

HOT-PRESSED IRON FROM LUNAR SOIL.

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Introduction: The amount of iron in the elemental form (Fe^0) is about 10X greater in lunar soil than in the rocks from which the soil was formed [1-2]. At first, it was assumed that this was meteoritic metal. However, it was later shown that the amount of meteoritic contamination to the soil is only about 2% at best. The majority of the native Fe in the lunar soil was formed by the auto-reduction, by solar-wind implanted hydrogen, of the FeO in the silicate melts formed by micro-meteorite impacts. The FeO in the melt is essentially reduced to elemental Fe which homogeneously nucleates into myriads of nanophase-sized (3-33 nm) Fe^0 . This melt quenches, thereby forming the glass which binds together the aggregates of soil particles called 'agglutinates.' This fine-grained Fe (abbr. 'np-Fe') in the agglutinitic glass is not visible with an optical microscope.

Formation of Lunar Soil: The major factor in the formation of lunar soil involves micro-meteorite impacts. Larger particles are comminuted to finer and silicate melt welds together soil grains into glassy aggregates called agglutinates. These two competing processes complicate the formational characteristics of the soil. Recently, we have become aware of yet another set of processes that significantly affect lunar soils. This is the formation of surface-correlated "nanophase Fe^0 " (4-33 nm), resulting from impact-induced vaporization and deposition of Fe-, Al-, and Si-rich patinas on all soil particles [3-6], as well as sputter-deposited contributions [7]. The average grain size of this nanophase Fe^0 is substantially less than that in agglutinitic glass such that it causes the major portion of the space weathering effects to reflectance spectra [4-6; 8-9].

Agglutinitic Glass versus Grain Size and Maturity: It has been demonstrated recently that for a given mare soil, *the abundances of agglutinitic glass increase significantly with decreasing grain size,* as evidenced by the I_s/FeO values which increase with decreasing grain size. The maturity index, I_s/FeO , is used as an indication of the amount of iron in a sample that is present as np-Fe. As shown by Taylor et al. [5-6], the percentage increase in I_s/FeO and agglutinitic glass, from the larger grain sizes to the smaller size fraction is only on the order of 10-15%, whereas the I_s/FeO changes by about 100%. That is, *with a decrease in grain size, the change in agglutinitic glass content is relatively small compared with the change in I_s/FeO .* This logically leads to the conclusion *that the large increase in I_s/FeO is direct proof of the presence of another source of nanophase Fe^0 , in addition to the agglutinitic glass.*

Surface-Correlated Nanophase Fe: The thesis on vapor-deposited patinas [3] has also found supporting evidence in several subsequent studies [4-6; 8-10]. *The presence of nanophase Fe^0 in the vapor-deposited patinas (rims) on virtually all grains of a mature soil provides an additional and abundant source for the greatly increased I_s/FeO values.* In fact, for grain sizes of lunar soils <45 μm , the amount of np-Fe on the surfaces is large, possibly equal to that in the agglutinitic glass in these fine grains.

Magnetic Separation of Lunar Soil Particles: Taylor and Oder [11] performed studies on lunar soils in order to determine the optimum conditions for the beneficiation of soil components for in-situ resource utilization (ISRU) at a lunar base. Using a Frantz Isodynamic Separator, specifically calibrated for

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susceptibility measurements, they studied various size fractions of hi-Ti and low-Ti mare soils, as well as some from the highlands. They were able to successfully beneficiate the soil particles with decreasing efficiency as grain size decreased, down to 45-20 μm . However, with sizes $<20 \mu\text{m}$, they determined that separation was not possible. It appeared that 'clumping' of these fine-sized grains was responsible. It was apparent that this size fraction behaved as if virtually all the particles had relatively higher magnetic susceptibilities than the coarser particles. In retrospect, this behavior is now explainable, with our new knowledge, that each of these fine grains contains a surface patina of ferromagnetic nanophase Fe^0 .

Uses for the nanophase Fe: Recent experimentation by the author with the $<10 \mu\text{m}$ fraction of mature hi-Ti mare soil 79221 has shown that a small hand magnet will easily attract practically all the grains, even those that are plagioclase, but have a thin patina of np-Fe. This fine fraction, along with the high-magnetic susceptibility agglutinitic glasses from coarser sizes can be easily beneficiated from the lunar soil to make a feedstock for roasting. The nanophase Fe present both on the particle surfaces, as well as in the agglutinitic glasses, is readily ripened by annealing at 1000°C . This can render this product a valuable feedstock from which to retrieve the enlarged Fe grains even by rather crude magnetic separation.

The presence of extensive amounts of np-Fe on virtually all surfaces of soil grains is particularly advantageous where the grain-size of a soil fraction is small (e.g., $<45 \mu\text{m}$), since the surface to volume ration is largest and the concentration of agglutinitic glass is the greatest. It will be possible to easily shape and form the soil and to sinter it slightly by "hot pressing." The np-Fe will grow during this process thereby adding significantly to the ad-

hesion and strength of the aggregates. In addition, the nanophase Fe is located within a silicate glass, which being inherently unstable, will readily add addition fusion of the particles to each other. The 'discovery' of the abundance of this nanophase native Fe on the surface of lunar soil grains has potential for numerous uses for ISRU.

References: [1] Taylor, 1988, Proc. Space 88, ASCE, 67; [2] Taylor and Cirlin, 1985, In IONICS - ESR Dating and Dosimetry, Tokyo, 19; [3] Keller & McKay, 1997, GCA 61, 2331; [4] Taylor et al., 1999, LPSC 30, LPI-CD #1859, #1885; [5] Taylor et al., 1999, New Views of the Moon II, LPI; [6] Taylor et al., 2000, LPSC 31, LPI-CD #1697, #1706, #1842; [7] Bernatowicz et al., 1994, LPSC XXV, 105; [8] Keller et al., 1999, LPSC 31, LPI-CD 1820; [9] Keller et al., 2000, LPSC 31, LPI-CD 1655; [10] Taylor et al., 2000, MPS, in press; [11] Taylor and Oder, 1990, Proc. Space 90, ASCE, 143.