PLACING THE APOLLO 12 BASALTS IN THEIR GEOLOGICAL CONTEXT. J.H.C. De Oliveira[1] and C.R. Neal[2], [1,2]University of Notre Dame, Notre Dame IN, 46556; ([1]jdeolive@nd.edu; [2]cneal@nd.edu).

Introduction: The basalts returned from the Apollo 12 site, located in Mare Procellarum, provide us with perhaps the only meaningful examination of basaltic volcanism on the western nearside of the Moon. The nearby Apollo 14 samples are predominantly clasts within breccias [1]. Although the site is situated upon thick mare and the vast majority of rock samples returned are basalts, the regolith is far more diverse, composed of mare and nonmare material from local and distant impacts (i.e., Reinhold and Copernicus) [2]. The returned soil samples provide us with KREEP-enriched material that has been linked to various impacts, providing the opportunity to gain insight into the geology of far-off targets [3]. The Apollo 12 basalts we classified into 4 mineralogical types [4]: olivine, pigeonite, ilmenite, and feldspathic basalts. This was revised by [1] such that the feldspathic basalts consist of only one sample — 12038.

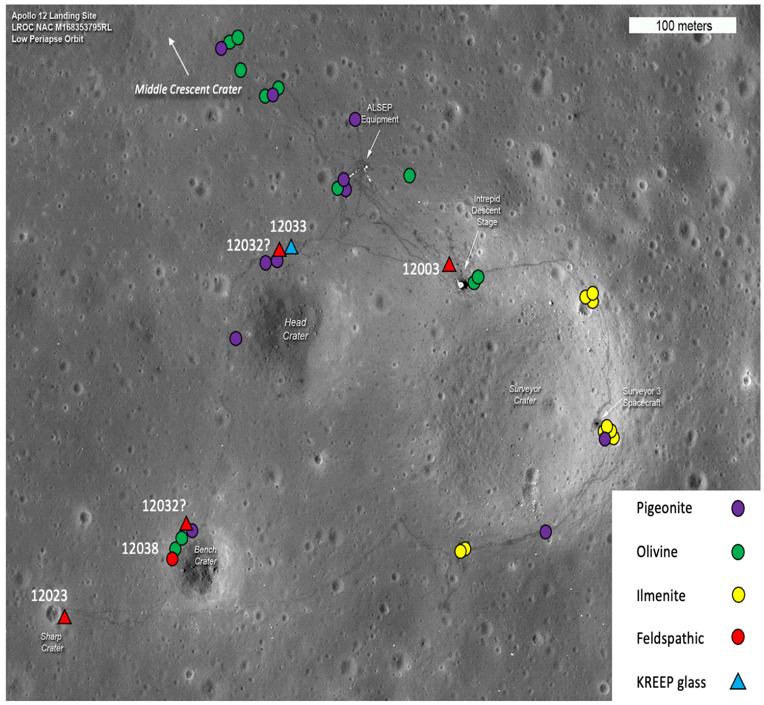

Figure 1. Map of Apollo 12 basalt locations [6]. Circles indicate rock samples, while triangles indicate soil samples. 12032's location is debated [2]. 12038 and all soil samples with feldspathic material are listed; additionally, the ropy KREEP glass, 12033, is labelled.

Previous Work: Many attempts have been made to understand various facets of the Apollo 12 site. The site is heterogenous — made up of the following units: Eratosthenian Mare 2, Imbrian Mare 1 (age classifications determined by crater size frequency distributions), and ray/ejecta material from the crater Copernicus to the north. The mare basalt units are characterized by the presence of highly mafic and ferrous materials, as well as similar abundances of clinopyroxene, orthopyroxene, and plagioclase. The Eratosthenian unit is blanketed by Copernican ejecta which has higher amounts of plagioclase than the underlying rock [5].

Motivations for this Study: Understanding the geological context in which these basalts were formed, emplaced, and discovered is critical to answering many of the questions that remain about the Moon's past volcanic and cratering activity. The feldspathic basalt is sample 12038 and was originally thought to be the only representative of its flow in the region. More recent analyses of soil fragments (from samples 12003, 12023, and 12032), however, have found that there was more feldspathic mare material than previously thought [6], but this category still contains the fewest samples. Our goal in this review is to use the geological context of the Apollo 12 site to examine potential answers to this question: where did the feldspathic basalt material come from?

Discussion: Of particular interest are those regolith samples containing feldspathic basalt fragments. Thus far, three such soils have been analyzed. 12003 had 17 chips analyzed (3 are pigeonites, 7-9 are olivines, 4-6 are ilmenites, and 1 is feldspathic) [6]. 12 fines from soil sample 12023,155 were analyzed (2 are feldspathic, 5 are olivines, 1-3 are ilmenites, and 1 is pigeonite, with difficulty classifying at least 1 of the fragments) [7]. Additionally, 38 and 60 fragments were analyzed for soil samples 12023 and 12032, respectively (12023,143_03 and 12032,366_03 were identified as feldspathic basalts similar to 12038) [2].

Of greatest importance is that these studies assert that more parent feldspathic basalt flows are required for the diversity of basaltic material now identified [2,7]. If derived locally, it is expected that feldspathic basalts would be more numerous in the sample collection.

Two possibilities are presented for the presence of feldspathic basalts at the Apollo 12 site. The first possibility is that 12038 represents a poorly sampled local lava flow. The second is that 12038 (and the fragments found in soil samples 12003, 12023, and

12032) are exotic to the Apollo 12 site and were transported there via the impact process [1].

The first possibility is supported primarily by analyses of soil samples 12003, 12023, and 12032 (**Fig. 1**; [2,6,7]), indicating that there is more material related to 12038 at the Apollo 12 site. While definitive stratigraphic analysis is difficult because of overlapping age data between the basalt classes (pigeonites are 3129 ± 10 Ma to 3176 ± 6 Ma, olivines are 3163 ± 10 Ma, ilmenites are 3187 ± 6 Ma, and the feldspathic basalt is 3242 ± 13 Ma [8]), 12038 is older than the other basalt types (3350 ± 90 Ma [9]; 3242 ± 13 Ma [10]) and is representative of the earliest (and therefore lowest) basalt layers in the region. This could explain the paucity in feldspathic basalts in the region if craters are too shallow to excavate significant amounts of material from the old, buried feldspathic basalt flow(s) [6].

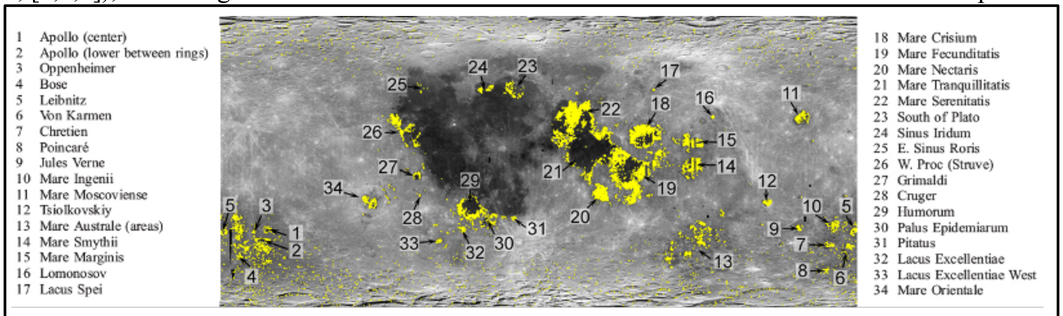

Figure 2. Potential locations of high-Al (feldspathic) basalts. Modified from [13].

The second possibility is supported by 12038 originating in the vicinity of Copernicus Crater to the north, as a ray of Copernicus crosses the Apollo 12 site [3]. Material returned by Apollo 12 has been identified as exotic to the site. For example, soil sample 12033 contained a ropy KREEP glass that has been interpreted as a proxy for the age of impact for Copernicus (~0.8 Ga [11]). Moreover, for typical soils recovered from the Apollo 12 site, an estimated upper limit for the proportion of Copernicus ejecta is 45% [2]. However, orbital data have been used to identify high-Al (feldspathic) basalt flows but none were identified around Copernicus [12,13].

Exposure ages for 12038 have been calculated at 230 ± 15 Ma (^{81}Kr/^{83}Kr) and 215 ± 43 Ma (^{126}Xe/Ba) [14]. For two KREEP glass fragments from 12033, the exposure ages were calculated to be 210 and 190 Ma [11]. This implies that the KREEP glass, which was ejected ~0.8 Ga, was rapidly buried (most likely by secondary impact material), and only introduced to the lunar surface ~0.2 Ga. A similar conclusion cannot be made for 12038 - if it were also primary ejecta from Copernicus, it would likely have been buried in the same wave of secondary cratering and brought to the surface by the same mechanism that exposed the KREEP glass. Also, 12038 does not contain shock features and noticeable degassing or a "reset" of chronometers at ~0.8. Coupling this with a lack of high-Al (feldspathic) basalts in the vicinity of Copernicus [12,13] rules out this ejecta for the origin of 12038.

If 12038 is exotic to the Apollo 12 site, where did it come from? **Fig. 2** identifies regions of interest for exploring high-Al, feldspathic basalts as identified by [12,13] (see these papers for details) using Clementine and Lunar prospector data. The closest areas where 12038 could have originated are the vicinity of Mare Humorum, Western Procellarum (Struve), Orientale, Sinus Iridum, and south of Plato (Fig. 2).

Conclusion: Understanding the geologic context of lunar samples allows local stratigraphy to be developed, but also understand the presence of samples exotic to the site that were transported there by the impact process. Although additional samples of feldspathic basalts have been identified in regolith samples from Apollo 12 [2,6,7], these are still few in number. Integrating orbital compositional data with samples has identified several sites of origin for 12038 and other feldspathic basalts. Further work is needed to investigate the validity of these locations as viable source regions

References: [1] Neal C.R. et al. (1994) *Meteoritics 29*, 334-348. [2] Korotev R.L. et al. (2011) *GCA 75*, 1540-1573. [3] Barra F. et al. (2006) *GCA 70*, 6016-6031. [4] James O.B. & Wright I.L. (1972) *Geol. Soc. Am. Bull. 83*, 2357-2382. [5] Iqbal W. et al. (2020) *Icarus* 352, 113991. [6] Snape J.F. et al. (2014) *MaPS 49*, 842-871. [7] Alexander L. et al. (2014) *MaPS 49*, 1288-1304. [8] Snape J.F. et al. (2018) *Chemical Geology* 482, 101-112. [9] Nyquist L.E. et al. (1981) *EPSL 55*, 335-355. [10] Snape J.F. et al. (2016) *EPSL 451*, 149-158. [11] Eberhardt et al. (1973) *Moon 8*, 104-114. [12] Kramer G.Y. et al. (2008) Icarus 198, 7-18. [13] Kramer G.Y. et al. (2008) *JGR 113*, E01002, doi:10.1029/2006JE002860. [14] Burnett D.S. et al. (1975) *Proc. Lunar Sci. Conf.* 6th, 2219-2240. [8] Marvin U.B. et al. (1971) *Geochimica et Cosmochimica Acta* 2, 679-699. [9] Pieters C.M. et al. (1985) *Journal of Geophysical Research* 90, 12393-12413.