FINDING TERRESTRIAL ROCKS AND OTHER "EXOTIC" MATERIALS ON THE LUNAR SURFACE.
P.R. Christensen, S.W. Ruff, A. Anbar, School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287, phil.christensen@asu.edu

Objective: The objective of this mission concept is to remotely identify terrestrial rocks, meteorites, and "exotic" lunar samples exposed on the Moon's surface using a robotic rover. This investigation is based on the highly-successful use of the Mini-TES infrared spectrometer [*1*] on on the Mars Exploration Rovers that has identified five meteorites, several impact ejecta rocks, and numerous compositional extremes along the traverses of these two rovers [*2, 3*].

Transfer of Terrestrial Samples to the Moon: The discovery of ancient (<3.7 Ga) terrestrial rocks would represent a finding of significant importance. Rocks from this period of Earth's history could contain a chemical record of early life and the environmental conditions on Earth when life was initially forming and evolving. The terrestrial record from this period is extremely limited, and in all cases these ancient rocks have been significantly altered. The Moon provides a unique opportunity to store these rocks in an environment free of water and tectonic recycling [*4*].

The concept of exploring the Moon to search for terrestrial and other extra-lunar samples was explored in detail by Armstrong et al. [*4*]. This study showed that for a well-mixed regolith, that the median surface abundance of terran material corresponds to a mass of approximately 20,000 kg of terran material over a centimeter deep,10x10-square-km area [*4*].

One of the key questions that remain is the size of the meteoritic materials would be preserved on the lunar surface following their emplacement. Armstrong et al. suggested that the likelihood of terrestrial material surviving in a large aggregate sample is quite high [*4*]. On Earth in the presence of a thick atmosphere, stones up to several meters in diameter readily survive entry and impact. However, the Earth's atmosphere plays a role in their survival, significantly decelerating them. The discovery of 10-50 cm sized meteorites and impact ejecta on Mars provides direct evidence for the survivability of cobble-sized fragments in the case where a thick atmosphere is lacking. Based on these observations, it is plausible that meteorites could reach the lunar surface and survive the impact process with sizes sufficient to identified as rocks, rather than merely a fine-grained component of the lunar regolith.

Materials deposited on the Moon are subject to erosion and burial by micrometeorite bombarment. Thus, in order for exotic stones to be present on the surface today, these stones would have to have been buried beneath the ejecta of later impacts and brought to the surface by relatively recent impacts. The probability of these rocks being subsequently reexposed is low, but their scientific importance is of sufficient interest to warrant further analysis [*4*].

Remote Identification Using IR Spectroscopy: Vibrational spectroscopy is based on the principle that vibrational motions occur within a crystal lattice at frequencies that are directly related to crystal structure and elemental composition (i.e. mineralogy) [e.g. *5*]. The fundamental and overtone frequencies of geologic materials typically correspond to wavelengths greater than ~3 µm, and provide a diagnostic tool for identifying virtually all minerals and providing quantitative determinations of mineralogy and petrology [e.g. *5, 6, 7*]. The fundamental stretching and bending vibrations within different anion groups produce unique spectral bands that allow carbonates, sulfates, phosphates, silicates, oxides, and hydroxides to be readily identified. Significant progress also has been made in the development of quantitative models to interpret the vibrational spectra from complex, natural surfaces [e.g. *8, 9*]. Finally, direct experience with IR spectroscopy from orbit and on Mars has demonstrated the utility of this technique for exploring a planetary surface [e.g. *2, 3, 10, 11*].

The rapid search for terrestrial rocks and other exotics on the lunar surface would be greatly facilitated by the significant mineralogic differences between these rocks and the background lunar geologic materials. For example, terrestrial rocks of interest would contain quartz, carbonates, sulfates, hydrated minerals, and clays – minerals that are totally lacking in lunar rocks. In addition, lunar mantle rocks, which would be of high scientific value, have significantly different abundances of key igneous minerals such as olivine, pyroxene, and feldspar that would allow them to be readily idenfitied from the surfical volcanic units.

The proof of concept for the rapid, remote identification of rocks has been completed usng the Mars Rover Mini-TES experiments. Figure 1 shows examples of rocks identified with Mini-TES on the martian surface. These samples are representative of the range of materials observed, and include olvinine-, glass-, and plagioclase-rich rocks. However, these rocks have a much narrower compositional range than the quartz-, carbaonate-, or sulfate-bearing rocks expected from Earth, yet were readily identified from their surroundings in remotely acquired spectra.

Implementation: The proposed mission concept would use an infrared spectrometer operating from 3 to 50 µm, together with stereo imaging, on a long-range robotic rover. The IR spectrometer would have a spectral resolution of 2 cm^{-1} that would allow mineral discrimination and absolute abundance determination to ~5% [*1*]. The spectrometer would have a 16x16 pixel imaging array with a field of view of 4 mrad in each detector element. This instrument concept is based on recent developments in field-portable imaging spectrometers with significantly higher spectral resolution than the Mini-TES [*12*]. The spectrometer would consist of two separate focal planes, a cryocooled photovoltaic Mercury Cadmium Telluride (PVMCT) detector array operating from 3 to 14 µm, and an uncooled microbolometer array operating from 14 to 50 µm.

The IR spectrometer spatial resolution would allow a 10 cm rock to be resolved at a distance of 25 m. Each 16x16 pixel observation, covering 64x64 mrad (3.6°x3.6°), would be acquired in 10 seconds.

The mission operations scenario would involve beginning each drive sequence by imaging the entire near-field, forward-looking arc (180°x30ª). These data wculd be acquired in ~1.5 hours. The rover would then drive ~25m and stop to image the near-field (90°x30°) in ~0.75 hours. Automated drive software similar to that developed for the MER rovers would allow the drive and data collection sequences to be compelted without human intervention. Alternating full and partial viewing sequences, together with driving would permit the rover to traverse ~250 m per 24 hour period. A solar powered rover could travel ~3.5 km in each 14-day cycle. Given the distribution of surface rocks seen at the Apollo and Surveyor sites, it would be possible to characterize hundreds of rocks per day, and many thousands over each 14-day cycle.

Relationship to Lunar Exploration Architecture: This investigation is intended to be performed as a robotic mission in conjunction with follow-up human activity. The rover would identify and locate lunar surface samples of high scientific value that would later be collected by an astronaut. This investigation could be combined with other robotic reconnasance activities, but this concept is intended to focus on the rapid characterization of surface samples over a large distance. The intent of this mission concept is not to perform detailed *in situ* analysis by the robotic system, but rather to provide the initial characterization of thousands of interesting rocks for subsequent human collection and study of a select few.

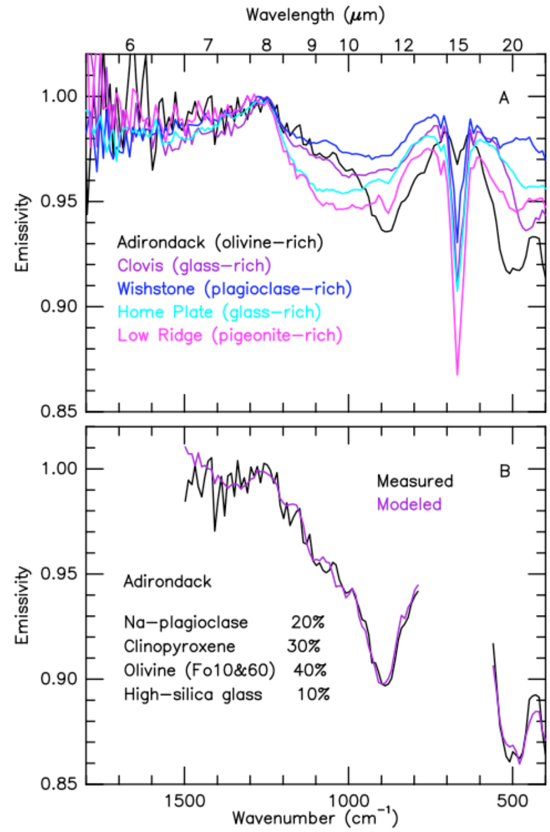

Figure 1. Mini-TES spectra of a suite of rocks showing (A) the spectral diversity measured on Mars; and (B) the precision to which the rock mineralogy can be determined remotely using IR spectroscopy,

References:

1. Christensen, P.R., et al. *J. Geophys. Res.*, *108*, 8064, Doi:10.1029/2003JE002117, 2003.
2. Christensen, P.R., et al. *Science*, *306*, 1733-1739, 2004.
3. Ruff, S.W., et al. *J. Geophys. Res.*, *111*, doi:10.1029/2006JE002747, 2006.
4. Armstrong, J.C., L.E. Wells, and G. Gonzalez. *Icarus*, *160*, 183-196, doi:10.1006/icar.2002.6957, 2002.
5. Farmer, V.C., The Infrared Spectra of Minerals. 1974, London: Mineralogical Society. 539.
6. Christensen, P.R., et al. *J. Geophys. Res.*, *105*, 9735-9738, 2000.
7. Hamilton, V.E., P.R. Christensen, H.Y. McSween, Jr., and J.L. Bandfield. *Meteoritics and Planetary Science*, *38*, 871-885, 2003.
8. Ramsey, M.S. and P.R. Christensen. *J. Geophys. Res.*, *103*, 577-596, 1998.
9. Bandfield, J.L., M.D. Smith, and P.R. Christensen. *J. Geophys. Res.*, *105*, 9573-9588, 2000.
10. Christensen, P.R., et al. *Science*, *305*, 837-842, 2004.
11. Glotch, T.D., J.L. Bandfield, P.R. Christensen, W.M. Calvin, S.M. McLennan, B.C. Clark, and S.W. Squyres. *J. Geophys. Res.*, *111*, doi:10.1029/2005JE002672, 2006.
12. Chamberland, M., C. Belzile, V. Farley, J.-F. Legault, and K. Schwantes. *Proceedings of SPIE, Chemical and Biological Sensing V*, *5416*, 63-72, 2004.