# TRACE ELEMENTS IN LUNAR PLAGIOCLASE AS INDICATORS OF SOURCE LITHOLOGY.

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**Introduction:** Lunar meteorites [1] are sourced from random localities on the surface, and, thus, provide a global understanding of the geological diversity of the Moon, even though their precise provenance is unknown [2]. These important samples are, therefore, helping to shed new light on the heterogeneity and evolution of the lunar crust from regions of the Moon that were not sampled by the Apollo and Luna sample return missions.

Many lunar meteorites are breccias composed of small (<5 mm) fragments of different parent lithologies (Fig. 1) that are often too small to extract and analyse by traditional bulk compositional techniques. Therefore, *in situ* micro major, minor and trace element analysis of the minerals in these fragments (e.g., by electron microprobe (EMPA), secondary ion mass spectrometry (SIMS) and laser-ablation inductively coupled mass spectrometery (LA-ICP-MS)) is key to classifying these rock fragments in relation to Apollo rock suites, and providing information about their petrological evolution.

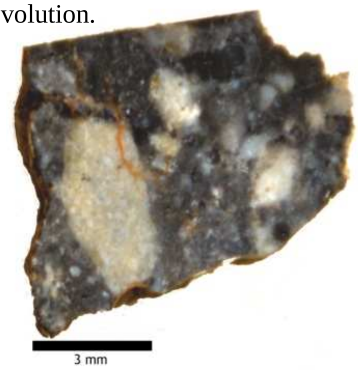

Figure 1. Scanned thick section of feldspathic regolith breccia lunar meteorite Dar al Gani (DaG) 400 [3]. Many small rock fragments (clasts) of impact melt breccias, anorthositic lithologies and mineral fragments are consolidated together in a fine grained glassy matrix.

**Samples and Methods:** We have compiled a database of literature lunar plagioclase compositions from pristine (i.e., non-impact derived, >3 mm crystal size) crustal rocks including ferroan anorthosites [4,5], Mg-Suite [6,7], and High-Alkali Suite [8], and also in volcanic mare basalts [9-11]. We focus on datasets where both major, minor and trace elements are reported.

We also collected our own major and trace element data of plagioclase in feldspathic lunar meteorites Dar al Gani (DaG) 400 (×3 analyses), Pecora Escarpment (PCA) 02007,34 (×5 analyses) and MacAlpine Hills (MAC) 88105,159 (×10 analyses) and in KREEPy regolith breccia North West Aftrica (NWA) 4472 (×5 analyses: see also [11]) using EMPA and LA-ICP-MS techniques (following the methods of [3, 9, 11]). Plagioclase were analysed as small monomineral fragments in the meteorite matrix (<0.5 mm in size), and in partially shocked anorthositic mm sized clasts. In all cases clast/phase sizes are too small to establish if the clast is pristine or not.

**Results:** Details of the usefulness of trace element analysis of lunar plagioclase is discussed below:

*Apollo rock suites:* It is well established that the relationship between mafic mineral Mg# (atomic Mg/Mg+Fe] and plagioclase An# (atomic Ca/[Ca+K+Na] or Ca/[Ca+Na]) in pristine samples compositionally define the major lunar crustal rock suites (Fig. 2a). We observe that abundances of Na (as a proxy for An#) and Eu/Sm in plagioclase phases also well replicate these trends between the FAN, High Mg-Suite and High Alkali Suite (Fig. 2b), indicating that plagioclase mineral chemistry alone can be used to compositionally characterise the sample's parent rock-type, without always needing mafic minerals to also be present (see also [13]).

*Feldspathic lunar meteorite plagioclase:* Feldspathic lunar meteorites (*e.g.*, see Fig. 1, [3]) provide the opportunity to investigate rocks from the inner and outer Feldspathic Highlands Terrane, offering new perspectives to the compositional diversity of the lunar primary feldspathic crust [14-21], and the history of its formation.

The bulk composition [14-15, 17-18], major element mineral composition [20], and isotopic diversity [21] of anothositic clasts and mineral fragments in lunar meteorites indicate hint at differences to the pristine Apollo FAN primary crust and High Mg-Suite secondary crustal suites. It has, thus, been suggested that this evidence may support the view that the anorthositic highlands may not have formed in a simplistic floatation magma ocean event, and that more complex geological processes (multiple magma oceans, serial magmatism, differentiated basin melt sheets?) may have been responsible for its evolution. However, it has also been argued [22] that small mm sized fragments in lunar meteorites likely do represent pristine lunar lithologies (i.e., often their petrographic context has been lost, including indication of true pristinity), and so it is unclear if clasts in lunar meteorites are truly representative of large scale lunar lithologies. We bear this point in mind, and seek to use trace element concentrations to, in the first instance, compare plagioclase data between Apollo and lunar meteorite samples.

We note that previous studies [13] have suggested that Sr measurements in plagioclase help classify mineral fragments with unknown parent heritage. However, plagioclase in hot desert lunar meteorites may contain small fractures on the scale of LA-ICP-MS or ion probe beam sizes (ten to tens of microns), which are infilled with terrestrially deposited Sr (and Ba) that may erroneously effect the determination of these elements, and reduce their usefulness in comparison with Apollo rocks. We, therefore, concentrate this study on elements that are not easily mobilised by terrestrial processes.

Trace element mineral chemistry data of plagioclase phases in feldspathic lunar meteorite DaG 400, PCA 02007 and MAC 88105 (Fig. 2a-d) indicate that these minerals were sourced from rocks compositionally distinct from Apollo anorthosite samples. They are, in terms of Na vs. Eu/Sm (Fig. 2b), intermediate to the FAN and High Mg-Suite, replicating trends observed by [20] for lunar meteorite mafic minerals and plagioclase compositions. In terms of Eu and Sm abundances alone (Fig. 2c and d), these plagioclases are unique from Apollo samples: they have lower Eu-abundances (i.e., larger Eu-anomalies), and marginally higher Sm concentrations than most FAN rocks, with the expectation of the Mafic Ferroan subgroup of FAN rocks [5]. Plagioclase in sample NWA 4472 are akin to High Mg-Suite and Alkali Suite plagioclase [12], consistent with this meteorites KREEP-rich nature.

**Conclusions and future work.** Trace element concentrations in lunar meteorite plagioclase are effective diagnostic tools at helping to classify feldspar mineral fragments in lunar samples with little or no petrolgraphic context [13]. We will use these datasets to further probe the evolution of the lunar crust.

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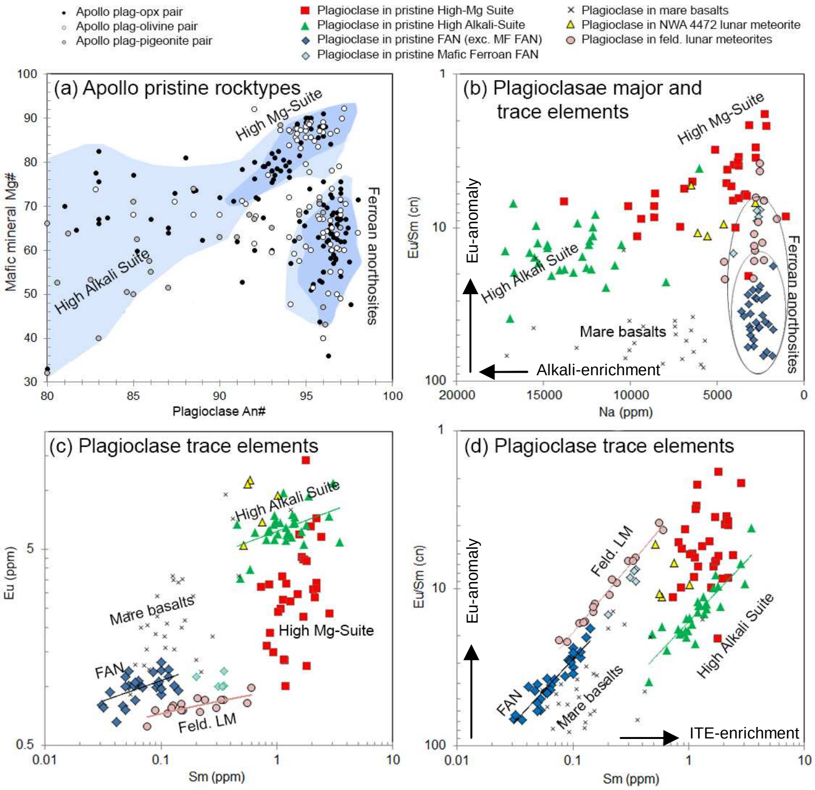

Figure 2. (a) Comparison of plagioclase (atomic Ca/Ca+Na) vs. mafic mineral (olivine, orthopyroxene and pigeonite) Mg# in pristine Apollo rocks [23]. The blue fields are taken from [24] and highlight the differences between rocks in the primary crust FAN suite and the secondary crust High-Mg and High Alkali Suite (see [24] for details). (b) Plagioclase phase Na concentrations vs. chondrite normalised (cn) Eu/Sm ratios in Apollo samples and lunar meteorites. Here the plagioclase mineral chemistry trends show similar rock suite relationships as shown in (a). In this diagram two fields are shown to highlight the extent of the FAN field. The inner field contains all FAN plagioclases except those in the mafic fan (MF FAN) sub-group, and the outer field includes samples from the MF FAN subgroup. (c) and (d) Log-log plots of plagioclase mineral compositional data where trace element Eu and Sm ratios and concentrations also help to characterise the different lunar rock suites. Power trends are fitted to the different rock suite data.