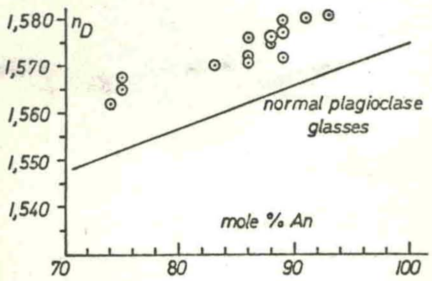

Fig. 1. Refractive indices of lunar diaplectic plagioclase glasses. (Solid line) Refractive indices of fused plagioclase. [After Barth (5)]

variability of chemical composition, with the SiO_2 content ranging from 33 to 50 percent. Each individual piece of glass can be interpreted as a fusion product of a particular mixture of the lunar rock-forming minerals plagioclase, pyroxene, and ilmenite, in some cases with admixtures of free SiO_2 olivine, or even metallic Fe.

The chemical heterogeneity of the lunar glass bodies and fragments distinguishes lunar fine material and breccias from terrestrial pyroclastic rocks. The individual glass pieces constituting the latter are all of essentially the same chemical composition. Because of their heterogeneity, it is concluded that the lunar glass bodies and fragments did not originate in large and homogeneous lava pools. Instead, they must have been formed, individually, by fusions of relatively small rock volumes.

Notwithstanding the chemical differences between the individual glasses, at least two major chemical types can be distinguished.

Type 1: colorless to green glasses. Average composition (weight percent; 13 microprobe analyses): SiO_2, 46; TiO_2, 0.8; Al_2O_3, 24; FeO, 7; MnO, 0.08; MgO, 8; CaO, 13; Na_2O, 0.6; and K_2O, 0.1. Average norm: plagioclase, 67; pyroxene, 21; olivine, 9; and ilmenite, 1.5.

Type 2: yellow, brown, red, and violet glasses. Average composition (13 microprobe analyses): SiO_2, 40; TiO_2, 9; Al_2O_3, 11; FeO, 19; MnO, 0.2; MgO, 10; CaO, 11; Na_2O, 0.5; and K_2O, 0.1. Average norm: plagioclase, 32; pyroxene, 35; olivine, 16; and ilmenite, 17.

Generally, spherules and the other regular bodies of both types contain less SiO_2 than the corresponding fragments, so that calculation of the norm results in relatively high percentages of olivine and, in the case of two green spherules, even of metallic Fe (2 and 4 percent). Metallic Fe occurs in many lunar glasses as minute Fe spherules. There are two possible explanations for their formation: (i) admixture of meteoritic Fe, condensing from the vapor phase, produced by the impacts of Fe-bearing meteorites, or (ii) preferential volatilization of SiO_2 (or SiO) from a rock-melt heated to very high temperatures in the lunar vacuum.

3) Coatings of vesicular glass are frequent on breccia and rock fragments occurring in breccias and fine material. The glasses of this kind so far investigated belong to type 2. Microprobe analyses of some glassy coatings showed that the crust was not formed by fusion of the coated rock and has taken up, at most, minor amounts of it. The glass crusts may be considered in most cases projectiles ejected from meteorite craters as splashes of melt or small rock fragments which have impacted rock fragments on the lunar surface, causing progressive shock metamorphism within them. This could be best demonstrated by a small gabbroidic fragment ($10 \times 6 \times 4$ mm). In the immediate vicinity of the glass crust (up to 0.3 mm thick), within a zone of 2.5 mm maximum thickness, all plagioclase is transformed into isotropic diaplectic glass. A very narrow transition zone (maximum thickness, 0.2 mm) with partially isotropic plagioclase separates the outer zone from the interior of the rock, where the plagioclase shows normal birefringence.

The boundary between diaplectic glass and birefringent plagioclase represents a shock wave amplitude of about 300 kb. The small extension of the transition zone indicates a rapid decay of the shock wave along its path into the rock. Therefore, the thickness of the impacting projectile must have been rather small, probably not more than 2 mm.

We conclude that all types of glasses have been produced by shock-induced fusion of lunar rocks due to meteoritic impacts, presumably at pressures up to the megabar region. Some parts of the melt have been dispersed as fine droplets which are preserved as regularly shaped bodies of rotational symmetry. Larger masses have been broken into fragmental grains, and still other parts of impact melts are found as crusts adhering to the surface of rocks.

The obvious division of the glasses into two major chemical types indicates that, at the Apollo 11 landing site, material occurs which has been produced by meteoritic impact events in at least two areas of the lunar surface which differ in chemical composition. The yellow, brown, red, and violet glasses of high TiO_2 and FeO content (type 2) have a composition similar to that of mare material represented by the alpha-scattering experiments of Surveyor 5 and 6 and the rocks of Apollo 11. They may be products of impacts within the Sea of Tranquillity area. The colorless and greenish glasses of higher SiO_2 and Al_2O_3 and lower TiO_2 and FeO content (type 1) correspond to the highland material north of Tycho analyzed by Surveyor 7. We suggest that these glasses came from an impact site at the highlands.

The two types of shock-melted material may perhaps be connected with the two ray systems in the vicinity of the Apollo 11 landing site. The north-northeast-trending ray, which is perhaps related to Tycho or another crater on the highlands, may have delivered the colorless and greenish glasses of type 1.

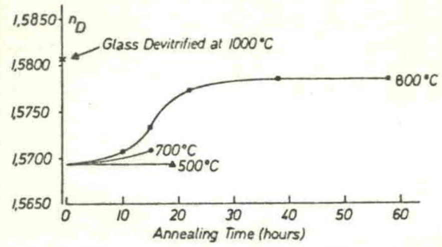

Fig. 2. Results of annealing experiments with lunar diaplectic plagioclase glass (anorthite, 86 mole percent).

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