The *In Situ* Rock Thin Section Instrument for Space Exploration

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Team and History

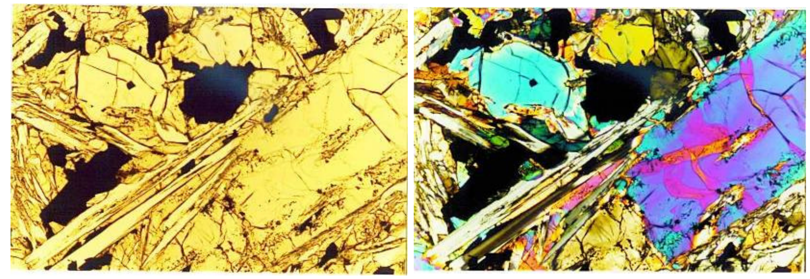
- CSM 2005 Senior Design Project initiated by Mike Duke
- PIDDP 2006-2009 CSM and Honeybee Robotics
- R. C. Anderson, JPL – developed a TRL 3 thin section device on JPL RTD funding

- NOW

  CSM, Honeybee and JPL (Anderson) working together to take it to the next level

- Why rock thin sections?

  A powerful tool for understanding the origin and evolution of rocks.



Apollo 12 Lunar Basalt – reflected light and cross polarizer transmitted light

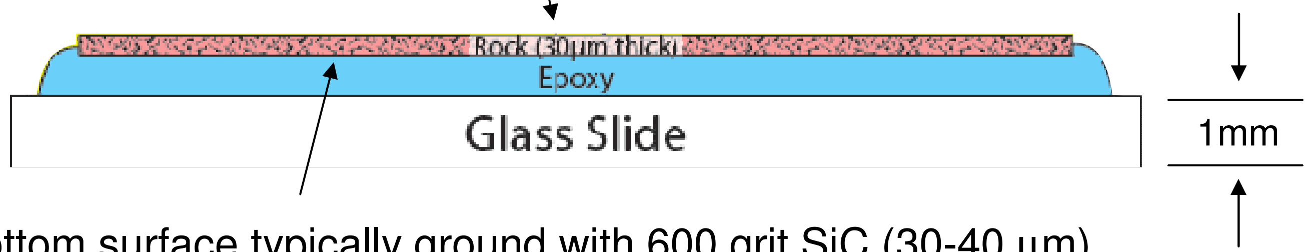
- Thin Sections are ubiquitous in geological sciences and engineering

  Used to identify minerals, size, shape, weathering, voids, associations…

For Use in Space Resources – **Prospecting Tool**

What is a thin section? (Polished Thin Section)

Top surface typically ground with <1 μm particles (diamond or Al_2O_3)



Bottom surface typically ground with 600 grit SiC (30-40 μm)

<u>Key attributes</u>

1. 30 μm thick
2. Flat – varies by << 30 microns
3. Polished surfaces

   Top < 0.2 μm Ra

   Bottom ~ 1 μm Ra

Terrestrial Labs

Step 1. Selecting an appropriate rock specimen.

Step 2. Cutting of a rock to an appropriate shape and size: a tablet ~26mm wide x 46mm long x 5mm thick.

Step 3. Grinding the tablets' 26mmx46mm surface to remove any saw or wire cutter marks

Step 4. Epoxy the rock tablet ground surface to a glass slide

Step 5. Grinding the tablets top (free) surface it to a required thickness (~30 micron), polishing it to a required surface roughness (0.1 micron)

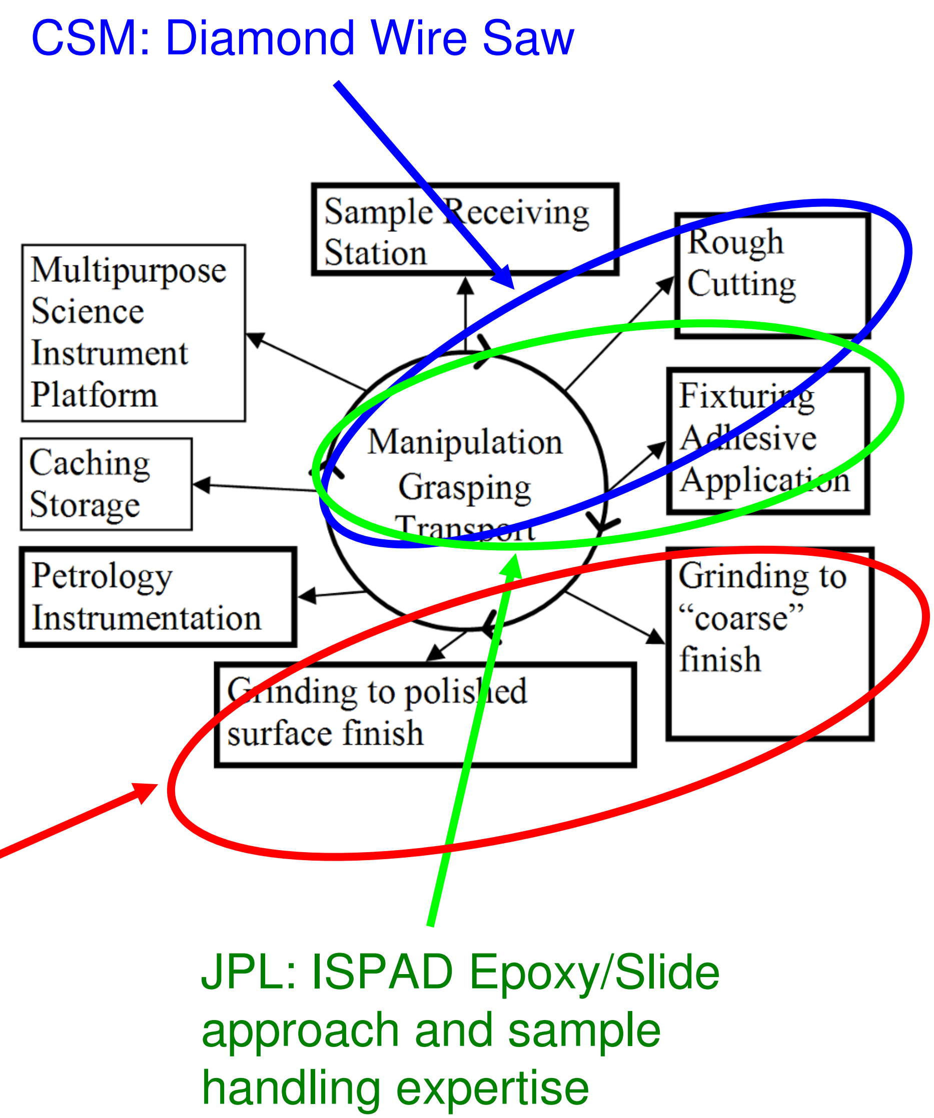
Step 6. Viewing the thin section under reflected and transmitted light

Take it to Space

Major Hurtles

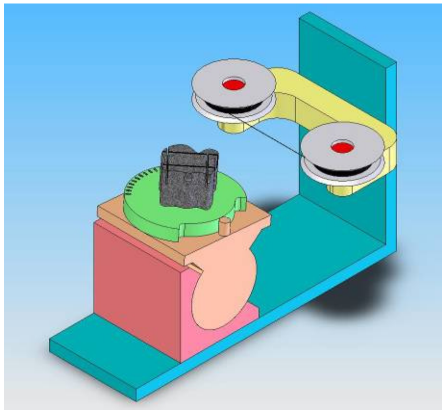
- Cutting of an irregular sample to a workable size and shape
- Fixturing of the sample
- Grinding and polishing of cut sample to finished thin section.

- Reduction or elimination of consumables normally used.
- All grinding, cutting and polishing to be done DRY
- Reduce and measure wear of surfaces



Rough cutting

<u>Diamond Wire vs. Cutting Wheel for Tablet Generation</u>



<u>Diamond Wire Pros</u>:

- Small Cut Volume (kerf) → reduced dust generation and thermal stress
- Low applied cutting force → reduce gripping requirements, lower power
- Flat and smooth surface
- Cut orthogonal planes

<u>Diamond Wire Cons</u>:

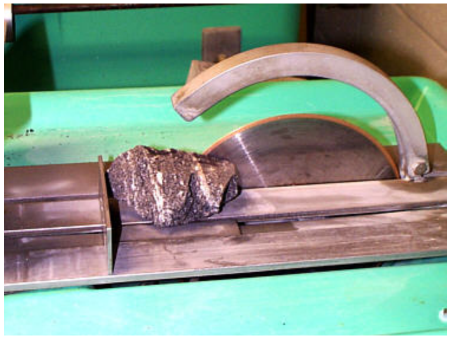
- Requires instrumentation to control cutting.
- Possibility of wire breakage

<u>Cutting Wheel Pros</u>:

- Higher total volume of cutting media.
- Simpler control (only contact force required)

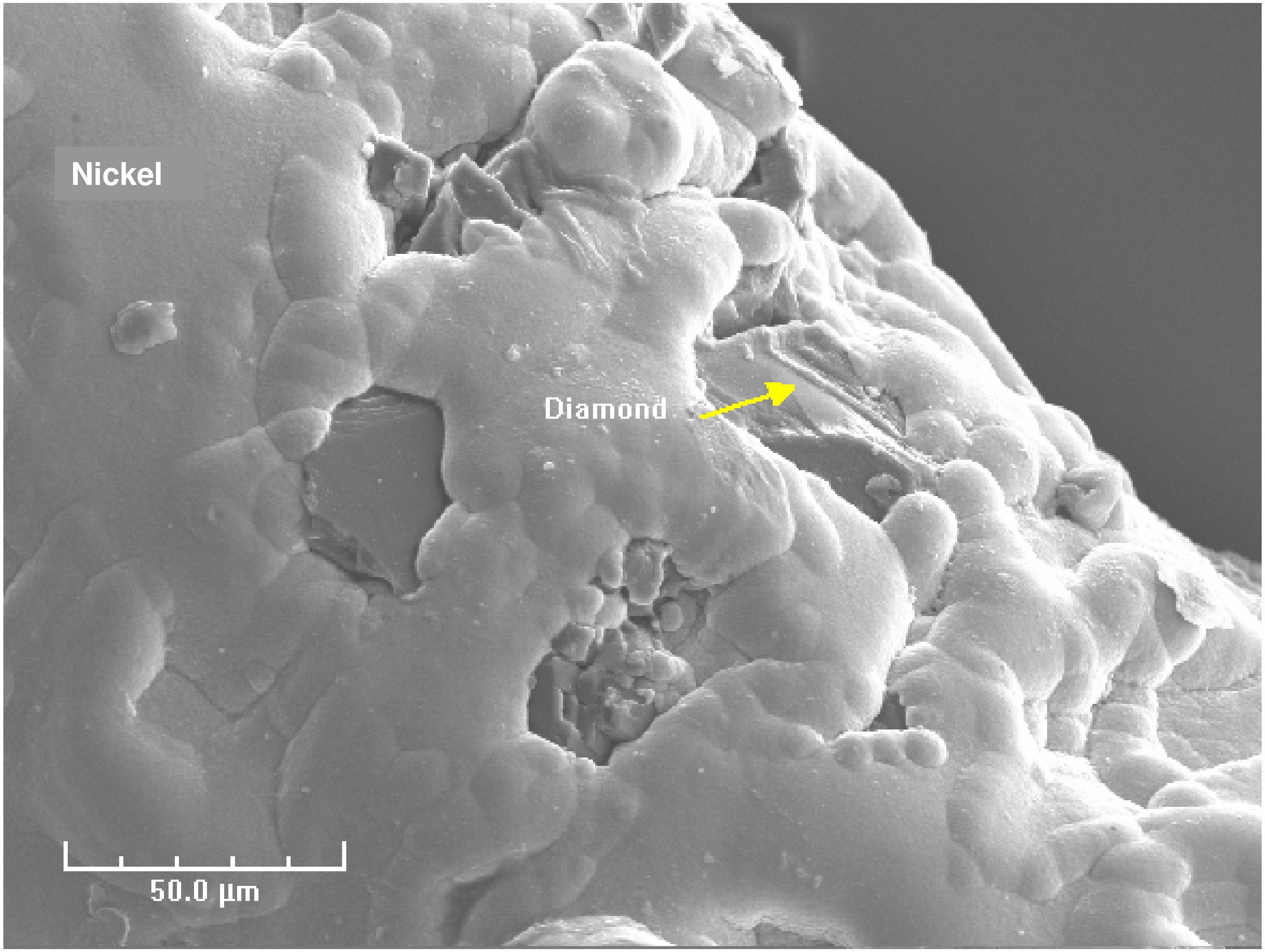
<u>Cutting Wheel Cons</u>:

- Higher power requirements.
- Larger kerf → more dust generation, more heating during cutting.
- Requires more degrees-of-freedom to cut in multiple planes, relative to wire.
- Wheel diameter determines size of sample that can be cut



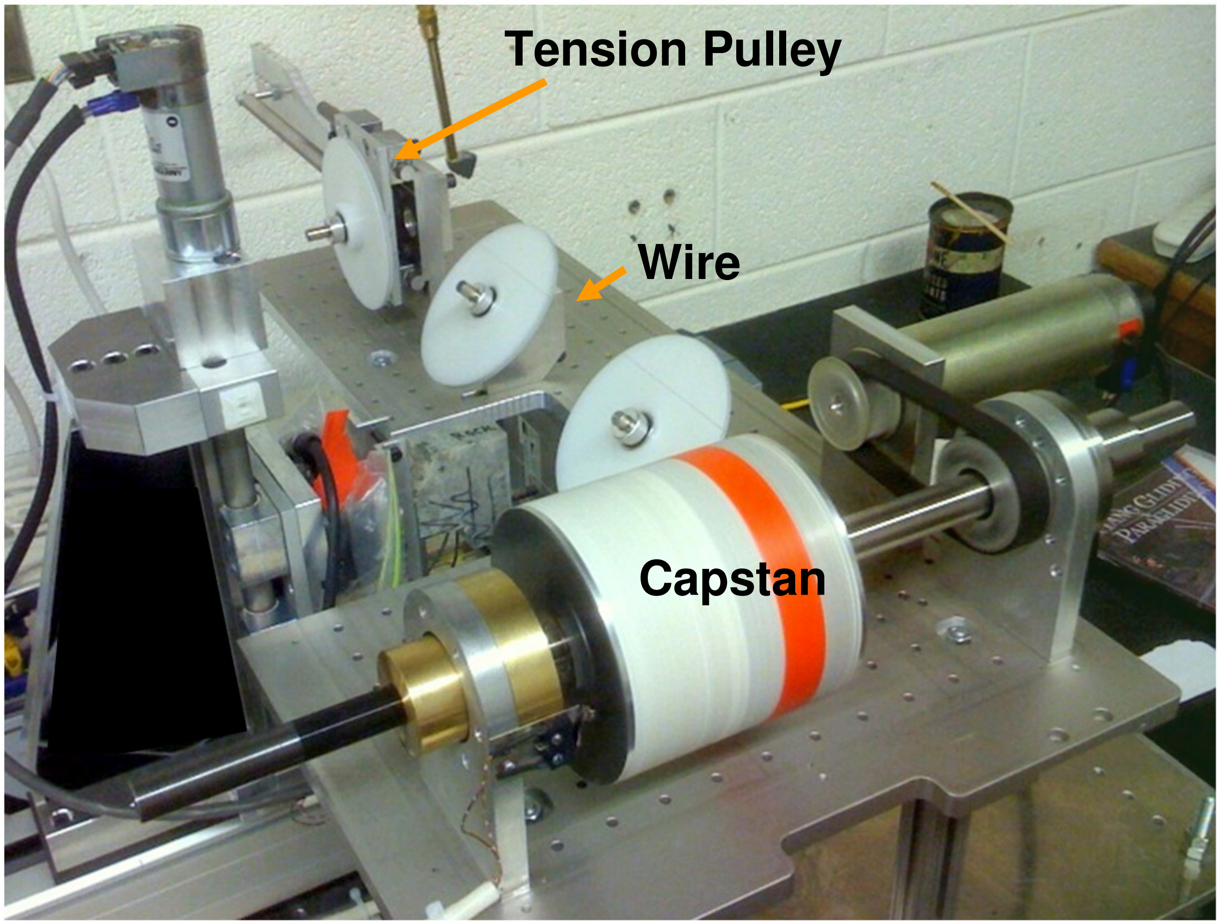
Diamond Wire

Diamond Wire

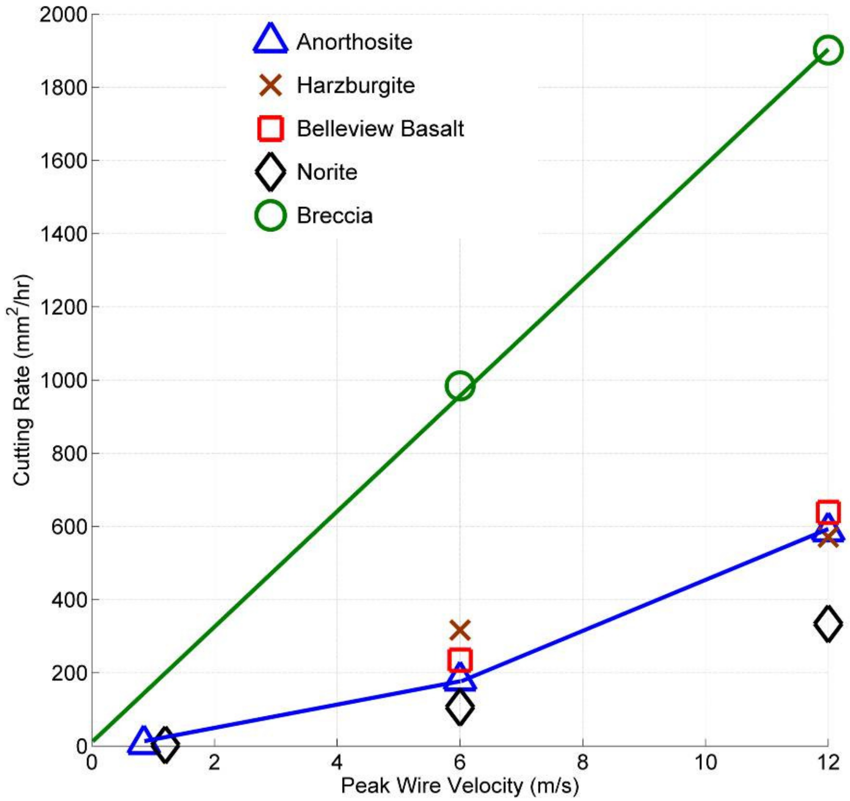


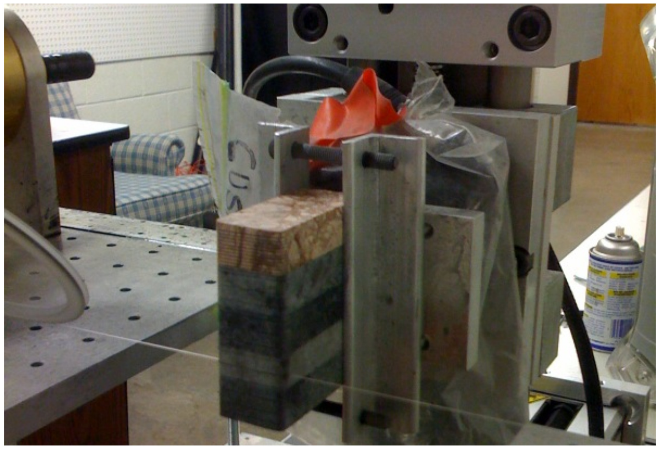
Diamond Wire Saw Testbed

Developed 4 test beds in total. Final was a capstan design.

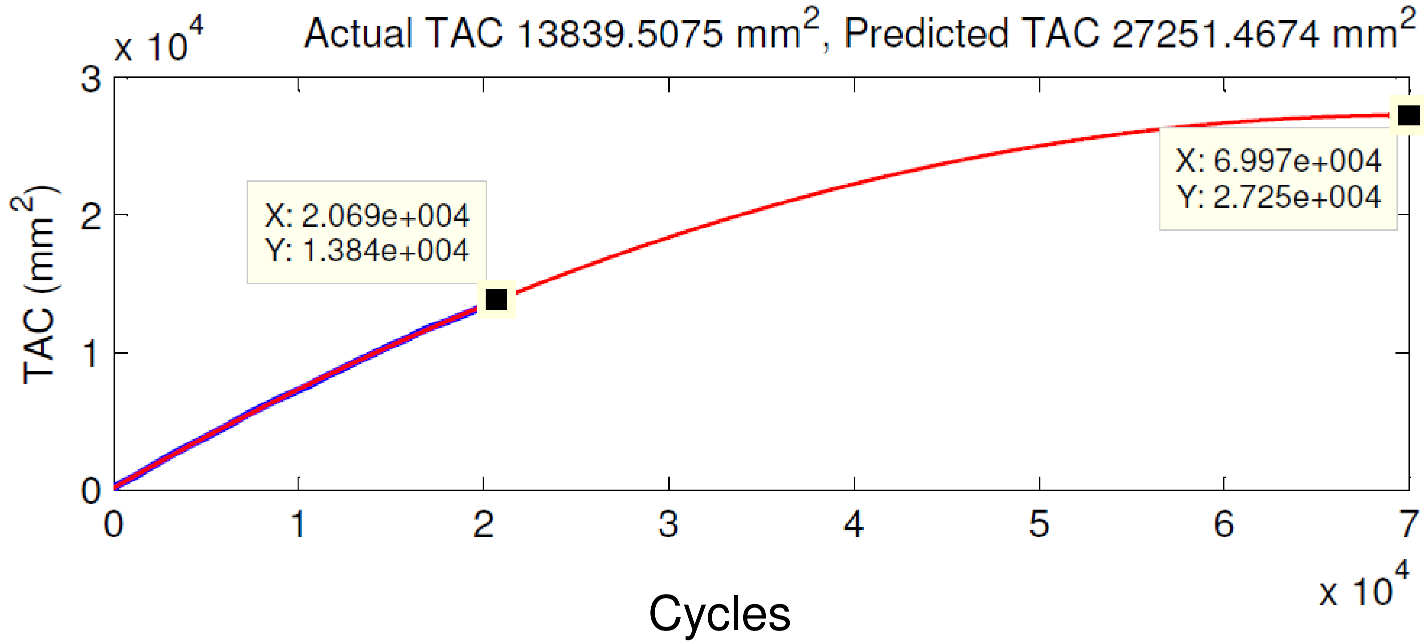


Diamond Wire Saw Test Results





Wire Lifetime test: total area cut (TAC)



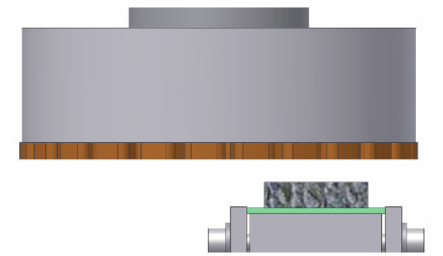
- 35m of wire
- Anorthosite
- 12m/s peak linear velocity

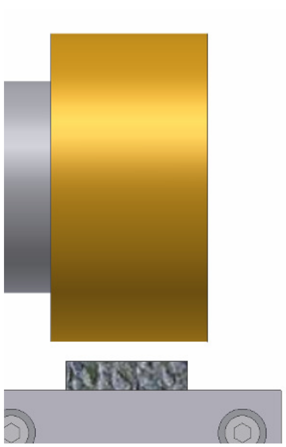
Cutting odd shapes

Gripping odd shapes

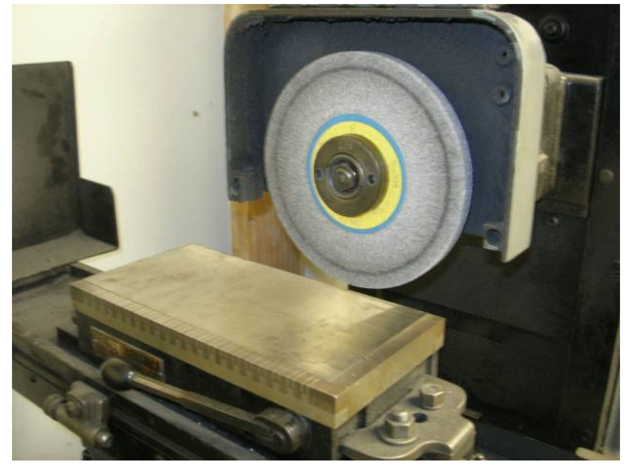
Fine grinder and polisher - Concepts

- Testing Concepts
  - Surface Grinder
    - Plunge Grinding
      - Electroplated Diamond
      - Resin Bond with Synthetic Diamond
    - Side Grinding
      - Resin Bond with Synthetic Diamond
      - Resin Bond with Cubic Boron Nitride (CBN)





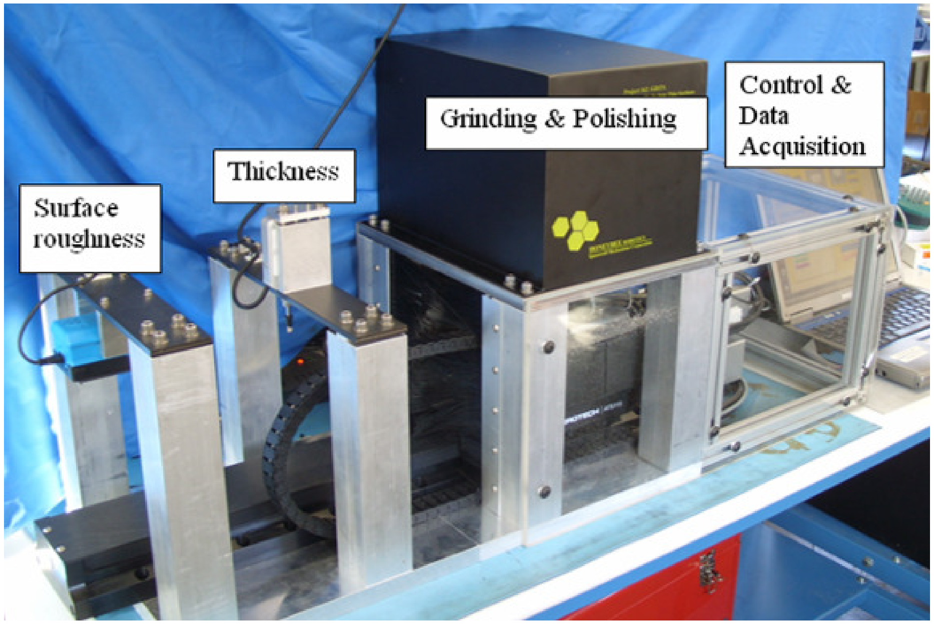
Surface Grinder

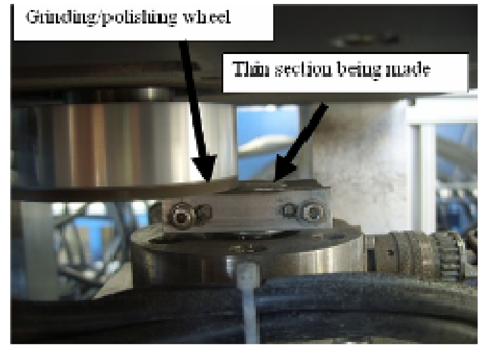


COTS Grinding Wheels

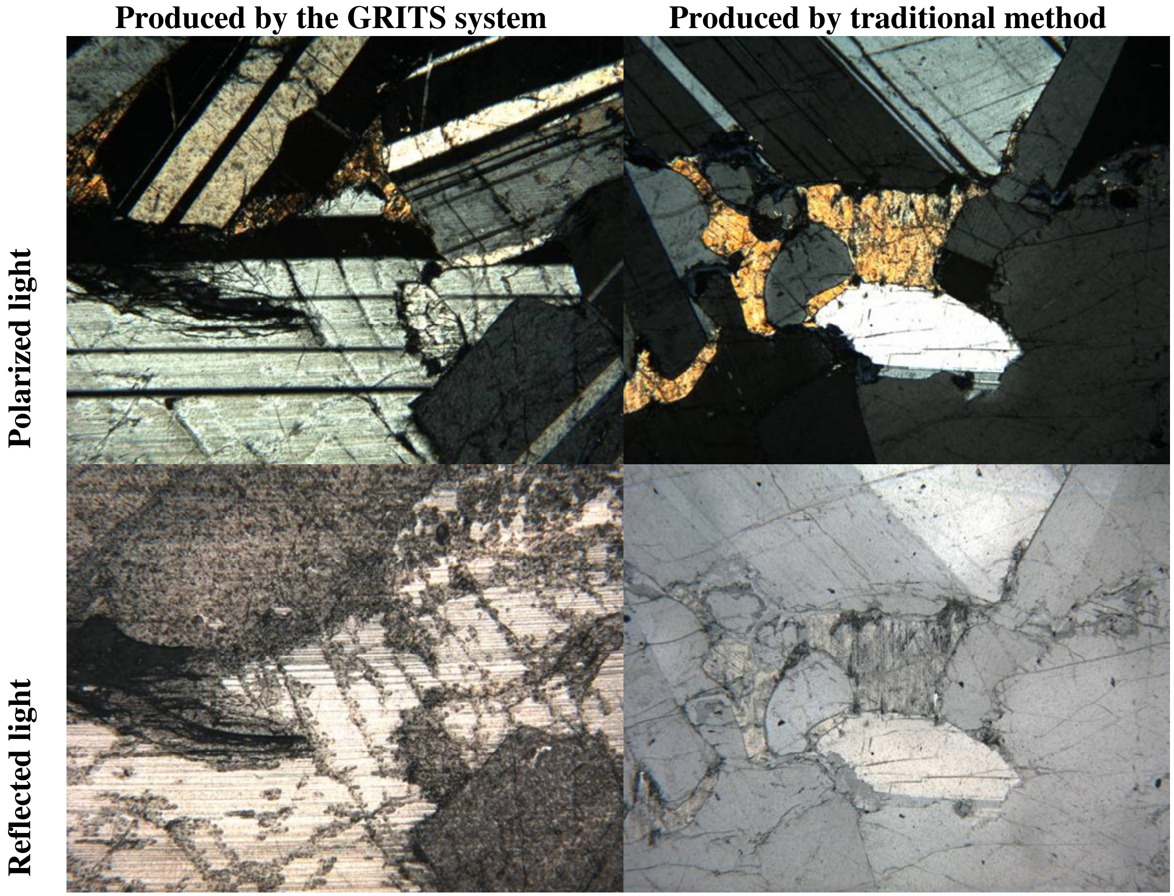
Fine grinder and polisher – Testbed

GRITS: Grinding Rocks Into Thin Sections



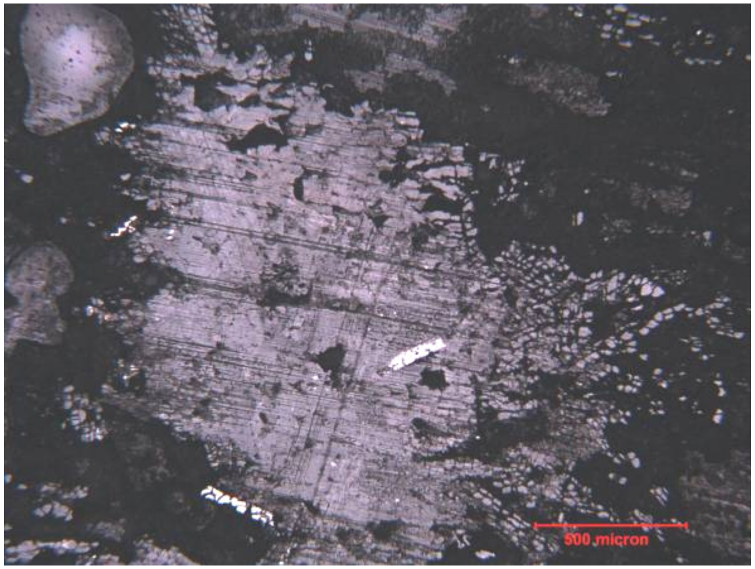


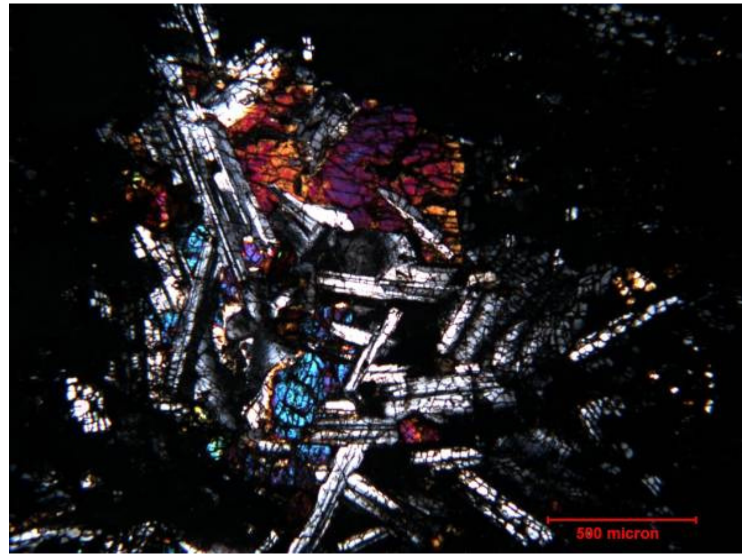
GRITS Test Results



Anorthosite
0.2 to 0.3 mm/hr grind rate
G-ratio ~13 (volume rock removed)/(volume grinder lost)
Traditional mount with epoxy on a microscope slide

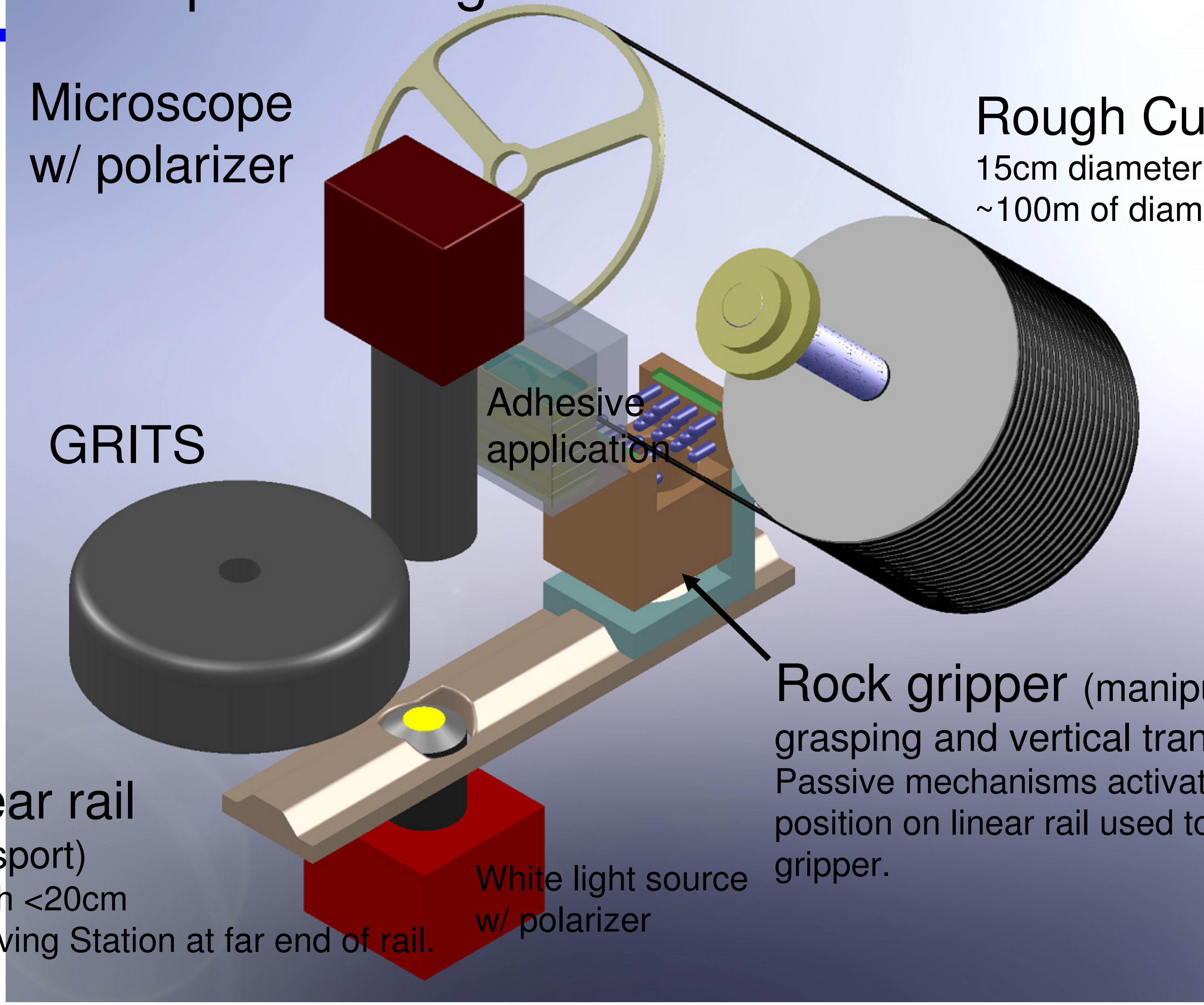
GRITS Test Results





Saddleback Basalt (Mars Mojave Simulant Rock)
0.2 to 0.3 mm/hr grind rate
G-ratio ~6 (volume rock removed)/(volume grinder lost)
Sample cut by CSM Diamond Wire Saw
Traditional mount with epoxy on a microscope slide

Conceptual Design



Performance estimates, mass, power…

- Produce 50 thin sections of samples of ~3cm basaltic rock, 1cm cores and dust/soil.
- Several days to process one thin section
- Autonomous steps with remote verification and analysis
- Motor count: 3 + clutch or 4
- ~100 meters of wire, GRITS thickness ~1 cm

Educated estimates of a finished flight system…

Item	Basis	Mass (kg)	Item Power (W)	Power (W) during a sustained operation				
				Cutting	Grind/ polish	Imaging	Manipulation	Verification
GRITS	TRL4 Device, RAT	3	Power is listed with the combined motor item					
GRITS/Wire Cutter Shared Motor	TRL4 Device, RAT	1.2	7 to 10	7	15			
Microscope	MAHLI [17]	0.7	5			5		
Epoxy/Slide	TRL3 JPL ISPAD	0.5	0					
Wire Cutter	TRL4 Device	1.5	Power is listed with the combined motor item					
Linear Rail	Estimate	1.0	3	3			3	
Gripper and Vertical Translation	Estimate	0.5	3				3	
Engineering Camera	Estimate	0.2	2					2
Structural system, housing etc.	Estimate	3						
Electronics	Estimate	3						
	Total	**14.6**		**10**	**15**	5	6	2

Number of sections that can be produced is very dependent on mechanical properties of samples → NEED GOOD ANALOG SAMPLES

Conclusions

•Have shown a completely dry method to make thin sections

•Have shown that an *in situ* thin section instrument is possible for near term missions.

•Number of sections that can be produced is very dependent on mechanical properties of samples → NEED GOOD ANALOG SAMPLES

•Next step:

Develop a completely automated system to TRL 6

Acknowledgements

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