

**LUNAR MINERAL FEEDSTOCKS FROM ROCKS AND SOILS: X-RAY DIGITAL IMAGING IN RESOURCE EVALUATION** John G. CHAMBERS, Allan PATCHEN, Lawrence A. TAYLOR, Stefan J. HIGGINS, Planetary Geosciences Inst. Dept of Geol. Sci., Univ. of Tennessee, Knoxville, TN 37996; and David S. McKAY, Mission Sci., & Tech. Office, Code SN14, Johnson Space Center, Houston, TX 77058.

The rocks and soils of the Moon provide raw materials essential to the successful establishment of a lunar base (e.g., [1]). Efficient exploitation of these resources requires accurate characterization of mineral abundances, sizes/shapes, and associations of "ore" and "gangue" phases, as well as the technology to generate high-yield/high-grade feedstocks. Only recently, have x-ray mapping and digital-imaging techniques been applied to lunar resource evaluation ([2-6]). Our previous efforts have involved quantitative characterization of mineral liberation and beneficiation of hi-Ti basalt 71055 ([5-6]) with software from Oxford Inst. Inc. coupled with an EDS attached to a Cameca SX-50 EMP.

X-ray digital-imaging techniques supply a quantitative method of mineral resource evaluation ([5]), and therefore, application of these methods provide the best way to compare the mineral resource potential of soils and rocks. Previous studies have compared various soils, rocks, regolith breccias, and pyroclastic glasses as potential ilmenite feedstock sources ([2] and [4]), but no x-ray digital-imaging study has addressed the mineral feedstock potential of lunar soils. This is largely due to the difficulty of using chemical criteria to distinguish the complex impact-glass-welded components present in lunar soil. Integration of recent software development for digital-imaging combined with traditional petrographic methods has permitted "automated" characterization of lunar soil mineralogy and components (e.g., agglutinates) by Higgins et al.[9].

The use of lunar ilmenite as a reactant for hydrogen reduction to produce a Lunar-Liquid-Oxygen (LLOX) supply has received considerable study ([10]), and ilmenite concentrates will be used in this process. Therefore, it will be necessary to obtain beneficiated ilmenite feedstocks from either hi-Ti basalts or hi-Ti mare soils [4]. It is uncertain which raw material, rocks or soils, is the more feasible to beneficiate for an ilmenite concentrate ([2,7, and 8]). By combining rock ([5, 6]) and soil [9] x-ray digital-imaging data it will be possible to quantitatively compare feedstock grade and yield.

**Inherent Differences Between Lunar Basalts and Soils-** Because of the complicated process of soil formation, a simple crushed lunar rock has many inherent differences as compared to lunar soil. Crushed lunar basalt consists primarily of monomineralic (i.e., clean) and multimineraleic (i.e., lithic) particles. However, lunar soil is not simply comminuted rock material, but it is a complex array of primary and secondary phases (minerals and glasses) and particles (mineral and rock fragments and impact-glass welded particles). In fact, the lunar soil consists of monomineralic particles, basaltic microrocks, highland microrocks, impact glasses, meltrocks (i.e., impact glass + primary fragments), microbreccia, pyroclastic glasses, and agglutinates. These first-order differences are due to the complex weathering processes, comminution and agglutination, that create the lunar soil by meteorite and micrometeorite bombardment (e.g., [11]). In addition, while the amount of clean mineral fragments initially increases with soil exposure-time, the modal abundances and percentage of clean mineral fragments decreases as a soil approaches maturity, a function of agglutinate content ([8]). In addition, the magnetic properties of soil and crushed rock are very different due to the generation of native Fe<sup>0</sup> in the former. The process of auto-reduction during soil formation generates a myriad of single-domain (44-330 Å) native Fe<sup>0</sup> spheres, and this mineralogical change greatly increases the bulk magnetic susceptibility of a soil with exposure-time ([12]).

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**Quantitative Comparison of Rock- and Soil-derived Ilmenite Concentrates-** As an application, mineral distribution data were compared for the most ilmenite-rich magnetic splits from the 45-90  $\mu\text{m}$  size fraction of 71055 (crushed hi-Ti basalt material) and 10084 (mature hi-Ti soil). The beneficiation of these materials was discussed in Taylor and Oder [1] and Taylor et al. [4]. Ilmenite in these splits was concentrated to 70 and 18 vol% by magnetic separation of this rock and soil, respectively. However, the yields of these concentrates are quite low at only 5 wt% for both raw materials. Figure 1 compares the distribution of ilmenite in the rock- and soil-derived feedstocks. The bars represent the percentage of particles with various amounts of ilmenite, and the curves are cumulative mineral liberation curves for ilmenite. The graph shows that ilmenite in the 71055 concentrate occurs mostly as clean fragments (i.e., 80% of the ilmenite is in particles which are 80-100% pure), but the ilmenite in the 10084 concentrate is not as clean (i.e., only 58% of ilmenite is 80-100% pure). Both concentrates show nearly bimodal particle distributions of 0-10% and 90-100% ilmenite particles, but the trends are opposite.

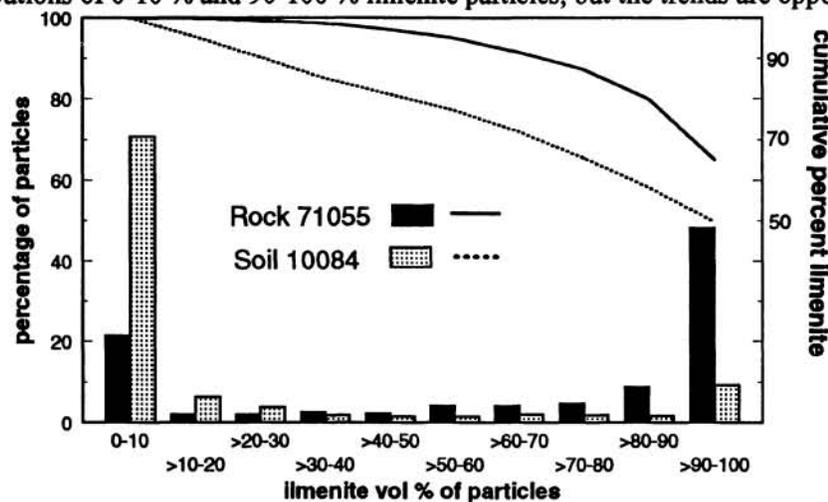


Figure 1. Comparison of the most ilmenite rich magnetic splits of the 44-90  $\mu\text{m}$  fractions of hi-Ti rock 71055 and mare soil 10084.

Magnetic separation of rock material (71055) produced a richer ilmenite concentrate due to the simpler nature of the crushed rock. In both rock 71055 and soil 10084, ilmenite is attached to pyroxene, plagioclase, and olivine; however, the ilmenite 10084 is also associated with impact glass, Ti-glass, and pyroxene-like glass. Therefore, soils are more difficult to magnetically beneficiate due to impact glass which welds together minerals and rock fragments (agglutination).

**Conclusions-** X-ray digital-imaging characterization of lunar raw materials provides a quantitative comparison that is unattainable by traditional petrographic techniques. These data are necessary for accurately determining mineral distributions of soil and crushed rock material. Application of these techniques will provide an important link to choosing the best raw material for mineral beneficiation.

**References** [1] Taylor and Oder, 1990 *Space 90, ASCE*, 143-152; [2] Heiken and Vaniman, 1990 *PLPSC20*, 239-247; [3] Heiken et al., 1992, *Space 92, ASCE*, 555-564; [4] Taylor et al., 1992, *PLPSC23*, 1415-16; [5] Taylor et al., 1993, *PLPSC24*, 1409-10; [6] Chambers et al., 1994, *Space 94, ASCE*, in press, [7] DeLa'O et al., 1990, *Space 90, ASCE*, 177-186; [8] Taylor and McKay, 1992, *Space 92, ASCE*, 1058-1068; [9] Higgins et al., 1994, *PLPSC25*, in press, [10] Gibsen and Knudsen, 1990, *Space 90, ASCE*, 197-205; [11] Taylor, 1990, *Space 90, ASCE*, 68-77; [12] Taylor, 1988, *Space 88, ASCE*, 67-77.