MAGNETIC CHARACTERIZATION OF LUNAR SOILS,* R. R. Oder, EXPORTech Company, Inc., New Kensington, PA 15068-0588; Lawrence A. Taylor, Dept. of Geological Sciences, University of Tennessee, Knoxville, TN 37996; Rudolf Keller, EMEC Consultants, Export, PA 15632.

Resource Recovery from Lunar Soils. Lunar soil will probably be the first extraterrestrial material to be exploited for resource recovery. Because of the unusual nature of the lunar environment, the soil is rich in resources which have potential for practical applications. Some of the soil components are unique to the moon. For example, fine-grained, single-domain, metallic iron (Fe^0) can be found in abundance in the agglutinate fractions (impact glass welded aggregates of lithic and mineral fragments).[1] The agglutinate fraction of the soil as well as the native iron normally present in disaggregated lunar rocks, may prove to be rich sources of iron for use as a non-terrestrial construction material. Additionally, ilmenite ($FeTiO_3$) found in abundance in mare soils is under investigation as a potential source of oxygen, iron and titanium.[2] Further, ilmenite is known to concentrate solar-wind implanted ^3He. Recovery of ilmenite would provide a rich source of this helium isotope for use as a fuel for fusion reactors.[3] In addition, other portions of the soil may serve as feedstocks for manufacture of metals such as calcium, aluminum, and silicon.[4] Efficient separation of lunar soil into its rock, mineral, and agglutinitic components will be required if recovery of these constituents is to be realized. The present study was undertaken with this goal in mind.

Table I
Lunar Soil Samples for Magnetic Separation Study

Sample Number	I_s/FeO	Agglut. Wt.%	Maturity	FeO Wt.%	Ilmenite Wt.%
	<-Maturity Parameters->				
Highland Soil Samples					
64421	83.0	54	Mature	5.03	---
65701	106	---	Mature	5.87	---
67511	8.8	---	Immature	4.10	---
Mare Samples					
10084	78	52-Petrog	Mature	16.2	---
71501	35	35-Petrog	Submature	17.41	8.0
71061	14	27-Petrog	Immature	17.8	4.6

__Magnetic Characterization of Lunar Soils.__ Magnetic characterization of the resource is the first step in determining the feasibility of beneficiating lunar soil. The assessment is of both scientific and technological interest because of the unusual nature of lunar soil and because of effects resulting from the low oxygen fugacity of the lunar atmosphere. Dry magnetic methods are well suited to this application, where no water is present, because these methods can be applied to recovery of fine-sized and feebly magnetic materials.

The focus of our continuing work is directed at assessing the magnetic recovery of: 1) ilmenite, a feedstock for extraction of ^3He, oxygen, iron, and titanium; 2) agglutinates for separation of native iron; 3) glassy components for recovery of refractory materials in some instances and a variety of volatiles in others; and 4) selected minerals(e.g., anorthite) of lunar soil for electrochemical extraction of oxygen, silicon, aluminum, and other valuable elements. This investigation encompasses magnetic characterization of a selected set of lunar soil samples listed in Table I. Below is a preliminary report on measurements of the magnetic susceptibility and particle size dependencies of the distribution of agglutinates and anorthite, $CaAl_2Si_2O_8$, in Apollo 16 sample #64421.

Table II
Distribution of Magnetics for >150 Micron Fraction of Lunar Soil No. 64421

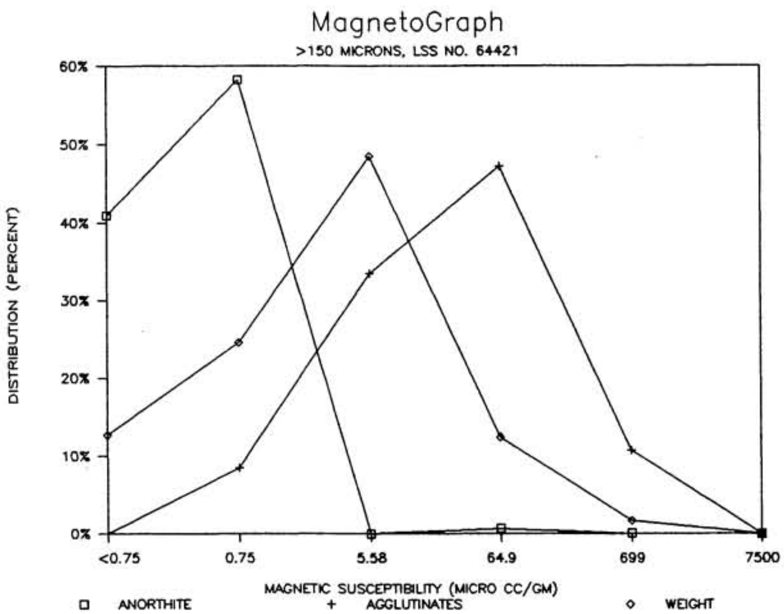
Magnetic Susceptibility Range (10^{-6} cc/gm)	Wt. Rec. >150 um Fraction (Wt.%)	Concentration Anorth. %	Concentration Aggl. %
< 0.75	12.7	95.0	0.0
> 0.75 < 5.58	24.6	70.0	5.0
> 5.58 < 64.9	48.6	20.0*	10.0
> 64.9 < 699	12.5	1.7	55.0
> 699 <7470	1.7	1.0	95.0
> 7470			

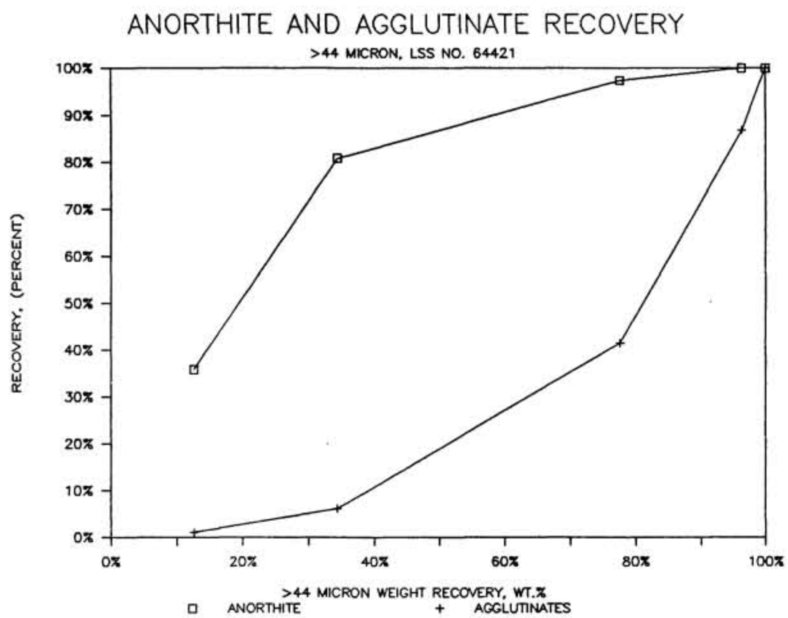
* Estimated

In this study, we have employed a Frantz Isodynamic Separator which is instrumented for both separations and magnetization measurements. Using the separator, we have isolated a series of components from the lunar soil and measured their low field magnetic susceptibilities. The magnetic separation procedure is described elsewhere.[5] Modal analyses were performed on the magnetic isolates to determine the relationship between magnetic susceptibility and distribution of agglutinates and anorthite.

__Lunar Highlands Soil No. 64421__. Approximately one gram of Apollo 16 lunar soil sample 64421 (the <1mm portion of soil 64420) was screened into three fractions. The weight distribution was: 41.1 wt% > 150 um, 27.3 wt% 44-150 um, and 31.7 wt% <44 um. Magnetic and modal data for the >150 micron fraction are shown in Table II.

The weight distribution of magnetic fractions separated from this material is shown in Figure 1. Relatively little __strongly__ magnetic material was observed contrary to expectations based on the presence of agglutinates containing ferromagnetic iron. Evidently the magnetism of the very fine-sized iron particles is diluted by the bulk of the agglutinates. Secondly, the peak in recovery of the paramagnetic component occurs at a magnetic susceptibility of 5.5×10^{-6} cc/gm. Thirdly, the measurements indicate a significant amount of weakly magnetic material including the possibility of some diamagnetism in the lunar sample.





__>150 um Fraction.__ Figure 1 shows the observed distribution of anorthite/ agglutinate for the >150 um size fraction and illustrates the high degree of separation of these fractions achieved for this soil. The distribution of anorthite peaks at a magnetic susceptibility of 0.75×10^{-6} cc/gm while the distribution of agglutinates peaks at 64.9×10^{-6} cc/gm. Separation at a magnetic susceptibility of 0.75×10^{-6} cc/gm would recover about 40% of the anorthite at 95% concentration while rejecting the greater portion of the agglutinates.

__>44 Micron Fraction.__ Measurements of the distribution of magnetics were made for the 44-150 um size fraction. The results are similar to those of the coarse fraction. The tradeoffs possible in separating agglutinates and anorthite for the >44 um fraction of this soil are illustrated in Figure 2.

__Magnetism of Lunar Soils Vs Terrestrial "Analogs."__ We have recovered agglutinates from the lunar sample whereas there are no agglutinates in natural or man-made terrestrial materials. Because of the presence of the agglutinates and their included free iron, the resulting MagnetoGraph of the lunar sample bore no resemblance to our unpublished results on either anorthosite from Minnesota (peak recovery at 0.75×10^{-6} cc/gm) or a lunar simulant prepared from Minnesota basaltic sill.[6] Additionally, we have found that relatively pure anorthite (An95) can be recovered from mature lunar soil by magnetic separation. The magnetism of the lunar anorthite is similar to that of anorthite (An78) recovered from Minnesota anorthosite even though the terrestrial anorthosite has a magnetic characteristic which is distinctly different from that of the lunar soil.

__Future Work.__ Five additional lunar soil samples are listed in Table I. These samples will be investigated in the next few months. Each sample was selected for specific reasons. For example, the Apollo 17 soils, from the same station, have differing degrees of maturation and differ in ilmenite contents by a factor of two even though the iron contents are nearly the same. Characterization of the six soils of Table I will be important to development of successful magnetic beneficiation methods for extraterrestrial applications.

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1. Taylor, L.A. (1989) __2nd Sym. Lunar Bases & Space Act. of 21st Cent.__, LPI, in press.
2. Gibson, M.A., and C.W. Knudson (1985) __Lunar Bases & Space Act. of 21st Cent.__, LPI, pp. 543-550.
3. Sviatoslavsky, I.N., and M. Jacobs (1988) __Proceedings of Space 88__, pp. 310-321.
4. Anthony, D.L. et al. (1988) __Lunar Bases & Space Act. of 21stCent.__, LPI, LBS-88-066.
5. Oder, R. R. (1987) __Proc. 4th Pittsburgh Coal Conf.__, pp. 359-371.
6. Weiblen, P.W., and K. L. Gordon (1988) __Lunar Bases & Space Act. in the 21st Cent.__, LPI, LBS-88-213.