LUNAR FIELD GEOLOGY ENABLED BY GROUND-BASED GEOPHYSICS. J. M. Hurtado, Jr.,1 and A. A. Velasco2, 1Department of Geological Sciences, University of Texas at El Paso, 500 West University Avenue, El Paso, TX 79968 (hurtado@utep.edu, aavelasco@utep.edu).

Introduction: Whereas Apollo focused on the directed collection of samples and imagery from carefully pre-selected sites, future lunar missions must also incorporate increasing amounts of independent, exploratory geologic and geophysical work. As with geoscience field work on Earth, this type of investigation will be driven by multiple working hypotheses, and it will involve detailed, systematic data collection and in-situ, real-time analysis. The realities of working on the moon will demand a close integration of ground-based geophysics and field geology to achieve the scientific goals as outlined by the National Research Council [1] and others [2, 3].

Lunar surface Extra Vehicular Activities (EVAs) during the Apollo missions were planned far in advance of the missions. Mission planners relied on imagery obtained from precursor missions (e.g. Lunar Orbiter and Surveyor) to select landing sites and to construct surface traverses [4]. Few geophysical datasets were available to inform site selection or to direct EVA activities. While valuable geophysical datasets were obtained from the Apollo Lunar Surface Experiment Packages (ALSEPs) [5, and references therein], the experiments were not designed to support field geologic operations. Instead, the ALSEP geophysical experiments were focused on planetary-scale characterization of the Moon, rather than near-surface geophysical methods that could assist the astronauts in mapping and sampling activities.

Challenges for Future Lunar Geologic Field Work: The return of astronauts to the Moon to continue geologic exploration will require a new approach that can benefit from new geophysical technologies and methodologies. Among the challenges are:

Geologic Mapping in the Absence of Outcrop. With the exception of the edge of Hadley Rille at the Apollo 15 landing site, no exposed bedrock was encountered at the Apollo landing sites [5]. Impact processes have effectively blanketed much of the lunar surface with a layer of regolith and impact rocks and ejecta. While many fundamental questions regarding the evolution of the Moon will continue to be addressed by studying lunar regolith samples, the lack of geologic context for regolith samples and observations (i.e. where did it come from?) remains. This limits the application of methods of structural geology, stratigraphy, and other important geologic approaches to mapping the lateral variations in the lunar crust. Alternative geophysical methods for mapping concealed bedrock, or for discovering locations of easily-accessible (via coring, drilling, etc.) bedrock in the shallow subsurface, are needed.

Constraining the Vertical Structure of the Lunar Regolith. A related problem concerns detailed investigation of the vertical structure (depth, stratigraphy, lateral extent, composition, etc.) of the upper crust of the Moon, including the lunar regolith. Vertical exposures through the regolith are available in crater or rille walls, but accessing such exposures that are sufficiently deep to reveal a complete stratigraphy will prove difficult and potentially hazardous. Near-surface geophysical methods are an ideal method for mapping vertical structure and do not rely on direct access to stratigraphy.

Assessments of Lunar In-Situ Resources. Current lunar (and Mars) exploration plans include aspects of in-situ resource utilization [6], an enterprise reinvigorated by recent discoveries of potentially usable water deposits in the lunar regolith and the poles [7]. Additional lunar resources also include extractable metals (e.g. Al, Fe, Ti), the regolith itself (for building material), and even subsurface voidspaces (e.g. lava tubes for habitation). Efficient exploitation of these resources will require geophysical methods for locating them on and below the lunar surface.

Ground-Based Geophysical Enabling Technologies: Since the Apollo era, advances have been made in field geophysical technologies that employ new techniques, achieve finer resolution and sensitivity, allow (near) real-time data processing, and/or include instrumentation with improved portability and power requirements. Most of these are currently employed in terrestrial environmental and near-surface geophysical investigations, but are also well-suited to address the challenges described above. They include:

Small-Scale Active Seismic Reflection Surveys. Seismic reflection surveys over short (1-20 km) traverses have proven effective at imaging the top 10 to 1000 m within complex, unconsolidated materials on earth [e.g. 8]. On Earth this has been applied to paleo-seismic interpretations of buried faults and folds, but on the Moon these techniques should be useful for determining the structure within (and beneath) complex, heterogenous material like the regolith. A pilot study addressing these issues is currently underway at UTEP.

Microgravity Surveys. Microgravimetric methods benefit from high-precision instrumentation, careful field acquisition techniques, and specialized data analysis methods to measure variations in the gravity
field due to small-scale features such as voids and cavities, features that would otherwise not be detectable due to the long-wavelength gravity potential variations they are superimposed on [e.g. 9, 10]. Microgravity is ideal for locating subsurface features such as lava tubes or for mapping short wavelength subsurface density variations due to changes in bedrock type, thickness or composition of regolith, etc.

Ground Penetrating Radar (GPR). Radar studies of the Moon and Mars from orbit are already imaging subsurface structure [e.g. 11]. However, since they are conducted from orbit, these studies are limited in their resolution. Ground-based GPR conducted by astronauts on the lunar surface can provide much higher resolution images of the subsurface. Moreover, the sensitivity to the dielectric, grain size, and geometric properties of the subsurface and the better resolution at shallower depths that GPR provides makes it a natural complement to shallow seismic and gravity. Experimental work using GPR on rovers (e.g. the NASA/Ames K-10 robot) is ongoing [e.g. 12].

Conclusion: Future human lunar exploration should include an integrated program ground-based geophysical measurements performed in support of geologic mapping, geochemical sampling, and resource exploration activities. Geophysics can provide access to geologic information not available with surface observations alone and can better inform the geologic context of samples and observations made at the surface. Moreover, many of these technologies allow the capability for (near) real-time acquisition and analysis of the data by astronaut crews themselves, allowing for an additional source of ground-truth information that can be applied to planning further exploration activities.

The technologies we advocate are proven on Earth and well-suited to rapid, near-surface characterization of the lunar regolith and upper crust. Future research should include continued use of these methods in planetary analog settings and in operational simulations. The appropriate technological infrastructure to support geophysical operations on the lunar surface should also be included in lunar surface hardware development and in EVA planning.

References: