Sample Acquisition and Manipulation for Planetary Missions

4th International Planetary Probe Workshop
Pasadena, CA
29 June 2006

Stephen Gorevan

HONEYBEE ROBOTICS
Engineering the Future

Subsurface Access & Sampling

Overview | **Subsurface Access & Sampling** | Additional Technologies

Note: images not to scale

RAT Rock Abrasion Tool

TGSS Touch & Go Surface Sampler

Mini-Corer

GSFC Mole

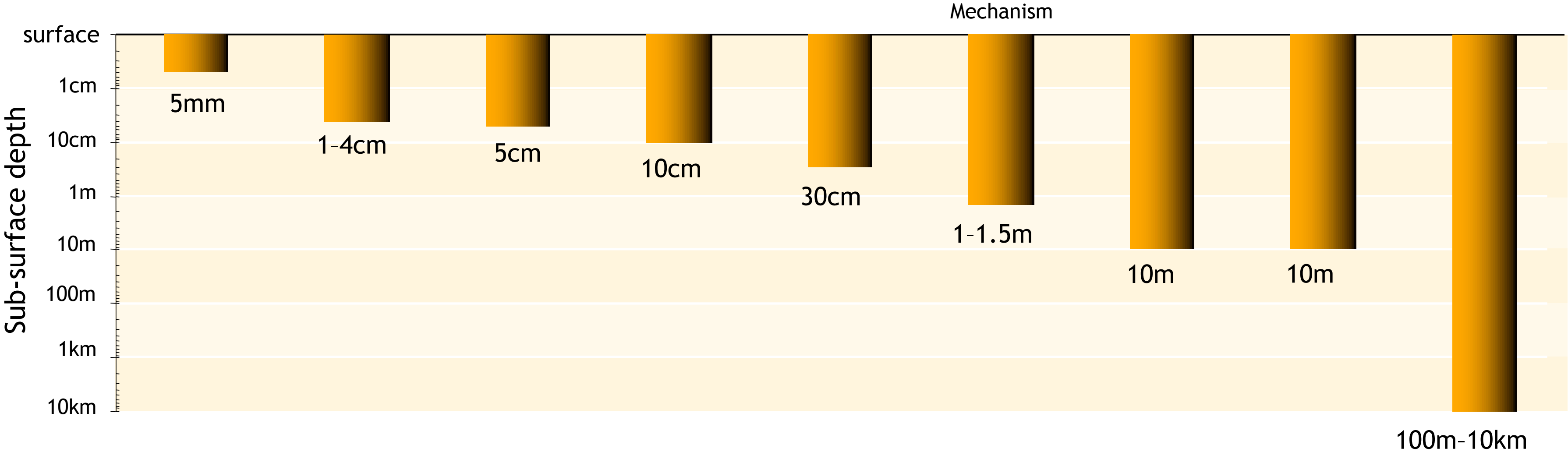
Sniffer Sampling and Gas Analyzer System

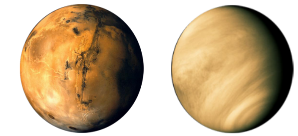
SATM Sample Acquisition & Transfer Mechanism

Telescoping Drill

Deep Drill

Inchworm Deep Subsurface Platform



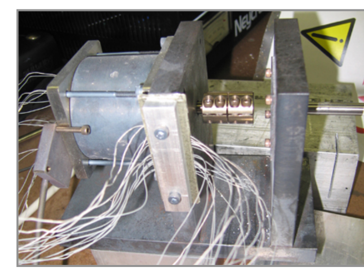


Venus Surface Exploration Enabling Technology Development
High Temp & Pressure Motor
1st use: Sampling System: HTPSS

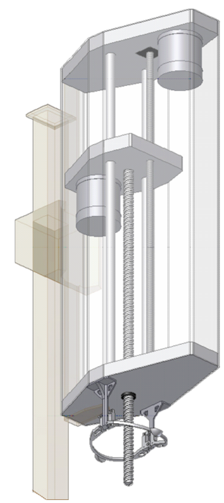
- Switched reluctance electric motor designed to operate at Venus surface conditions (460°C, 96 atm)
- No other motors currently available anywhere that function continuously at these temps
- Initially designed for heavy duty cycle drill motor.
- 1st prototype motor ran at 460°C under no load discontinuously for over two hours, and subsequently continued to function at ambient

Latest Test Results:

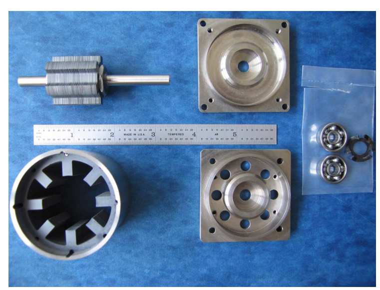
• motor was operated under load continuously for 1.5 hours in CO_2 filled, 460 deg. C environment and showed no significant change in performance



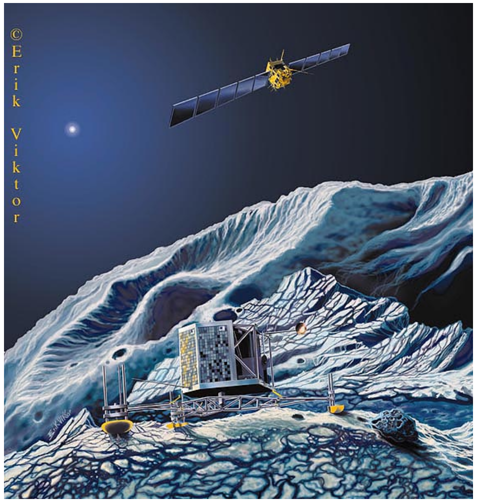
Motor and Test Fixture after testing

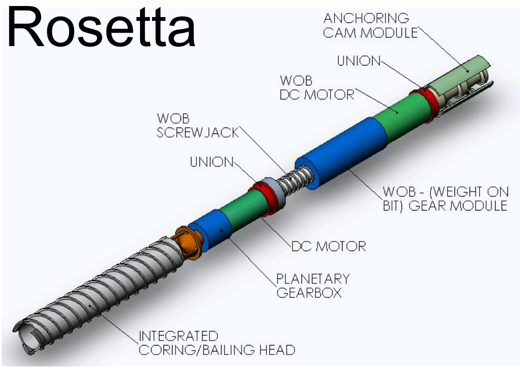


HTPSS Concept



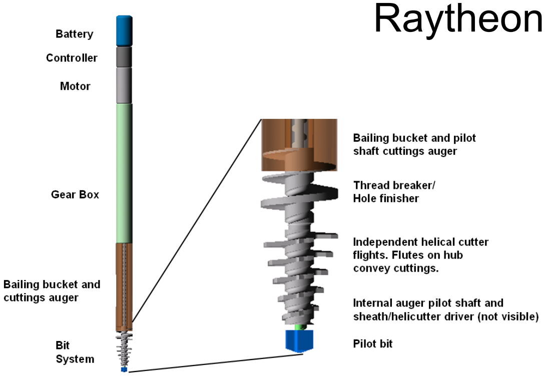
SRM Components

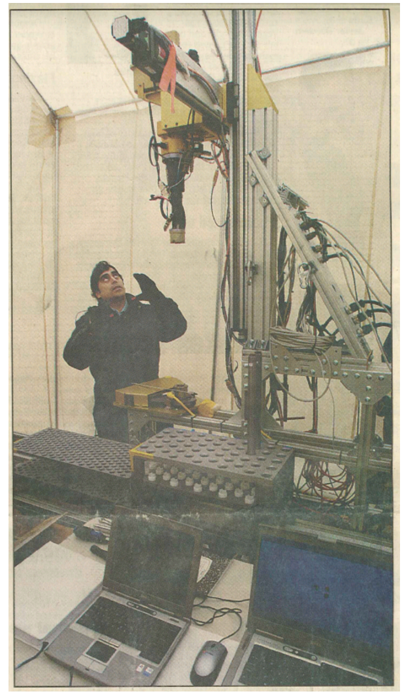




Rosetta

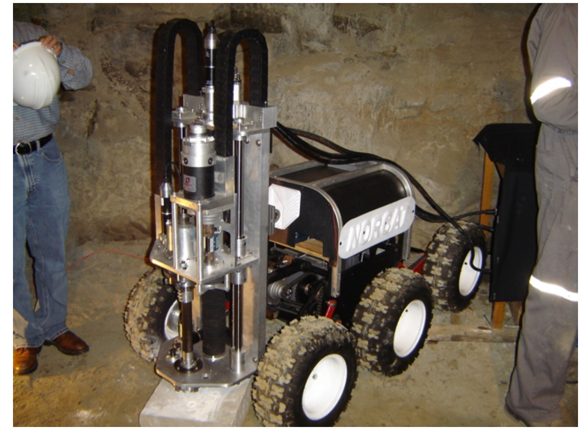
UTD
Raytheon





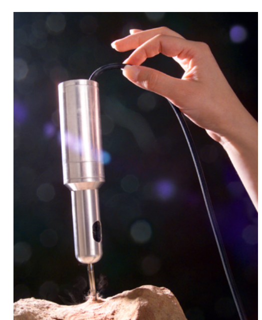
Swales

JPL Cryobot



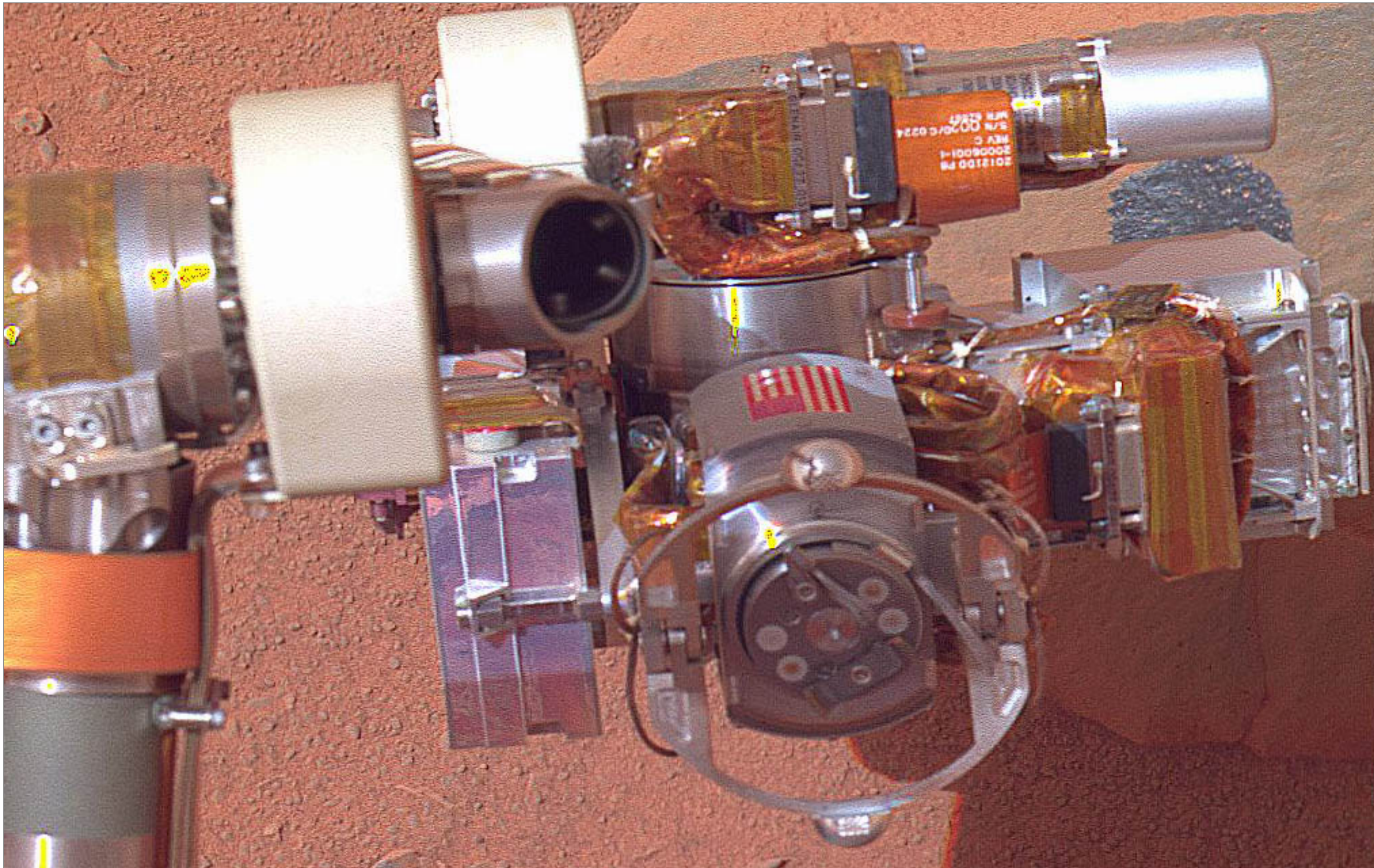
NORCAT

JSC - Baker Hughes



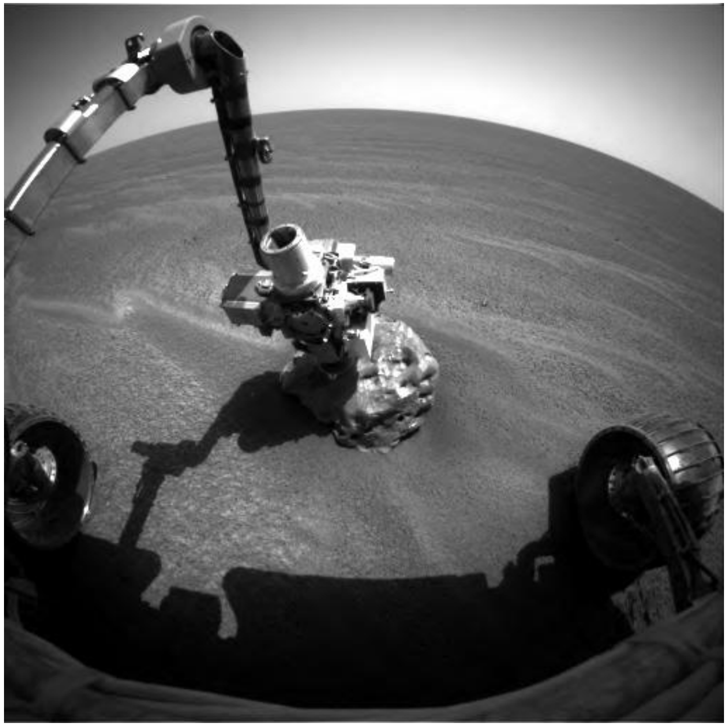
JPL
ultrasonic

The MER Rock Abrasion Tool

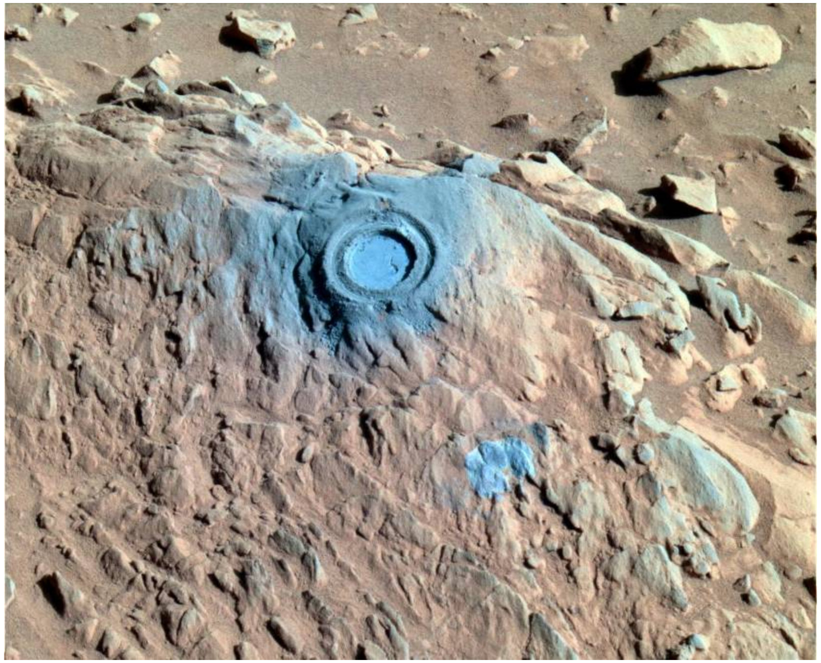


RAT Operation

- Targets selected to balance science desires, minimize surface curvature and roughness, and have enough area for placement
- After RAT calibration and initialization sequences, the IDD places and pre-loads the RAT
- Seek/scan routine finds highest rock surface, then brushing or grinding begins



Heatshield Rock



Uchben

Resource Usage

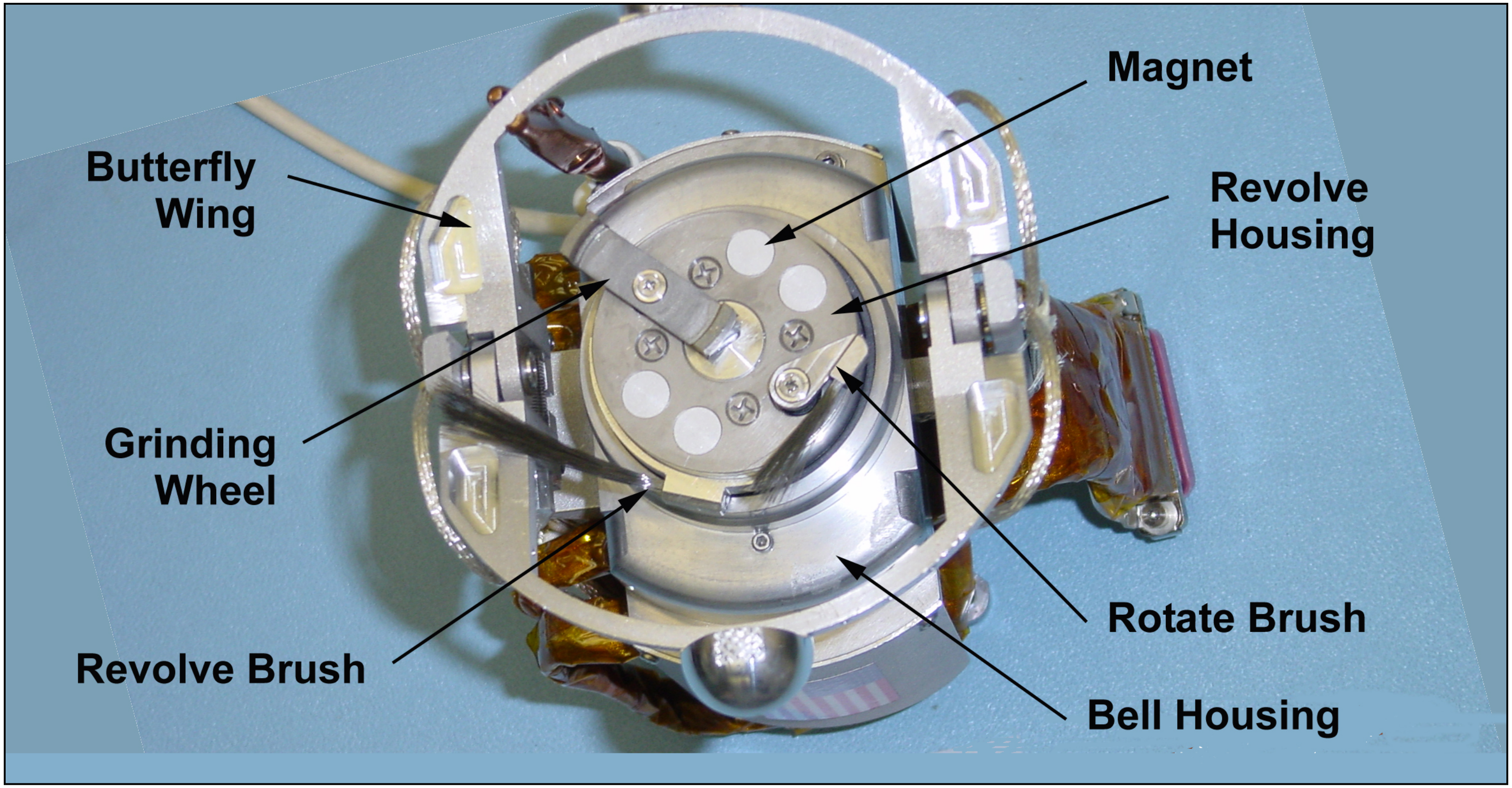
Resources required for a RAT grinding operation

•	Time:	~1.0 – 4.0 hrs
•	Power:	~ 34 W (≤ 10 W RAT, ~24 W Motor Control Boards)
•	Data:	< 3 Mbits / Hour of operation

Conditions required for a RAT grinding operation

•	IDD preload:	10 – 40 N	(sweeping)
		40 – 100 N	(grinding strong rock)
•	IDD placement:	0 – 15° off local surface normal	
•	Rock surface:	≥ ∅100 mm planar area	
		≤ 10 mm roughness in local planar area	

Bit and Brushes & Other RAT Elements



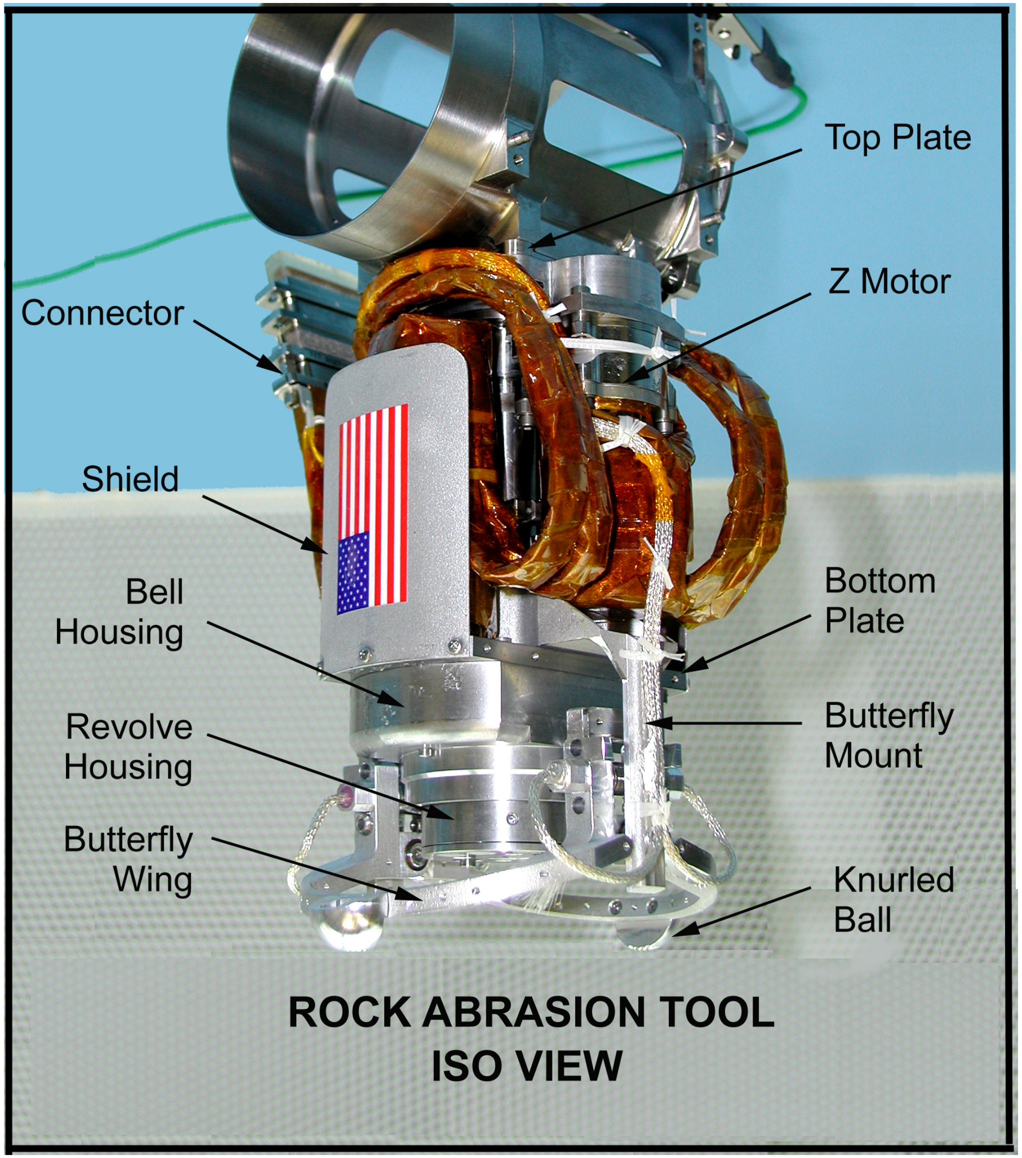
Grinding bits (Grind Wheel)

- Two resin grinding pads embedded with synthetic mono-crystalline diamonds (~ 0.1 mm diameter)
- Grinding bit is consumable
  - inherent to grinding process
- Grind disc diameter of 45.5 mm

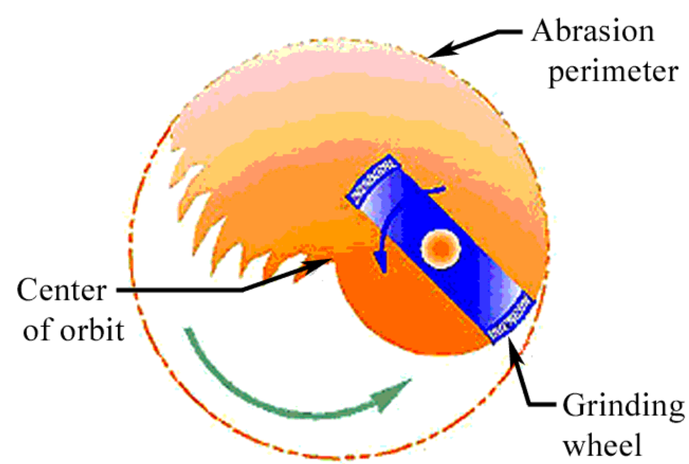
Brushes

- Rotate brush spins with bit
- Revolve brush sweeps perimeter
- Grind brush clears grind area, revolve brush pushes cuttings further away
- Brushes still effective, showing little wear

RAT Elements



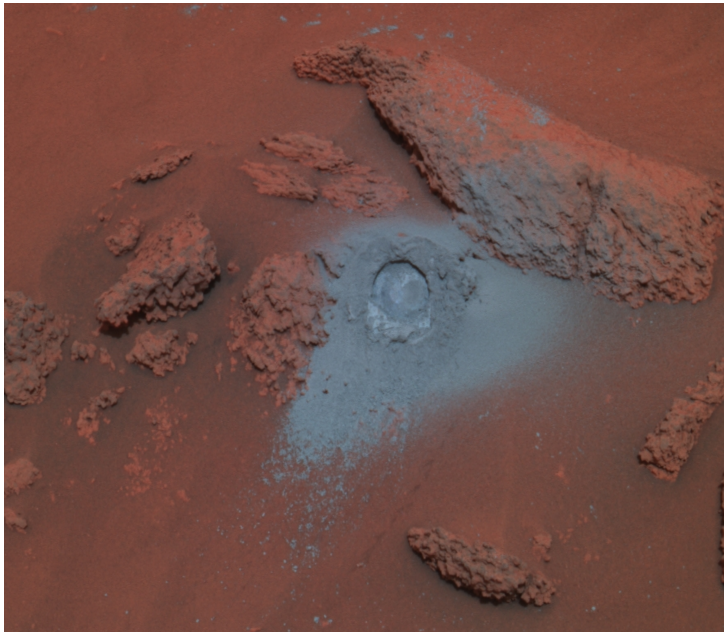
- 3 actuators
  - Rotate - bits about their centers ~3000 RPM *grind*
  - Revolve - bits about common center
    - ~1-2 RPM *orbit*
  - Z-axis – linear translation
    - ~0.025 mm/ step *plunge*
    - steps twice per revolution
- Control algorithm
  - Rotate axis runs open loop
  - Revolve axis closed loop reacting to current draw of Rotate motor i.e. torque on bit
  - Z axis open loop



Grinding

- 10 mm deepest grind

Peace

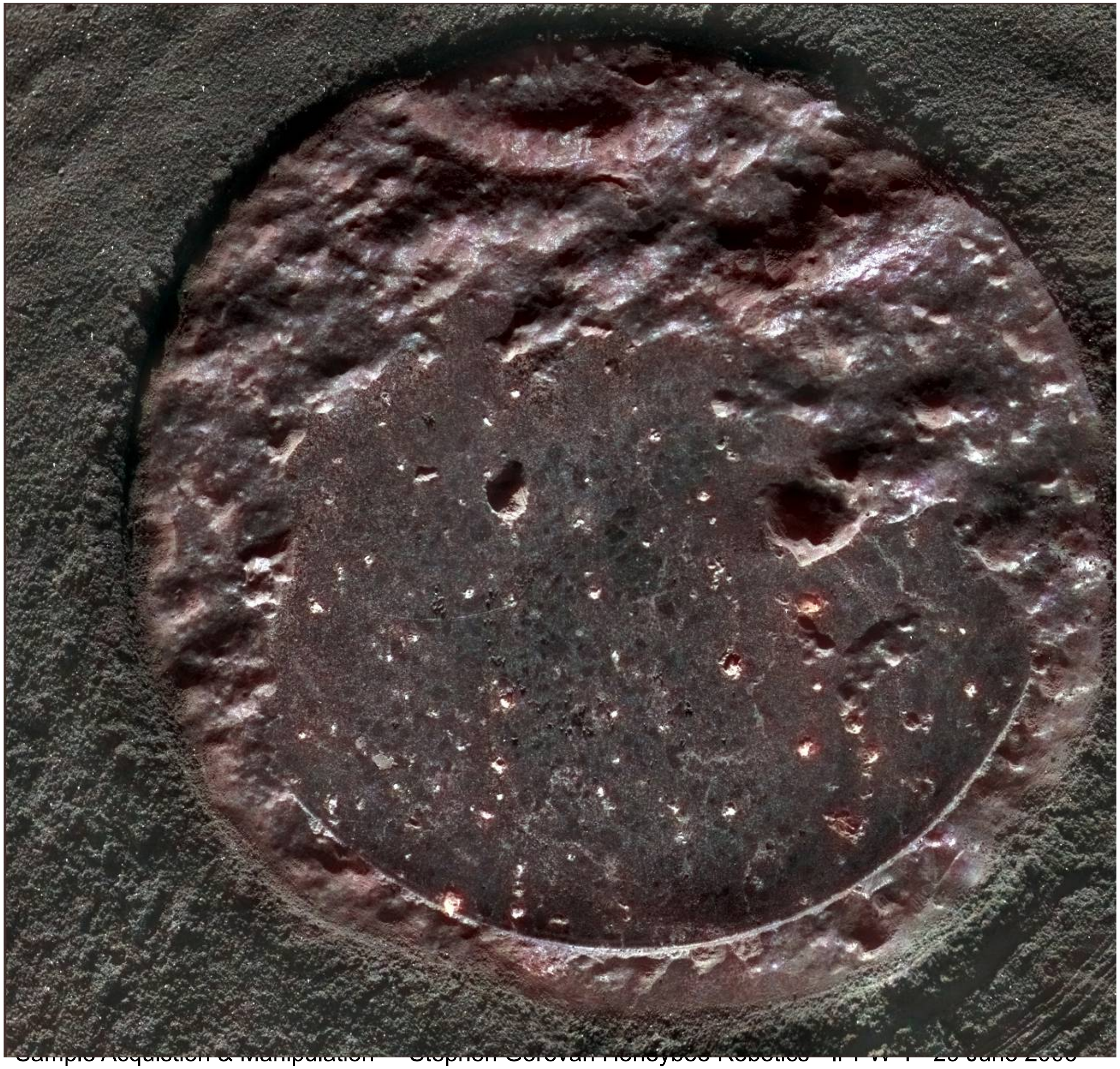


Bounce Rock

Layer D – London

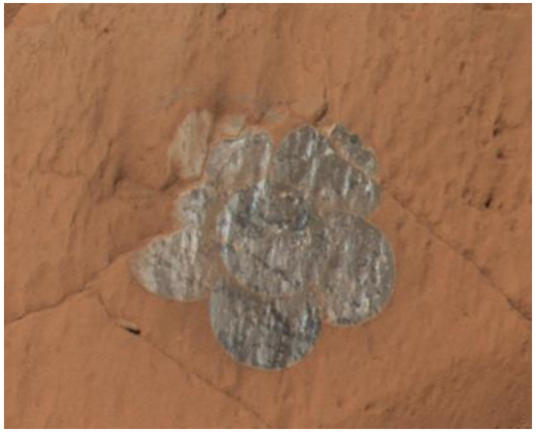
Curved Surface

RAT and Microscopic Imager
Target Humphrey



Brushing

- Brushing removes overlying surface material on target rocks
- Brush mosaics performed for Mini-TES observations
- Bristle wear has not been an issue
- Soil Brushing

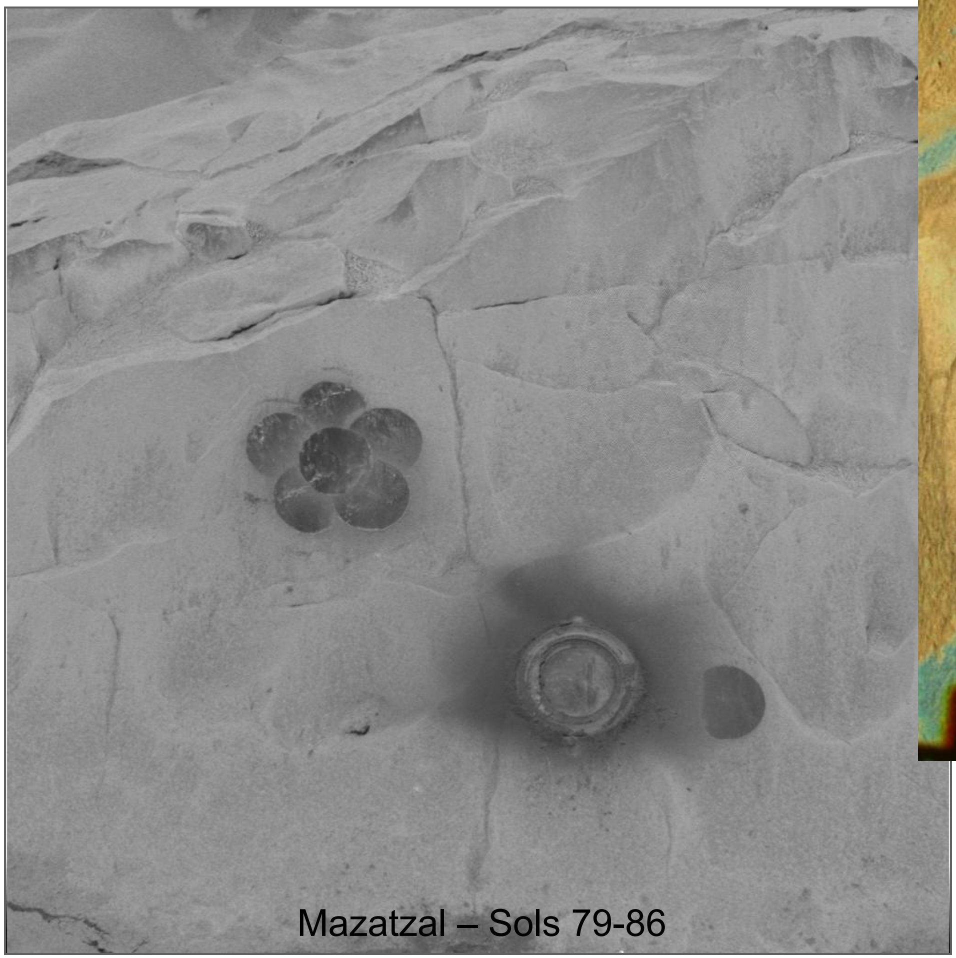


Route 66 - Soho

Berry bowl

Mazatzal - New York >>>

6 Brushings commanded to form mosaic for wide field of view Mini Tes



Mazatzal – Sols 79-86

Ebenezer – Sols 230-236

Current RAT Tally

29 June 2006

MER-A

Grinds: 15

Brushings: 71

MER-B

Grinds: 28

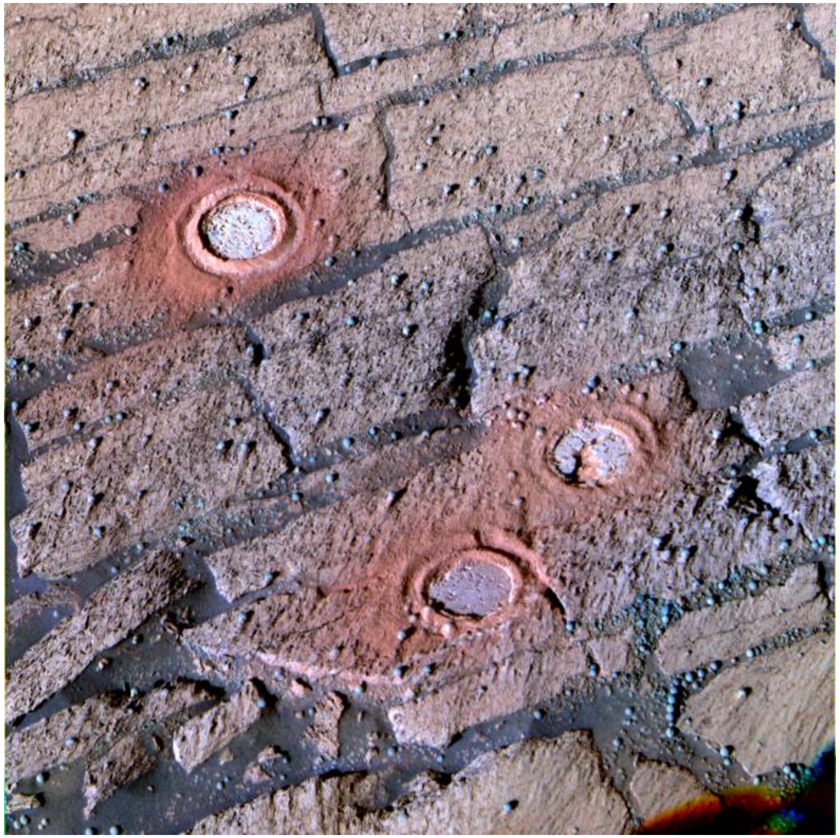
Brushings: 18

Total

Grinds: 43

Brushings: 89

Operations: 132



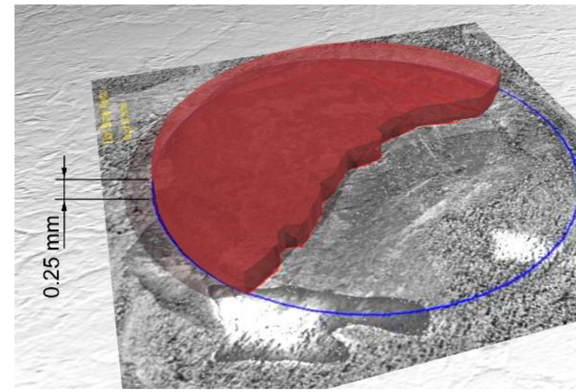
Calculation of Grind Energy

Energy to grind a given volume of rock

Specific Grind Energy [SGE] J/mm^3

- Energy expended by grinding
- Volume of rock removed

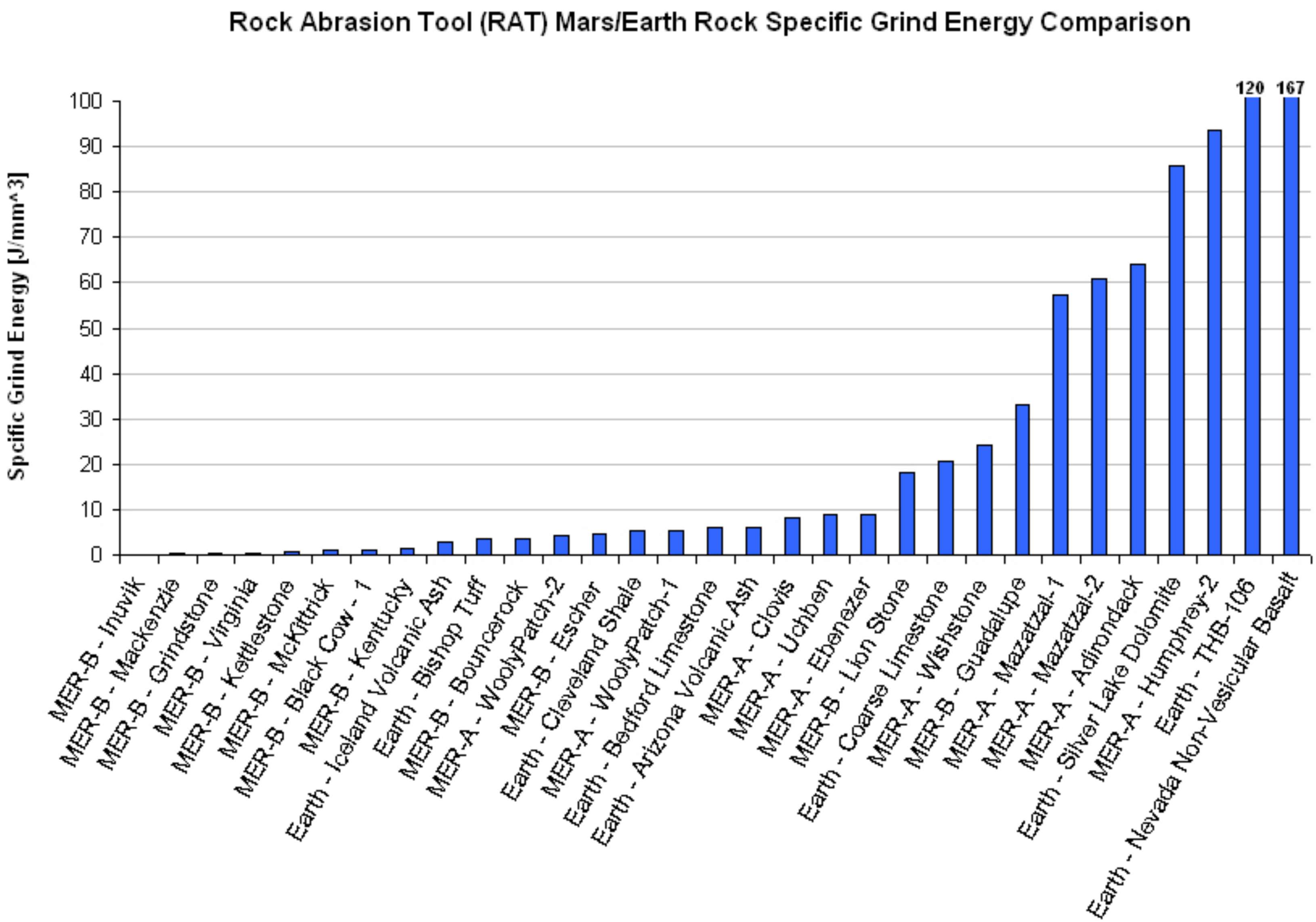
$$SGE = \frac{Energy}{Volume} = \frac{N\Delta t\left(\bar{I}_{grind} - I_{noload}\right)V_{grind}}{A_{abraded}\Delta Z}$$



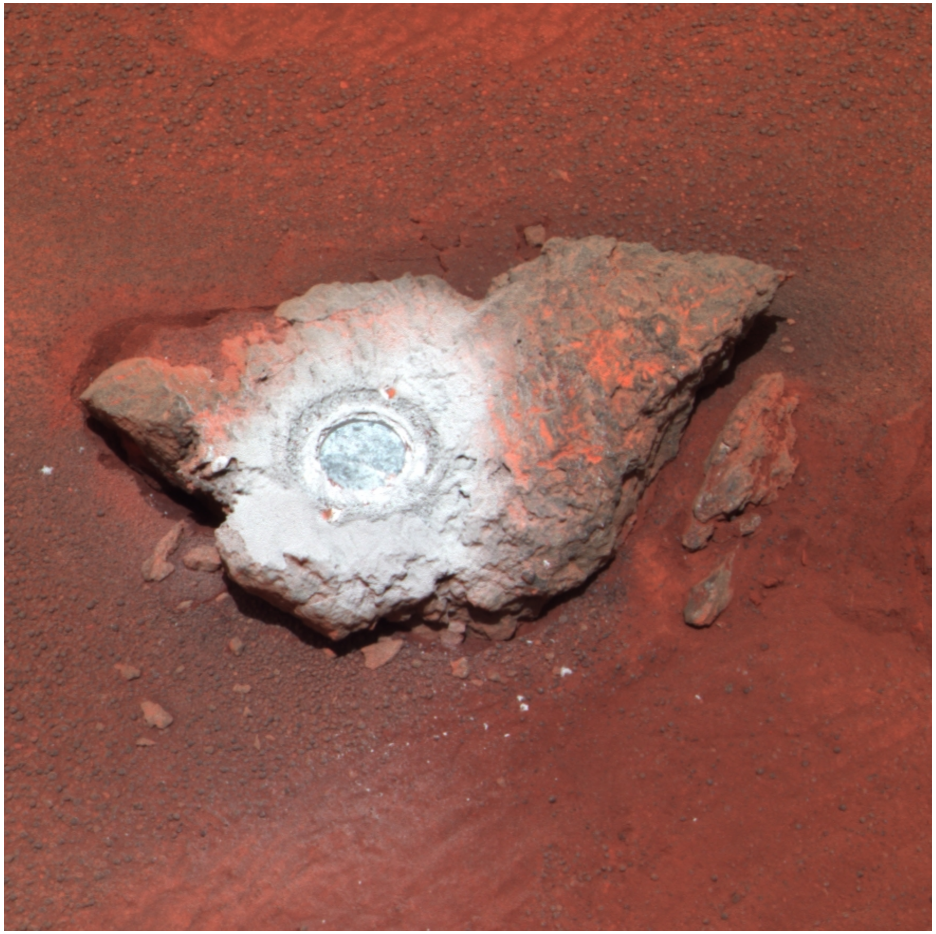
- N is the number of points in the data set,
- Δt is the sampling period,
- I_{grind} is the mean current drawn by the grind motor,
- I_{noload} is estimate of the current required to drive mechanism without load,
- V_{grind} is the mean voltage applied to the grind motor ($0.88V_{bus}$),
- $A_{abraded}$ is the grind area, and
- ΔZ is the overall change in depth across the data set.

- Interpretation
  - *Grindability* index vs. rock *hardness, strength*
- Calculated over last 0.25 mm of grind depth
- Grind area determined using MI mosaics
- No-load current taken from post-grind brush

Mars-Earth SGE Comparison



Notable RAT Targets – MER B



Bounce Rock – Sol 66

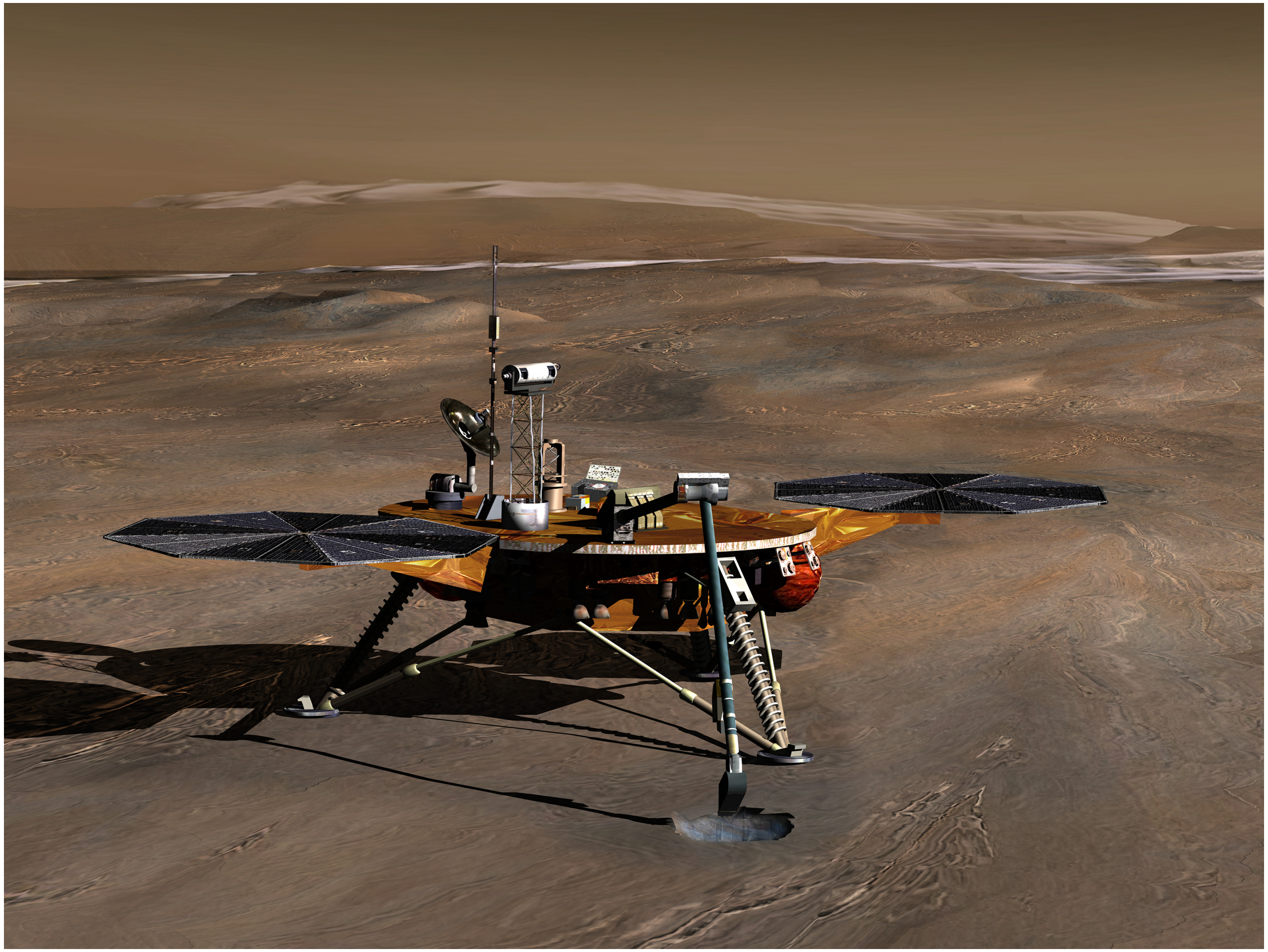
Bounce Rock Microscopic Imager Mosaic – Sol 66

Notable Targets – MER B

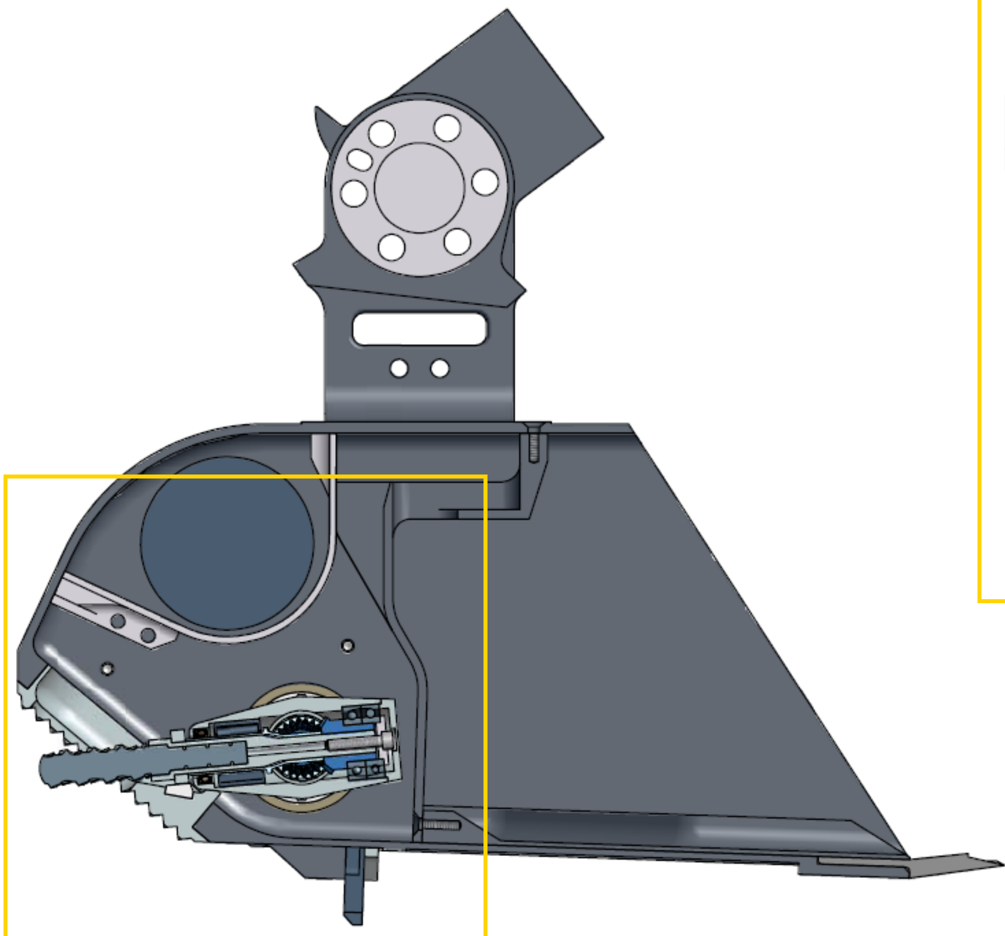
Eagle Crater - Guadalupe – Sol 34

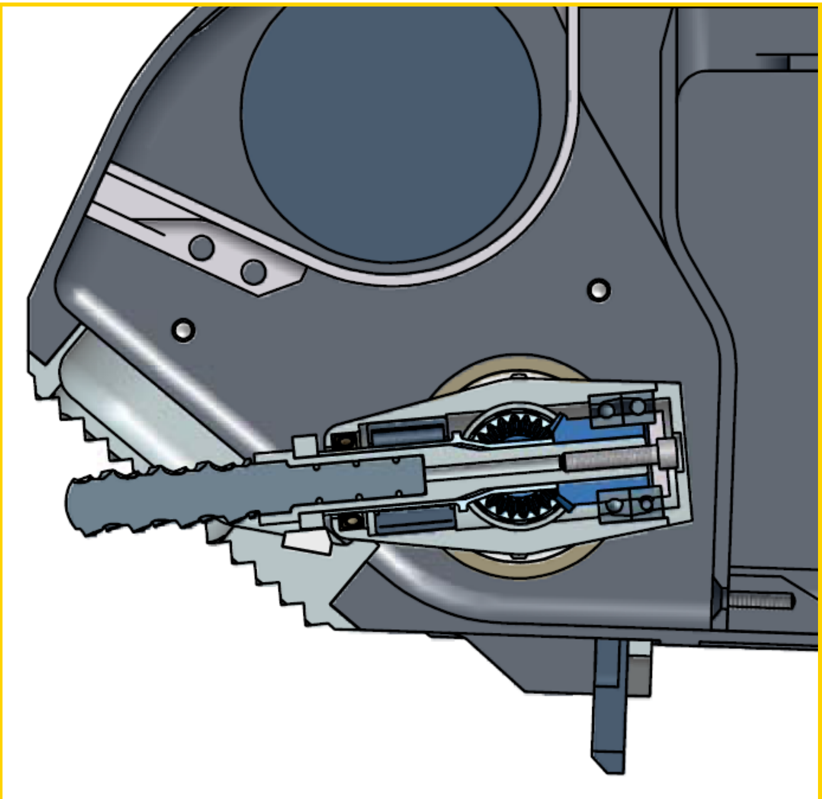
Endurance Crater Sols 143-148

Phoenix Scoop &
Icy Soil Acquisition Device

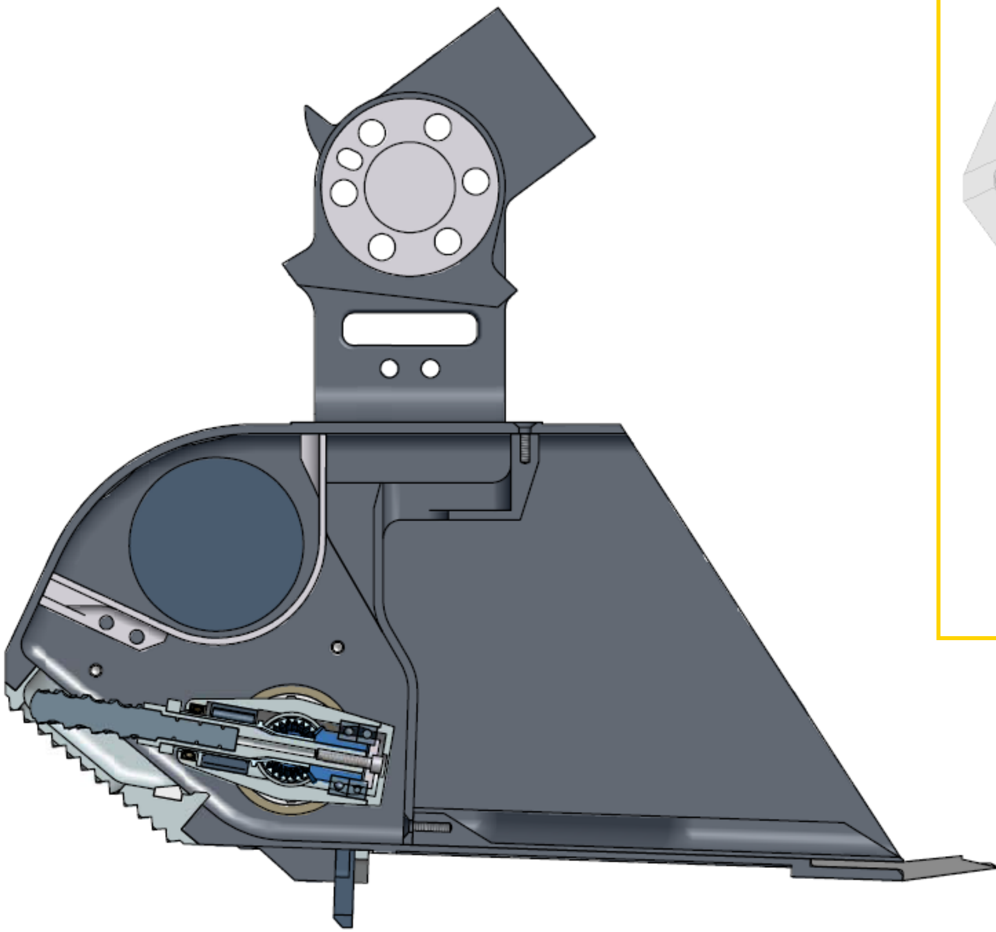


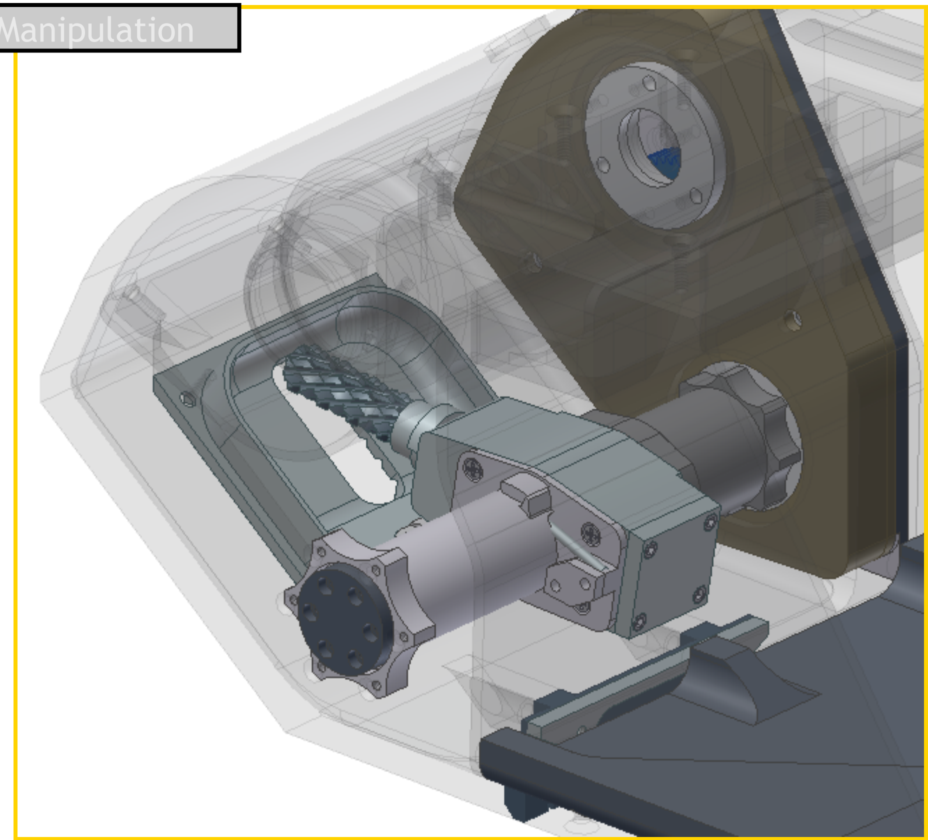
Rasp Bit Extended





Rasp Bit Retracted

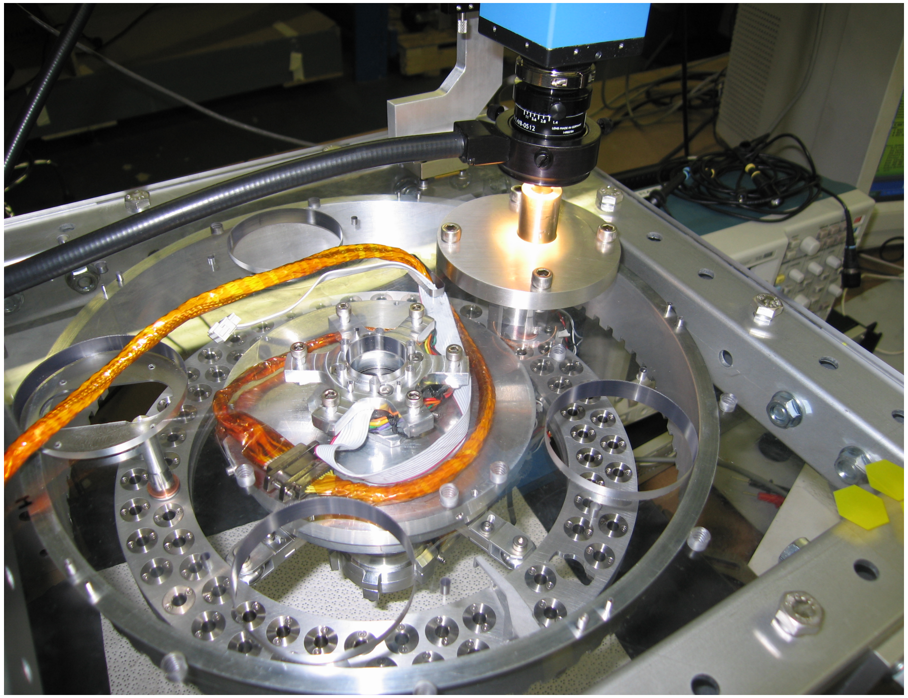




Sample Manipulation, Transport and Processing

Sample Manipulation System

- Automated, precision sample handling and distribution system
- Two axes, 3 degrees of freedom
- 74 sample reuseable cups or cells
- System is capable of hermetically sealing a sample cell in a pyrolysis oven
- for MSL's Sample Analysis at Mars (SAM) PI: Paul Mahaffy NASA GSFC



SMS

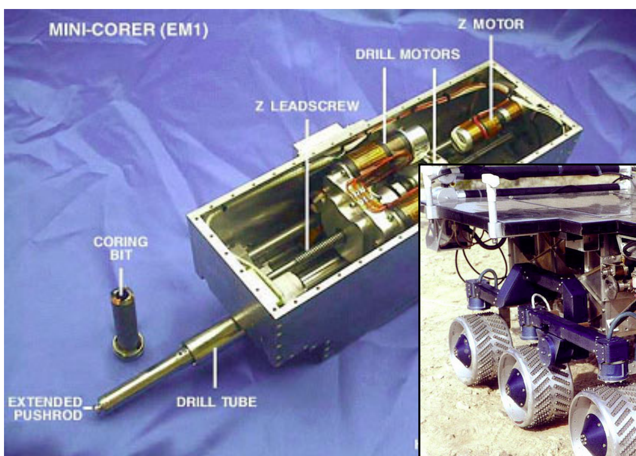
Mini-Corer & Mars Technology Program: Corer/Abrader

Mars Sample Return Mini-Corer

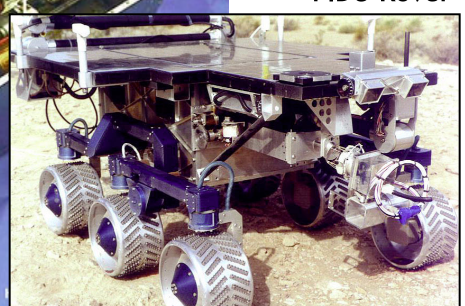
- Core acquisition and transfer system
- Acquires cores 2.5 cm in length and 0.8 cm in diameter
- 6 minutes of drilling per core
- Power consumption ~ 3 W-hr per core
- Mass = 2.7 kg
- Technology Readiness Level (TRL) 5/6

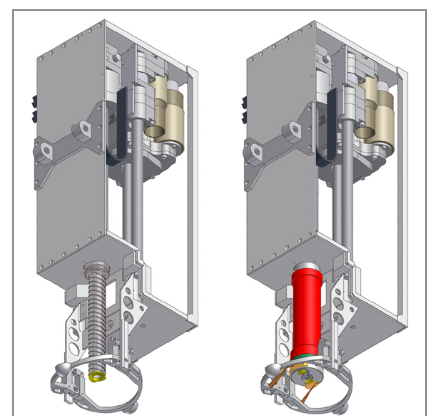
Mars Technology Program Corer/Abrader

- A combined coring and abrading tool
- Enhanced performance to that of the RAT and Mini-Corer
- Includes bit change-out capability
- Development funded under Mars Technology Program.
- Brassboard delivered to JPL in March 2006

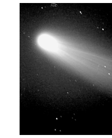


Mini-Corer on JPL FIDO Rover



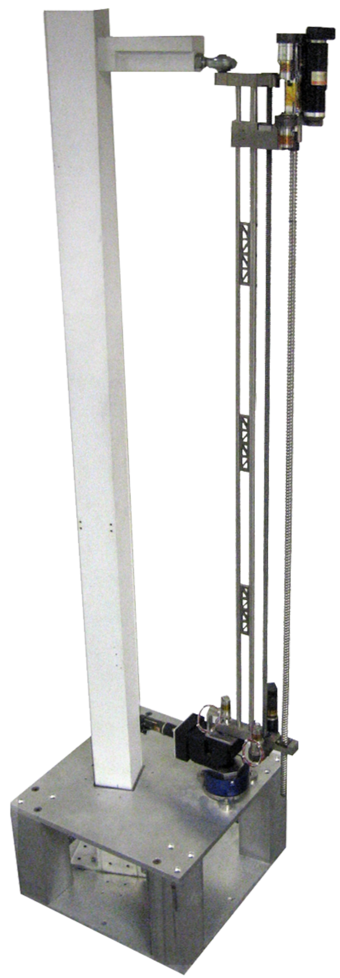


One Meter Class Robotic Drilling and Sample Acquisition Systems



current	Subsurface Access & Sampling	Sample Manipulation

- ST4/Champollion Comet Sample Return Mission
- Mass < 10 kg
- 1.2-meter drilling stroke; 13-mm drill string diameter
- Power consumption: 25 W-hr
- Drill Rate: 1 cm/min (40 MPa material)
- Acquires locally mixed powder sample (up to 0.1 cc)
- TRL 5



Cryogenic testing

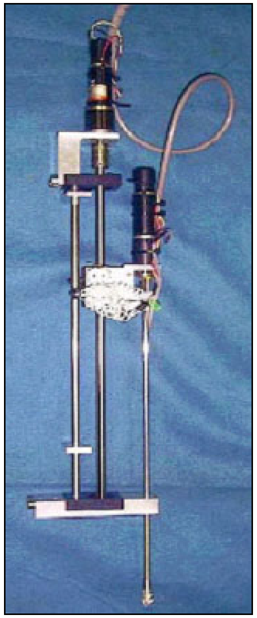
SATM Prototype Drilling into chalk

ST4/Champollion Mission Concept
Image courtesy of NASA/JPL

Survey Sampling
The 'Sniffer'

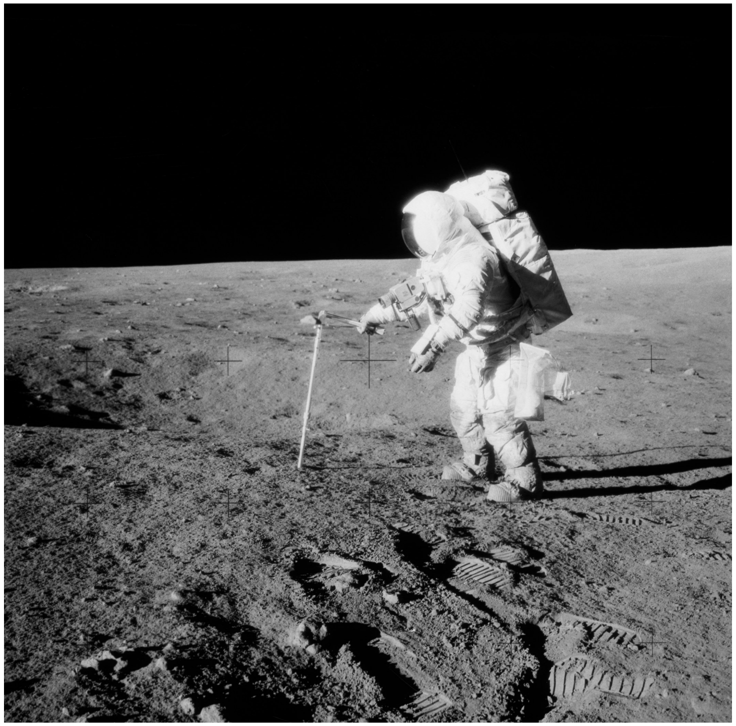
- In situ sampling drill and gas analyzer system
- 30 cm drill depth
- Door opens in drill tip exposing a gas permeable ceramic with a heating element to drill cuttings.
- Gases travel through a flex tube mounted on the drill string up to a mass spectrometer on the rover
- Since no samples are brought back to the surface, this allows for drilling with a very narrow bit diameter which translates into fast, low power and low force-torque

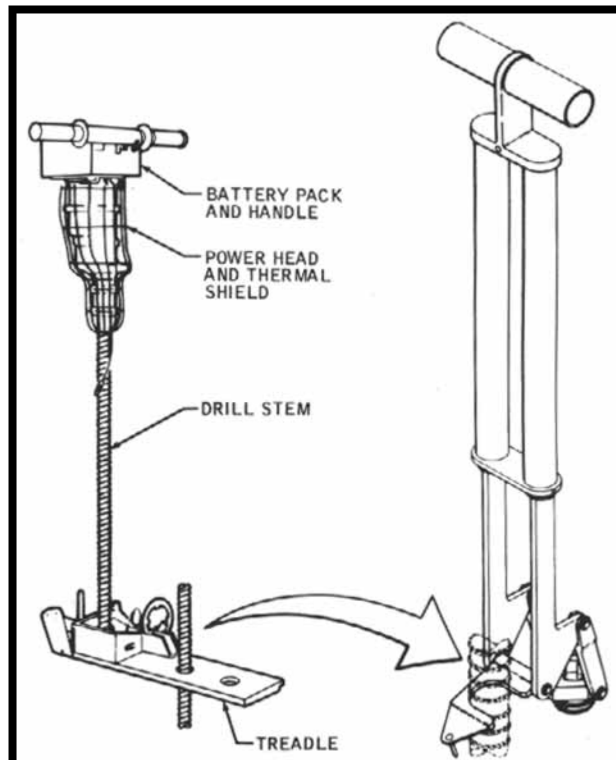
Sniffer drilling from rover mock-up

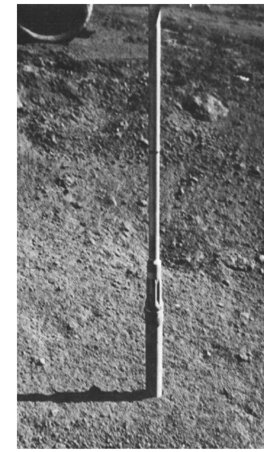


Sniffer Breadboard

Developed under PIDDP funding for GSFC
By Honeybee Robotics




BATTERY PACK
AND HANDLE
POWER HEAD
AND THERMAL
SHIELD
DRILL STEM
TREADLE



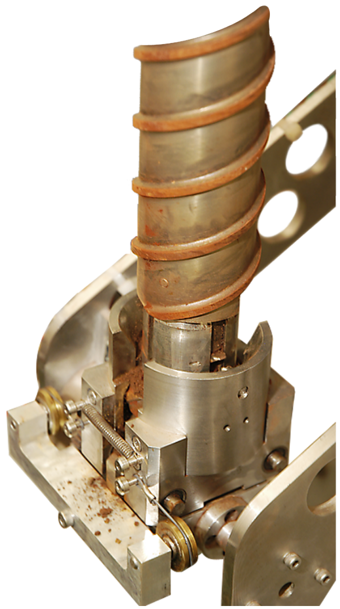
MARTE & DAME

10 meter class drills

NASA Ames
Honeybee Robotics Hardware Support

Mars Analog Research and Technology Experiment (MARTE)

- Employs autonomous connection of drill string segments and core transfer
- Allows for electrical and data transfer across interface, allowing imbedded instrumentation
- Capable of taking continuous core samples (27 mm diameter, 25 cm length) down to 10 meters
- Field Tested in Northern California in 2005, and tested in Rio Tinto, Spain in 2006



MARTE drill system during testing in Rio Tinto

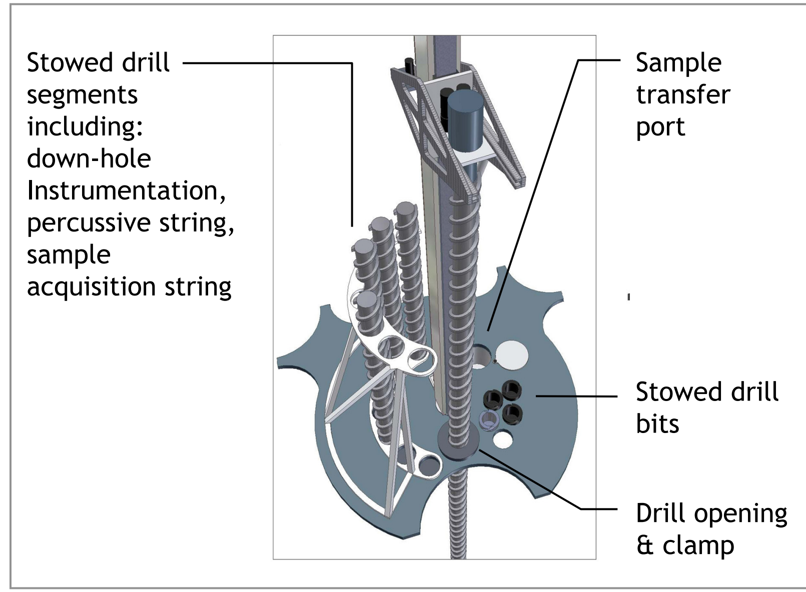
Drilling Automation for Mars Exploration (DAME)

- Similar in design to 10-Meter Deep Drill, MARTE
- Focus on autonomous drill control and diagnostics, down-hole sensing, bit development
- First Mars analog drill field tested in permafrost in Canadian Arctic in 2004
- New iteration prototype recently tested at Devon Island

DAME Drill being tested in the Arctic

10 meter class robotic drilling and sample manipulation for Construction Resource Utilization eXplorer S(CRUX)

- Testbed for development of lunar drill technology, funded by NASA H&RT
- Autonomous subsurface access & sample handling subsystem design based on DAME/MARTE systems
  - Multi-meter drilling and sample acquisition system
  - Downhole instrumentation/ sensing and sample return capability for gathering engineering data
  - Drill string connection and change-out capability
- Testing in lunar regolith simulant to several meters depth in lunar cold regions simulated environment.



Bit and Drill String Change-out Early Concept Schematic

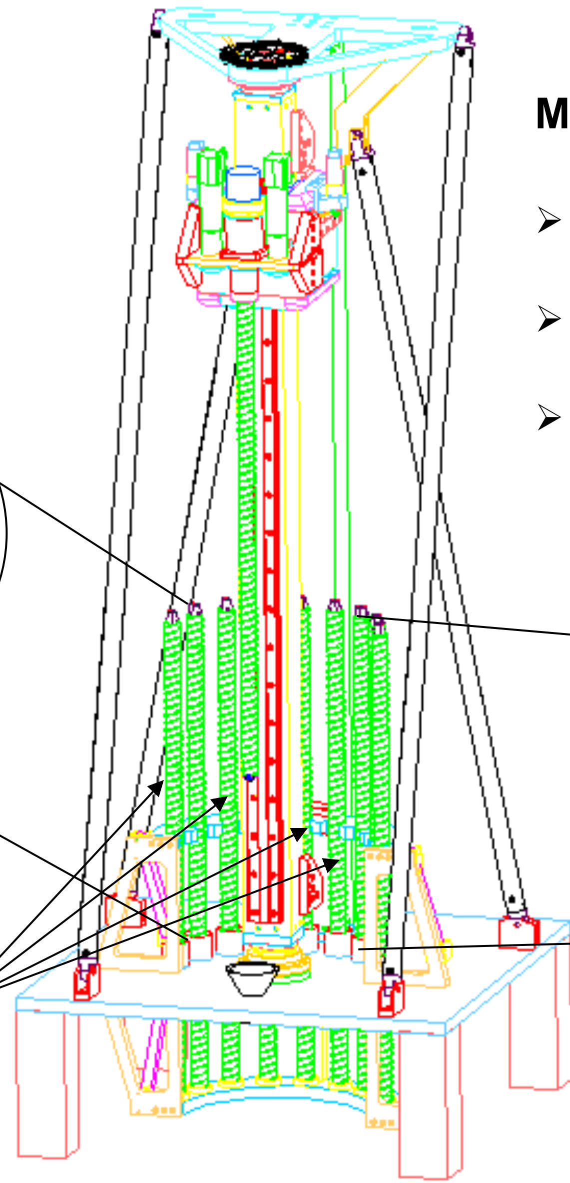
1st Generation Lunar Drill Bit and Auger Development Station

Coring in Icy Lunar Simulant

Borehole Science Approach

Multi-segment Borehole Science

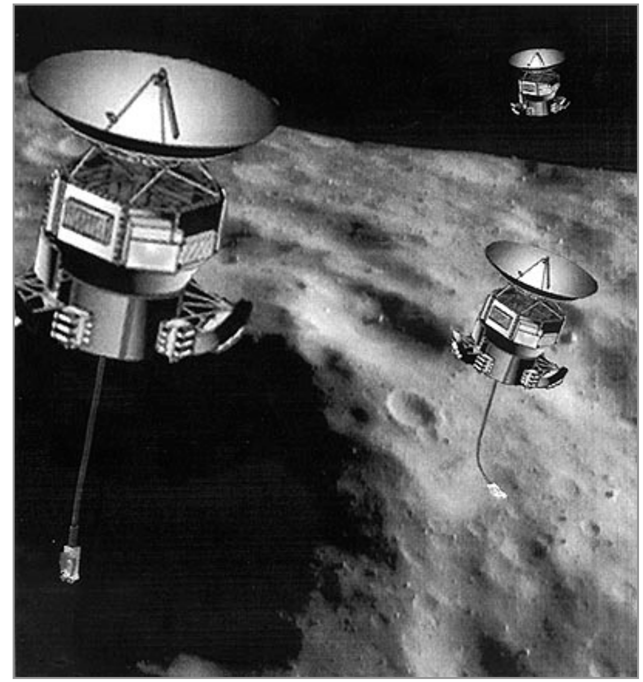
- Large volume in drill string available
- Power & Data available down the hole
- Individual instrumented drill segments selectively chosen based on site specifics



Mars Odyssey heritage spectrometer at installation

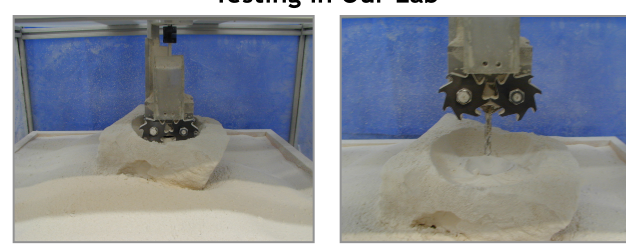
Touch and Go Surface Sample Acquisition (TGSS) (& Aerobot Harpoon)

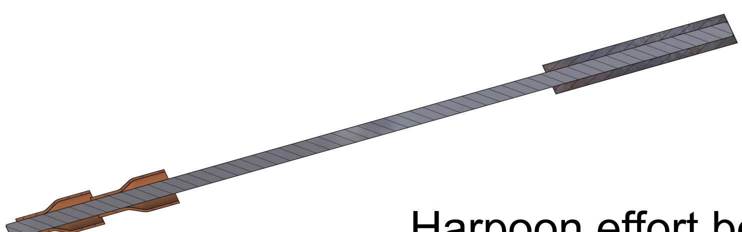
- TGSS Allows for "sloppy" touch and go subsurface access
- Designed for Titan aerobot. Mars ballon or small body spacecraft boom deployment
- High speed cutters (5,000—8,000 RPM) capable of collecting a sample at 30 cm3/sec in unconsolidated rock and 30 cm3/min in competent material
- Highly scalable (size, mass, sample volume)
- TRL 5



TGGS Space Deployment

Testing in Our Lab

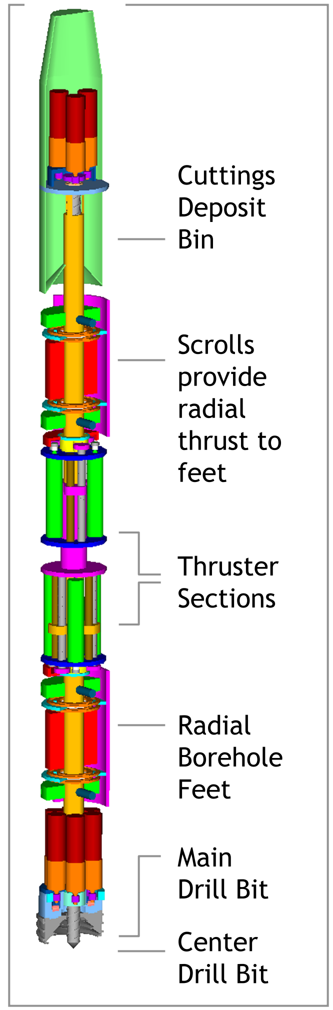


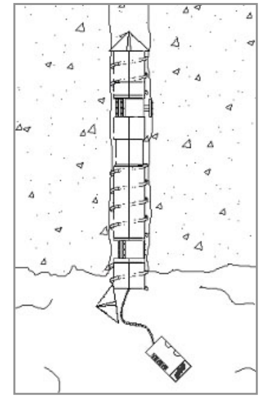


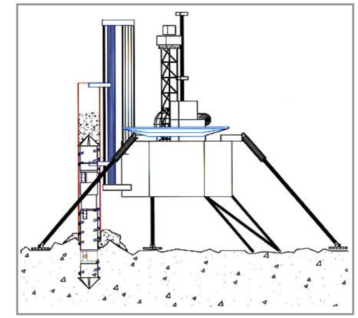
Harpoon effort beginning (NASA SBIR)

R&D directed toward breakthroughs:
Inchworm Deep Drilling System (IDDS) Mini-IDDS

- Compact, novel access technology capable of accessing deep, subsurface regions
- Semi-autonomous robotic device employs inchworm motion for movement in borehole
- “Launch tube” deployment from lander or mobile platform
- Targets include ice environments (Europa) and Mars subsurface – (100 m) consolidated soil, rock, and permafrost
- Long-range goal is a fully self-contained system achieving 1-km drill depth, constituting a revolutionary breakthrough in subsurface access







Early concept depictions

IDDS
7’ long, 4.25” dia

Mini-IDDS
7’ long, 1.89” dia