COMPAS spectral capabilities for rock and mineral samples will be incorporated into an instrument prototype specifically for lunar measurements, compatible with rover capabilites.

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LUNAR UV-VISIBLE-IR MAPPING INTERFEROMETRIC SPECTROMETER. W. Hayden Smith[1], L. Haskin[1], R. Korotev[1], R. Arvidson[1], W. McKinnon[1], B. Hapke[2], S. Larson[3], and P. Lucey[4], [1]Washington University, St. Louis MO, USA, [2]University of Pittsburgh, Pittsburgh PA, USA, [3]University of Arizona, Tucson AZ, USA, [4]University of Hawaii and Ball Aerospace Group, Honolulu HI, USA.

We have developed ultraviolet-visible-infrared mapping digital array scanned interferometers [1] for lunar compositional surveys. The research has defined a no-moving-parts, low-weight and low-power, high-throughput, and electronically adaptable digital array scanned interferometer that achieves measurement objectives encompassing and improving upon all the requirements defined by the LEXSWIG for lunar mineralogical investigation. In addition, LUMIS provides a new, important, ultraviolet spectral mapping, high-spatial-resolution line scan camera, and multispectral camera capabilities. We describe an instrument configuration optimized for spectral mapping and imaging of the lunar surface and provide spectral results in support of the instrument design.

References: [1] Smith W. H. and Schempp W. V. (1991) *Experimental Astronomy, 1,* 389–405.

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LUNAR RESOURCE ASSESSMENT: STRATEGIES FOR SURFACE EXPLORATION. Paul D. Spudis, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058, USA.

Use of the indigenous resources of space to support long-term human presence is an essential element of the settlement of other planetary bodies. We are in a very early stage of understanding exactly how and under what circumstances space resources will become important. The materials and processes to recover them that we now think are critical may not ultimately be the raison d'etre for a resource utilization program. However, the need for strategic thinking proceeds in parallel with efforts to implement such plans and it is not too soon to begin thinking how we could and should use the abundant resources of materials and energy available from the Moon.

A plan to assess the resources of the Moon (or any extraterrestrial body) must be based on at least a rudimentary understanding of the following questions: (1) What materials and energies are likely to be needed by the envisioned space-faring infrastructure? (2) Where are these commodities on the Moon and what are their physical states and concentrations? (3) What types of processing are required to produce the desired products and how can such processing yield the maximum possible return? Once the first question has been addressed, resource assessment concerns itself primarily with question 2. However, the realities of question 3 must always be kept in mind during resource assessment; the distinction between ore and gangue is economic, not geologic.

My supposition is that at a minimum, we will want the following commodities: (1) bulk regolith, for shielding and construction on the lunar surface (ultimately for export to human-tended stations in Earth-Moon space), and (2) oxygen and hydrogen, for propellant and life support. I confine my attention to these essential products.

Synergy with Orbital Missions: Resource assessment requires both orbital and landed prospecting. Moreover, landed missions can be more effectively planned and conducted if some orbital reconnaissance is carried out before the landed payloads are sent. The issues associated with orbital prospecting are ably summarized by Taylor [1] and I touch on them here only from the perspective of the need to carry out a successful series of lander missions.

The lunar surface composition should be surveyed globally. This survey is the number one priority and should be carried out as soon as possible. From these data, a set of potential prospects can be selected and characterized to a first order. It will then become the task for a follow-up lander mission to obtain the data of quality sufficient to make judgments on the type of processing to be done, availability of feedstocks, and estimated product yields.

Bulk Regolith—The First Lunar Resource: Although the initial return to the Moon requires no *In Situ* Resource Utilization (ISRU), the long-term presence of people on the Moon compels us to consider the likely first needs of these lunar inhabitants. One can envision bringing along enough consumables (oxygen, water, food) to support the crew members for significant lengths of time, but shielding from the harsh radiation environment at the lunar surface requires mass, and lots of it. Several scenarios envision the use of bulk regolith piled over habitation modules. Bulk regolith is available in virtually unlimited quantities nearly anywhere on the Moon (it is hard to come by only at very fresh, large crater melt sheets, such as King). I believe that we understand the nature, formation, and evolution of the regolith well enough from Apollo to begin using regolith immediately for shielding purposes. If terrain-moving and construction equipment is built robustly enough, there is little need for precursor characterization of the site regolith. However, for completeness, Table 1 lists the desired knowledge of regolith properties and an estimate of the required fidelity of information.

Oxygen for Fuel and Life Support: After bulk regolith, lunar oxygen seems to be the most important resource for human use on the Moon. The amounts of oxygen required to support human life are trivial; in the following, I am assuming that oxygen is being produced primarily for use as propellant to support the Earth-Moon transportation infrastructure. If so, abundant oxygen will also be available to support life at the lunar outpost.

There is no shortage of this commodity: Lunar soils are at least 45% by weight oxygen. However, a strategy to assess oxygen resource potential must assume some type of processing scheme. Both high-yield and low-yield processes have been proposed to extract lunar oxygen. High-yield processes (e.g., magma electrolysis [2]) can effectively use any lunar material as feedstock and thus have no real assessment requirements for potential prospects. One low-yield process has received considerable attention: reduction of lunar ilmenite by hydrogen (e.g., [3]). This technique has been validated, at least at the workbench level, and produces oxygen at roughly 3% efficiency. The ilmenite reduction method requires a specific feedstock: lunar ilmenite grains or, at least, ilmenite-rich lunar soils. This requirement drives prospecting to high-Ti-composition maria; the ore should be as rich as possible in modal ilmenite (Table 1).

Given low-yield ilmenite reduction, the resource assessment task is simplified to identifying the highest ilmenite concentrations on the Moon and at specific sites, characterizing ilmenite gross abundances and their lateral and vertical variability (on a scale of a few meters). The location of ilmenite-rich regions is well suited to orbital prospecting [1]. Once such areas have been identified,

TABLE 1. Resource assessment needs: Initial surface missions.

Knowledge Needed	Obtained By	Precision Required
Regolith thickness	Lander imaging	0.5 m
Regolith fragment size distribution	Lander imaging	±10 cm
Bulk chemistry/ mineralogy	XRF/XRD/Mössbauer	± few %
Solar wind gas concentration	Lander GRS/NS	10s of ppm
Bulk	Lander EGA	1 ppm
Variability (10-m scale)	Rover EGA	1 ppm

promising sites should be investigated by selected *in situ* measurements. The heterogeneity of the ilmenite concentrations should be measured at scales commensurate with the those of the expected mining operations; nominally, this is likely to be on scales of a few meters. Concurrent documentation of regolith physical properties is also required, as the presence and abundance of large blocks, for example, might significantly influence mining operations. The data needs, some selected techniques for their acquisition, and precision required are estimated in Table 1.

Hydrogen for Fuel and Life Support: In contrast to oxygen, hydrogen is rare on the Moon. Hydrogen is important both as a fuel to support the transportation infrastructure, but it is also an essential resource to make water for life support, thermal control, and agriculture.

As far as we know, lunar hydrogen predominantly takes the form of molecules of solar hydrogen, adsorbed onto fine grains of lunar dust [4]. About 90% of the solar-wind-implanted hydrogen can be extracted by heating the lunar soil to about 700°C. Typical concentrations of hydrogen in Apollo soil samples are between 20 and 50 ppm [4]; there seem to be positive correlations between Ti content of mare soils and total hydrogen abundance and between soil maturity and hydrogen abundance. However, we have never made *in situ* measurements of lunar hydrogen and we do not know how it varies laterally or vertically in the regolith on a scale of meters. We also do not know how these supposed correlations hold up over the entire Moon or whether they exist at scales appropriate for resource extraction.

If hydrogen extraction from the Moon's surface is to become a reality, we must characterize its presence, abundance, and distribution in detail. I would give initial attention to high-Ti areas, including regional pyroclastic deposits [5]. A surface rover mission should simultaneously analyze soil chemistry, maturity, and adsorbed gas concentration; such a prospect should be carried out within a small area (e.g., a few kilometers square). Measurements of hydrogen concentration measured *in situ* on the Moon could then be correlated with both chemistry and maturity, two properties easily measured remotely from orbit at scales of meters to kilometers. In this case, a detailed site survey would have implications for estimates of the global reserves of lunar hydrogen.

Conclusion: This work is an attempt to understand what resource assessment means for an initiative that attempts to utilize indigenous lunar resources, quite probably on an experimental basis. I have discussed what I consider to be top-priority commodities and the knowledge needed to efficiently extract these products. As our knowledge improves on what space resource utilization requires and entails, we should develop a flexible strategy that will ensure we obtain the information we need in a timely manner.

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HIGH-RESOLUTION EARTH-BASED LUNAR RADAR STUDIES: APPLICATIONS TO LUNAR RESOURCE ASSESSMENT. N. J. S. Stacy and D. B. Campbell, National Astronomy and Ionospheric Center and Department of Astronomy, Cornell University, Ithaca NY 14853, USA.

The lunar regolith will most likely be a primary raw material for lunar base construction and resource extraction. High-resolution radar observations of the Moon provide maps of radar backscatter that have intensity variations generally controlled by the local slope, material, and structural properties of the regolith. The properties that can be measured by the radar system include the dielectric constant, density, loss tangent, and wavelength scale roughness.

The radar systems currently in operation at several astronomical observatories provide the ability to image the lunar surface at spatial resolutions approaching 30 m at 3.8-cm and 12.6-cm wavelengths and approximately 500 m at 70-cm wavelength. The radar signal penetrates the lunar regolith to a depth of 10–20 wavelengths so the measured backscatter contains contributions from the vacuum-regolith interface and from wavelength-scale heterogeneities in the electrical properties of the subsurface material. The three wavelengths, which are sensitive to different scale structures and scattering volumes, provide complementary infor-

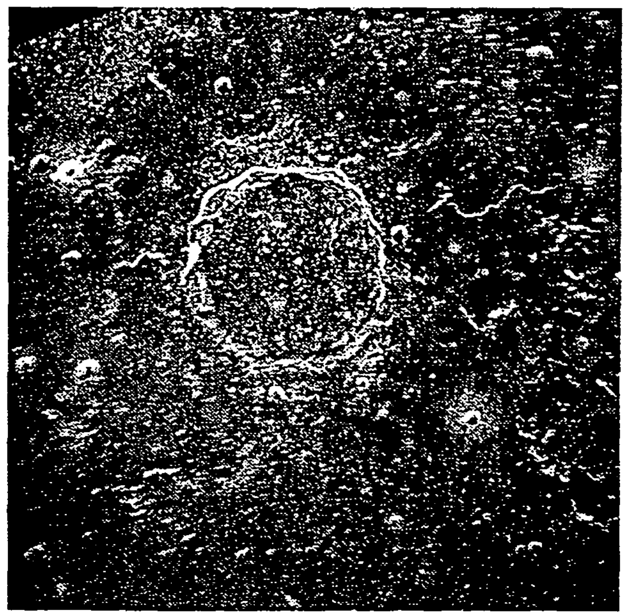

Fig. 1. Averaged 12.6-cm radar image of the depolarized relative backscatter cross section of the 100-km-diameter crater Plato (52°N, 9°W) and surrounding terrain. The incidence angle is 56° in the center of the image, north is to the top, and illumination is from the south-southeast.