METALLIC PARTICLES IN THE GLASS COATINGS OF LUNAR HIGHLAND SAMPLES 65315, 67435 AND 78235

S. Mehta and J. I. Goldstein, Dept. of Metallurgy and Materials Engineering, Lehigh University, Bethlehem, PA 18015

Metal particles are a minor but an ever present component of lunar rocks, breccia and soils (1). The sources of these particles, include the indigenous lunar metal, the metal reduced from iron-bearing silicate or glass during shock and/or thermal metamorphism and the metal phases of an impacting meteorite. Irrespective of their origin, the metal may have experienced subsequent multiple shock and/or reheating cycles and interactions with the surrounding rocks and soils. These effects could lead to obliteration of the original characteristic structure and chemistry of the metal via exsolution, remelting and introduction of other elements. In spite of uncertainties involved in establishing the origin of metal particles, their relatively simple chemistry and phase equilibrium relationships have proven useful in determining the effective temperature of equilibration of the host silicate rock (2).

Electron microprobe techniques have been extensively used to study lunar metal particles in the 10 μm to 1 mm size range (3). However, except for the magnetic studies (4) there are virtually no data on the chemistry and structure of metal particles in the submicroscopic range. Last year we reported for the first time the application of scanning transmission electron microscopy (STEM)--X-ray microanalysis to characterize metal particles in the $\leq$ 10μm to 500Å size range in the glassy constituents of lunar breccias (5). The purpose of this study is to apply these techniques to characterize metal particles in the glass coatings of 3 highland samples--65315, 67435 and 78235. Using this data an attempt is made to establish the origin of the metal particles.

65315 is a coherent, pristine, cataclastic anorthosite with an irregularly distributed glass surface (6). The glass is partially devitrified and contains numerous microscopic and submicroscopic spherical metallic inclusions. The internal structure of the inclusions > 5 μm in diameter revealed an eutectic-like intergrowth of α-Fe dendrites and phosphide that were occasionally rimmed with troilite (Fig. 1). The dendritic structure of the particles indicate rapid solidification of the liquid-metal system (7). The average Ni, Co and P content of the metal portion of several three phase α-Fe-phosphide-sulfide bearing particles is 18.4, 0.66 and 1.4 wt% respectively. This composition falls within the compositional limits of meteoritic metal as defined by Goldstein and Yakowitz (8) but does not necessarily imply meteoritic origin.

In addition to the large metal particles, several finely dispersed spherical metallic inclusions in the > 80Å to 0.5 μm size range are observed in 65315 glass. The structure of these particles is quite analogous to the textures of rapidly solidified molten droplets of metal-sulfide liquids (7). A transmission electron micrograph (TEM) of a typical microstructure of a submicroscopic spherical metallic inclusion is shown in Fig. 2. The particle is ~ 0.5 μm in diameter and consists of a (dark) FeNi core surrounded by a (light) FeS rim. Although, texturally almost all submicron sized particles are similar, compositionally they fall into three groups. One group of particles in the 0.25 to 0.5 μm size range is disseminated through the glass. The FeNi core of these particles contains on an average of 18.7 ± 1 wt% Ni and a trace of phosphorous. It is apparent that the Ni content of these particles overlaps the Ni content associated with the metal phase of the large (> 5 μm) metal inclusions (Fig. 1). This implies a common source of origin for these particles, which on the basis of their compositional limits may be ascribed to the shock melting and rapid resolidification of sulfide-metal-phosphide phases of

© Lunar and Planetary Institute • Provided by the NASA Astrophysics Data System

meteoritic origin.

A second group of particles constitutes 80 to 200Å inclusions of metal-troilite dispersed in the glassy matrix. These inclusions contain on an average of 6.3 ± 1 wt% Ni. Since the STEM does not have the required resolution to analyze < 100Å metal core in a 200Å metal-troilite assemblage, the Ni content is biased toward low values. It is therefore suggested that most of the inclusions in the 80Å to 200Å size range probably result from the same shock generated metal-sulfide liquid described earlier.

A third group of submicroscopic particles are clustered in a 100 μm^2 area of the glass. These particles are in the 0.3 to 0.5 μm size range and show two phase metal-troilite assemblage. The Ni content of these particles is 60.8 ± 3 wt%. The unusually high Ni content of these particles indicates that either a chemical fractionation of the original metal sulfide composition or an unidentified reduction process may have occurred during the impact event.

67435 is a glass coated breccia which consists of pink spinel troctolite clasts, a dark aphanitic-matrix breccia material with poikilitic texture, feldspathic material with sugary texture and numerous feldspathic clasts (9). A thin section of the glass shows extensive devitrification and the presence of several lithic clasts. In addition, the glass also contains several metallic particles in the < 1000Å to > 5 μm size range. These particles do not show any evidence of melting and are irregular in shape. The majority of the > 5 μm particles are largely single phase FeNi containing a "meteoritic" Co-Ni composition (8) with Ni contents primarily between 5 and 7 wt%. The remaining particles are inclusions of chromite that contain ~ 0.4 wt% Ni. STEM investigation of an ion-thinned foil of 67435 glass reveals several submicroscopic irregular FeNi inclusions in the 1000Å to 1 μm size range. These particles are primarily concentrated in the feldspathic area and do not appear to have melted. The average Ni content of these particles is 14.3 ± 5 wt%. Some of these inclusions are associated with troilite. Occasionally Ni free Fe metal grains are also observed. It appears that the difference in the Ni content between the < 1 μm and > 5 μm metal particles can be explained by the presence of metal of two different sizes and compositions in the breccia prior to the shock event. Alternatively, the source of the particles may be the lunar soil which contained preexisting meteoritic fragments of variable Ni content that were incorporated when the glass formed.

78235 is an intensely shocked norite chip from the top of a boulder at Station 8 near the base of the Sculptured Hills. It is composed of about equal amounts of 3-5 mm long crystals of plagioclase (An_{93-97}) and magnesian orthopyroxene ($En_{78}Fs_{19}Wo_3$). The rock displays a layering of pyroxene and plagioclase which is typical of cumulus textures (10). The rock is coated with a semi-opaque, partially devitrified brown glass that appears to have flowed. This is revealed by color and/or refractive index differences defining flowage lines. The glass is interpreted to have formed as a result of a quenched splash of a shock-induced melt derived from the host norite (11).

In the rock the plagioclase grains are reported to contain several minute rods of metallic iron which are absent in the glass (12). The glass, however, contains numerous metallic inclusions which show complex intergrowths of FeNi, troilite and schreibersite (13). Several metallic inclusions in the ≥ 5 μm size range were analyzed in the electron microprobe. A considerable range of compositions, from 4.9 to 17.1 wt% Ni, 0.3 to 1.9 wt% Co and 0.5 to 2.3 wt% P were observed. The Co/Ni ratio for most of the metal particles however fall in the meteoritic range. This is consistent with the results of McCallum et al (1975) who further report that the metal in the glass is considerably different from the primary metal with uniform composition found in the crystalline part of the rock. This suggests that the glass is an impact melt contaminated

© Lunar and Planetary Institute • Provided by the NASA Astrophysics Data System

by meteoritic material.

TEM study of a fragment of the glass reveals both devitrified and undevitrified regions. In the devitrified areas submicroscopic structures that resemble spherulitic and sub-parallel fibrous textures are observed. These textures are analogous to those present in devitrified shock-produced silicate glasses. STEM X-ray microanalysis of these structures indicate that they are a submicroscopic intergrowth of quenched plagioclase and pyroxene in a matrix that contains pyroxene, plagioclase and residual glass. In addition to the quenched phases, the devitrified glass also contains numerous 50-200Å Ni free metallic Fe droplets. These droplets in many areas appear to have nucleated at the interfaces or in the cores of the spherulitic structures. These metal droplets probably result from the reduction of Fe^{+2} in the shock produced melt.

Figure 3 shows a small vein of undevitrified glass adjoining a devitrified region. The undevitrified glass contains numerous submicron-sized metallic droplets. Nearly 95% of the droplets are metallic Fe, while the remaining 5% contain varying amounts of Ni. STEM X-ray microanalysis indicates that the undevitrified glass is rich in feldspathic component. If the feldspar contained numerous metallic Fe rods (12) before melting, the metal droplets now observed in the undevitrified glass were probably derived from dissolution and reprecipitation of Fe in the rods. Unlike the large (> 5 μm) particles, none of the submicroscopic metal particles in both the devitrified and the undevitrified regions were of meteoritic composition.

REFERENCES

(1) Gose,W.A. et al.(1972) PLSC 3, p.2387; (2) Gooley,R.C. et al.(1973) PLSC4, p.799; (3) Hewins,R.H. and Goldstein,J.I.(1975) PLSC 6, p.343; (4) Morris,R.V. et al.(1975) Geophy. Res. Lett. 2, p.461; (5) Mehta,S. and Goldstein,J.I. (1979) PLSC 10, p.1507; (6) Dixon,J.R. and Papike,J.J.(1975) PLSC 6, p.263; (7) Blau,P.J. and Goldstein,J.I.(1975) Geochim. Cosmochim Acta, V.39, p.305; (8) Goldstein,J.I. and Yakowitz,H.(1971) PLSC 2, p.177; (9) Warner,R. et al. (1976) PLSC 7, p.2379; (10) Jackson,E.D. et al.(1975) GSA Bull. 86, p.433; (11) McCallum,I.S. and Mathez,E.A.(1975) PLSC 6, p.395; (12) Sclar,C.B. and Bauer,J.F.(1975) PLSC 6, p.799; (13) ElGoresy,A. et al.(1976) abstract in Lunar Science VII, p.239.

Figure 1: Optical micrograph of ~ 50 μm metal particle in 65315 glass. Note dendritic FeNi-schreibersite eutectic intergrowth rimmed by troilite.

Figure 2: TEM micrograph of ~ 0.5 μm metal particle in 65315 glass showing two phase FeNi (dark) and FeS (light) assemblage.

Figure 3: STEM micrograph of devitrified and undevitrified glasses in 78235. Note the presence of numerous submicroscopic Fe droplets in undevitrified glass.

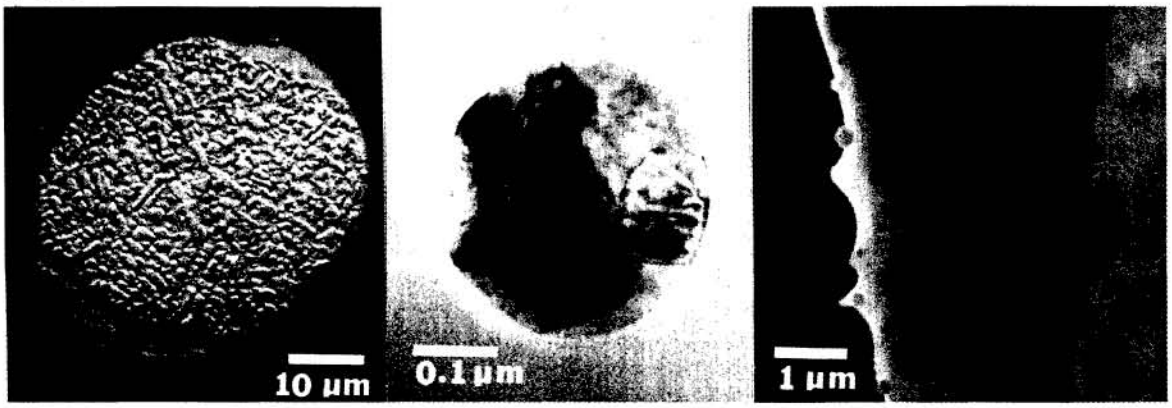

Fig. 1 Fig. 2 Fig. 3

© Lunar and Planetary Institute • Provided by the NASA Astrophysics Data System