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# The age of lunar impact melt rock 67935 – Imbrium or not?

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## 1. Introduction

Apollo 16 sample 67935 belongs to the so-called "mafic melt breccias" presumably formed during the Imbrium event [1], which most likely happened 3910-3940 Ma [2]. However, an old $^{187}$Re-$^{187}$Os date (4210 ±130 Ma [3]) for sample 67935 is inconsistent with an Imbrium origin. To resolve this contradiction, we are trying to date this sample using a multichronometer approach, in which $^{176}$Lu-$^{176}$Hf, $^{147}$Sm-$^{143}$Nd, $^{87}$Rb-$^{87}$Sr, and Pb-Pb are analysed on the same split [4, 5].

## 2. Methods and Results

We were allocated a ~1 g aliquot (,39) of 67935 comprising 2 pieces. White clasts were present in both pieces, and glass veins intruded the larger piece. During crushing, the clasts and glass phases were separated. This sample is too fine-grained (~20 µm) for standard magnetic separation procedures. To solve this problem, we developed an enclosed system for magnetic separation in ethanol [6] (based on [7]). With this setup, we successfully separated six compositionally different mineral fractions from a ≤ 20-µm bulk fraction. The separates, numbered 1 to 6 grade continuously from dark grey and most magnetic (#1) to light grey and least magnetic (#6). After digestion, elements for all six separates plus a 'bulk fine' fraction (whole rock fraction from which metal was removed using a hand magnet) were separated following the two-stage elution scheme of [8], followed by additional steps to separate Sm and Nd (using Ln-Spec columns), and to clean up the Sr fraction (using Sr-Spec columns). Strontium was measured on a Thermo Triton MC-TIMS, and all other elements (Lu, Hf, Rb, Sm, and Nd) on a Neptune Plus MC-ICP-MS.

The resulting ranges in parent-daughter ratios are $^{176}$Lu/$^{177}$Hf: 0.017-0.022, $^{147}$Sm/$^{144}$Nd: 0.161-0.174, and $^{87}$Rb/$^{86}$Sr: 0.024-0.081 and all three systems have apparently been disturbed. Using all 7 isochron points does not yield a statistically relevant isochron for any of the three systems (Lu-Hf: 2689 ±1400 Ma, MSWD = 181; Rb-Sr: 4527 ±550 Ma, MSWD = 20; Sm-Nd: 3614 ±560 Ma, MSWD = 9.5). When excluding #3 and #4, the remaining 4 mineral fractions and the 'bulk fine' fraction yield a 3902 ±160 Ma Sm-Nd isochron (MSWD = 1.4, Figure 1C). The Lu-Hf and Sm-Nd isotopic systematics of samples on the lunar surface can be affected by neutron capture (NC) effects [9], which then would have to be corrected [4, 10]. However, no resolvable $^{180}$Hf/$^{177}$Hf or $^{149}$Sm/$^{152}$Sm anomalies were found when measuring an unspiked 'bulk fine' fraction. This indicates that no significant NC effects are present, and thus no correction was applied.

## 3. Discussion and Future Work

As can be seen in Figure 1A and 1B, the scatter in the Rb-Sr and Lu-Hf systems significantly exceeds the area covered by the two reference isochrons that reflect the two most likely ages of this sample. Thus, those two systems cannot be used to better constrain the age of sample 67935. However, our 5 of 7 point $^{147}$Sm-$^{143}$Nd isochron date (3902 ±160 Ma, Figure 1C) is distinct from the 4210 ±130 Ma $^{187}$Re-$^{187}$Os date of [3], but is in line with a 3910-3940 Ma Imbrium age [2]. At the moment however, we do not understand why points #3 and #4 deviate from the isochron.

We will analyse all six mineral separates with Raman spectroscopy to identify the minerals present and to better discern the differences between them. Furthermore, we are in the process of analysing the glass and clast fractions, which were separated from the sample during sample preparation. Some of our analysed mineral fractions might be "contaminated" with clast or glassy material. Thus, identifying the isotopic compositions of these two components could help to quantify the contamination and explain at least some of the scatter in our isochron plots. We will also try to date the sample using Pb-Pb as we recently did for 14310 [5].

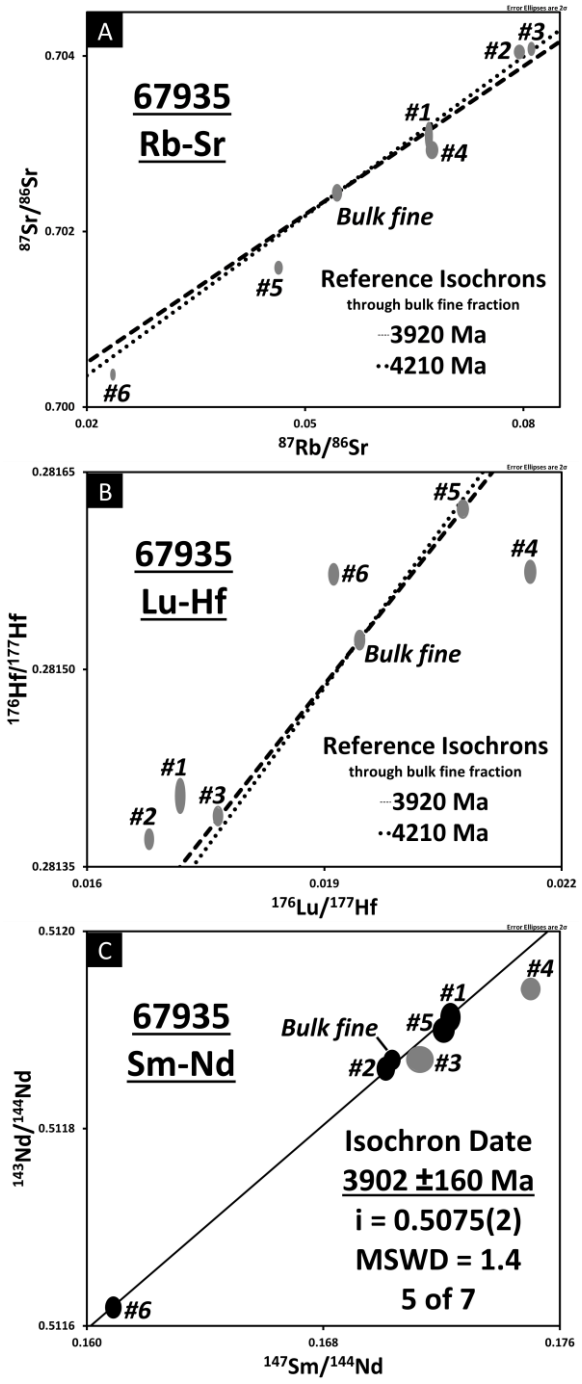


**Figure 1:** $^{87}$Rb-$^{87}$Sr (A), $^{176}$Lu-$^{176}$Hf (B), and $^{147}$Sm-$^{143}$Nd (C) data obtained here for 67935. Reference isochrons are shown in panels A and B. The $^{147}$Sm-$^{143}$Nd isochron (3902 ±160 Ma) through the bulk fine and 4 mineral fractions (#1, #2, #5, and #6) is shown in panel C. Error ellipses are 2σ standard deviation.

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