COOLING HISTORY OF APOLLO 15 GREEN GLASSES: IMPLICATIONS FOR THEIR FORMATION; J. Arndt, W. v. Engelhardt, I. Gonzalez-Cabeza and B. Meier, Mineralogisches Institut, Univ. Tübingen, 7400 Tübingen, Fed. Rep. Germany

Since the discovery of green glasses by the Apollo 15 astronauts, several hypotheses about their origin have been discussed such as volcanic formation, impact melting, impact into lava lakes and vapor condensation (e.g. (1), (2), (3), (4)). Main and trace element chemistry and surface enrichment of volatile elements favour the hypothesis of the formation of the green glass beads by explosive fire-fountaining of a magma from the deep lunar interior.

To elucidate the process of formation, we have tried to determine the cooling history of the droplets by an investigation of green glass beads in soil breccia 15427 and by cooling and crystallization experiments with a synthetic melt of green glass composition.

28% of the green glass beads in thin section 15427,29 are glassy and 72% contain olivine (no other phases have been observed). The majority of the olivine crystals are thin skeletal plates // (001), consisting of a grating of laths, bounded by (120); the plates appear as needles if seen in a direction // (001). 51% of the vitrophyric beads show circular and 49% elliptical cross sections; 62% of the glassy cross sections are circular and 38% are elliptical. Fig. 1 shows measured size frequency distributions of glassy and vitrophyric cross sections (diameter of elliptical cross sections = arithmetic mean of long and short diameters). Neglecting the sectioning effect, we regard the measured distributions as representative for the true size distributions of green glass beads in 15427,29. A correction would result in a slight shift of the curves to larger diameters (5). The size distributions of vitrophyric and glassy beads are nearly symmetrical and well sorted (sorting coefficients are 1.46 and 1.41, respectively). The vitrophyric beads are in the average larger than the glassy ones by a factor of about 2 (Fig. 1). It follows that in the average melt droplets 0.094 mm in diameter cooled so rapidly that no olivine crystals could be formed, whereas the cooling rate of droplets 0.22 mm in diameter was slow enough to allow the growth of large olivine crystals. The fact that vitrophyric and glassy beads occur close together in breccia 15427 indicates that they were incorporated in the solid state. Cooling from above the liquidus temperature (1270°C, (6)) to the glass transition temperature (610°C, (7)) took place prior to embedding.

In the cooling experiments, liquid droplets of a synthetic green glass composition (Table 1) were allowed to cool either in "free-flight" radiation cooling or at predetermined cooling rates in an induction-heated vacuum furnace as described in (8). According to these experiments, green glass droplets of 0.22 mm in diameter would cool by radiation in free flight at a rate of about 2000°C/sec through the temperature range 1050 - 1000°C. This range corresponds approximately to that of the maximum crystallization rate in green glasses (6). Experiments at predetermined rates yielded a critical cooling rate (minimum rate required for the green glass melt to solidify as glass) of about 1°C/sec in the temperature interval 1050 - 1000°C, in close accordance with the figure 0.8°C/sec derived theoretically (9).

We conclude that the green glass beads in breccia 15427 were formed by cooling of liquid droplets in an hot environment which caused them to cool through the range of olivine crystallization at cooling rates three orders

of magnitude slower than in free flight. Cooling in a hot vapor would be a possible scenario.

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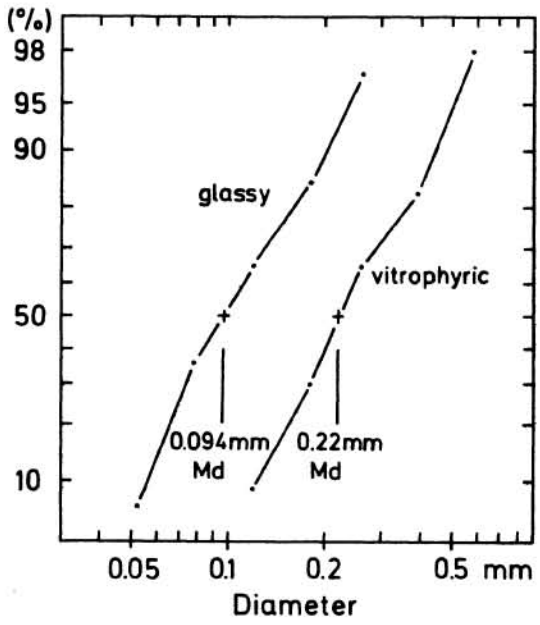

Fig. 1 Size frequency distribution of glassy and vitrophyric cross sections (15427,29). Log-probability scale.

Table 1. Chemical composition of green glasses.

wt.%	Synth.	Lunar (Aver.(10))
SiO_2	45.57	44.9
TiO_2	0.35	0.5
Al_2O_3	8.15	7.5
FeO	18.89	20.5
MgO	17.22	17.4
CaO	8.86	8.4
MnO	0.26	n.d.
Na_2O	0.24	0.1
K_2O	0.00	0.0
Total	99.54	99.3