LUNAR-SAMPLE-PROVENANCE (LSP) PROGRAM: DETERMINING THE POTENTIAL SOURCE REGIONS OF LUNAR BASALTIC METEORITES A. Madera[1] and J. Gross[1,2,3,4], [1]Department of Earth and Planetary Sciences, Rutgers University, Piscataway, NJ, 08854; [2]Department of Earth and Planetary Sciences, American Museum of Natural History, New York, NY, 10024; [3]ARES, NASA Johnson Space Center, Houston, TX, 77058; [4]Lunar and Planetary Institute, Houston, TX, 77058; (am1505@eps.rutgers.edu).

Introduction: The Apollo and Luna missions returned ~382 kg of rock and regolith from known locations of a geologically unique region on the lunar surface [1]. As a result, samples from these critical missions are not chemically representative of the bulk Moon. Lunar meteorites represent a more global, albeit random, sampling of the lunar surface [2], and thus, are critical for our understanding of lunar evolution. However, contrary to the Apollo and Luna samples, launch regions and thus, the geological contexts of lunar meteorites are unknown, making it difficult to interpret their geological history and importance within the global lunar evolution correctly [3].

Decades of lunar remote sensing missions (e.g., Clementine, Lunar Prospector, Lunar Reconnaissance Orbiter) have provided readily available chemical data of the lunar surface. These global datasets have been further refined to produce maps of compositions, chemistries, and mineralogies. Comparison of the compositions of lunar samples with such derived datasets of the lunar surface can help to constrain potential sample source regions [e.g., 3,4]. This is a useful tool that may provide further geologic context to the chemical and evolutionary interpretation of meteoritic samples.

Motivation: Northwest Africa (NWA) 8632 is a porphyritic, low-Ti lunar basaltic meteorite [5-7] with similar bulk composition and trace elements to lunar meteorites NWA 032, NWA 4734, and the LaPaz Icefield (LAP) 02205 meteorite clan. Due to overlap in radiometric ages (between ~2.8 Ga and ~3.1 Ga) [3, and *references therein*], chemistry, mineralogy, and textures of these meteorites, they are grouped together as the North-North-LaPaz (NNL) clan [7,8]. The NNL clan (including NWA 8632) is younger in age and slightly enriched in incompatible trace elements (ITE) when compared to mare basalts with similar bulk compositions, mineralogies, and textures e.g., from the Apollo 12 and 15 collections [8-10]. Therefore, the NNL clan could provide unique insight into late-stage magmatism, including parent magma production, magma chamber dynamics, and eruption-styles that might differ from Apollo basalt magmatism.

Previous studies determined that the NNL clan is not paired but, alternatively, may share a common launch history from the same volcanic complex [8,9] that could consist of multiple mare flows [3]. There is discrepancy in the potential source regions of NNL clan meteorites; previous studies suggested these samples could originate from multiple mare regions on the nearside including Mare Serenitatis, Imbrium and Western Oceanus Procellarum [3,4,10-12]. The difficulty in discerning source regions is due to pairing small-scale geochemical analyses of lunar meteorites with large-scale remote sensing datasets of the lunar surface, in which the pixel size of the dataset out-scales the size of the meteorite sample by several orders of magnitude.

In this study, we further refine our newly developed program, called Lunar-Sample-Provenance (LSP) program [3] by comparing lunar orbital datasets of varying spatial resolutions to Apollo 12 and 15 samples and landing sites, to ultimately better refine potential sample source regions for the NNL clan and understand their geologic evolution.

Methods: We developed a computational program that is an expansion of [3,4], which previously only utilizes Lunar Prospector - Gamma Ray Spectrometer (LP-GRS) data to constrain potential surface source region(s) of lunar meteorites. The new LSP program incorporates multiple datasets, including: LP-GRS (60km/pixel) [13], the Lunar Reconnaissance Orbiter Diviner (LRO-DOM; 948 m/pixel) [14,15], and the Chang'e-1 Interference Imaging Spectrometer (IIM; 200m/pixel) [16]. Bulk-rock oxide compositions (FeO, TiO_2, SiO_2, MgO, Al_2O_3, and CaO) and trace element (Th) compositions are averaged from previously

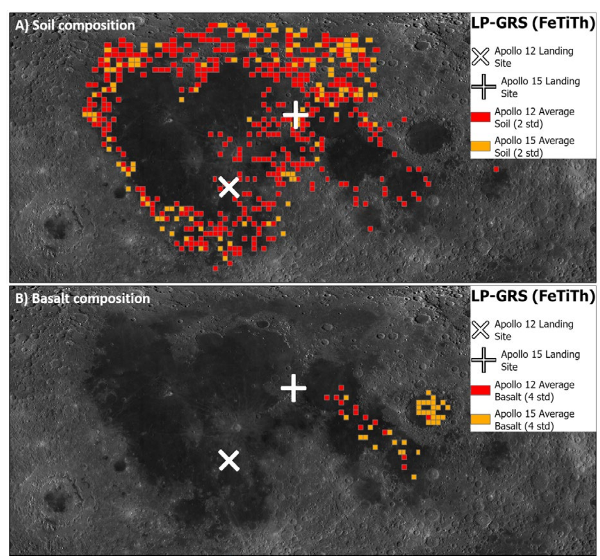

Figure 1: *Potential source regions for Apollo 12 and 15 samples using the LSP program compared to their respective landing sites (Apollo 12 = x; Apollo 15 = plus).* ***A)*** *Using average soil composition for Apollo 12 (red) and 15 (orange) to locate their respective source regions;* ***B)*** *Using average compositions of Apollo 12 and 15 basaltic samples.*

reported analytical analyses of the Apollo 12 and 15 soils, basalts, and NNL clan samples. The outputs files are shapefiles of matching surface compositions that lie within the given minimum and maximum for an individual sample composition. Each shapefile represents individual sample source coordinates that are further mapped in *ArcGISPro* over a LRO-Wide Angle Camera (WAC) global mosaic (Figs. 1,2).

Results & Discussion: Combining remote sensing observations with geochemical data to provide potential source location(s) for the meteorites can be a powerful tool to place the small-scale petrographic observations of samples into the larger scale petrogenetic scheme of the Moon. However, there are limitations when comparing small-scale sample analyses to large-scale orbital datasets [3] including the large-pixel sizes of the global datasets (e.g., 60 km^2) that represent regions with multiple lunar lithologies and mixing of the lunar surface through impact gardening, that affect the ability to unambiguously identify source locations [3].

To test the LSP program for finding potential source regions of small scale single lithological samples, such as lunar basaltic samples like the NNL clan, and better understand the limitations for each dataset, we performed two experiments: We used the Apollo 12 and 15 missions to map their respective source regions by using 1) average regolith or soil sample compositions which are more representative on a larger scale of the surface composition of their respective landing sites (Fig. 1a); and 2) Apollo 12 and 15 basaltic sample compositions that represent small scale sample locations within their respective landing sites (Fig. 1b). The LP-GRS mode of the LSP program was used in both cases.

We were able to identify the landing sites for each mission only when using the average regolith/soil sample compositions; using the small-scale basaltic samples of Apollo 12 and 15 the LPS program was not able to correctly identify their respective landing sites. This is most likely due to the large pixel to surface ratio of 60km/pixel for the LP-GRS dataset and indicates that interpreting potential source region(s) for single lithologies such as basaltic meteorites is more challenging using low resolution global datasets. The higher spatial resolution LRO-DOM [14] dataset uses only oxide compositions versus oxide and elemental compositions (i.e., Th, LP-GRS). Using the LRO-DOM mode of the LSP program produces a larger spread of potential sample source regions for basaltic samples within the near-side mare, including the respective landing sites of both Apollo 12 and Apollo 15 missions (Fig. 2). We are currently running the program using the even higher spatial resolution dataset of Chang'e-1 Interference Imaging Spectrometer (IIM; 200m/pixel) [16]. Results will be presented by the time of the conference.

Conclusion: Comparison of the two datasets (LRO-DOM and LP-GRS) shows that global trace element data as well as oxide data are an important constraint in refining sample source regions. Lower resolution global datasets, such as LP-GRS, could be used when trying to identify potential source regions for regolith breccia. Such meteorites represent the average composition of their source region, and thus, are more comparable to the lower resolution of the LP-GRS dataset. Higher spatial resolution datasets such as LRO-DOM and IIM are more useful in constraining potential source regions of single lunar lithologies, such as basaltic meteorite samples but result in a larger spread in potential source regions and thus, further constraining datasets might be needed. Future work will continue to expand the LSP program to include new orbital chemical datasets to better constrain the potential source region for basaltic lunar meteorites including the NNL clan.

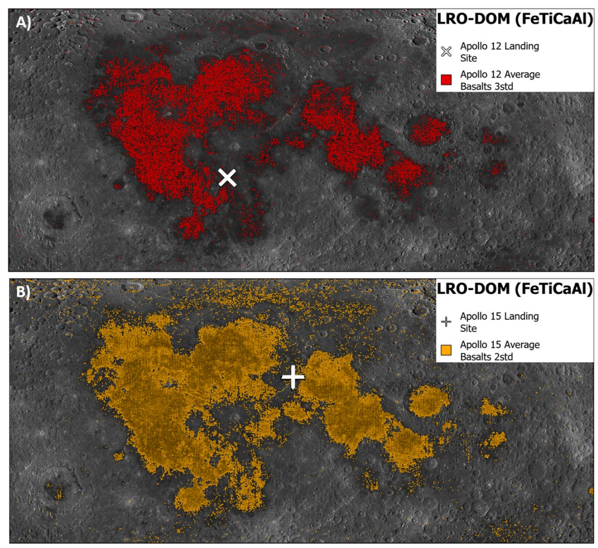

Figure 2: *Potential source regions for Apollo 12 and 15 samples compared to their respective landing sites (Apollo 12 = x; Apollo 15 = plus) using the LSP program in LRO-DOM mode.* ***A)*** *Using average basaltic compositions from Apollo 12 (red), and* ***B)*** *using average basaltic compositions from Apollo 15 (orange), to locate their respective source regions.*

References: [1] Vaniman et al. (1991) *Lunar Sourcebook, p*5-25. [2] Korotev (2005) *Geochem, 65,* 297-346. [3] Madera & Gross (2021) *52^{nd} LPSC*, Abstract #2686 [4] Calzada-Diaz et al. (2015) *MaPS, 50,* 214-228 [5] Korotev et al. (2015) *46^{th} LPSC*, Abstract #1195 [6] Fagan et al. (2018) *49^{th} LPSC*, Abstract #2568 [7] Korotev & Irving (2021) *MaPS, 56,* 206-240 [8] Korotev & Zeigler (2014) *35 Seasons of US Antarctic Meteorites, 68*, 101-130 [9] Elardo et al. (2014) *MaPS, 49,* 261-291 [10] Anand et al. (2006) *GCA, 70,* 246-264 [11] Nyquist et al. (2005) *LPS XXXVI,* Abstract #1374 [12] Fernandes et al. (2009) *MaPS, 44,* 805-821 [13] Prettyman et al. (2006) *JGR., 111* [14] Me et al., (2022) *Icarus, 371,* and [15] Lucey et al., (2021) *JGR:Planets, 126*. [16] Xia et al., (2019) *Icarus, 321*, 200-215.