LUNAR GLASS BEADS: A COMPARISON OF SEM, FMR(I), AND COMPOSITIONAL FEATURES

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As unaltered samples of lunar magma, volcanic-glass beads contain potentially powerful information. The entire subject of identification of such glasses is addressed in the preceding paper (1). The use of ferromagnetic resonance (FMR) intensity (Ig) as a signature of origin was proposed. Data from that study show a good correlation between low Ig and volcanic-glass beads and equate high Ig with impact-melt beads (1; fig. 1); 95% of volcanic beads have an Ig value less than 10 while an Ig greater than 20 is impact glass at near 90% confidence level. Factors contributing to deviation from perfect correlation are outlined below. In this paper, the detailed results of that study are compared to various observations made using a Scanning Electron Microscope (SEM) and integrated with the overall glass chemistry.

Glass beads were handpicked from soil samples representing all Apollo missions. The mass of individuals particles ranged from less than 0.5 micrograms up to more than 300 micrograms. The size of the beads ranged from less than 5 microns up to about one mm. The color of the glasses involved constitute a veritable rainbow: black, brown, purple, red, orange, yellow, green, yellow/green, and colorless, as judged by viewing with a binocular microscope.

Ig measurements on individual beads were made with a Varian E-12 Electron Paramagnetic Resonance (EPR) spectrometer. Spectra were produced at room temperature at a microwave frequency of approximately 9.5 GHz. Each spectrum was scanned over a range of 10,000 Gauss in 8 minutes. After FMR data were obtained, each bead was analyzed with a JEOL JSM U3 Scanning Electron Microscope (SEM) equipped with a Princeton Gamma Tech 1000 energy dispersive X-ray system. Time, instruction, and use of this equipment was graciously extended for the duration of this study by Richard Morris (EPR) and David McKay (SEM) of NASA-JSC.

In order to adequately correlate grain-type (i.e., volcanic or impact) to Ig data, it was necessary to construct a matrix. This matrix allows the direct comparison of surface features unique to either grain type with its ferromagnetic intensity. The features used here are definitive criteria for characterization of lunar glass-bead origin (2-11). These areas.

<table>
<thead>
<tr>
<th>Ig</th>
<th>0 compound morphology</th>
<th>&lt;1 volatile coats</th>
<th>1-10 outgassing pores</th>
<th>&gt;1000A FeO mounds</th>
<th>500A FeO mounds</th>
<th>250A FeO mounds</th>
<th>'lacey' FeO mounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volcanic</td>
<td>O</td>
<td>0</td>
<td>0</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Impact</td>
<td>△</td>
<td>△</td>
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<td>△</td>
<td>△</td>
<td>△</td>
<td>△</td>
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</tbody>
</table>

FIGURE I.

Compound Morphology - Grains with this feature are irregularly shaped due to rounded mounds and protuberances of glass which exhibit various degrees of wetting (2,3). These "blisters" possess the same composition as the bead and formed in an early phase of volcanic fire-fountaining (4,5). Volatile Coats - Volcanic beads possess surface volatile coatings which differ from their internal compositions (6,7). The coatings are formed during fire-fountaining and are quite distinctive (7,8). The coats represent the remnants of the fountaining propellant (8).

Iron Mounds - These small protuberances (<250A->1000A) surface features of native iron are direct results of autoreduction (by FeO and C) and indicate impact processes (9,10,11). See the preceding paper (1) for a discussion of the formation of this native FeO.

"Lacy" Iron - This relatively rare form of native iron has a dendritic, sometimes very delicate, structure which is produced as a vapor condensate during impact (9,10,11).

Iron Mounds with Volatile "Waists" - This feature is similar to iron mounds with the addition of a distinguishing volatile-rich (especially P) rim at the bead/mound interface (9,10,11).

DISCUSSION OF Ig vs SEM

Some beads in this study could not be positively identified using SEM-observed surface features. Some glass particles purposely chosen for analysis are broken fragments without surfaces. Other beads lacked all diagnostic features described above and thus were categorized as "uncertain" along with the fragments.

Figure 1 shows the frequency of occurrence of the diagnostic features with respect to Ig. Those possessing volcanic characteristic are concentrated in the low Ig (<1) column. Glass beads with impact features are concentrated in high (>10) Ig regions.

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Some impact-melt beads exist with low Is; reasons for the existence of these include the possibility that the melts were derived from a) "immature" soils (i.e., soils exposed to solar wind for only a short period of time), or b) impact of unexposed bedrock.

Impact-melts derived from areas with little FeO content (e.g., highlands) should not have a highly elevated Is. Several exceptionally high readings for these grain types are possibly due to the adherence of minute soil particles to the surface of the melt beads, while the glass was still soft.

Two of the volcanic grains exhibit moderate levels of Is. In both cases, the fragments were extensively reworked and contain zarp pit-produced impact-melt which could harbor some single-domain iron particles.

CHEMISTRY

Each bead was analyzed subsequently for composition. Analysis for 10 elements were performed with a fully-automated electron microprobe. The EMP was operated at an acceleration of 15 keV with a beam diameter of 7 to 10 microns using standard correction procedures (12, 13).

Results of the electron microanalyses are shown in fig. 2. They are compared to reported volcanic compositions by Delano (14). Most of our volcanic bead compositions found correspond to previously reported types. However, many other volcanic compositions could not be substantiated. It is probably that some of the glasses used by previous investigators, indeed, are not volcanic but are impact in origin. A detailed synthesis of this new glass chemistry will lead to new magma types as well as firmly establish previously known ones.

FIGURE 2

REFERENCES CITED