A 4.15 Ga age of Serenitatis or Crisium implied by the $^{207}Pb/^{206}Pb$ systematics of Apollo sample 77017

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Introduction: The majority of Apollo 17 sample 77017 constitutes a feldspathic impactite that was recrystallized at subsolidus temperatures as a result of a basin impact [e.g., 1]. We dated this recrystallisation event at ~4.17 Ga using ^{147}Sm-^{143}Nd systematics [2]. On the basis of a geological investigation of craters that could have excavated sample 77017, in combination with a numerical modelling of impact-induced redistribution of basin melts, we also found that a basin-forming event—either Serenitatis or Crisium—was the most likely cause for the recrystallisation [3]. Here, we present $^{207}Pb/^{206}Pb$ data that provide a more precise recrystallization age and to further constrain the origin of the protolith.

Methods: 535 mg of a fine (<20 µm) bulk fraction of split 77017,199 was used for Pb isotope analyses. Stepwise digestion, chemical separation, and isotopic analyses were adopted from [4, 5]. A Monte Carlo approach (10000 cycles) was used for blank subtraction and error propagation.

Results: The sample-to-blank ratios of the Pb isotope analyses of the six digestion steps of the bulk fraction range from 0.3 $x10^6$ to 9.8 $x10^6$. Thus the effect of procedural blanks on the Pb isotope systematics is negligible. Nevertheless, a substantial terrestrial lead component was present in the first two digstion steps and a minor terrestrial component affected the penultimate step. The remaining digestion steps define a 4143 ±9 Ma (MSWD = 0.99) isochron. Additionally, further analyses of mineral fractions combined with the data originally presented in [2] now yield a 4159 ±16 Ma ^{147}Sm-^{143}Nd isochron (MSWD = 1.3; originally a 4170 ±80 Ma errorchron, MSWD = 8.1) when using 6 of the 9 data points.

Discussion: The $^{40}Ar/^{39}Ar$ dating by [1] has established a minimum age estimate (4034 ±58 Ma; recalculated) for the metamorphic sub-solidus recrystallization of 77017. This minimum age is consistent with our $^{207}Pb/^{206}Pb$ isochron date (4143 ±9 Ma), which, more importantly, is concordant with our ^{147}Sm-^{143}Nd isochron date (4159 ±16 Ma) obtained on the same sample split [2]. We consider the weighted average of the two dates (4147 ± 8 Ma, MSWD = 3.0) to be the best age estimate for the recrystallisation event.

Our isochron intersects within error the initial Pb isotopic composition of the LMO at the time of differentiation determined by [6]. As [6] consider this event to have taken place at 4376 ±18 Ma, this would require that the $^{207}Pb/^{206}Pb$ of the 77017-protolith did not change significantly over the next ~229 Ma until the recrystallisation event at 4147 ± 8 Ma. This in turn, requires a very low µ-value (=$^{238}U/^{204}Pb$) in the protolith, which is typical for crustal materials and suggests that little or no KREEP component is present. However, U-Th-Pb systematics of 77017 were previously obtained by [7] and on the basis of the U and Th concentrations, the authors concluded that it is possible that "77017 contains about 5-6% KREEP component" [7]. Using our $^{207}Pb/^{206}Pb$ data, we attempted to constrain whether this KREEP component could have already been present in the protolith before impact. We solved for a protolith isotopic composition that would yield an initial $^{207}Pb/^{206}Pb$ on our 77017 Pb-Pb isochron using a 2-stage model (Stage 1: bulk moon from moon formation to protolith formation, Stage 2: protolith from its formation to recrystallisation event; after [6]). Even when choosing from the possible range of parameters (time of moon formation, time of protolith formation, µ during stage 1 and 2; [6, 8]) those that produce the highest µ-value (i.e., closest to KREEP) in the protolith, this value never exceeds that of the bulk silicate moon in the respective scenario. This is indicative of crustal material that preferentially incorporated Pb. Furthermore, even the highest possible µ-value in such a 2-stage model is lower than the µ-value of 77017 (658-870) measured by [7]. We conclude that this measured µ-value of 77017, which is suggestive of the presence of a KREEP component, must result from a process (most likely addition of a KREEP component or Pb loss) that occurred during the recrystallisation of the sample or even a later event. Therefore, it seems likely that the protolith of 77017 was free of any KREEP component.

A KREEP-free 77017 protolith supports our interpretation that the basin impact that led to the recrystallisation of 77017 was either Serenitatis or Crisium [3]. A 4.15 Ga age of either basin contradicts terminal lunar cataclysm models that require both basins to be ~3.9 Ga [9, and references therein].

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