## Composition and Texture of Soil and Breccia

The lunar soil—returned from the Apollo 11 landing site—is a loose sediment of rather unsorted angular to subrounded particles and regularly shaped bodies of different size and origin.

The constituents range in grain size from less than a few microns up to the decimeter size covering a broad variation in composition and structural state. Most conclusive is the presence of fragments of breccias. They are composed of about the same constituents as the soil but consolidated by a glassy fine-grained matrix.

A detailed knowledge of the petrographic composition and the relationships between unconsolidated and consolidated material may well be the key to the evaluation of the complex genesis and shock metamorphic history of the lunar soil.

In the next paragraphs a general description of the compositional and textural properties of the soil and of its constituents will be given to provide a basis for the discussion of shock effects described in the following chapter.

The main constituents of the soil are:

1. Fragments of minerals;
2. Fragments of glasses, some recrystallized;
3. Regular glass bodies of rotational symmetry and fragments of the same, some recrystallized;
4. Fragments of rocks;
5. Fragments of meteoritic material.

Genetically, the constituents belong to two different groups. The first group comprises particles formed by crystallization from a magma. The second group consists of particles formed by a metamorphic process which transformed minerals and rocks of the first group to glasses. This metamorphism was apparently caused by strong shock waves, as shall be demonstrated below.

*Mineral fragments* include, in order of decreasing frequency, pyroxenes of various composition, plagioclase (60–100 mole % An), ilmenite, olivine and a series of other minerals such as cristobalite, quartz, alkali-feldspar which are very rare and of subordinate importance in the shock history of the soil. The main minerals show varying degrees of shock deformation, which are especially recognizable in pyroxene and plagioclase. The grain size of all mineral fragments varies greatly ranging from some microns up to several millimeters.

*Glasses* in angular to subangular fragments occur up to some millimeters in size, but most frequently in the submillimeter fraction. Two kinds of glasses are present:

(a) colorless clear glass fragments of pure plagioclase, or very rarely of alkali feldspar composition (diaplectic glasses);
(b) colorless, pale, greenish, yellow, yellow-brown, red-brown, orange, brown and violet-brown fragments.

Most characteristic are *regular glass bodies* with rotational symmetry of different shape such as spherules, ellipsoids, dumbbell- and teardrop-shaped bodies. Most of them occur in the submillimeter fraction, a few are larger than one millimeter. The variation in color is quite similar to that of the angular glass fragments, type b.

Both, the type b angular fragments and the regular glass bodies are either very homogeneous or are heterogeneous to varying degrees in their vesicularity, schlieren, and amount and kind of inclusions. The most frequent inclusions are pyroxene, plagioclase and very tiny iron–nickel–spherules or opaque cube-shaped bodies. A small amount of all kind of glasses has been recrystallized.

*Rock fragments* may be divided into magmatic rocks and breccias. They range from particles consisting of only two or three mineral grains up to the decimeter size.

The *magmatic rocks* have a wide textural and grain size variety. The grain size ranges from a few microns to a few millimeters. Most frequent are rocks of basaltic composition with clinopyroxene, plagioclase, ilmenite and less common olivine and cristobalite. They are relatively uniform in mineralogical and chemical composition (LSPET, 1969). Rocks of anorthositic composition with plagioclase, olivine and/or pyroxene are less frequent and only present in the less than 1 cm grain size fraction.

Very rarely fragments of magmatic rocks are coated with brownish vesicular and streaky glass containing mineral inclusions like pyroxene and feldspar and minute iron-spherules.

The most abundant type of *breccias* principally consists of a mixture of all 5 types of constituents of the loose soil described above embedded in a matrix of vesicular, brownish glass (Fig. 1). The fragmental debris within the breccias has a grain size generally smaller than one centimeter and mostly even smaller than the millimeter range. The amount of matrix glass varies resulting in variable degrees of consolidation. The size range of the breccia fragments is similar to that of the crystalline rocks. However, breccias are more frequent than crystalline rocks in the less than 1 cm fraction.

Table 1. Grain size distribution of the soil <1 mm (10084-106)

| Dia. ($\mu$m) | wt. % |
|---|---|
| 1000–500 | 4·8 |
| 500–250 | 9·1 |
| 250–125 | 14·1 |
| 125– 63 | 16·0 |
| 63– 20 | 23·8 |
| 20– 10 | 16·1 |
| 10– 4 | 8·2 |
| <4 | 7·7 |

Another type of *breccia* was found very rarely, as small fragments. It is composed mostly of fragments of plagioclase, pyroxene and colorless but recrystallized glass with some fragments of basaltic and anorthositic rocks embedded in a more or less homogeneous, recrystallized brownish glass matrix with large mostly spherical or irregular vesicles (Fig. 2). Colored glass fragments and colored glass globules are absent. This type of breccia was also observed as inclusions within the first type of breccia.

The grain size distribution of the less than 1 mm fraction of soil (10084-106) is given in Table 1. It is very nearly log-normal. The average diameter is 0·044 mm.