STATISTICAL ANALYSES OF COMPOSITIONS AND AGES OF LUNAR IMPACT GLASSES

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Introduction: Lunar impact glass samples, which are impact melt droplets formed during impacts on the Moon, can be used to help interpret the lunar impact flux over time, from >3900 Ma to the time when the samples were collected by the Apollo astronauts (1969 – 1972). Over 700 lunar impact glasses were assessed for ^{40}Ar/^{39}Ar age (when available), composition, and location of collection by the Apollo astronauts. The intent of this study was to use these data, along with physical characteristics of the glasses (e.g., color, shape), to determine which glasses may have been formed in the same impact event, in order to prevent an overestimation of impact flux within a given time period. Excel and the Statistical Program for the Social Sciences (SPSS) software were used to categorize glasses of similar composition and age in order to evaluate which impact glasses were formed at the same time in the same impact event.

Sample Selection and Sorting: Shape (i.e., sphere, shard), size, major-element compostions, and ^{40}Ar/^{39}Ar age data (when available) from hundreds of lunar impact glasses [1-8] from the Apollo 12, 14, 15, 16, and 17 landing sites were assessed. When physical characteristics were noted, only samples that were clean (i.e., xenocryst- and xenolith-free) were included in this study.

Since lunar impact glass compositions reflect the geology in which the glasses were formed, oftentimes several hundreds of kilometers away from the site where they were collected by the astronauts, compositions were further categorized as “local” or “exotic” [e.g., 2]. “Local” means that the glass was formed in the same location where it was collected, while “exotic” means that it was formed elsewhere. A comparison and sorting method based on parameters related to the composition of the local regolith was thus established in order to determine whether a glass composition was “local” or “exotic”.

Once the glass data had been collected, compositional similarities and overlapping ages (within 2σ uncertainties) were used to determine which glasses may have been formed at the same time in the same impact.

Discussion: In this study, we find that 185 glasses meet the above-mentioned criteria. Furthermore, sorting methods indicate that there are several glasses from different Apollo regolith samples (i.e., landing sites) that most likely formed in the same impact (Figure 1), when sorted into 500-Ma-age bins. At the most, though, four glasses can be attributed to a single impact event. Thus, it is unlikely that a single lunar impact was responsible for creating a large number of impact glasses.

Figure 2 shows the distribution of ^{40}Ar/^{39}Ar ages of lunar impact glass spheres and shards from the Apollo 12, 14, 15, 16, and 17 landing sites. When sorted for shape (i.e., sphere vs. shard), Figure 3 shows that the glass spheres from Apollo 12, 14, 15, and 16 are more likely to have young ages. While some studies [e.g., 3, 5, 7, 9] have suggested that an abundance of young (i.e., <500 Ma) ages of lunar impact glasses from these same regolith samples may indicate an increase in the recent lunar impact flux, our statistical sorting method indicates that this may be a consequence of the shape of the glass, since these studies reported the ^{40}Ar/^{39}Ar ages of glass spheres. Thus, this finding supports the conclusions of Zellner and Delano [10], who suggest that impact-produced glass spheres are short-lived (i.e., are broken into shards due to gardening of the lunar regolith over a short time period) and therefore young in general.

Conclusion: The goal of this project was to develop a statistical sorting method that could compare lunar impact glass compositions and ^{40}Ar/^{39}Ar ages in order to determine how many (and which) impact glasses from many different regolith samples were formed in the same impact event.

After comparing glass compositions and ages, using the sorting method in Excel and SPSS, it was noted that on average, 1.45 glasses per impact were formed. This number, however, does not consider whether the age of the glass is a “true” age or an “apparent age”, the latter of which may be a result of diffusive loss of Ar [e.g., 10, 11]. Further investigations to understand how this loss of Ar may affect "# glasses/impact" are ongoing. No single impact event was responsible for creating a large number of glasses.

Additionally, a sorting method for determining whether a glass was "local" or "exotic" was established; it confirmed the results of previous studies [2, 4].

Finally, sorting the $^{40}Ar/^{39}Ar$ age data into 500-Ma bins indicates that glass spheres are more likely to be young (i.e., <500 My), but whether the age is "true" or "apparent" is as yet unknown. Past studies that have reported the young $^{40}Ar/^{39}Ar$ ages of impact glass spheres in the context of impact age-distributions [e.g., 3, 7] will need to be reexamined.

References: [1] Zellner N. E. B. *et al.* (2009) *GCA*, **73**, 4590-4597. [2] Delano J. W. *et al.* (2007) *MAPS*, **42**, 6, 993-1004. [3] Levine J. *et al.* (2005) *GRL*, **32**, L15201. [4] Zellner N. E. B. *et al.* (2009) *MAPS*, **44**, 839-852. [5] Hui S. (2011) PhD Dissertation, ANU. [6] Zellner N. E. B and Norman M. D. (2012) *43rd LPSC*, 1711.pdf. [7] Culler T. *et al.* (2000) *Science*, **287**, 1785-1788. [8] Zellner N. E. B. *et al.* (2013) *44th LPSC*, 2539.pdf. [9] Norman M. D. *et al.* (2012) *AJES*, **59**, 291-306. [10] Zellner N. E. B. and Delano J. W. (2014) *GCA*, in review. [11] Gombosi D. et al. (2014) GCA, in review.

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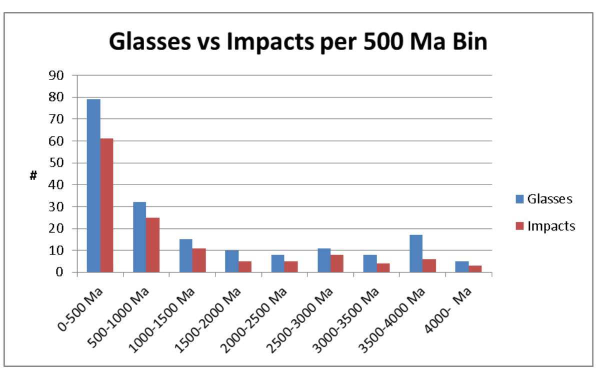

Figure 1. Histogram showing the number of glasses (blue) and the number of impacts (red) in 500-Ma age bins. The number of impacts was determined by counting the number of glasses with compositional similarities and overlapping ages (within 2-σ uncertainty).

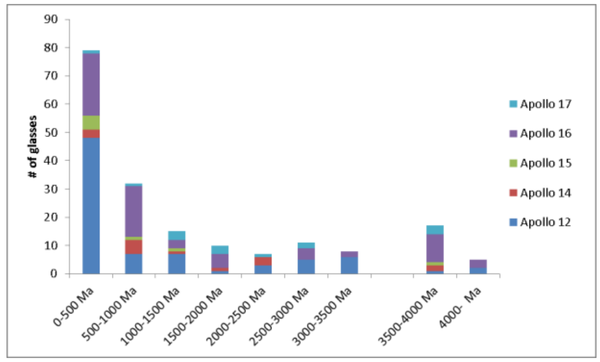

Figure 2. Histogram showing the number of glasses in each 500-Ma age bin, according to Apollo regolith sample (i.e., landing site). Most of the Apollo 12 glasses (all spheres) show a young age.

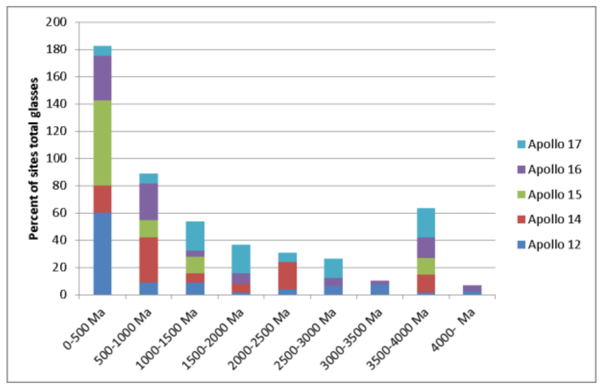

Figure 3. Histogram showing the percent of glasses in 500-Ma age bins, according to Apollo regolith sample (i.e., landing site). For example, this shows that 60% of the Apollo 12 glasses (all spheres) have ages ≤500 My.