FORMATION AGES, COGENETIC RELATIONS AND FORMATION PROCESSES OF A SET OF APOLLO 16 IMPACT MELT ROCKS.

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Introduction: This study aims to produce ages, elemental compositions, radiogenic isotopic data, and petrographic observations for a diverse suite of Apollo 16 (A16) impact melt rocks. Elemental and isotopic data are also acquired for some Apollo 14 (A14) and 17 (A17) rocks for comparison. Our aim is to link the $^{40}Ar/^{39}Ar$ ages with the chemical compositions and petrographic characteristics in an attempt to identify sets of the breccias that could be related to specific impact events in order to better define the impact history represented by the crystalline lunar melt rocks, and the petrogenetic processes that influence the chemical and petrologic characteristics of lunar melt breccias.

Samples and Methods: Crystalline lunar melt breccias from the A14 (n=1), A16 (n=25) and A17 (n=9) landing site were studied. Whole rock major element, trace element, and Rb-Sr and ^{147}Sm-^{144}Nd isotopic data were measured at RSES-ANU by solution aspiration ICP-MS (*Varian 820-MS*) and TIMS using a *Thermo-Triton* for the Sr-Nd-Sm analyses and a refurbished *MAT-261* for the Rb measurements. $^{40}Ar/^{39}Ar$ data were obtained using *MAP215-50 mass spectrometer* coupled with a *NewWave Nd-YAG infrared (1064 nm) laser* at Curtin University.

Results: The major and trace element data were used to group the A16 samples following the scheme of Korotev [1] (Figure 1; Table 1) with six additional rocks added to the scheme. All but two (60335, 61156) of the 19 previously-studied samples show the same grouping as in [1]. Our split of 60335 has a more aluminous composition and lower REE-concentrations compared to the split analyzed in [1] and groups as 2F instead of 2M. Sample 61156 was included in Group 3 by [1] but our split is more aluminous and it shows a slight offset in the Sm-Sc plot compared to the other Group 3 samples (Figure 1). It is also characterized by a lower Cr concentration and a lower relative abundance of the heavy REE compared to other Group 3 samples. These differences are qualitatively similar to those used by [1] to distinguish Groups 2NR from 2DB. We therefore tentatively assigned 61156 to a new supgroup 3A, which is also justified by the apparent age difference between 61156 and the other Group 3 melt rocks (Figure 2, Table 1).

$^{40}Ar/^{39}Ar$ ages can be considered together with the chemical data to further evaluate possible cogenetic relationships within the melt rock groups. Here we only present $^{40}Ar/^{39}Ar$ ages which satisfy the criteria for a plateau age [2].

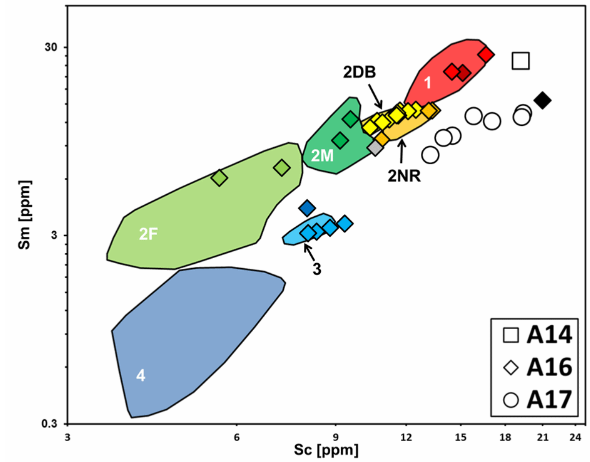

Figure 1: Sm and Sc contents of melt rocks measured by ICP-MS. A16 groups from [1]. Color coding as in Table 1.

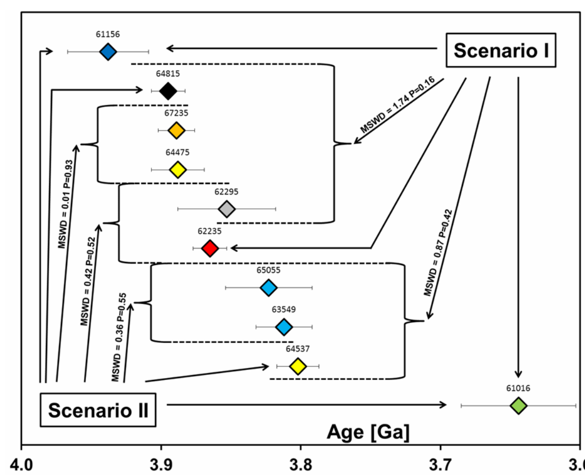

Figure 2: $^{40}Ar/^{39}Ar$ plateau ages and two possible grouping scenarios. Color coding as in Table 1.

Figure 2 depicts two of numerous possible scenarios of cogenetic sample groups that could be inferred from the determined ages based on a χ^2 statistical concordance test. While Scenario I contains the lowest possible number of cogenetic groups (n=5) another extreme scenario would be that each sample represents separate events with overlapping ages. Independently from an assessment of which samples are likely to be cogenetic [3] we conclude that there are at least 5 different age groups represented within our sample set and that the chemical group 2DB consists of at least 2 cogenetic subgroups (Figure 2).

Initial $^{87}Sr/^{86}Sr$ (I_{Sr}) compositions measured here in combination with I_{Sr} calculated using literature data (Figure 3) and our $^{40}Ar/^{39}Ar$ ages also reflect the chemical grouping. For example, the I_{Sr} of Group 1 samples indicate a KREEP-rich source, consistent with their trace element compositions. In contrast, Group 3 samples (excluding 61156) have I_{Sr} compositions consistent with a pre-impact source region having a low $^{87}Rb/^{86}Sr$, similar to ferroan anorthositic suite rocks including the more noritic varieties at the Apollo 16 site (Figure 3). The I_{Sr} data also confirm the distinction of 61156 from the other Group 3 samples. The wide range of I_{Sr} in the Group 2 samples implies a heterogeneous set of crustal target lithologies with diverse $^{87}Rb/^{86}Sr$. This suggests mixtures of anorthosites or Mg-suite norites such as 78238 (WR = 0.09, [3]) with more KREEP-like compositions. Within Group 2 the samples of subgroups 2Mo and 2M have identical I_{Sr} values (within error) while sample 64537 (2DB) has a slightly higher I_{Sr}.

The A17 rocks have chemical compositions that are distinct from those of the A16 groups (Figure 1) and range from KREEP-rich melt rocks to more anorthositic compositions in pristine clasts or granulites. The I_{Sr} for the three A17 poikilitic impact melt rocks shown in Figure 3 are similar to those of some A16 Group 2 samples and to Mg-suite norites such as 78238 [3].

Discussion: The compositional variability within cogenetic groups of impact melt rocks could be caused by either physical mixing of different target lithologies and/or magmatic processes like crystal fractionation within a melt sheet. For the latter case a relatively large melt body would be required which could provide homogenous I_{Sr} values. Our preliminary isotopic data and the comparison with literature data (Figure 3) show that similar I_{Sr} seem to be characteristic within the Groups 1 and 3 and for some subset of samples within Group 2. If this can be verified by our ongoing Rb-Sr analysis and if the ^{147}Sm-^{143}Nd system shows similar characteristics, then the chemical trends observed within these groups (Figure 1, [1]) are likely candidates for magmatic processes within melt sheets. In the case of the 2DB samples the isotopic data might also help to resolve the suggestion of at least two distinct ages within this relatively narrow chemical group.

In conclusion the data obtained by this study allows us to narrow the hypotheses given for the origin of the compositional variety of A16 impact melts by [1] from four to two: The age data (Figure 2) rule out one small or basin scale impact as the only source, but support the hypothesis of two or more basin impacts or the hypothesis of two or more smaller, local impacts or a combination of both. Intergroup chemical and isotopic variations between Group 1, 2 and 3 likely reflect the mixing of different target lithologies. Further isotopic analysis will be used to test the role of magmatic processes such as crystal fractionation in the generation of intragroup chemical variations.

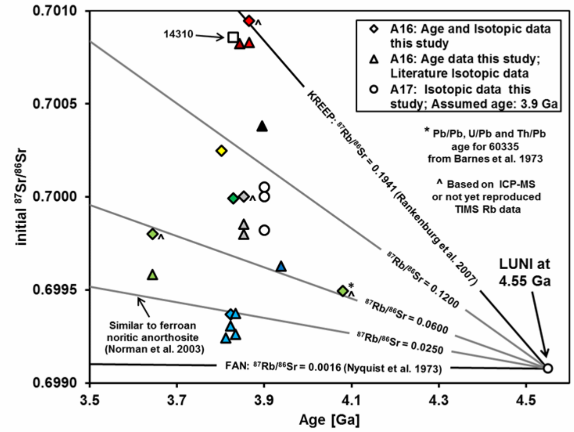

Figure 3: I_{Sr} of lunar samples. Color coding as in Table 1. Literature data from [5] to [10].

Table 1: Chemical grouping scheme for the A16 melt rocks [1] based on ICP-MS data.
*: Not previously grouped.
{}: $^{40}Ar/^{39}Ar$ plateau age in Ma.

Group	Samples
1M	60315
1F	62235 {3865 ± 12}, 65015
2DB	60625, 61015, 62255, 64475* {3888 ± 19}, 64476, 64536, 64537* {3802 ± 15}, 66095
2NR	63355, 67235* {3889 ± 13}, 67935*
2M	65075*, 67095*
2Mo	62295 {3853 ± 35}
2F	60335 (Group 2M in [1]), 61016 {3644 ± 41}
3	63549 {3812 ± 20}, 65055 {3823 ± 31}, 68415, 68416
3A	61156 (Group 3 in [1]) {3938 ± 29}
U	64815 {3895 ± 12}

References: [1] Korotev (1994) *GCA, 18,* 3931-3969. [2] Jourdan (2012) *AJES, 59,* 199-224. [3] Haber et al. *in preparation.* [4] Edmunson et al (2009) *GCA, 73,* 514-527. [5] Nyquist et al. (1973) *Proc. Lunar. Sci. Conf. 4th, 2,* 1823-1846. [6] Mark et al. (1974) *GCA, 38,* 1643-1648. [7] Reimold et al. (1985) *Proc. Lunar. Sci. Conf. 15th, 2,* C431-C448. [8] Barnes et al. (1973) *Proc. Lunar. Sci. Conf. 4th,* 1197-1207. [9] Norman et al. (2003) *MAPS, 38,* 645-661. [10] Rankenburg et al. (2007) *GCA, 71,* 2120-2135.