requirements. A similar design presently being developed for the Cassini mission is currently undergoing prototype testing.

Our mass-measuring technique, based on the motion of ions *in a region of linear electric field (LEF), is quite simple.* For a z-directed electric field $E_z(z)$ that increases linearly with distance along the axis, z, $E_z(z) = -kz$, where k is a constant solely dependent upon the electromechanical configuration of the device. Since the electrostatic force on a particle is qE, where q is the particle charge, the equation of motion for the particle in the z direction is that of a simple harmonic oscillator of mass m. A particle entering the LEF region at $z = 0$ will return to the $z = 0$ plane after completing half of an oscillation cycle, i.e., when $t = \pi/\omega = \pi\,(m/qk)^{1/2}$.

This timing is accomplished by passing the arriving ions through an ultrathin carbon foil; secondary electrons produced at the foil are accelerated in the LEF region to a detector that starts a timing clock. Positive ions emerging from the foil enter the LEF region and are reflected as described above, and are counted at a second detector that provides the stop signal for that ion's time of flight.

However, another feature of the mass spectrometer described here involves the analysis of molecular ion species. In addition to providing start timing pulses, the carbon foil also dissociates molecular ions. All ions are electrostatically energy-selected and arrive at the foil with a known energy/charge. Passing through the foil, it is dissociated into fragments that all travel with nearly the same velocity so that the energy is partitioned in proportion to the mass of each fragment. These fragments then have less E/q than the initial molecular value and will not travel as deeply into the LEF region of the device as would directly analyzed atomic ions of the same nominal E/q. Because of small E-field nonlinearities in an appropriately detuned LEF3D device, especially at the low-potential entrance end of the device, the times of flight of the fragments can be made shorter than those of atomic ions, an effect that allows separation of molecular and atomic interferences.

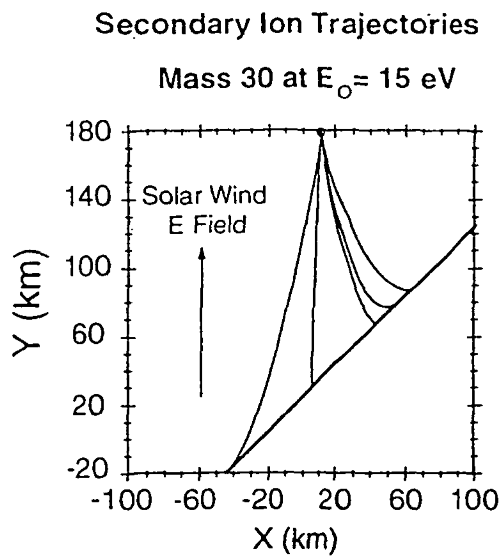

Fig. 2. Trajectories of sputtered secondary ions for typical solar wind conditions. Two representative paths illustrate how ions originating at different locations pass through a 100-km lunar orbit; the two ions are distinct in their arrival directions and their energies.

Finally, in addition to its orbital reconnaissance role, an LEF3D instrument can also perform surface composition measurements in conjunction with an active sounding technique. For example, *ions produced by laser-induced breakdown of lunar materials would* facilitate remote assessment of exposed materials not accessible to direct rover sampling, for example. An LEF3D instrument on a stationary landed platform would also provide synoptic monitoring of the atmosphere and volatile environment in conjunction with a geophysical station.

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LUNAR RESOURCE ASSESSMENT: AN INDUSTRY PERSPECTIVE. S. C. Feldman, B. H. Altenberg, and H. A. Franklin, Bechtel Corporation, P.O. Box 193965, San Francisco CA 94119, USA.

Introduetion: The goals of the U.S. space program are to return to the Moon, establish a base, and continue onward to Mars. To accomplish this in a relatively short time frame and to avoid the high costs of transporting materials from the Earth, we will need to mine resources on the Moon. Oxygen will be one of the most important resources, to be used as a rocket propellant and for life support. Ilmenite and lunar regolith have both been considered as ores for the production of oxygen.

Resource production on the Moon will be a very important part of the U.S. space program. To produce resources we must explore to identify the location of ore or feedstock and calculate the surface and underground reserves. Preliminary resource production tests will provide the information that can be used in final plant design. Bechtel Corporation's experience in terrestrial engineering and construction has led to an interest in lunar resource assessment leading to the construction of production facilities on the Moon.

There is an intimate link between adequate resource assessment to define feedstock quantity and quality, material processing requirements, and the successful production of lunar oxygen. Although lunar resource assessment is often viewed as a research process, the engineering and production aspects are very important to consider. Resource production often requires the acquisition of different types, scales, or resolutions of data than that needed for research, and it is needed early in the exploration process. An adequate assessment of the grade, areal extent, and depth distribution of the resources is a prerequisite to mining. This paper emphasizes the need for a satisfactory resource exploration program using remote sensing techniques, field sampling, and chemical and physical analysis. These data can be used to define the ore for oxygen production and the mining, processing facilities, and equipment required.

Background: The lunar environment is harsh and the emplacement of production facilities and mining will not be simple. Adequate data gathered now will prevent costly errors later. There are special problems associated with the lunar environment and mining operations. Temperature fluctuations will cause materials to become brittle. Reduced gravity will affect material handling and transport. The near-vacuum conditions will result in outgassing of materials and difficulties with lubrication around bearings and seals.

Some extreme conditions that provide construction challenges are also found on Earth. Bechtel Corporation has successfully designed, engineered, and constructed the Polaris mine, processing plant, and support facilities for COMINCO of Canada. The Polaris lead and zinc mine is located 90 miles north of the Arctic Circle and 600 miles from the North Pole. The entire processing plant was built on a single barge and delivered to the site during the last high tide, before the end of the six-week-long ice-free shipping season. It was docked in a dredged area, frozen in place, and has operated year round.

We can take advantage of our resource processing experience in the terrestrial environment in planning for lunar oxygen production. However, the Moon presents unique processing challenges. One of the unique problems on the Moon is that the ore or feedstock is being characterized at the same time that processing design decisions need to be made. Various authors have rated the favorability of different oxygen production processes. There is no general agreement on the best process or the most desirable feedstock [1]. Processes such as pyrolysis, electrolysis, and hydrogen reduction have been cited as being the most feasible. The process finally chosen will depend on the type of feedstock and will dictate the number of operating units, the reagents, and the power supply required. Since the required facilities and some materials will need to be transported from the Earth at great expense, at least initially, careful decisions must be made for process selection and plant design.

The feedstocks most often cited as resource material are bulk soil and ilmenite. However, we cannot choose a process that requires ilmenite unless we know that there are sufficient reserves at and below the surface. The consistency of the bulk soil composition, the impurities, and the grain size of the bulk soil at proposed mining sites also need to be determined if lunar regolith is to be used as the feedstock.

The ore or feedstock grade and the areal and depth distribution of the ore will control the amount and type of mining equipment needed to supply the process plant. Hypothetically, an ore with 5% ilmenite might require 20 mining and transport vehicles, while an ore with 20% ilmenite might require 5 vehicles.

Remote Sensing of Lunar Resources: Various remote sensing methods have been devised to assess lunar resources, specifically ilmenite. Telescopic measurements from Earth with spatial resolutions of between 1 and 20 km have been our greatest source of mineralogical data. The telescopic measurements have been used in conjunction with chemical analyses of a very limited number of lunar samples. The information that will be needed for material processing will require even higher resolution.

Based on earlier work by Charette and others [2], Pieters [3] has graphed the TiO_2 content of lunar samples from Apollo and Luna missions against the telescopic reflectance of those sample sites. These authors have found a distinctive relationship between the weight percent of TiO_2 and the ratio of the spectral bands at 0.40- and 0.56-μm wavelength. This relationship is only applicable to sites with mature regolith that contain abundant agglutinate and other glass. A linear relationship was found at higher concentrations of TiO_2. Johnson and others [4] have mapped surface ilmenite concentrations from telescopic reflectance measurements and have identified two regions with greater than 8 wt% TiO_2. The projected concentrations are based on concentrations in returned lunar samples. Most of our knowledge of the chemical and mineralogical composition of the Moon has come from the 832 kg of samples returned during the Apollo missions from six sites.

To examine the lunar resource assessment process, a known mining area in northern California was selected as a lunar analogue. Bechtel contracted for a flight line of remote sensing data over the New Almaden mercury mine, south of San Francisco, near San Jose. This mine has produced 40% of the mercury mined in the U.S. The site was chosen because the area contains some rocks and minerals that are analogous to lunar rocks, including iron oxide minerals. The data were acquired with the Geoscan MkII Airborne Multispectral Scanner. The sensor has 24 spectral bands in the visible, near infrared, shortwave infrared, and thermal infrared parts of the spectrum. The spatial resolution on the New Almaden flight was about 5 m. Existing topographic and geologic maps were used in the resource assessment in conjunction with the remote sensing data.

By examining the spectral curves of minerals associated with the mercury ore, processing strategies were defined to map iron-stained silica carbonate rock and serpentinite. Two separate mappings were produced. The first indicated a conservative estimate of mineral distribution, and the second a less conservative estimate. From indications in the field, the true mineral distribution is somewhere between the two estimates. The remote sensing data are most effective when used together with field sampling and chemical and mineralogical testing. This will be especially important in the lunar resource assessment program.

Conclusions: It is essential to define the lunar ore material and assess its grade and areal and depth distribution. Experience with Canadian gold mines shows that two to three times as many mines fail as succeed. We cannot afford a failure on the Moon, and accurate resource assessment is a key part of the success strategy. The keys to the success of lunar mining operations are caution with new processes, the collecting and testing of bulk samples, and adequate ore reserve calculations.

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LUNAR RESOURCES USING MODERATE SPECTRAL RESOLUTION VISIBLE AND NEAR-INFRARED SPECTROSCOPY: Al/Si AND SOIL MATURITY. Erich M. Fischer, Carlé M. Pieters, and James W. Head, Department of Geological Sciences, Brown University, Providence RI 02912, USA.

Introduction: Modern visible and near-infrared detectors are critically important for the accurate identification and relative abundance measurement of lunar minerals; however, even a very small number of well-placed visible and near-infrared bandpass channels provide a significant amount of general information about crucial lunar resources. The Galileo Solid State Imaging system (SSI) multispectral data are an important example of this. Al/Si and soil maturity will be discussed below as examples of significant general lunar resource information that can be gleaned from moderate spectral resolution visible and near-infrared data with