Field Testing Near-IR and Neutron Spectrometer Prospecting: Applications to *Resource Prospector* on the Moon

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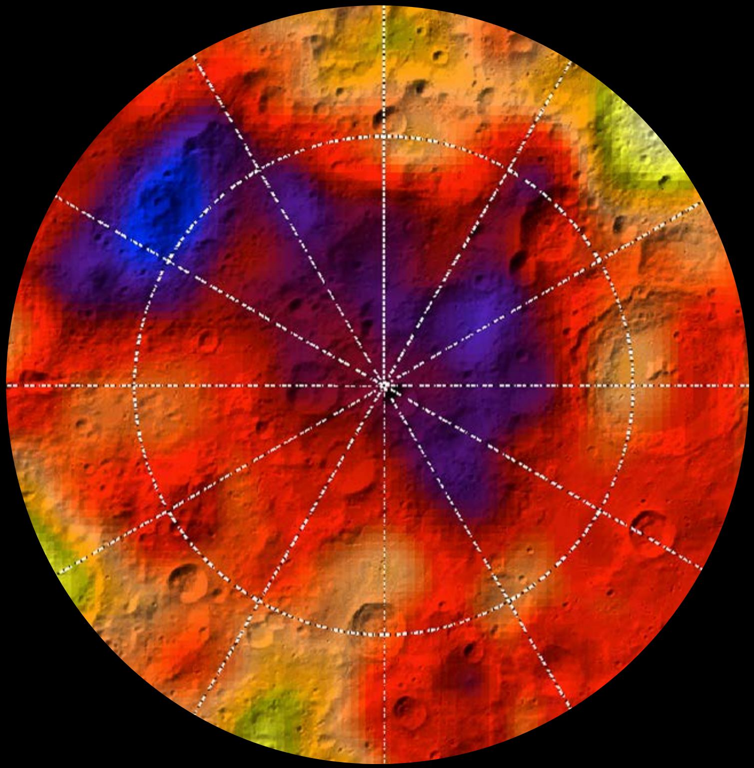
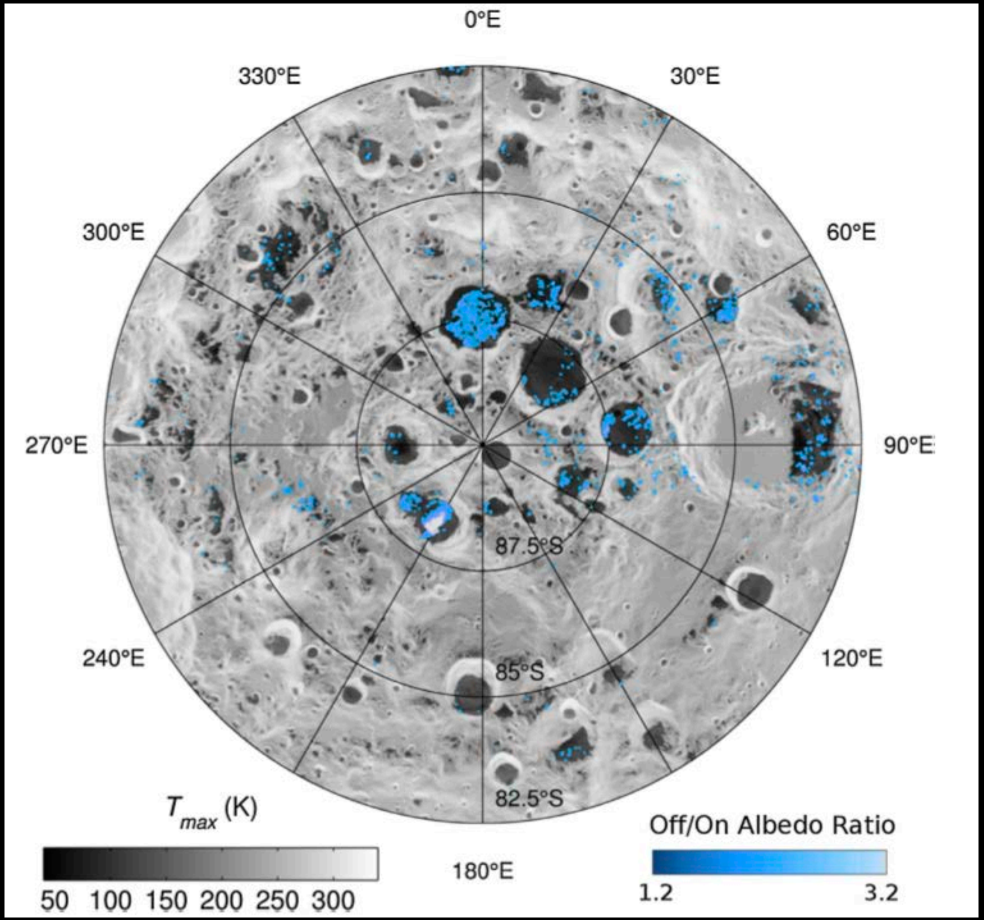
Prospecting for Lunar Polar Volatiles

Volumetric Hydrogen

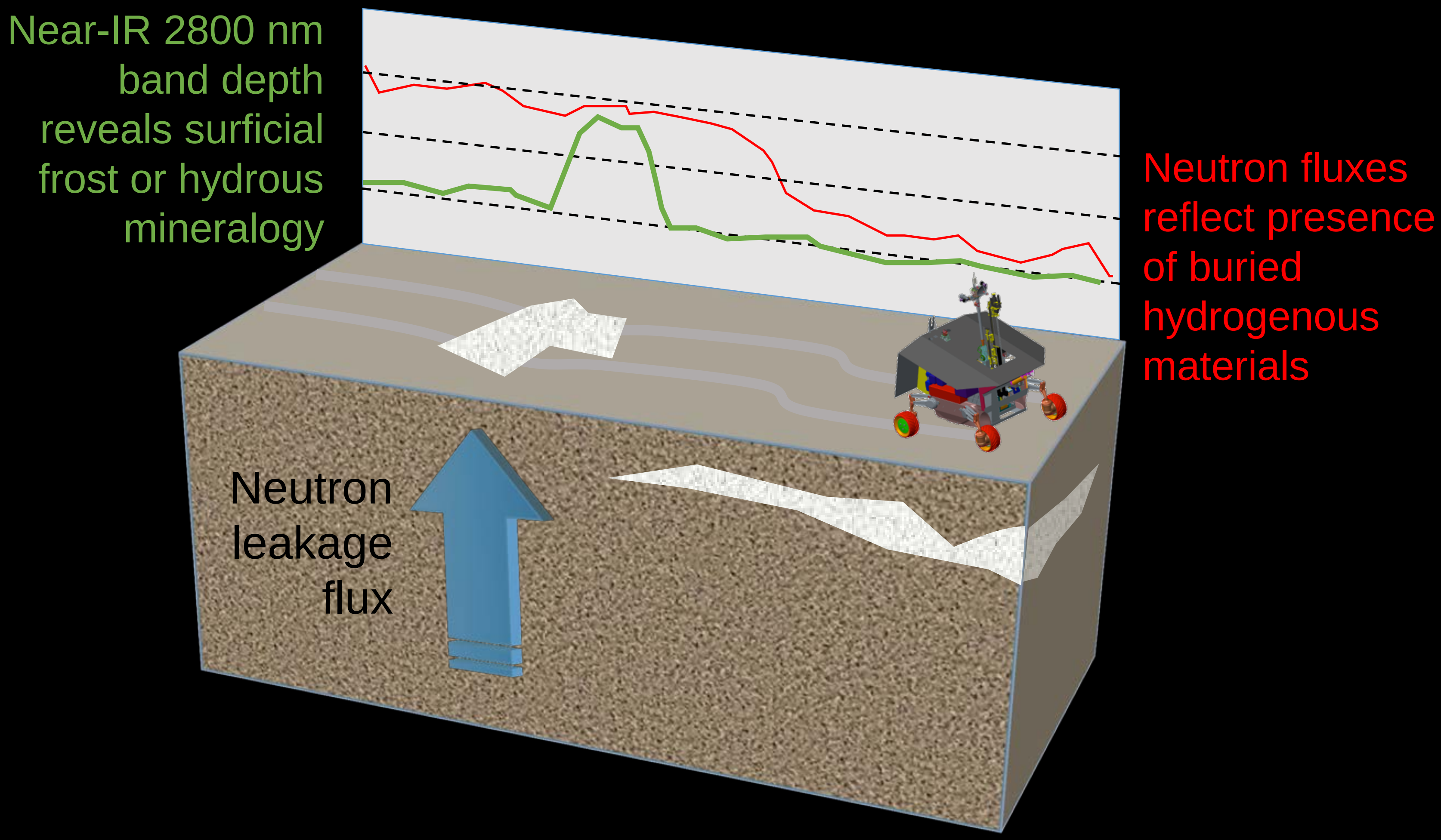


Surface Frost?



Hayne et al., Icarus, 2015

How Near-IR and Neutron Spectrometers Work in Tandem on *Resource Prospector*



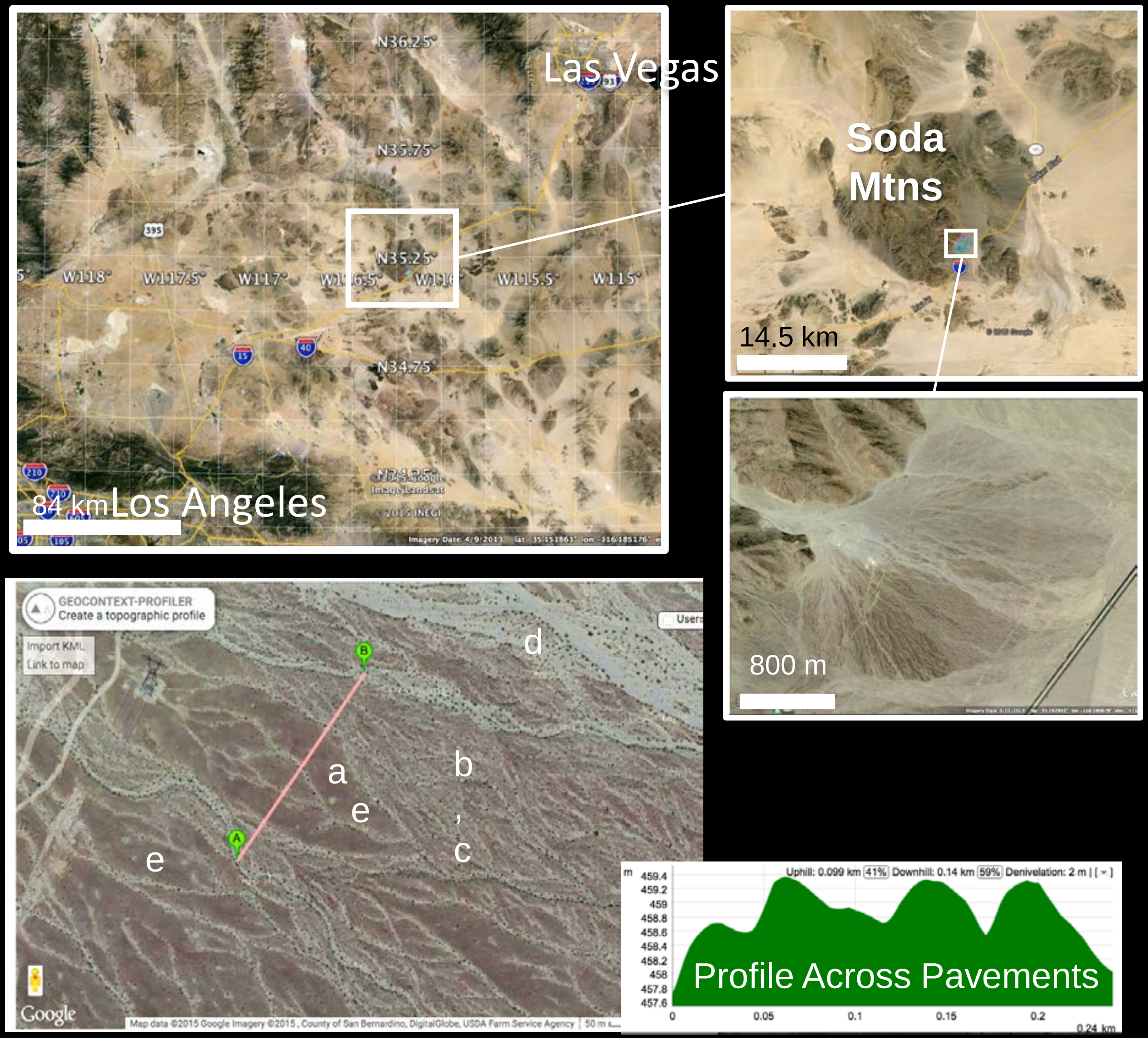
Mojave Volatiles Prospecting Project

Goal 1: Mature RP instrument (Near-IR and Neutron Spectrometers) prospecting operations concept through robotic testing in natural setting.

Goal 2: Mature the ARC Exploration Ground Data System (xGDS) real-time science tools through analog science ops in natural setting.

Goal 3: Conduct scientific investigation of water content on a Mojave Desert alluvial fan with low but possibly variable water abundance.

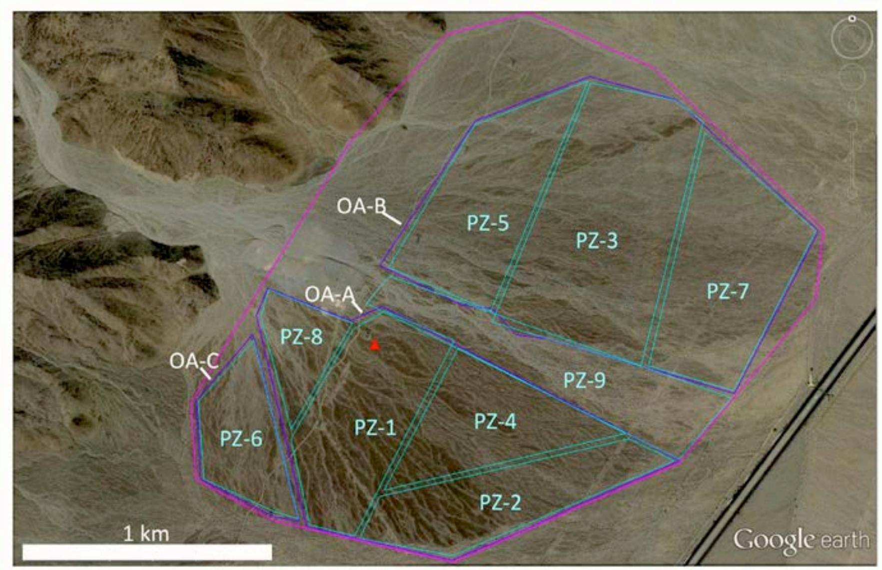
MVP Field Site



a. Mature desert pavement (dark visible reflectance)
b. Partially dissected pavement (medium tone)
c. Bar-and-swale (lighter tone)
d. Wash/channels (lightest tone)
e. Isolated mounds of bioturbated materials in dark pavement (light tone)

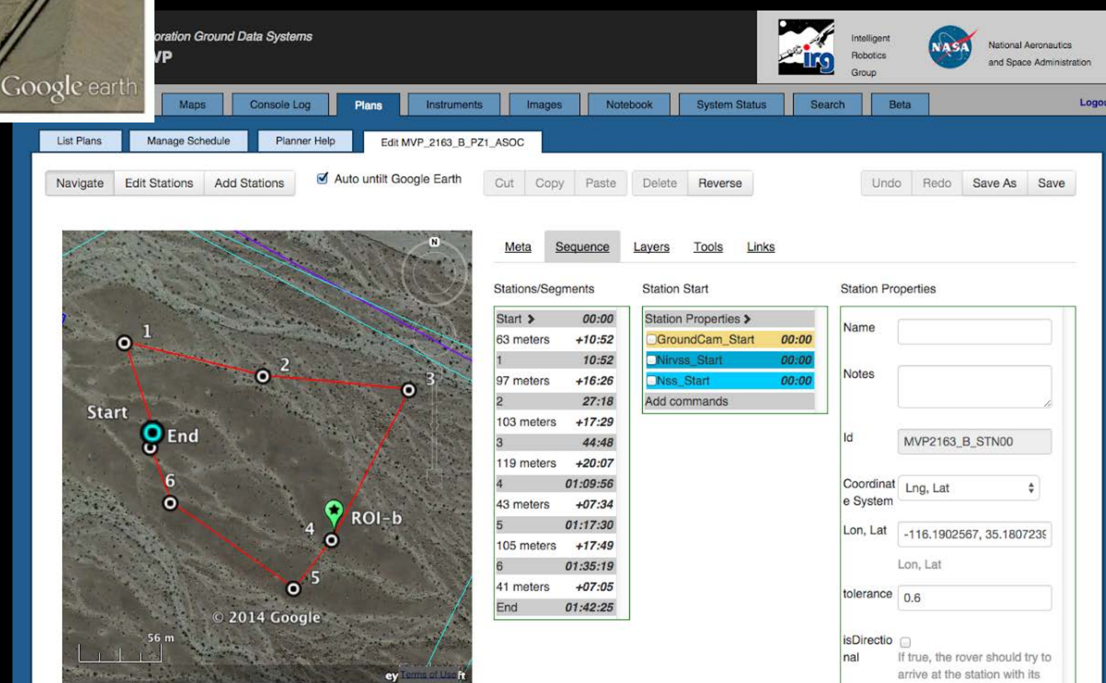
~ 2-3 m of relief

Traverse Planning

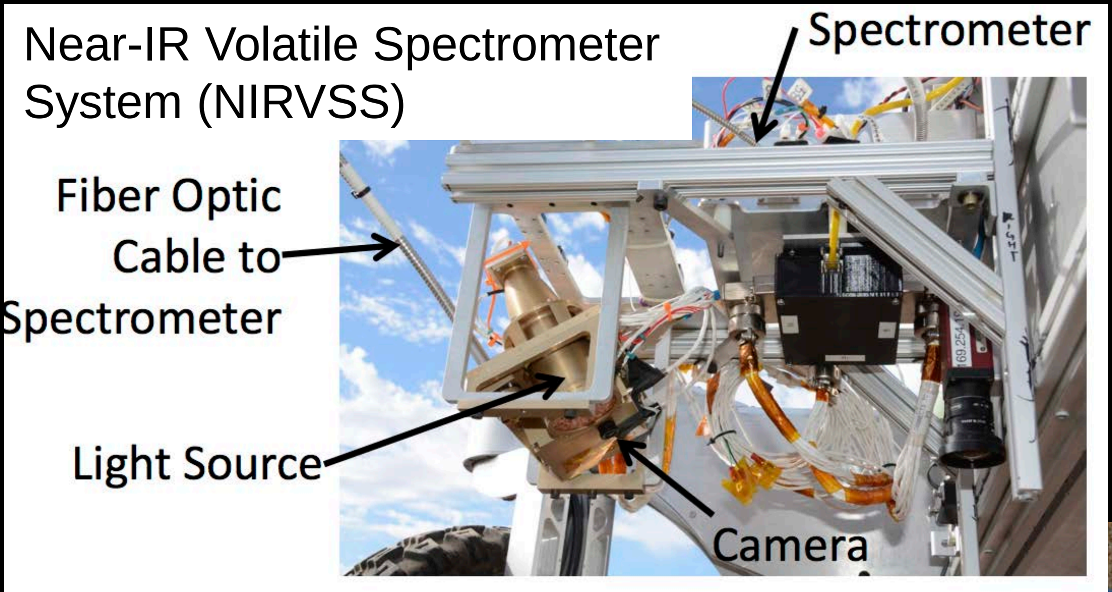


- Divide up field test site into Objective Areas and Prospecting Zones.
- Each contains variety of terrain types.
- Lay out traverse plans that cover the various terrains, priority order.
- In some cases, traverses designed to assess variations within a single type.

- Exploration Ground Data System (xGDS) used to create traverse plans, including instrument commanding.
- xGDS also provides an estimate of time to complete traverse.

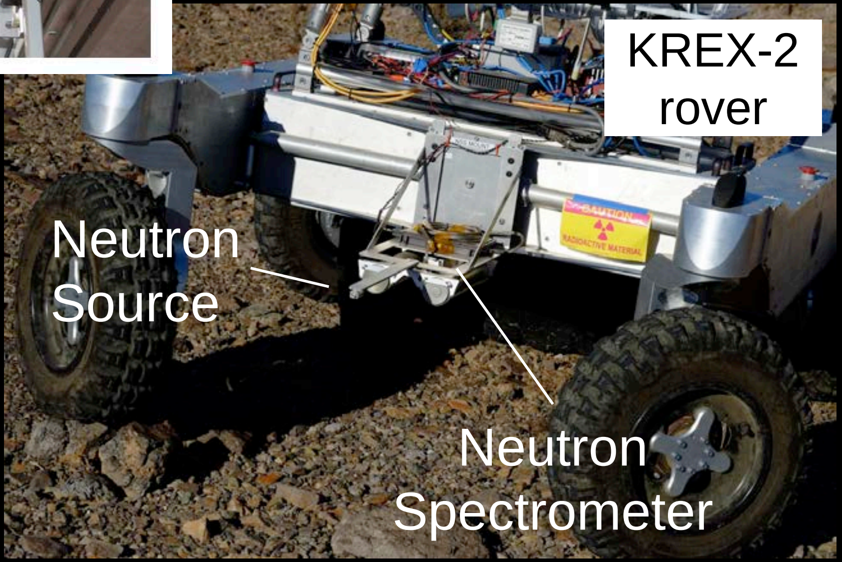


MVP Used Two Resource Prospector Payload Instruments

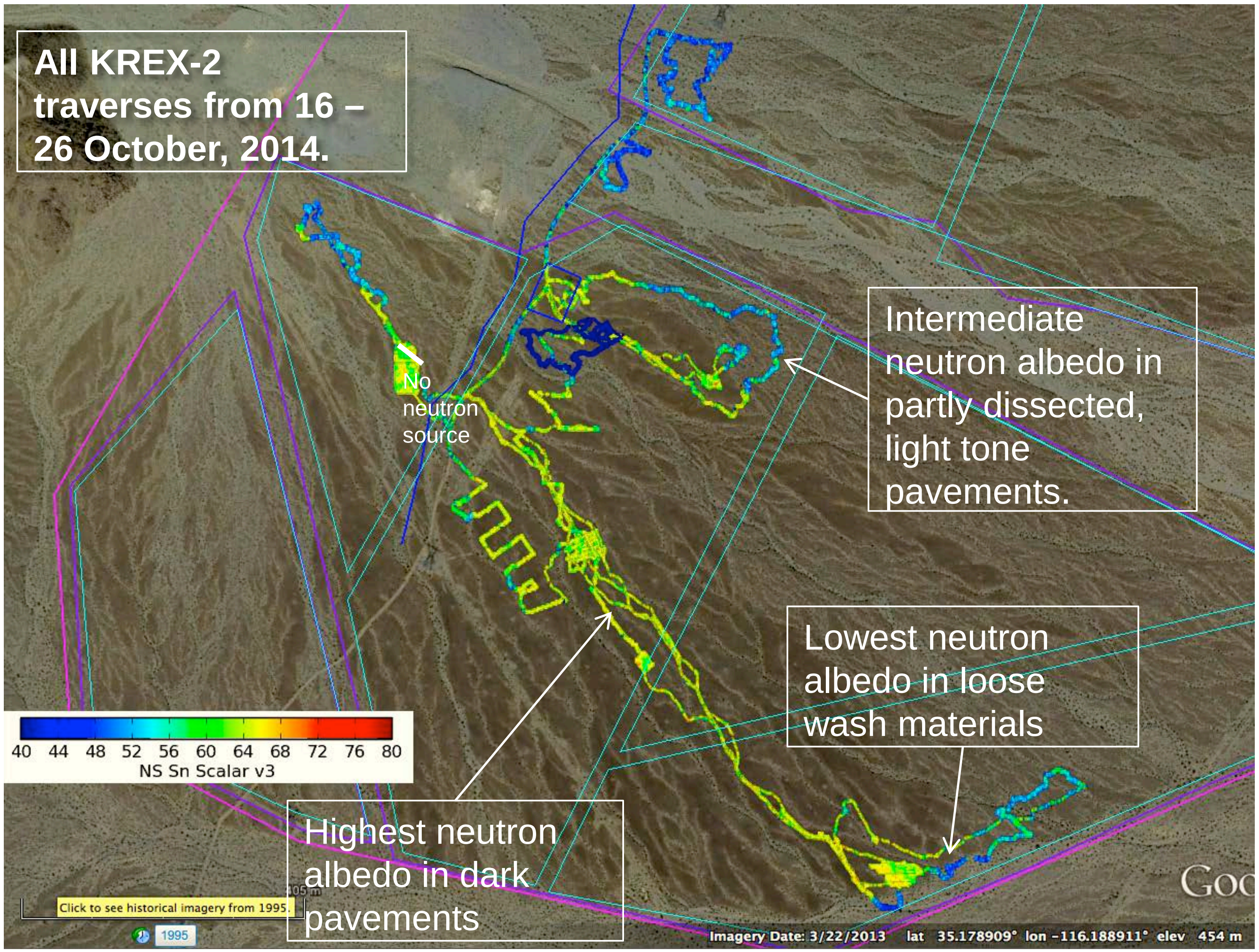


- NIRVSS: Near-IR Volatile Spectrometer System
- 1600 – 3400 nm band
- Covers major H_2O, OH and other mineral features

- NSS: Neutron Spectrometer System
- Thermal and epithermal neutron flux
- Volumetric hydrogen abundance

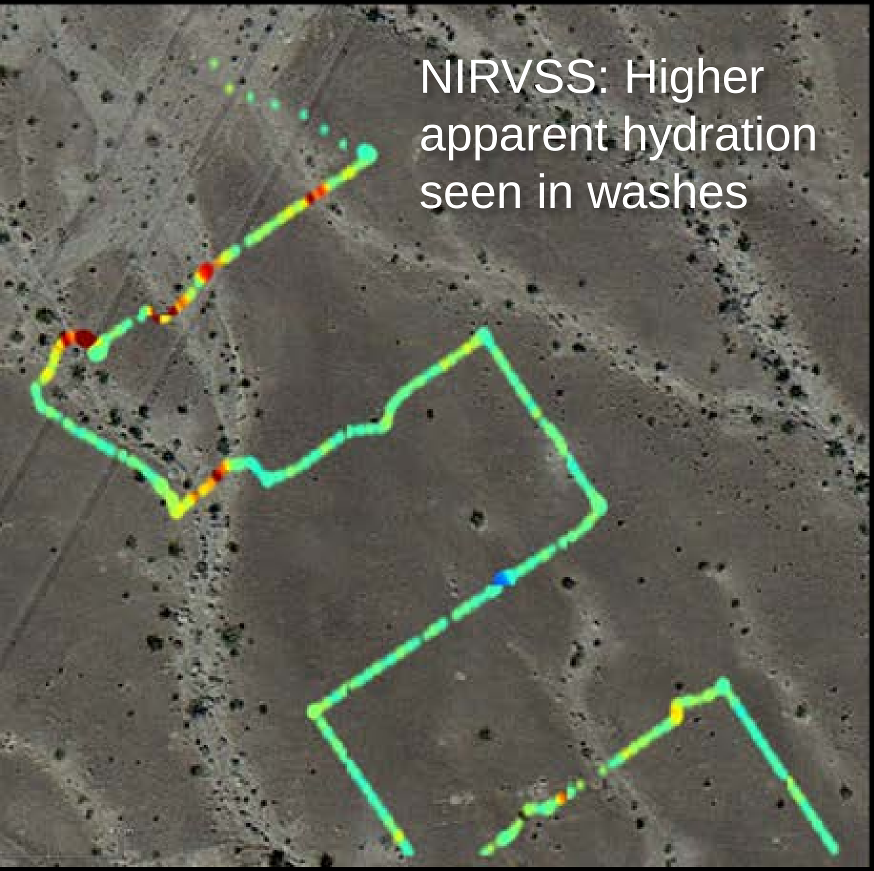


Thermal Neutron Albedo for MVP Traverses

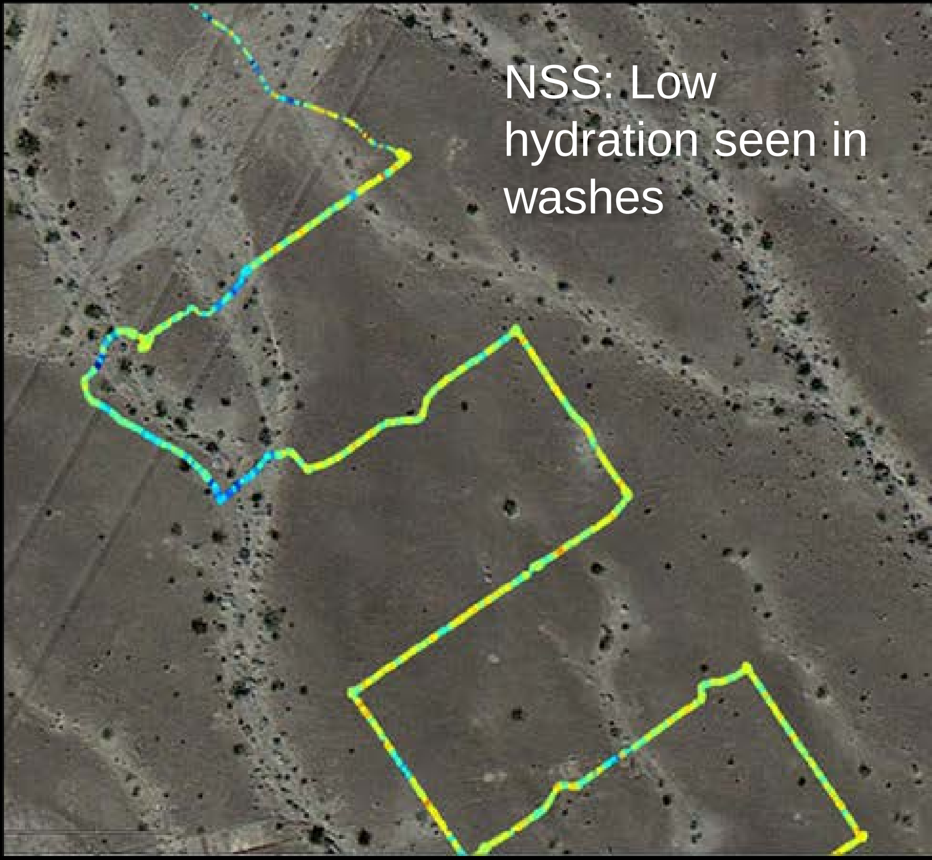


Comparison of NIRVSS Hydration Indicator and NSS Thermal Neutron Albedo

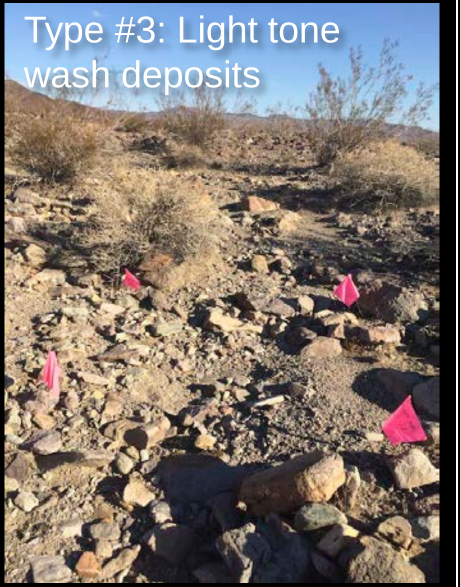
NIRVSS Hydration

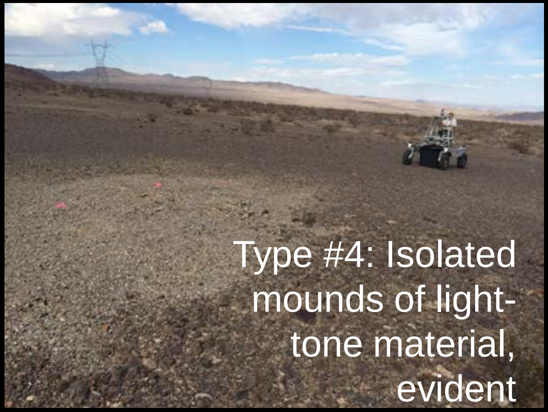


NSS Neutrons



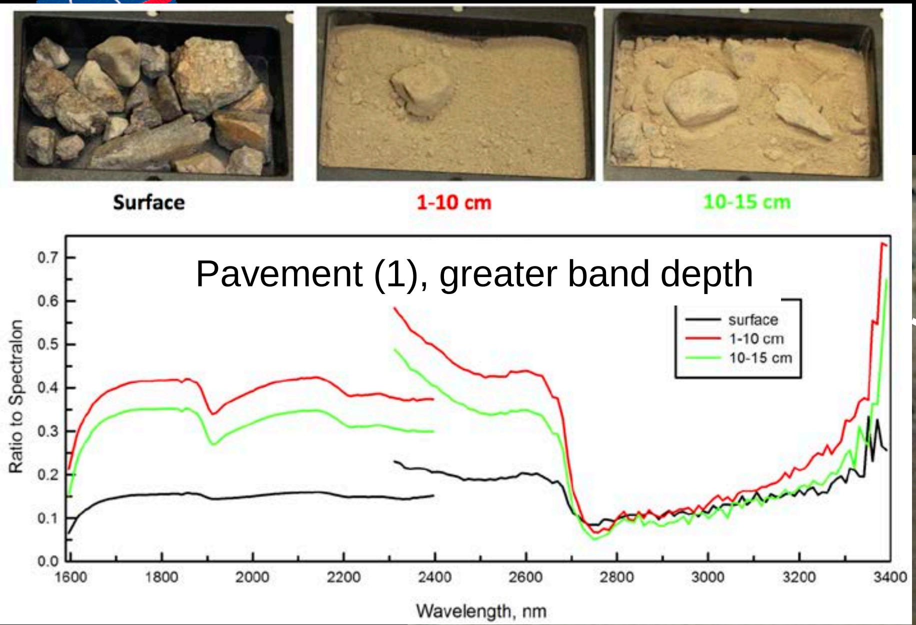
Surface Types

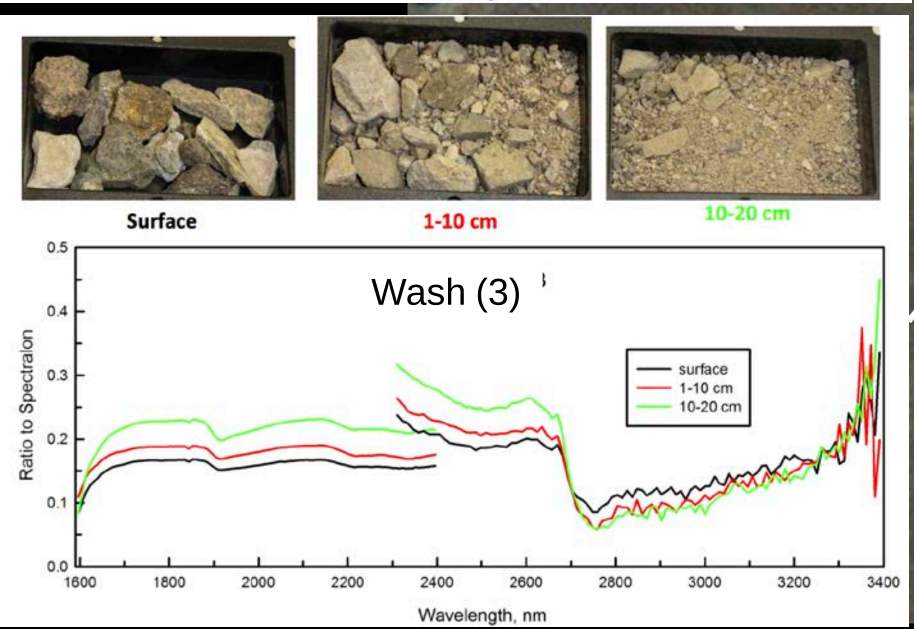


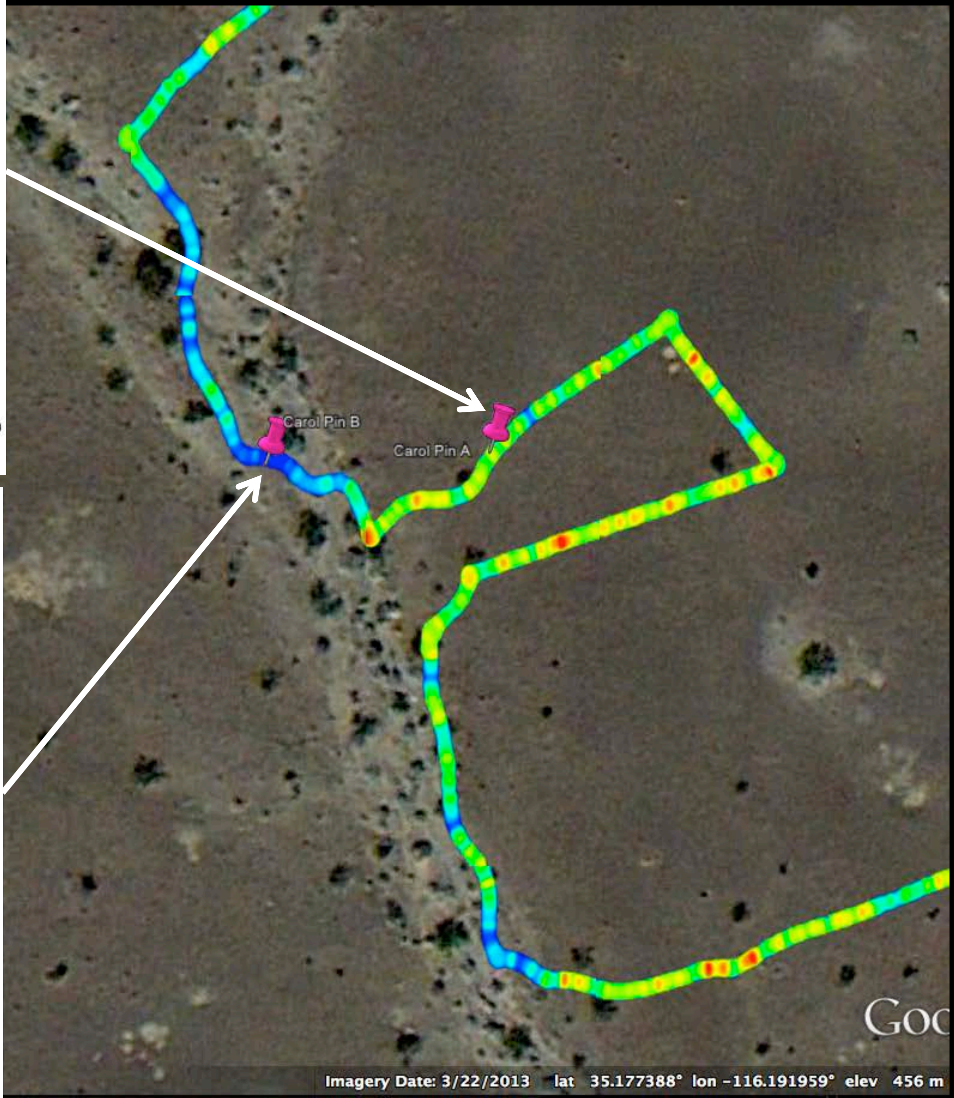


1. Mature, well-developed, heavily varnished pavements, mapped as the oldest units in the fan, Qf2 (70-140ka).
   - Highest neutron albedo, lower NIR hydration signature
1. Lighter tone units are younger, with weak to moderate pavement and varnish development (Qf3 and Qf4, 15 – 2 ka)
   - Intermediate neutron albedo, lower NIR hydration
1. End member is Qf5 – active wash and floodplain (1 – 0 ka).
   - Lowest neutron albedo, higher NIR hydration
1. Isolated light-toned mounds occur in the midst of the mature dark pavements. Evident bioturbation.
   - Low-intermediate neutron albedo, medium NIR hydration

NIRVSS Spectra & NSS







Semi-Quantitative XRD Mineralogy & Evolved Gas Analysis

	Sample	2:1 clays wt%	2:2 clays wt%	EGA Water Released% *	Neutrons
#1. Pavement	Surface	n.d.	n.d.	n.a.	High
	1 - 10 cm	16	6	41.4	
	10 - 20 cm	13	6	14.7	
#1. Pavement	Surface	4	n.d.	n.a.	High
	1 - 10 cm	15	6	46.1	
	10 - 20 cm	17	6	72.1	
#2. Bar unit	Surface	4	n.d.	n.a.	Low-intermediate
	1 - 10 cm	7	3	-23.5	
	10 - 20 cm	9	4	-22.9	
#3. Wash	Surface	4	2	n.a.	Low
	1 - 10 cm	14	3	-9.2	
	10 - 20 cm	8	3	*0.0 (ref)	
#4. Bioturb. Mound	Surface	3	n.d.	n.a.	Low-Intermediate
	1 - 10 cm	7	4	8.2	
	10 - 20 cm	11	5	-0.1	

- Clay mineral abundance higher in dark pavement – Av1 soil horizon
- Lower clay abundance in bar, wash and mounds
- EGA: Total H_2O goes with clay abundance
- Thanks to Tom Bristow for XRD and Mary Beth Wilhelm for EGA work!

RP Prospecting Matrix

	NIRVSS hydration	No NIRVSS Hyd.
NSS detects hydration	Both surface and subsurface ice/hydrous mineralogy	Only subsurface ice/hydrous mineralogy
NSS no hydration	Only surface frost/hydrous minerals	No surface or subsurface frost/hydrous minerals (<1m depth)

What is the Upshot for RP?

Prospecting:

- NIRVSS can sense surface frost, hydrous mineralogy
- NSS senses bulk hydration
- Estimate simple 2-layer model depth to ice-bearing material

Drilling - Near-surface assay:

- Didn’t drill in Mojave, instead dug samples after test
- Moon: NIRVSS can assess cuttings extracted from depth
- NIRVSS assessment constrains NSS depth distribution model

MVP exercise demonstrated RP prospecting tools

- Capable of

Clive's Questions: Lunar Resources

- What resources are most relevant for both near-term and medium-term use within the context of the LEAG Lunar Exploration Roadmap as well as the Global Exploration Roadmap (cis-lunar, lunar surface, asteroids, Mars)?
- Most readily exploited: surface frosts and subsurface volatile reservoirs, H_2?
- What is(are) the major impediment(s) for developing lunar resources and how can it(they) be overcome?
- Understanding the selenological (geological) setting for volatile resources (Compare to how petroleum industry locates/characterizes oil deposits)
- What is our current understanding of the location and characteristics of the resources?
- Limited to 10's km scales for subsurface volatiles – don't understand why some cold traps have H-bearing volatiles/frost and others don't.
- During the resource prospecting phase:
  - What are the major questions to be answered?
  - Where is it, what is it, what physics controls emplacement and sequestration?
  - What measurements are critical for ISRU, engineering, and science?
  - Determine 3D distribution, assess resource inventory, characterize environment/geological setting (esp. geotechnical challenges)
  - What new technologies are required to make these measurements and answer these questions ~~(i.e., what techniques/technologies are required to extract and process the ore, and store/transport the refined products)~~?

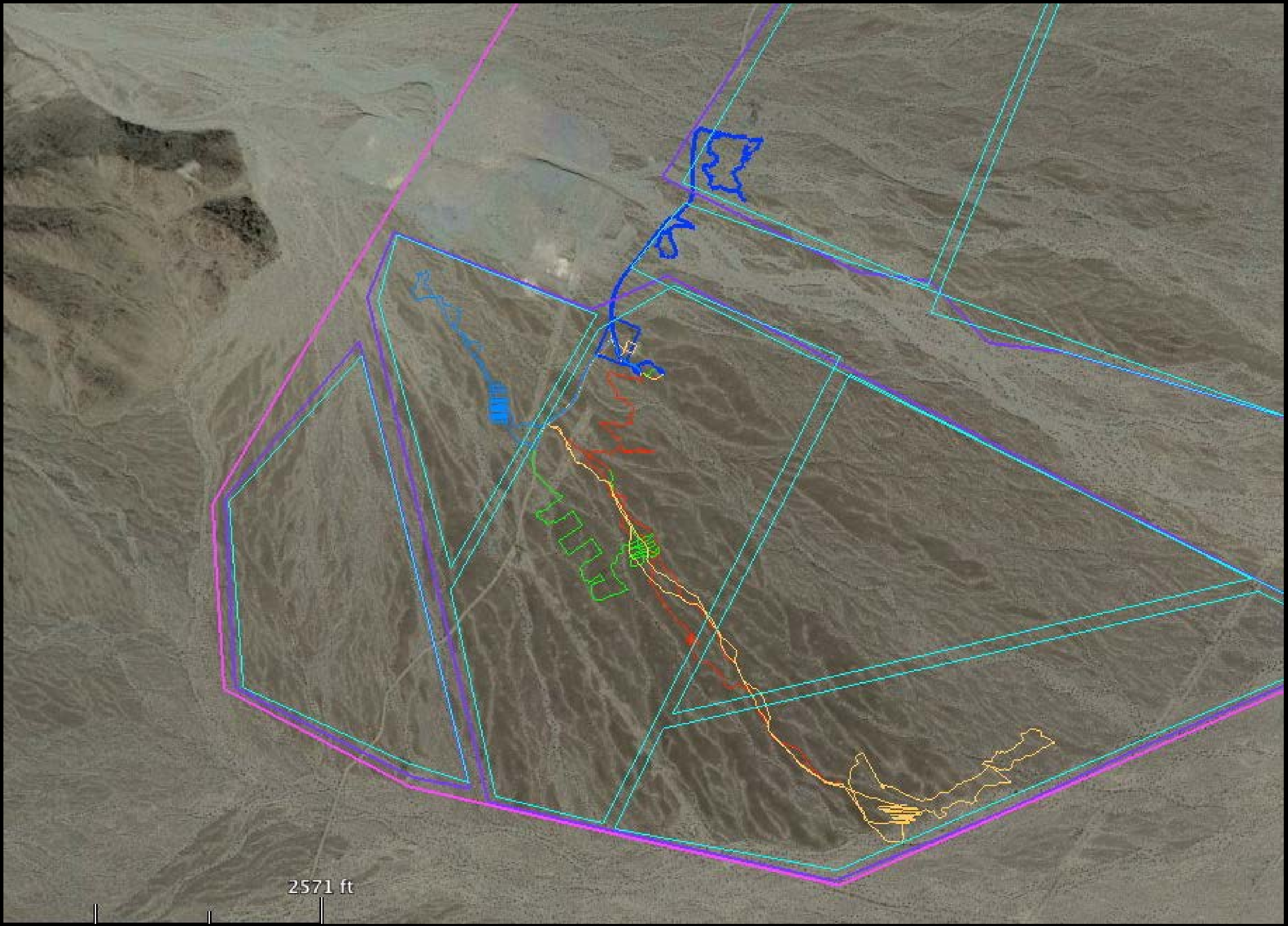
This is the phase after prospecting and characterization

Ground Truth Samples

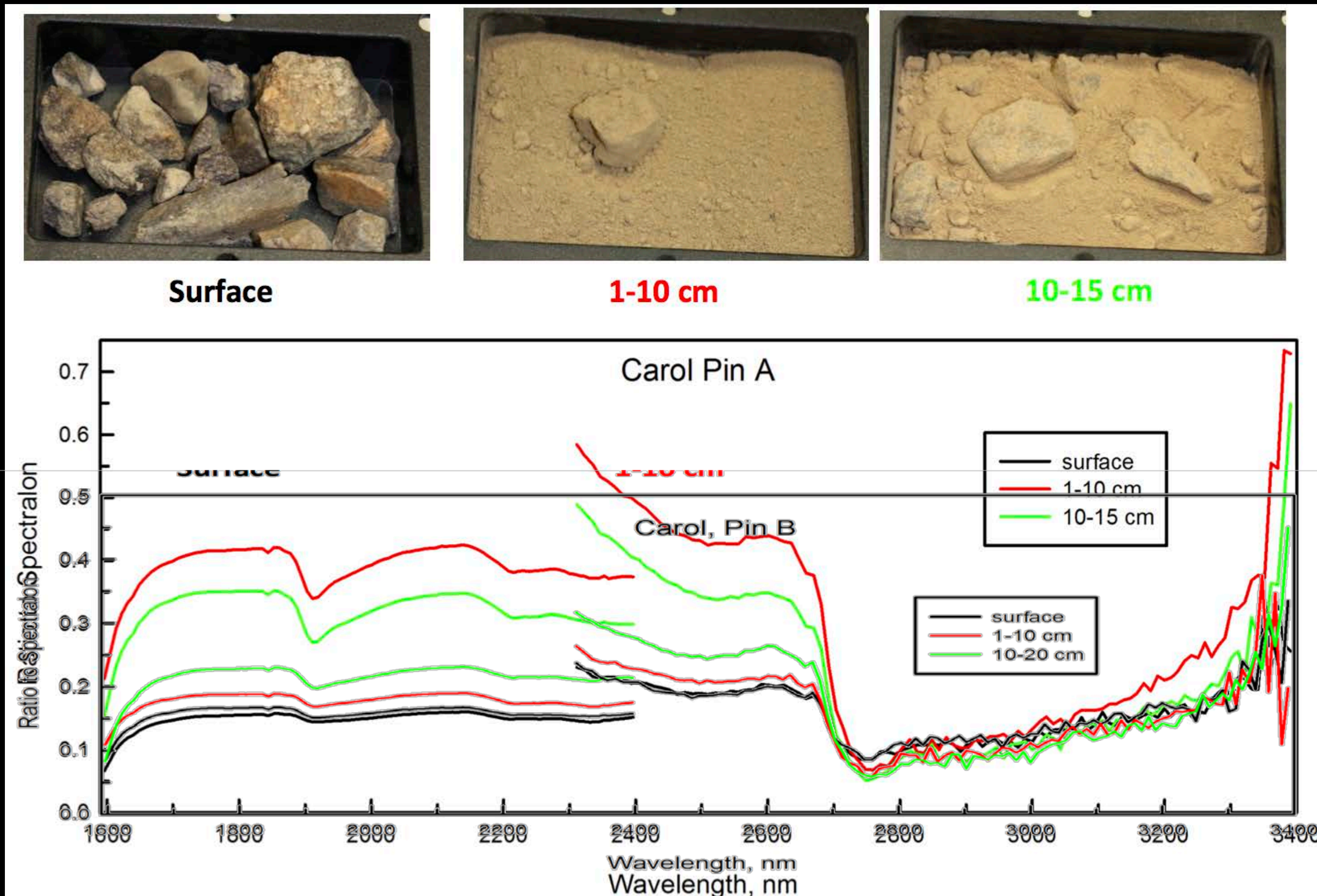
- The four surface types in the study area were sampled
- Top layer of clasts (or soil).
- Immediate substrate 1 – 10 cm.
- Deeper 10 – 20 cm.

1. Dark varnish, mature pavement
2. Lighter swale material
3. Wash deposits (active)
4. Bioturbation mound

Science Traverses During 5 Days of Test



Spectra



Surface
1-10 cm
10-15 cm
Carol Pin A
Carol, Pin B
surface
1-10 cm
10-15 cm
surface
1-10 cm
10-20 cm
Ratio to Spectralon
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
Wavelength, nm

Clive's Questions

- Lunar Resources:
  - What are the best targets for in-situ measurements, technical demonstrations, and sample return?
  - Poles for cold-trapped volatiles, high-Ti mare basalts for oxygen reduction
  - What new observations could LRO make and what new mission(s) would be required to address lunar ISRU questions?
  - Acquire highest achievable resolution DEMs of polar regions.
  - What knowledge and conditions would enable commercial sector involvement in the extraction, refinement, and utilization of lunar resources?
  - What could be the next mission after "Lunar Resurs" (Luna 27; Russia) and Resource Prospector (USA)?