IN SITU MAPPING THE LUNAR SURFACE AND SUBSURFACE.

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Introduction: Developing scientific insight requires a layered approach that provides focus for further detailed investigations and also a context for the discovery. This paper identifies prospecting as an important aspect of scientific discovery. We propose to utilize sensors in three configurations as part of our integrated approach to lunar prospecting:

- Astronaut's regolith probes
- Mobile platform near-surface sensors
- Mobile platform sub-surface instruments

Astronaut's Regolith Probes: As an astronauts traverses the lunar surface they leave bootprints as seen in Fig. 1. The depth of the bootprint is used to calculate the maximum allowable bearing capacity for the lunar surface material as seen in Fig. 2.

Figure 1. Astronaut lunar footprint used for bearing capacity measurements. The average bootprint depth in crater rims was 1.6 cm [1].

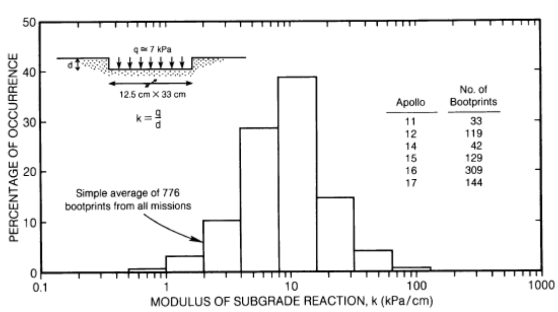

Figure 2. Bearing capacity determined from astronaut bootprints (Modulus of Subgrade Reaction) [2]. Inset (upper left) shows a cross-section of bootprint and the forces involved.

Other parameters can be measured using the astronaut's boot or walking stick. They include surface temperature, dust accumulation, and penetrometry. These and other sensors will provide useful material information to guide site selection as well as astronaut suit-material selection.

A simple dielectric constant sensor placed in the astronaut boot can be used to detect changes in lunar regolith. The graph in Fig. 3 shows the relation between dielectric constant and density. The red triangles are from Apollo lunar soil samples. Also plotted are values for solid minerals (rocks) from the same class of silicates found on the moon. The surprising result is that the data for both the soils (red triangles) and rocks (blue diamonds) are well fit by the power law expression given in the figure [3]. The exceptions are the titanates and water/ice. Since the density of the lunar regolith at the surface is reasonable constant, differences in dielectric constant will signal a change in lunar regolith that may be due to the presence of either water/ice or titanates.

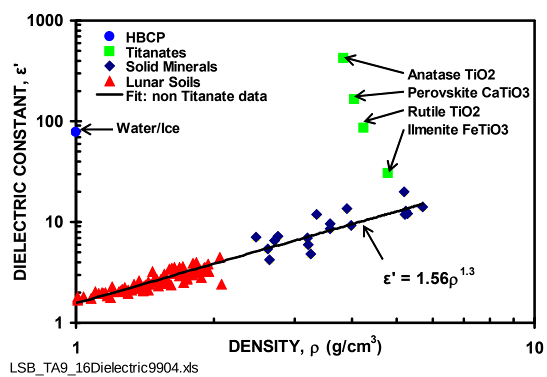

Figure 3. Dielectric constant of lunar soils and minerals [3] used for detecting outlier minerals such as water/ice and titanates.

2. Mobile Platform Near-Surface Sensors: A number of new sensor and instrument concepts for inclusion in the wheel of a rover are depicted in Fig. 4. The data is generated as the rover moves about. A notional set of sensors and instruments for inclusion in a rover wheel is listed in Table 1.

This information will be used in a number of ways. For example, the wheel data can be used for *exception-based monitoring* to determine when the rover has traversed a region with different mineral or geotechnical properties and alert the rover that more detailed measurements are warranted.

In addition, the sensors can be used to detect wheel slip. This has proven to be a problem with the MER and during the Apollo missions. On the moon, there are isolated areas of soft soil that have immobilized the rovers. In the MER, case it took about one month to extricate the MER from being stuck in a sand dune. In the case of Apollo 15, the LRV encountered loose soil at the ALSEP site and spun its wheels [4].

Table 1. Wheel-Based Sensors/Instruments

SENSOR/ INSTRUMENT	**QUANTITY DETECTED**
Reflectance IR Spectrometer	Surface mineral properties
Impedance Spectrometer	Subsurface dielectric constants
Electrometer	Surface electrostatic properties, and wheel slip detection
Magnetometer	Subsurface magnetic susceptibility

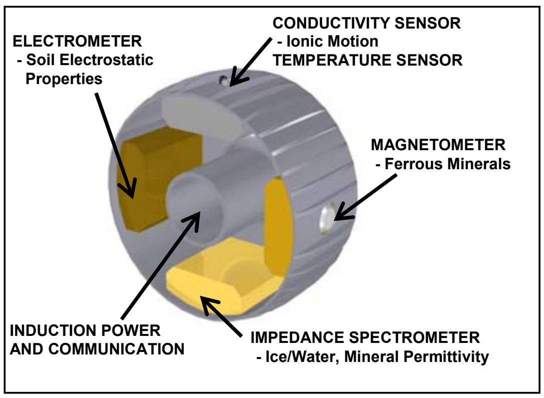

Figure 4. Wheel-based sensors/instruments for mapping the lunar surface and subsurface.

3. Mobile Platform Sub-Surface Instruments: Survey instruments attached to the under belly of a rover will acquire data as the rover traverses the surface. Three candidate rover survey instruments are:

- **Neutron Spectrometer** for detecting hydrogen, possibly in water-ice. [5]
- **Shear-Wave Seismometer** for detecting porous medium under dense material (e.g., buried lava-flow paleo-soils; lava tubes) [6].
- **Ground Penetrating Radar** for detecting subsurface structural features. [7].

Results from Ground Penetrating Radar [7] have shown the possibility of mapping the lunar subsurface for layer stratigraphy, for voids, and for inclusions such as nickel-iron meteorites. As seen in Fig. 5 the GPR was field tested at Dumont Dunes, CA, and traversed from M to N, along the edge of the dune. The GPR response revealed the layering of the sand dune.

The use of radars to characterize the lunar surface is not new. Measurements of the lunar surface were made from orbit during the Apollo 17 mission using penetrating radar reflections from the Apollo Lunar Sounding Experiment (ALSE) [1]. It provided information to a depth of >3000 m.

These types of instruments are best mounted underneath a rover and operated as it traverses across the lunar surface. In this study we will determine the feasibility of including such survey instruments with future rovers and determine their developmental costs.

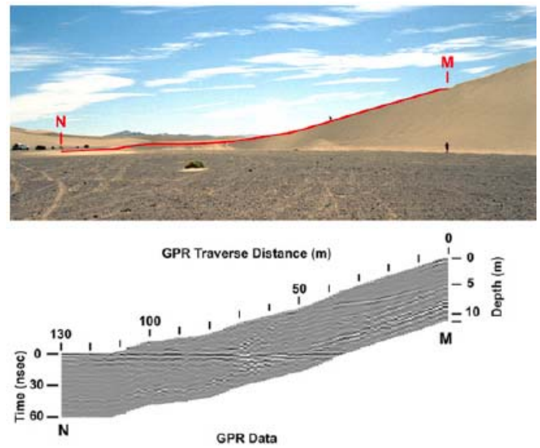

Figure 5. GPR field test site, Dumont Dunes, CA.

Discussion: The inclusion of suite of prospecting instruments with astronauts and rovers will assist in identifying locations where further investigations using other instruments such as spectrometers would be useful. Our approach will use guided search techniques that provides initial *in situ* information. This information when inserted into DSS (Decision Support System) being developed by CRREL (Cold Regions Research & Engineering Laboratory) will provide a multi-dimensional picture to resolve science issues such as composition of the lunar regolith leading to and understanding of its origins.

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