIR

Thank You!

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