IMPACT MELT ROCKS FROM APOLLO 17: A BRIEF REVIEW.

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Introduction: Apollo 17 landed on the rim of the Serenitatis basin. A critical mission objective was to study basin ejecta via boulders that can be traced to outcrops on the surrounding massifs. These boulders are composed predominantly of melt-bearing impactites and their entrained clasts; fragmental and granulitic breccias were also collected both from the boulders and as discrete samples around the landing site. The extent to which the Apollo 17 melt rocks and breccias can be related to ejecta from either Serenitatis, or some other source such as Imbrium, has profound implications for understanding lunar impact history and the geology of large impact structures.

Petrology: Apollo 17 melt rocks are commonly classified into melt-rich 'poikilitic' (Fig. 1) and clast-rich 'aphanitic' varieties, but in fact there is a substantial diversity of textures even within individual samples. Systematic variations of grainsize, clast content, and mineralogy in the poikilitic suite (Fig. 2) indicates progressive assimilation of increasingly refractory components into the melt with slower cooling.

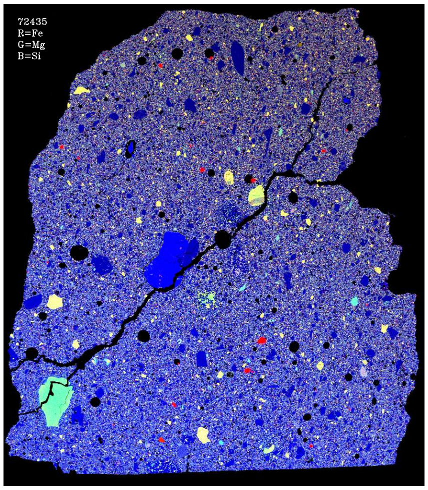

Fig. 1. Element map of poikilitic melt rock 72135. Image courtesy of Sam Lawrence.

Lithic clasts in these breccias have received substantial attention because many represent primary igneous lithologies of the lunar crust. Mineral clast compositions reveal lunar crustal lithologies that are not otherwise well represented in the sample collection [1, 2]. Mg-suite and KREEPy lithologies dominate the mineral and lithic clast population, although a small fraction (10-15%) of the plagioclase clasts appears to be derived from ferroan anorthosite.

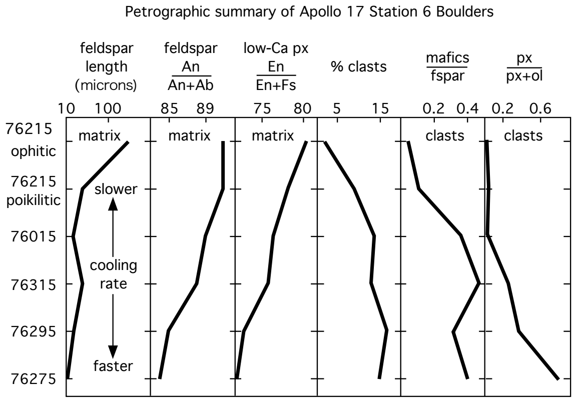

Fig. 2. Petrographic characteristics of Apollo 17 poikilitic melt rocks. After [3].

Geochemistry: The poikilitic melt rocks have relatively mafic (17-19 wt% Al_2O_3), KREEP-rich compositions (Figs. 3,4). Melt rocks with similar compositions were also collected at the Apollo 15 and 16 sites, although there are some site-specific differences in the proportions of mafic/felsic components (Fig. 3). Some poikilitic samples such as 76055 have distinct compositions, suggesting either multiple impact events or greater compositional heterogeneity in the poikilitic melt sheet than typically considered. Apollo 17 aphanites have diverse compositions (Fig. 3), apparently due to variations in the matrix melt composition rather than simply differences in clast content [4].

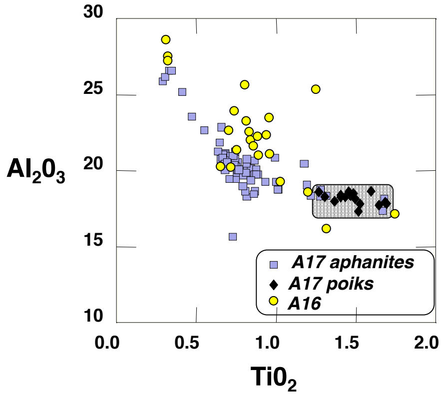

Fig. 3. TiO_2 vs. Al_2O3 vs. contents of Apollo 17 melt rocks compared to Apollo 16. After [5].

Geochronology: The age data for Apollo 17 melt rocks are messy. Fine-grained textures and the presence of clasts have discouraged attempts to obtain mineral isochrons, while the ^{40}Ar-^{39}Ar data are complex and equivocal at best.

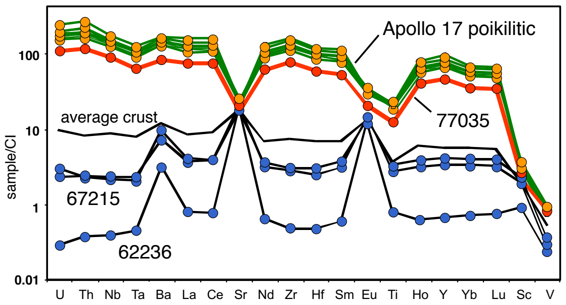

Fig. 4. Trace element compositions of Apollo 17 poikilitic melt rocks. After [5]

None of the ^{40}Ar-^{39}Ar plateau ages proposed by Dalrymple & Ryder [6] for the poikilitic melt rocks are statistically valid relative to current criteria (>50-70% ^{39}Ar) as they are based on only 25-35% of the released gas (Fig. 5). Recoil, multiple domains, and diffusive loss complicated the age assignments, and their preferred age of 3893 ± 9 Ma for Serenitatis was based on only three of the eight poikilitic samples that they analysed. Two of their samples gave minimum ages and including the other three in the weighted mean yields an age of 3880 ± 32 Ma (2σ), which is within error of the Imbrium age proposed earlier by these authors [7] based on Apollo 15 melt rocks (3866 ± 16 Ma).

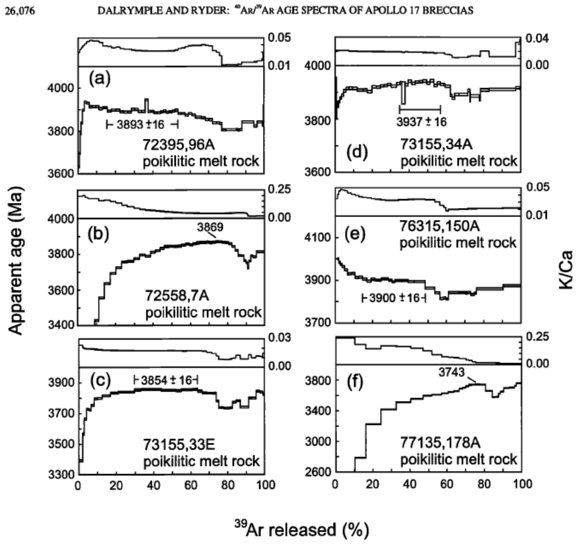

Fig. 5. Ar release spectra from Apollo 17 poikilitic melt rocks [6].

In contrast, a recent laser microprobe ^{40}Ar-^{39}Ar study of poikilitic sample 77115 [8] defined an isochron age of 3834 ± 20 Ma, interpreted as the time of impact melting. Data for the melt matrix formed a simple, monogenetic population whereas clast ages ranged from 3892-4230 Ma. That study also found that aphanite 73217 is isotopically heterogeneous, consistent with earlier work, and apparently requiring multiple impact events ranging in age from 3.81 to ≤3.27 Ga. Mercer et al. [8] note that their results tend to support an Imbrium origin for the Apollo 17 melt rocks.

Alternatively, U-Pb ages of KREEP-rich lunar meteorites and melt rocks from the Apollo 12, 14, 16, and 17 sites all seem to be converging on a common age of ~3.91-3.93 Ga [9, 10]. This may be consistent with a common origin for these deposits, probably as Imbrium ejecta. Alternatively, Imbrium and Serenitatis produced melt rocks very similar in composition and indistinguishable in age. The apparently older ages obtained by U-Pb compared to ^{40}Ar-^{39}Ar may be a systematic error related to calibration, but this needs to be addressed through additional integrated studies.

In summary, formation ages of the Apollo 17 melt rocks are poorly determined. Evidence exists for multiple events that are both older and younger than the proposed formation ages, and the significance of the data for basin ages is an open question. The Apollo 17 poikilitic and aphanitic suites appear to be coeval although depositional ages of the aphanites are highly uncertain due to their clast-rich nature and apparently more complex impact history.

Discussion: The combination of field relationships, compositional homogeneity, and systematic petrologic variations strongly implies that the main suite of Apollo 17 poikilitic melt rocks are cogenetic and were emplaced as melt produced by a single impact event. The critical question is whether this was Serenitatis, Imbrium, or something else. Geological analogues of the Taurus-Littrow graben at Orientale suggest deposition and uplift of the massif units by Serenitatis [11] but Imbrium structures are also concentric with the eastern rim of Serenitatis and an Imbrium overprint at the Apollo 17 site has long been recognized. Compositional and depositional differences between the Sculptured Hills and the massif melt rock units may not provide a critical distinction of Imbrium vs. Serenitatis ejecta if the Descartes and Cayley units at Apollo 16 provide a valid analogy for petrological and geochemical diversity of distal ejecta facies produced by Imbrium.

References: [1] Ryder G., Norman M., and Taylor G. (1997) *GCA, 61,* 1083-1105. [2] Lawrence S., Taylor G., and Norman M. (2008) *LPS XXXIX*, Abstract #1521. [3] Norman M. (2005) *Aus. J. Earth. Sci., 52,* 711-723. [4] Spudis P. and Ryder G. (1981) *PLPSC 12A*, 133-148. [5] Norman M., Bennett V., and Ryder G. (2002) *EPSL, 202*, 217-28. [6] Dalrymple B. and Ryder G. (1996) *JGR, 101,* 26069-26084. [7] Dalrymple B. and Ryder G. (1993) *JGR, 98,* 13085-13095. [8] Mercer C. et al. (2015) *Sci. Adv., 1*, e14000520. [9] Bouvier A. et al. (2011). *MetSoc, 74,* Abstract 5185. [10] Thiessen F., et al. (2017) *MAPS, 52,* 584-611. [11] Reed V. and Wolfe E. (1975) *PLSC, 6,* 2443-2461.