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Lunar Rocks and Minerals

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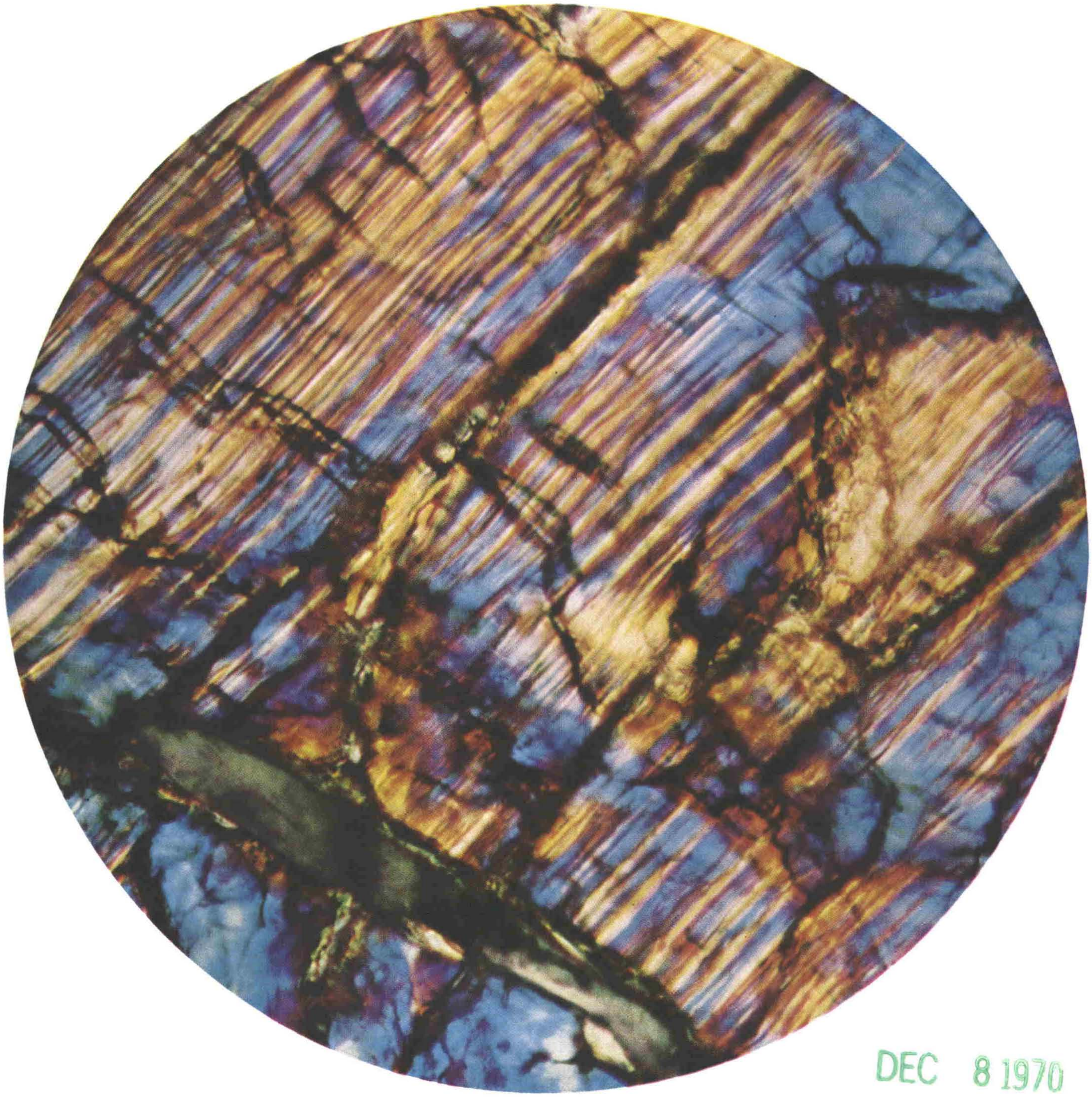

Cover: Apollo 12, thin section of lunar rock, pyroxene with deformation lamellae produced by meteorite impact at pressures of 300,000 at.

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Lunar Rocks and Minerals

by Wolf von Engelhardt

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The lunar surface at the landing site of Apollo 11, located in the southern part of the Sea of Tranquility, consists of a loose accumulation of fractured rocks, minerals and vitreous matter ranging in size from particles not visible with the naked eye to blocks with a diameter of more than one meter. The surface of the mare, although in general relatively smooth, is covered with innumerous craters having diameters from 2 cm to more than 100 m. The larger ones of these craters have a level bottom and a wall around the rim which contains large blocks of solid rock. The large craters apparently reach through the loose lunar surface soil down to a lower base of solid rock. From their depth it can be deduced that here the lunar surface layer is between 3 m and 6 m thick.

The samples brought to earth by the astronauts consist of the loose lunar soil including individual pieces of rock. The rocks found in the lunar soil as larger pieces and small fragments can be classified analogous to terrestrial rocks as lunar basalts, anorthosites and breccia.

The basaltic rocks are black to grey in color. They are composed chiefly of a calcium-rich feldspar (plagioclase, 0 – 20 % $NaAlSi_3O_8$ + 100 – 80 % $CaAl_2Si_2O_8$), pyroxene (clinopyroxene with different amounts of $MgSiO_3$, $CaSiO_3$ and $FeSiO_3$) and ilmenite $FeTiO_3$). Minor constituents found in varying trace amounts are some other minerals such as cristobalite, olivine, apatite, pseudobrookite, spinel, troilite and metallic iron. Some of the basalts also contain glass. Fig. 1 shows a small piece of a relatively coarse-grained, plagioclase-rich basaltic rock. The thin section (Fig. 2) shows pyroxene, plagioclase and ilmenite in a closely interlocked structure which is due to the crystallization from a liquid magma and resembles the structure of terrestrial basalt or diabase. Several lunar basalts have bubble inclusions, an indication that the magma contained volatile constituents (water?) and solidified at the lunar surface or just below it, i. e. under volcanic or subvolcanic conditions. Terrestrial rocks of similar composition show almost always the minerals in various forms of decomposition. Due to the absence of water and all weathering effects on the lunar surface, the lunar basalts are as fresh as if they had just been formed, despite their great age of 3.5 to 4.5 billion years.

The small fragments of white rocks, which may be called lunar anorthosites, are found in the lunar soil with much less frequency than the dark basaltic rocks. These white rocks are composed mainly of calcium-rich plagioclase; olivine, occasionally pyroxene, and very little ilmenite are present in the form of granular inclusions (Fig. 3). These rocks also solidified from a molten phase.

Very many of the fragments in the lunar soil are dark-grey, solidified debris rocks or breccias (Fig. 4). The thin sections (Figs. 5 and 8) show that they consist of sharp-edged fragments of rocks and minerals, glass fragments and glass bodies of rotational symmetry enclosed in a vitreous matrix. The rock fragments are mostly basalts of various grain size, some fragments of older breccias and few small pieces of anorthosite. The most frequently occurring mineral fragments are plagioclase, pyroxene and ilmenite. Less frequently found are nickel-containing iron granules, whose structure indicates that they are fragments of iron meteorites.

The finer constituents of the loose lunar soil are the same as those of the breccias. The breccias are lunar soil consolidated by a small amount of glass matrix.

Of special interest are the various glass fragments and evenly shaped glass bodies found solidly imbedded in the breccia and loose in the lunar soil. Among the evenly shaped glass bodies, the spherical form predominates (Figs. 4, 5, 6, 8, 9). The largest spheres have a diameter of up to 2 mm, the smallest are of submicroscopic size. In addition to spheres, elongated forms of roughly ellipsoid shape (Fig. 7) and dumbbell shapes with a contraction in the middle occur. All these bodies are rotation-symmetrical and apparently were formed from drops of liquid magma propelled through the vacuum of the lunar surface; due to the effect of surface tension they assumed the ideal spherical form, and due to rotational motion they were deformed to oblong and dumbbell shapes.

The evenly shaped glass bodies and the much more numerous irregularly shaped glass fragments (Fig. 6) differ in color and index of refraction. Most numerous are more or less dark glasses, with colors ranging from almost complete opaque, brown, red-brown and yellow-red to light yellow. There are also violet, green and colorless glasses (Figs. 8, 9). Microprobe analyses have shown the composition of the dark glasses to correspond to that of the basalts, while the composition of the light glasses corresponds to that of the anorthosites.

Basalts and anorthosites are of magmatic origin and were formed through volcanic processes at the lunar surface, whereas close examination of the constituents of the lunar soil and breccia has shown that this mass of debris was not formed through endogenic volcanic forces, but rather through the impact of meteorites which also produced the numerous craters in the mare surface. This is proven by characteristic deformation structures and transformations of primary minerals which – as known from experiments and observations on terrestrial meteorite craters – can be produced only through shock waves having peak pressures of several hundred thousand atmospheres. Such pressures can be caused only by high velocity meteorites impacting the lunar surface, but not by volcanic explosions.

Fig. 10 shows a plagioclase grain having such deformation structures; they are lamellae with lowered and reduced or entirely absent birefringence. High-intensity shock waves destroy the crystal structure of the

1 Coarse-grained rock consisting of plagioclase (white), ilmenite (black) and pyroxene (brown). Size of the original specimen 2.2 x 1.9 mm.

2 Basaltic rock consisting of plagioclase (grey laths), pyroxene (colored) and ilmenite (black). Thin section. Crossed polarizers. Size of the original specimen 2.2 x 1.9 mm.

3 Anorthositic rock consiting of plagioclase (light) with olivine (colored). Thin section. Crossed polarizers. Size of the original specimen 0.28 x 0.25 mm.

4 Fragment of a breccia with a dark glass sphere. Size of the original specimen 2.2 x 1.9 mm.

5 Breccia. In a dark matrix there are fragments of plagioclase and pyroxene (both colorless), fractured brown glass spheres and fragments of an older brown breccia. Thin section. Size of the original specimen 2.2 x 1.9 mm.

6 Spherical glass body and fragments of brown glass. Size of the original specimen 0.28 x 0.25 mm.

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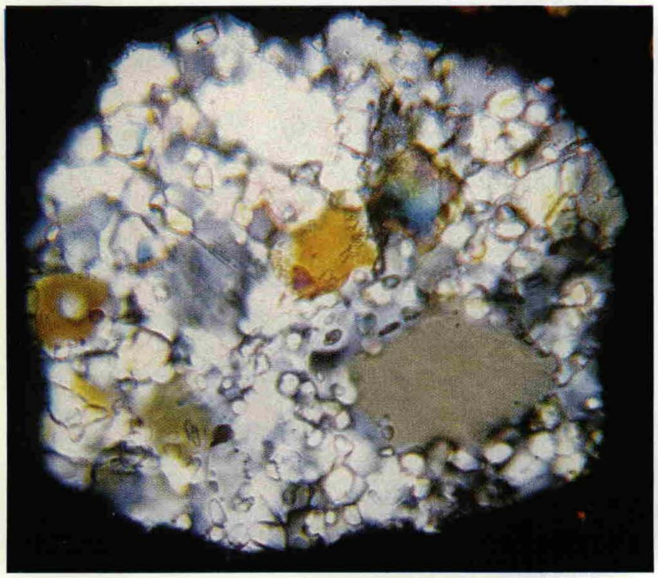

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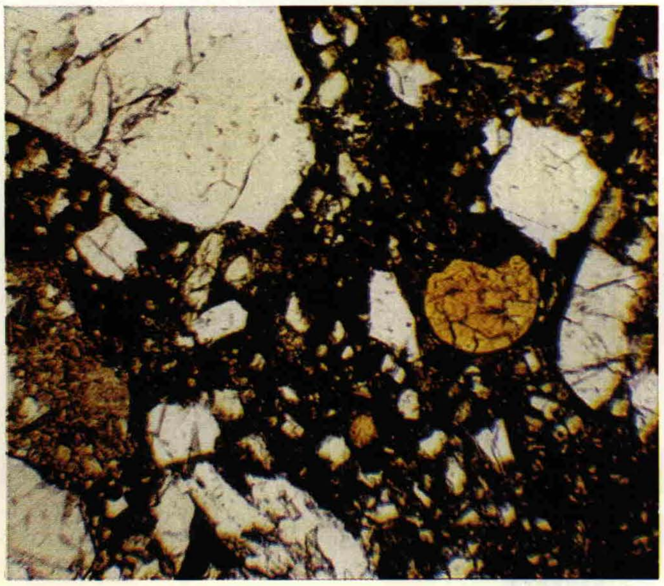

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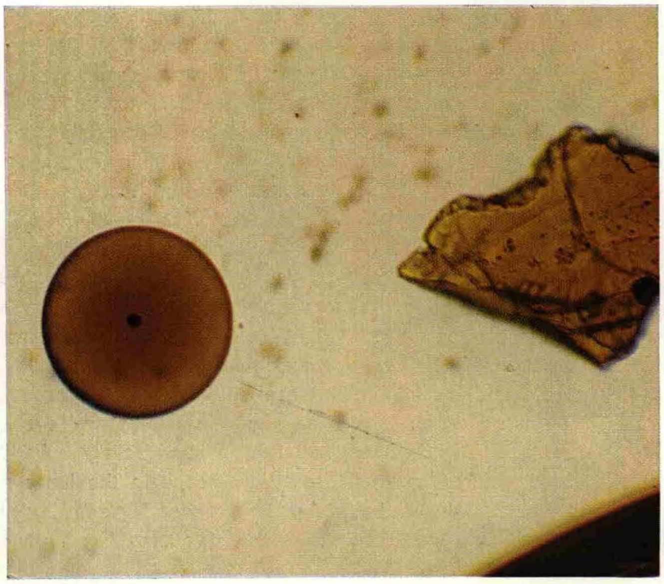

7 Oblong rotational body of dark-brown glass. Size of the original specimen 0.28 x 0.25 mm.

8 Spherical body of colorless glass in breccia. Thin section. Size of the original specimen 0.28 x 0.25 mm.

9 Spherical body of colorless glass, inside an unmolten pyroxene granule. Size of the original specimen 0.07 x 0.06 mm.

10 Deformation lamellae produced by a shock wave in plagioclase. Thin section. Size of the original specimen 0.07 x 0.06 mm.

11 Deformation lamellae produced by a shock wave in pyroxene. Thin section. Crossed polarizers. Size of the original specimen 0.7 x 0.6 mm.

12 Crust of brown glass resulting from hypervelocity impact of a small meteorite or a secondary particle on the surface of a basaltic rock. The shock wave transformed the plagioclase (colorless laths) into isotropic glass. Black - ilmenite, grey - pyroxene. Thin section. Size of the original specimen 2.2 x 1.9 mm.

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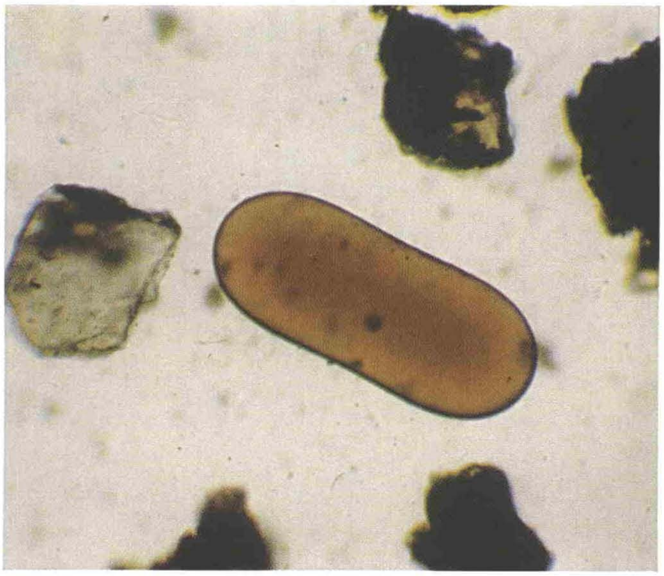

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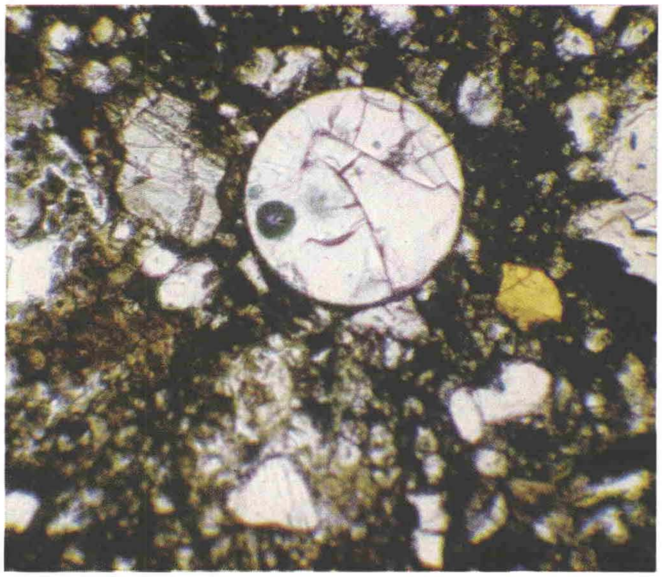

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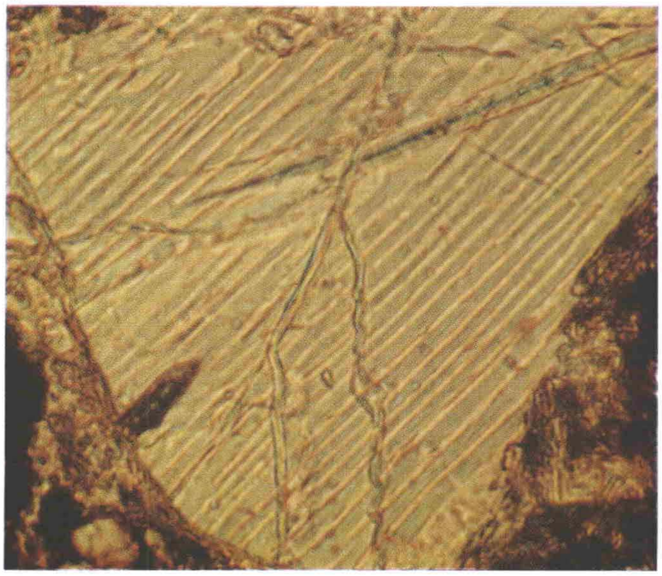

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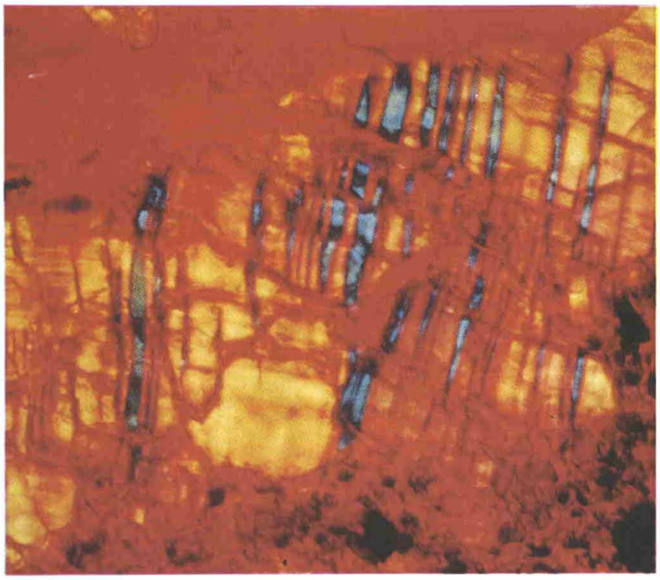

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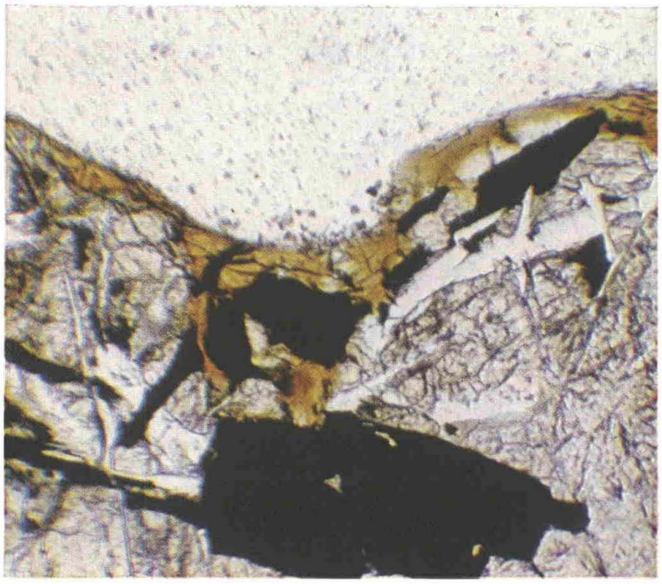

plagioclase completely and, while leaving the external dimensions of the granule unchanged, transform it into a glassy substance (diaplectic glass) that differs in density and refraction from molten plagioclase glass. These glasses are found frequently in the lunar soil and in the breccias.

Fig. 11 shows deformation structures produced by shock waves in a pyroxene grain.

Shock waves with peak pressures of more than 500,000 atmospheres produce in the impacted rock temperatures high enough to melt or vaporize all minerals. The various glasses in the lunar soil and in the breccia are proof of this most intense effect of meteoritic impacts on basaltic and anorthositic rocks. The evenly shaped glass bodies originated in part perhaps through condensation from the rock vapor, but mainly they are drops propelled upward from the molten rock. The irregularly shaped fragments are the debris resulting from the subsequent impact fragmentation of larger glass bodies.

On the surface of the larger rock pieces from the lunar soil there are often markings of the impact of small and extremely small meteorites in the form of small, glass-lined craters or solidified glass-melt coatings. The thin section shown in Fig. 12 illustrates exceptionally well the effect of a small meteorite or a small, secondary projectile produced by meteorite impact: The surface of the basaltic rock consists of a rock melt solidified to a brown rock glass. Below this coating, a layer some millimeters thick contains plagioclase transformed into diaplectic glass and pyroxene interspersed with deformation lamellae.

The microphotographs were taken with the following ZEISS instruments: the POL Photomicroscope and the GFL POL Standard Microscope with Camera Attachment.

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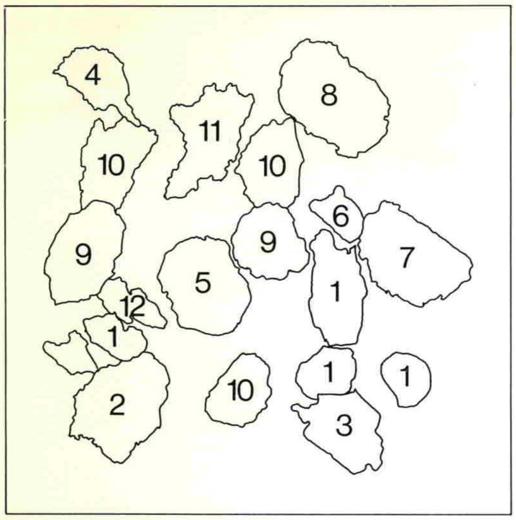

1 Rotational glass body
2 Fragment of a green glass
3 Fragment of a red glass
4 Fragment of a dark glass
5 Fragment of a greenish glass sphere
6 Pyroxene
7 Coarse-grained basalt
8 Fine-grained basalt
9 Anorthosite
10 Breccia
11 Breccia with glass crust
12 Feldspar

Apollo 11. Fragments of lunar rocks and minerals. Size 1/4 - 1/2 mm
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