TABLE 2. Selected X-ray escape depths (Å).

Material	Energies (eV) 30.5	72.4	91.5	151.1
10084 glass	190	430	530	670
67701 glass	180	470	510	630
ZnS		380	420	660

It is also useful to know how thick a region of the lunar surface will be sampled by these soft X-rays. We have estimated mean escape depths for several energies and compositions corresponding to a mare glass, a highland glass, and ZnS using the mass attenuation coefficients of Henke et al. [4], and present them in Table 2.

High spatial resolution combined with the thin surface layer from which these soft X-rays arise suggests the exciting possibility that X-ray telescopes could map lunar volcanic volatiles from orbit. The most characteristic feature of known lunar volcanic volatile deposits is a conspicuous enrichment in sulfur and zinc on grain surfaces [5,6]. These Zn,S-rich surface films can be seen in SEM images. In XPS studies [7] we have found surface Zn concentrations higher than 5 atomic percent and have estimated a depth of at least 100 Å. Thus Apollo 17 orange glass appears to have enough Zn and S to be seen from orbit, and it would be very surprising if there are not other lunar regions much richer in volcanic volatiles.

In our XPS studies of lunar regolith fines [8] we found that a significant fraction of the iron in the outer few hundred angstroms of grain surfaces was reduced to the metallic form, presumably as a result of micrometeorite vaporization and solar wind effects. Because of the strong possibility of substantial reoxidation of lunar material during storage, sample preparation, and analysis, we cannot know what the reduced fraction was on the lunar surface, but it may have been large. The M_{23} XPS lines and $M_{23}VV$ Auger lines of Fe^{++} and Fe° have different shapes and energies, allowing them to be easily distinguished. It seems likely that the $M_{23}V$ X-ray line will also, so the oxidation state of Fe in the regolith might be mapped with properly chosen telescopes.

We thus suggest that, in addition to major-element mapping, consideration be given to volcanic volatile mapping and regolith oxidation state mapping.

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ASSESSMENT OF THE LUNAR SURFACE LAYER AND *IN SITU* MATERIALS TO SUSTAIN CONSTRUCTION-RELATED APPLICATIONS.

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In this paper we focus on present and future technologies to facilitate lunar composition and resource assessment with applications to lunar surface construction. We are particularly interested in the construction activity associated with lunar-based astronomy. We address, as an example, the use of ground-probing radar to help assess subsurface conditions at sites for observatories and other facilities.

We feel that a multidisciplinary effort is desirable to identify what engineering data on the lunar environment and on the lunar soil and rock should be collected and how it should be obtained. Johnson and Burns [1] have urged action to acquire the following information and resolve issues indicated: (1) topographic maps of potential observatory sites (e.g., 10-cm contours over an area 1 km in radius); (2) detailed boulder sizes and counts over the same area; (3) surveys (e.g., by radar, microwave, or other means) for subsurface boulders over critical areas where foundations and excavation are desired; (4) surveys of depth-to-bedrock (with suitable definition and characterization of bedrock); (5) trenching and bulldozing experiments to establish energy requirements and depth limitations of these operations; (6) drilling and coring experiments (with energy consumption and depth limitations clarified); (7) force-vs.-depth cone penetrometer measurements to be used for siting settlement-sensitive telescope structures; (8) trafficability measurements including establishing energy consumption, slope-climbing capabilities, and formation of ruts or depressed surfaces by repeated traverses of unprepared surfaces; and (9) electrostatic charge measurements.

This listing has grown out of discussions with Dr. W. David Carrier III of the Lunar Geotechnical Institute and others. The list will vary somewhat depending on requirements for lunar-based facilities and operations. Johnson et al. [2] have noted that it is necessary to start now to develop the concepts and technologies for the next generation of space-based telescopes. A successor for the Hubble Space Telescope could be either in high Earth orbit (HEO) or on the Moon. To properly assess the merits of these suggested future telescopes, technology development for lunar as well as HEO telescopes should now be pursued so that properly informed decisions may be made. Part of the technology development requires improved understanding of engineering properties of lunar surface and subsurface materials and dust behavior. Johnson and Wetzel [3] note that the success of a large lunar-based telescope will depend on an appropriately engineered structure, a suitable interface (foundation) with the lunar regolith, and a carefully thought-out construction process. Johnson and Burns [1] have discussed the technology development required for large lunar telescopes and lunar optical/UV/IR synthesis arrays. They encourage the community to plan early lunar-bound payloads and surface operations to advance the knowledge and understanding required for building large telescopes on the Moon after the year 2000. Examples of key technologies for large lunar observatories that we feel deserve attention early in the program to return to the Moon are

1. Geotechnical (e.g., soils, excavation, foundations, and use of *in situ* materials for shielding).
2. Mitigation of detrimental effects of the environment (e.g., dust, thermal, primary and secondary impacts of micrometeoroids, radiation, and vacuum). This area includes obtaining a better understanding of the dust and debris environments above and on the surface of the Moon.
3. Approaches to use in construction on the Moon (e.g., extravehicular activity, robotics, telepresence, assembly aids, connectors). The appropriate choices can be made only with adequate knowledge of the surface conditions and variability.
4. Contamination/interference control and restoration processes. May vary with chemistry and mineralogy.
5. Performance of optical and related systems and charge-coupled devices (CCDs) on the Moon. CCDs deserve particular attention with respect to shielding requirements against cosmic and solar flare radiation. Shielding will probably be with *in situ* materials requiring excavation and placement at desired densities.
6. Test and evaluation techniques for lunar observatory systems and construction approaches to validate approaches before returning to the Moon. Depends on devising appropriate simulation of lunar conditions.

We anticipate that the initial telescopes on the Moon will be small automated instruments that have already been shown to be feasible by existing Earth-based robotic telescopes. These early telescopes will not only establish the viability of telescopes on the lunar surface, but will also perform excellent extended observations during the long lunar night to test models of active stars and galaxies, and do all-sky CCD surveys in the ultraviolet and infrared using a Schmidt wide-field telescope to complement the important sky survey done at Mount Palomar. We conclude that attention must be given to instrumenting these small telescopes in innovative ways to obtain information that will help find answers to unknowns in the areas listed above. We suggest that there are excellent opportunities to use the early landers to investigate the behavior of the soil under load, determine the extent of dust movement (e.g., levitation) associated with the passage of the lunar terminator, and place bounds on disturbances associated with vehicle operations on the Moon. Creative uses of information obtained from many innovative approaches may be used to help make lunar-based telescopes a reality.

For example, ground-probing radar has many terrestrial applications (e.g., in assessing pavement layer thicknesses in highway engineering applications, in determining the location of fissures in the dry lake bed at the Edwards Air Force Base shuttle landing site, and at Meteor Crater, Arizona, in investigations of the ejecta blanket). We propose to use this technology on the Moon in conjunction with other techniques such as penetrometers, borings, and core recovery to ascertain needed subsurface soil and rock properties. The goal is to minimize the use of labor-intensive subsurface sampling required during site investigations on the Moon and to improve approaches to assessing *in situ* lunar construction materials.

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AN *IN SITU* TECHNIQUE FOR ELEMENTAL ANALYSIS OF LUNAR SURFACES.

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An *in situ* analytical technique that can remotely determine the elemental constituents of solids has been demonstrated. Laser-Induced Breakdown Spectroscopy (LIBS) is a form of atomic emission spectroscopy in which a powerful laser pulse is focused on a solid to generate a laser spark, or microplasma. Material in the plasma is vaporized, and the resulting atoms are excited to emit light. The light is spectrally resolved to identify the emitting species.

LIBS is a simple technique that can be automated for inclusion aboard a remotely operated vehicle. Since only optical access to a sample is required, areas inaccessible to a rover can be analyzed remotely. A single laser spark both vaporizes and excites the sample so that near real-time analysis (a few minutes) is possible. This technique provides simultaneous multielement detection and has good sensitivity for many elements. LIBS also eliminates the need for sample retrieval and preparation preventing possible sample contamination. These qualities make the LIBS technique uniquely suited for use in the lunar environment.

LIBS has been demonstrated using several different types of samples at distances between 4 and 18 m. Analyzed samples include simulants of Apollo mission Moon rocks, Mauna Loa basalt samples, and rock powder reference standards. An example of the spectra obtained with this technique using an Apollo Moon rock simulant is presented in Fig. 1. The presence of several elements such as aluminum, calcium, iron, magnesium, silicon, and titanium is clearly evident.

A portable LIBS instrument has been field tested with good preliminary results. An exposed tuff face was interrogated by the laser spark at a distance of approximately 18 m in bright sunlight. Spectra obtained at this distance displayed very strong emission

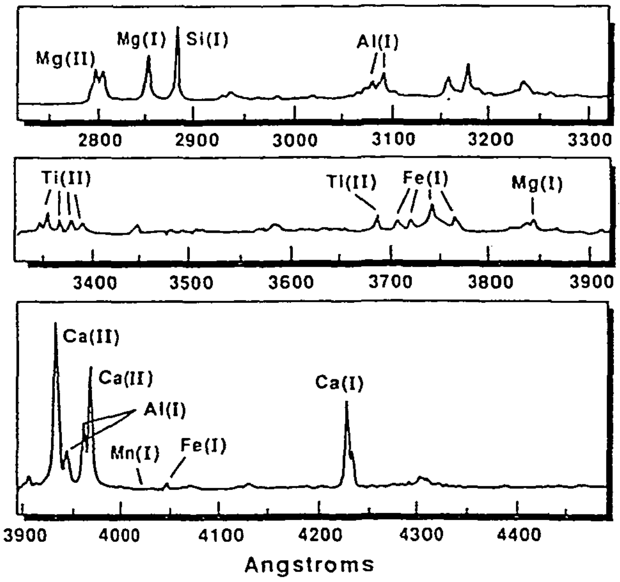

Fig. 1. Laser spark spectra of an Apollo Moon rock simulant in a vacuum chamber at a distance of approximately 10 m.