reduction was detected at lower temperatures. We consider these contributions to the oxygen yield to be negligible.

The predicted output from a lunar oxygen plant thus depends on the ilmenite and TiO$_2$ contents of the soil. In most lunar soils almost all the TiO$_2$ is incorporated in ilmenite [1]. The maximum oxygen yield therefore will equal 20% of the TiO$_2$ content if only ilmenite is reduced, and 25% if further conversion to TiO$_2$ occurs. Lunar soil 78221 contains 3.84 wt% TiO$_2$. The maximum predicted oxygen output from a plant using this feedstock is just under 1% of the total input mass. The output from a high-Ti soil such as 75061, with 18.02 wt% FeO and 10.38 wt% TiO$_2$ [4], is 2.6%.

Concentration or beneficiation of ilmenite would increase the process yield, but not the overall yield. An output of 2.6% means that 38 tons of lunar soil would be required to produce one ton of oxygen. By terrestrial standards this is a small amount of feedstock. A single medium-sized dump truck can hold 40 tons and can be loaded in under 10 min with a front-end loader [6].

Acknowledgments: The reduction experiments were performed at Carboteck with Shimizu Corporation funding. Samples were analyzed at the NASA Johnson Space Center with NASA funding.


Impact melt lithologies (noritic breccias) are rich in incompatible trace elements (ITE) (Fig. 1) and include very fine-grained crystalline and poliklitic impact-melt breccias, glassy matrix breccias, and regolith breccias and agglutinates that include only impact melt breccia lithologies. The latter may have developed in the regolith higher on the North Massif or prior to the introduction of mare materials into the soil. On the basis of Sc, Cr, Sm, and Eu concentrations, noritic melt lithologies from 76503 and matrices from station 6 and 7 boulders differ significantly from those of stations 2 and 3, except boulder 2, station 2. Among particles from sample 76503, evidence of more than one melt group is lacking (Fig. 2). Most of the melt breccias are tightly clustered compositionally and fall within the field of North Massif melt breccia compositions defined by analyses from the literature (Fig. 2). Those melt breccias having compositions outside this field contain clasts of highland material having low concentrations of ITEs; thus their compositions are displaced toward those of highland igneous lithologies and granulitic breccias.

Highland lithologies that have low ITE concentrations include fragments of shocked and unshocked anorthositic troctolite, anorthositic norite, gabbroic anorthosite, and granulitic breccias of generally anorthositic-norite or anorthositic-gabbro compositions. Coarse single crystals or clumps of several crystals of plagioclase are common in the 2-4-mm range. These are compositionally very similar to plagioclase in 76535 troctolite [4]; however, we believe these, and perhaps 76535 also, are members of a more anorthositic body [2]. We find no igneous particles whose compositions suggest affinity to ferroan-anorthositic suite igneous rocks. Granulitic breccias are generally more pyroxene rich than the samples having igneous textures, and, although they have low ITE concentrations, many are substantially contaminated by meteoritic siderophile elements.

Observations and Implications: Below, we summarize some important features of the distribution of lithologies and compositions of particles in 76503 by comparison to the model distribution of components determined for station 6 <1-mm soil by [3]. Several of these features distinguish this soil from soils of the South Massif.

(1) The mass-weighted average composition of the regolith breccias and agglutinates is very similar to the average composition of the station 6 <1-mm fines [3] (Fig. 2). (2) The proportions of components that have been used to model the station 6 soil [3] are similar to the proportions of groups we find in sample 76503 (i.e., the regolith breccias and agglutinates can be well accounted for as a mixture of observed mare basalt and orange glass fractions, noritic melt breccias, and ITE-poor highland lithologies).

The <1-mm fines can be modeled as 51% highlands [36% anorthositic norite and 14% MG component (norite/troctolite mix)], 21% noritic breccia, 21% mare basalt, and 6% orange glass, whereas the proportions of fragments in sample 76503 are 43% highlands, 34.5% noritic breccias, 19% mare basalt, 2% orange glass, and 0.6% VLT basalt (by mass on an agglutinate/breccia-free basis). (3) The proportion of noritic breccias in 76503 exceeds that determined as a mixing component in <1-mm fines by [3]; however, we have included in our particle count noritic breccias whose compositions are skewed toward ITE-poor highland compositions (see Fig 1). Therefore, a portion of the "MG" and "AN" highland components of [3] is taken up in our proportion of noritic breccias. This portion consists of mineral and lithic clasts that, on average, have a composition similar to magnesian granulite or magnesian anorthositic norite [2]. (4) More orange glass was found in the fines model than in the 2-4-mm particles because orange glass particles have a mean size of 40 μm [5] and so concentrate in the finer soil fractions. Particles with orange glass composition in sample 76503 were orange/black glass regolith breccias, not large, individual glass spheres. (5) Magnesian troctolite
76503 2-4mm particles

- Noritic Breccias
- Highlands - Ig. + Granulitic
- Anorthositic/Troctolitic
- Reg Breccias and Agglutinates
- Non-mare Breccias
- Orange Glass
- Basalt
- Mare Breccia
- Unclassified (not grouped)

Model Components of [3]
Fields determined from Literature Data (many sources)

Fig. 1.

76503 Noritic Impact Melt Breccias

N. Massif Boulder Matrices:
Station 6 and 7 Boulders
(also Boulder 5, Station 2)

Matrix from 72275
Boulder 1, Station 2

S. Massif Breccia Matrices:
73215, 73235, 73255, 72255

mass-weighted average anorthositic gabbro/norite composition

Fig. 2.
anorthosite appears to be the dominant lithology of the "MG" component and granulitic breccias, the dominant lithology of the "AN" component of [3]. The abundance of the Mg-rich component coupled with the absence of a KREEP component distinguish North Massif soils from South Massif soils.

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REFINING THE GRANULITE SUITE. Janet A. Cushing, G. Jeffrey Taylor, Marc D. Norman, and Klaus Keil, Planetary Geosciences, Department of Geology and Geophysics, University of Hawaii at Manoa, 2525 Correa Rd., Honolulu HI 96822, USA.

Early studies of rocks retrieved from the Moon during the Apollo missions defined a group of rocks as granulites or "granulitic impactites" [1,2]. This included rocks with cataclastic, granulitic, and poikilitic or poikiloblastic textures. Bickel and Warner [3] showed that the "granulites" have bulk compositions that fall into the two major pristine rock groups: the Mg-suite and ferroan anorthosites. Lindstrom and Lindstrom [4] further divided the granulites into four groups based on compositional distinction (Table 1). All these rocks have high contents of siderophile elements, indicating meteoritic contamination and indicating that impacts played a role in their origin. The conventional wisdom for the formation of the granulite suite involves post-"Apolloian" metamorphism of polymict breccias at near-solidus temperatures and low pressures, and for a relatively short period of time [2,5]. Nevertheless, some authors have drawn attention to the igneous appearance of some members of the granulite suite, such as 77017 and 67955 [6].

Petrographic studies indicate that the textures of "granulitic breccias" are significantly varied so as to redefine the granulitic suite into at least two distinct groups. The first group consists of rocks that have true granulitic textures: polygonal to rounded, equant grains that are annealed and have triple junctions with small dispersions from the average 120°. The second group of rocks have poikilitic or poikiloblastic textures, with subhedral to euhedral plagioclase and/or olivine grains enclosed in pyroxene oikocrysts. In some instances, the relationship between the minerals resembles an orthocumulate texture. The rocks

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* sf: strongly ferroan; mf: moderately ferroan; sm: strongly magnesian; mm: moderately magnesian.