A 3.91 BILLION YEAR AGE FOR APOLLO 12 HIGH-THORIUM IMPACT-MELT BRECCIAS: PRODUCTS OF IMBRIUM, OR AN OLDER IMPACT BASIN IN THE PROCELLARUM KREEP TERRANE?

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Introduction and Background: Zeigler et al. (2006) [1] reported finding a previously unknown group of impact-melt breccias in Apollo 12 regolith. These impact-melt breccias are compositionally distinctive in that they have higher concentrations of incompatible trace elements than high-K KREEP impact-melt breccias from Apollo 14, (i.e., 30 ppm Th [1] vs. 22 ppm Th [2]). The high-Th melt breccias are compositionally and texturally very similar, if not identical, to the impact-melt-breccia lithology of the SaU 169 incompatible-element rich lunar meteorite [3]. Analyses of zircons in the SaU 169 impact-melt breccia reported by Gnos et al. (2004) [4] indicated a $^{207}Pb/^{206}Pb$ age of 3909±13 Ma. Gnos et al. took this age to be the precise age of the Imbrium event, which leads to questions about which isotopic systems best date basin impact-melt crystallization [5].

On the basis of compositional and petrographic similarities, we hypothesized that the Apollo 12 high-Th impact-melt-breccia group might have the same age as the melt phase of SaU 169 [1]. We also noted that because of the elevated incompatible-element composition of the Apollo 12 melt-breccia group, members contain abundant zircon in their melt matrix, and in some cases the zircon grains are large enough to analyze with the SHRIMP. Moreover, textural evidence indicates that the zircon grains most likely crystallized from impact melt and thus should reveal the age of the event that generated the impact-melt breccia. This situation is not usually the case for lunar mafic impact-melt breccias, in fact, it is rare. Zircon crystallizes late and typically forms very tiny grains in the matrix of impact-melt breccias, too small even for the SHRIMP-II ion beam. In the Apollo 12 high-Th samples, however, zircon grains range up to 10-15 µm dimensions and greater, and can be analyzed with the SHRIMP-II ion beam that generates a pit of ~8-10 µm diameter. In other lunar impact-melt breccia groups, zircon grains coarse enough for SHRIMP analysis [e.g., 6] prove to have unexpectedly older ages, consistent, in our view, with inheritance from an older, zircon-bearing intrusive rock.

In this abstract we report ages obtained with the SHRIMP-II in the Beijing SHRIMP Center on a suite of zircon grains in several different fragments of Apollo 12 high-Th impact-melt breccia. The majority of the data reveal a robust age determination of 3914±19 Ma. A very few of the grains give older ages, and these we conclude could be remnants of grains inherited from impacted - but incompletely melted - target rocks.

Data: In total, 43 analyses were taken on 41 zircon grains in 5 different high-Th IMB fragments from soils 12032 and 12033. A concordia plot (Fig.1) shows the data, which indicate three ages. The overwhelming majority (38 of 43 analyses) align well along a discordant line with an intercept age of 3913±10 Ma. One grain (12033,638-1a1-7.1) is significantly older (4046 ±28 Ma) and two other grains (12033,638-1c-2.1 & 2.2 and 12033,638-1c-3.1) approach 4.2 Ga. We interpret the older ages of these three grains to mean that the grains are inherited and did not crystallize from the impact-melt matrix.

Many of the data in Figure 1 plot with reverse discordance (i.e., excess Pb). Also, many of the analytical spots overlap adjacent minerals. To address these issues, we checked if reverse discordance relates to gain of lead from the adjacent minerals because of beam overlap. We find there is no linear relationship between the percentage of overlap onto neighboring minerals and the degree of discordance, nor is there a relationship between the percentage of overlap and measured common lead concentrations. We conclude that the reverse discordance is not from gain of lead

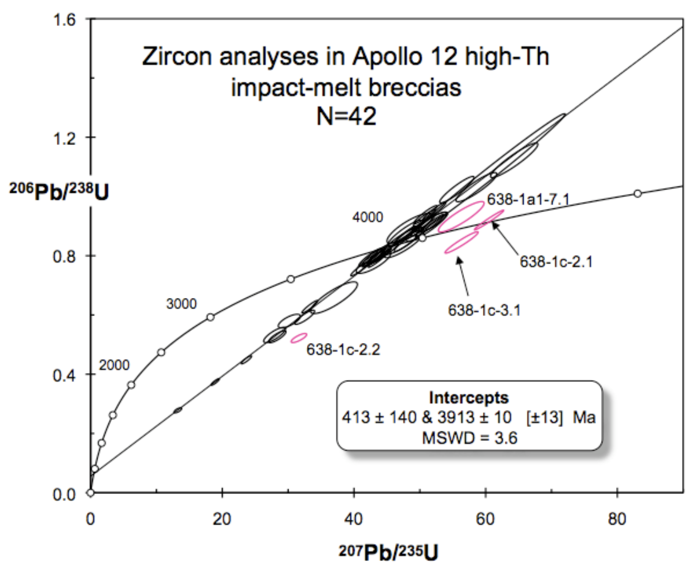

Figure 1. Concordia plot constructed from all of the zircon analyses. The four significantly older data points are excluded from age calculation. Error ellipses represent 68.3% confidence (1σ).

from neighboring minerals but may indicate ancient redistribution of daughter and parent isotopes resulting in local concentration of unsupported radiogenic Pb [7-9]. Moreover, if we exclude data points with the most discordance and spots with the most overlap, we still get the same result as the overall average. If we exclude points with >25% overlap, the data give an average intercept age of 3915±16 Ma. If we further exclude points with excess discordance, we obtain an intercept age of 3912±17 Ma and a mean $^{207}Pb/^{206}Pb$ age of 3909±14 Ma. The excluded data, taken together, yield an intercept age of 3916±13 Ma.

In Figure 2, we plot the data that are most concordant and that have the least outside mineral overlap. These 11 data points yield an intercept age of 3913±19 Ma and mean $^{207}Pb/^{206}Pb$ age of 3914±7 Ma. We prefer to take the mean $^{207}Pb/^{206}Pb$ age of 3914±7 Ma as the age of crystallization of zircon from the Th-rich impact-melt.

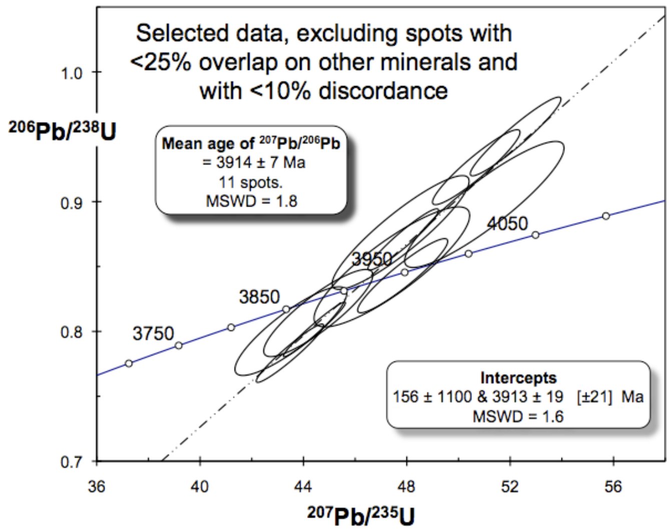

Figure 2. Concordia plot constructed from 11 zircon analyses for which the fraction of the ion beam spot occurring outside of zircon grain is <0.25 and the percentage of discordance is ± 10%. Error ellipses represent 1σ confidence.

Discussion: As a result of this work, the Apollo 12 high-Th impact-melt breccias have a well determined crystallization age, slightly older than 3.9 Ga. The age is identical (within error) to the age determined for zircons in the impact-melt lithology of lunar meteorite SaU 169 by both Gnos et al. [4] (3909±13 Ma) and Liu et al. [10] (3918±9 Ma). As pointed out by Korotev [5], Gnos et al. interpreted this age to be the precise age of the Imbrium impact. However, unless the commonly cited age of 3.85-3.86 Ga for Imbrium (e.g., 3850±20 Ma [11]; 3865±20 Ma [12]) is in error, the age indicated by the Th-rich SaU 169 and Apollo 12 high-Th impact-melt breccia is older. Alternatively, the zircon analyses reported by Gnos et al. and Liu et al. may reflect the Imbrium event, but differ systematically from previous ages, determined using other isotopic systems.

As an alternative to an Imbrium origin, perhaps these impact-melt breccias (Apollo 12 high-Th and SaU 169) formed in a basin impact event that occurred before Imbrium, in the Procellarum KREEP Terrane. Although we cannot say exactly which impact most recently delivered the small rock fragments to the Apollo 12 regolith, we can postulate that it (the delivery impact) excavated ejecta deposits from a basin only slightly older than Imbrium.

Unlike others reporting recently on zircons in impact-melt breccias who have measured larger zircon grains and found older ages, we have unambiguously measured the crystallization age of the impact melt by analyzing the very tiny zircon grains that are most likely to have crystallized from the melt phase and are not inherited. Our preferred age for formation of the Apollo 12 high-Th impact-melt breccias derived from these data is the mean $^{207}Pb/^{206}Pb$ age of 3914±7 Ma. Only a small number of the analyzed zircon grains (3 of 41) in these samples yielded older ages, thus indicating inheritance.

As inferred by Gnos et al. [4] and discussed by Korotev [5], the SaU 169 meteorite, as well as the Apollo 12 Th-rich impact-melt breccia, almost certainly originated from within the Procellarum KREEP Terrane. Matching of the Apollo 12 high-Th impact-melt breccia with lunar meteorite SaU 169 in terms of their compositions, petrography, and precisely determined ages represents the first such matching of a lunar meteorite to specific Apollo rock samples.

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