Lunar Breccia

Figure 44 - The large boulder at station 6, Apollo 17, has rolled down from the North Massif. Samples of this boulder are all breccias with a poikiloblastic texture typical of a melt sheet. NASA photo AS-17-164-5954. *(note the astronaut pushing his rover back uphill)*

Lunar breccias are the lithified aggregates of clastic debris and melt generated by meteorite bombardment of the lunar surface. Most of the breccias returned by the Apollo missions were formed in the ancient lunar highlands about 3900 to 4000 million years ago. A few breccias (sample 15405) are younger and were formed from the lunar regolith (fig. 2). In the Apollo collection, 59 breccia samples weigh over 500 g each, and there are many more samples with smaller sizes. These breccias have a wide variety of matrix-textures - from fragmental to vitric to crystalline. A wide range of crater sizes are found on the Moon, and it is easy to see why a wide range of breccia types is also present. Lunar breccias can originate from either large or small craters and/or from different radial distances from large craters.

This thin section set includes five different lunar breccias from the lunar highlands. Sample 60025 is a cataclastic anorthosite that has already been discussed as a plutonic rock. Sample 14305 is a crystalline matrix, fragmental breccia typical of the Fra Mauro Formation, which is ejecta from the Imbrium basin. An example of a breccia from a large crater is the poikilitic rock 65015, which is thought to have originated as part of a melt sheet in a large lunar crater. Poikilitic texture similar to that of sample 65015 was also typical of the large boulders at the Apollo 17 site (fig. 44). Sample 72275 is a friable fragmental breccia from the edge of the Serenitatis basin. Sample 15299 is a vitric matrix breccia that is probably from a small crater in the local lunar regolith at the Apollo 15 site. This breccia type is termed regolith breccia because it closely resembles consolidated lunar soil.

A committee report (Stöffler *et al.* 1980) classifies breccias as either monomict, polymict or dimict. The monomict breccias are cataclastic rocks formed by in-situ brecciation of a single lithology (monolithologic). Polymict (or polylithologic) breccias consist, of two main textural components which are termed matrix and clasts. Such breccias result from the mixing of different lithologies formed under different conditions at different selenological locations. Polymict breccias may have either a clastic matrix, a 'melt' matrix which is crystallized or glassy, or a metamorphic matrix. The clastic matrix consists of individual mineral grains, mineral clasts, and in some cases, of additional glassy particles. Breccia clasts, in tern, form the host for other rock clasts. The grain size of all clasts is more or less seriate. We define the matrix arbitrarily as the grain size fraction that is smaller than 20-25 microns. The 'melt' matrix is characterized by a variety of textures ranging from holocrystalline (crystalline matrix) to glassy (glassy matrix). Some crystalline and semicrystalline textures appear to result from devitrification of glass. The metamorphic matrix is represented by a recrystallization texture which is granoblastic to poikiloblastic.

In general, the breccia clasts are mineral fragments and fragments of rocks with igneous, metamorphic, and breccia texture, and glassy or partially recrystallized melt bodies or fragments thereof. Many of the clasts are themselves breccias, giving the rock a "breccia-in-breccia" texture. Dimict or dilithologic breccias are characterized by an unusual structural feature in which a crystalline matrix is combined with a monomict cataclastic breccia texture in an intrusive or vein-like relationship.

The geologic setting of breccias generated in large basin-forming impacts is illustrated in figure 45. Cratering mechanics is such that ejecta blankets have a reverse stratigraphy compared to that of the target where material that was from the bottom of the crater is deposited on top of the ejecta blanket (fig. 46). Material from the bottom of the crater also is deposited close to the crater rim, and material from the surface of the target is deposited further out *(in Texas, we call this the "laid back"' model).* Fragmental breccias are found in the ejecta blankets beyond the rims of impact craters. They can have fragmental, glassy, or crystalline matrices depending on the distance from the crater and/or the size of the crater. If the crater is large enough, melt sheets of partially digested clastic debris can form from fallback within the walls of large craters. Monomict or dimict breccias form in the bedrock or central uplift. The heat generated by frictional forces in the granular target material is carried

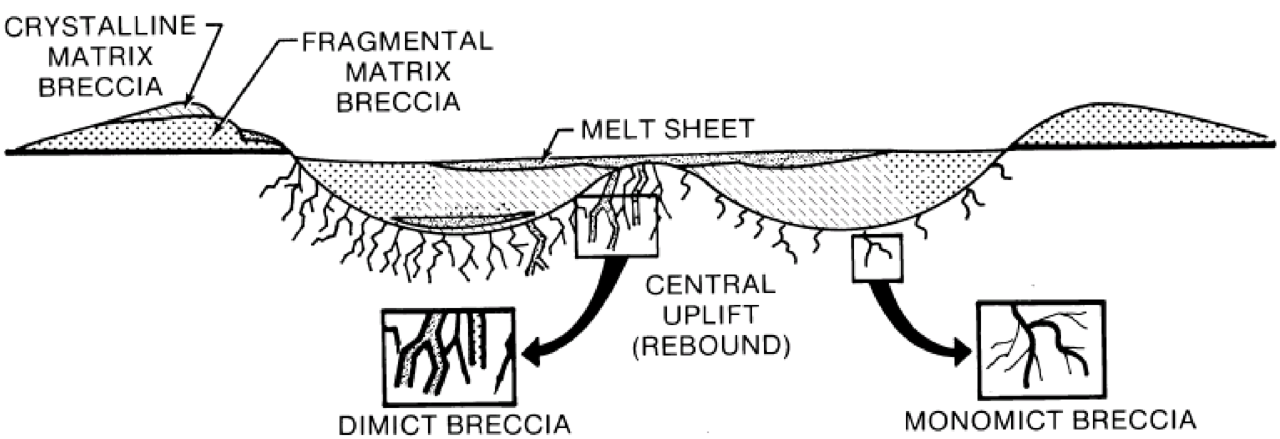

Figure 45 - Geological setting of impact breccias in a giant impact crater. The shock wave granulates the underlying bedrock producing monomict breccias. In some craters, there is a central peak formed by rebound of the substrate. Dimict breccias form when veins of shocked rock are filled with impact melt. Fragmental ejecta is ballistically thrown great distances from the crater and is a polymict mixture of rock fragments from the crater cavity. A mixture of hot and cold fragmental debris falls back into the crater forming crystalline matrix breccias and melt sheets.

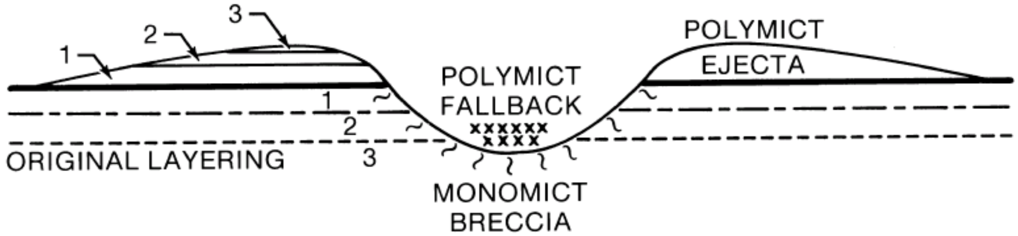

Figure 46 - The material that is thrown out of the crater is deposited in a reverse stratigraphy on the rim of the crater. This is called the overturned-flap concept. Material from the bottom of the crater is deposited on top of the ejecta blanket and close in to the rim.

to the depositional site where, consolidation occurs. Finally, lithification of the breccias is caused by sintering of the mixture of hot and cold fragmental material in the ejecta blanket or melt street.

Most lunar breccias are of a polymict nature. Mixing of rock types can occur in a single impact or can be the result of many impacts. Figure 47 is a photograph of the sawn surface of lunar breccia 14306 illustrating clasts of various rock types including mare basalts, norites, anorthosites, and microbreccias. All are included in a fine-grained matrix of lithic and mineral fragments. The compositions of lunar breccias are also consistent with mixtures of known lunar rock types (Schonfeld and Meyer 1972). All lunar breccias have relatively high Al_2O_3 content due to the abundance of plagioclase in the lunar highlands. It is not necessary to invoke a high percentage of exotic rock to explain the chemical composition of any lunar breccia. Compared with pristine lunar rock, all lunar breccias contain relatively high Ir and Au contents. It is thought that these trace elements come from meteoritic material that has bombarded the Moon. Distinctive chemical signatures of the added meteoritic component have even been used to identify the lunar basin of origin (Hertogen *et al.* 1977). Apparently, the vaporized meteorite becomes entrained and thoroughly mixed with the target material during a single impact. Calculations show that about 1 to 2 weight percent of meteorite material has been admixed, into lunar breccias. Melted iron particles from meteorites can be found in the matrix of lunar breccias. Other meteorite minerals are completely obliterated.

Figure 47 - Sawn surface of fragmental lunar breccia 14306 illustrating the polymict nature of lunar brcccias. This is a sample of the Fra Mauro Formation and is typical of ejecta from large basins. NASA photo no. 72-22103