A MAJOR ~2.1 GA IMPACT EVENT RECORDED IN SOME APOLLO 15 KREEP BASALTS: AUTOLYCUS?

Don Bogard[1], Graham Ryder[2], and Dan Garrison[1,3] 1) NASA-JSC, Houston, TX 77058, 2) Lunar & Planet. Inst., Houston, TX 77058, 3) Lockheed-LEMSCO, Houston. TX 77058.

Several Apollo 15 KREEP basalt fragments collected from the Apennine Front have mesostases that are a yellow Fe-, Ti-, K-rich glass that is a residue of fractional crystallization. These basalt fragments are disrupted, some negligibly, some extensively, with residual yellow glass intruding fractures in silicates. Ryder [1] proposed that their features were consistent with impact splashing and quenching from crystallizing KREEP basalt flows. A test of this hypothesis would be that all phases of the samples should have ages of 3.85 Ga, the age of crystallization of other Apollo 15 KREEP basalts. We measured ^{39}Ar-^{40}Ar ages on three petrographically distinct samples from Spur Crater; the results fail to confirm Ryder's [1] hypothesis. Instead, the samples had a more complicated thermal history in which a major impact event affected all three samples at ~2.1 Ga. The most likely event is the excavation of one of the Copernican craters north of the Apollo 15 site, Autolycus or Aristillus, whose rays have been postulated to cross the site. Autolycus is the most likely. A smaller crater in more local Apennine Bench material cannot be ruled out as the source.

Samples analyzed: Two were coarse fine particles (4-10 mm) and the other a rake sample, described in Ryder [2,3]. All have bulk chemical and mineral compositions of typical Apollo 15 KREEP basalt. 15434,25 is a coarse KREEP basalt with crystals up to 2 mm long and a mesostasis of residual yellow glass and immiscible Si-, K-rich glass. The fragment has been ruptured, and yellow glass moved into fractures in the silicates. A glass coat, that partially mingles with the yellow glass, has a composition similar to a bulk KREEP basalt, not to local regolith. The sample dated was picked to consist of silicates and mesostasis glass, avoiding the glass coat. 15434,29 is a totally disrupted KREEP basalt with broken silicates in a groundmass of residual yellow glass. Some splashed black glass appears on the surface. The sample dated was picked to avoid the extraneous glass and some adhering regolith. 15358 is a 14g chunk of glassy impact melt with a KREEP basalt composition containing clasts of KREEP basalts. All of the basalt clasts have yellow glass mesostases (some with immiscible Si-, K-rich glass), and some are very mildly disrupted. The melt groundmass is about 70% of the sample. The sample dated was picked from ,17 avoiding larger basalt clasts.

39Ar-40Ar ages: The ^{39}Ar-^{40}Ar ages (rectangles) and K/Ca ratios (filled triangles) for each stepwise temperature release are plotted against cumulative fractional release of ^{39}Ar in Fig. 1. Overall, the data imply that materials older than 3.2 Ga were outgassed partially to completely, according to the phase, approximately 2.1 Ga ago. 15434,29 and 15434,25 show similar releases, stepping up from 2.1 Ga at low temperatures to more than 3.0 Ga at high temperatures. The very youngest ages are given by phases with high K/Ca corresponding with Si-,K-rich immiscible glass (K/Ca~2-5) and yellow glass (K/Ca~0.12-0.16). That there is very little of the very high K/Ca phase, consistent with the petrographically minor Si-, K-rich glass, is shown by the small proportion of total ^{39}Ar that is released by this K-rich phase. The lower temperature release from 15434,25 is from phases with higher average K/Ca than that in 15434,29, consistent with the petrographic difference that 15434,29 does not have obvious immiscible Si-, K-rich glass. The highest temperature releases appear to be dominated by plagioclases, which have K/Ca less than 0.025. Releases at intermediate temperatures appear to be from mixtures of yellow glass and plagioclase. 15358 is different: its high temperature release, which is a good plateau, is dominated by material with the same bulk K/Ca as the impact melt glass matrix, which can thus be inferred to be 2.1 Ga old. The lower temperature releases appear to be dominated by partially degassed basaltic clasts (similar to 15434,25 and 15434,29), with lower ages shown by the higher K/Ca phases (i.e. their yellow glass and immiscible Si-,K- rich glass). These did not completely degass at 2.1 Ga, the age of the melt matrix.

The Ar age data strongly suggest that for all three samples, material older than 3.2 Ga (i.e., the Apollo 15 KREEP basalts) was heated in a single event at ~2.1 Ga, and partially degassed. From the petrographic, chemical, and Ar evidence, one can infer that an impact event heated the samples, remobilized the yellow glass, and partially degassed plagioclases, partially degassed yellow glass (but more than plagioclase), and totally degassed phases with higher K/Ca, such as immiscible glass and potash feldspars. This event ruptured the silicates in some cases, and intruded the mobilized yellow glass into fractures. The yellow quench glass existed prior to the impact, as shown by the clasts in 15358, and presumably reflect quenching during the original crystallization of the basalts at 3.85 Ga. However, this quenching was probably not a result of impact splashing that Ryder [1] hypothesized. The melt matrix of 15358 was created by total melting of KREEP basalts at 2.1 Ga.

The 2.1 Ga event: Early analyses of the Apollo 15 landing site suggested that a ray from either of the Copernican-aged Aristillus or Autolycus crossed the area and deposited exotic material [4]. Apollo 15 KREEP basalts were suggested as being contributed by one of these craters (e.g.[5,6]). However, this concept became less favored as it was realized that the Apennine Bench not only corresponded chemically with Apollo 15 KREEP basalts, but that it outcropped closer to the landing site than earlier recognized, and probably underlay the local mare basalt (e.g. [7,8]). Nonetheless, studies by [9] suggest that, of any exotic ejecta at the Apollo 15 site, about 32% would come from Autolycus and about 25% from Aristillus. Autolycus is in the Apennine Bench, and is older than Aristillus. The Aristillus target was covered with mare basalts, with the Apennine Bench beneath them (P. Spudis, pers. comm.). Although it has been suggested that the older Copernican-age craters are not much older than a billion years (e.g. [10]), the calibration is so poor that an age of 2.1 Ga for Autolycus, or even Aristillus, is not improbable. Aristillus might be dated by the ~1 Ga age of the KREEP matrix of 15405. Although a more local, smaller 2.1 Ga crater as a source for these reheated Apollo 15 KREEP basalts cannot be ruled out, none can be clearly identified. We suggest that our data establish a probable age for Autolycus of ~2.1 Ga that is at least as well-established as the ages for Copernicus and Tycho that have been used in post-mare crater-age determinations.

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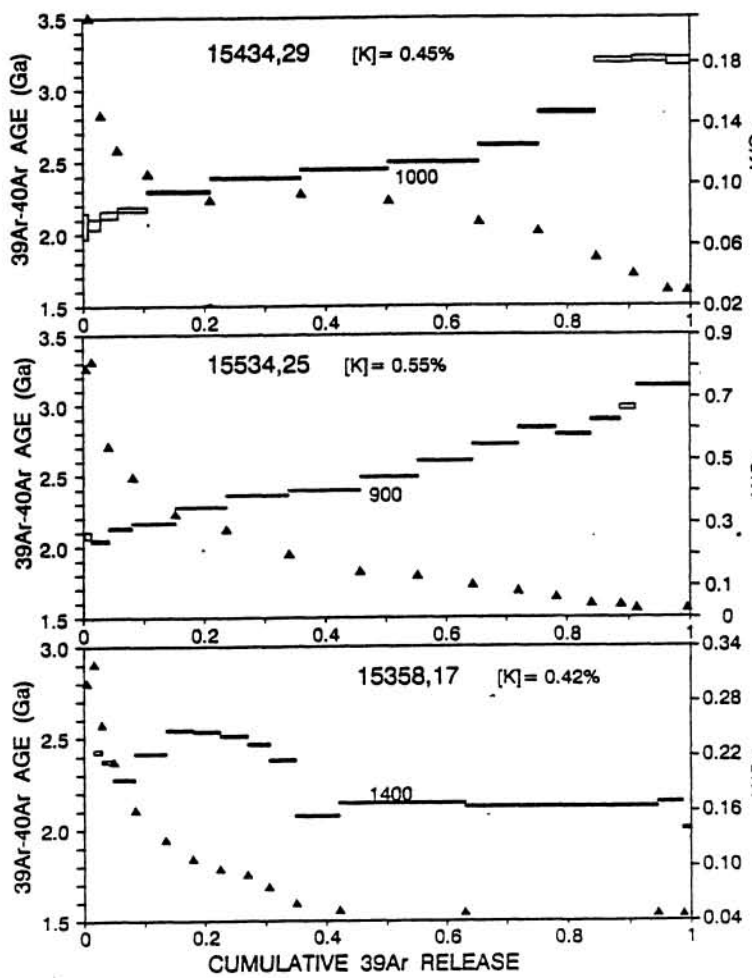

Fig. 1.