NEW INSIGHTS INTO THE COMPLEX HISTORY OF LUNAR HIGHLANDS: ALHA 81005 UNDER REINVESTIGATION

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Introduction: Lunar meteorites come from random sites on the Moon (including areas not visited by Apollo or Lunar missions) and so are crucial for understanding the development of the whole moon, and as ground truth for lunar remote sensing. Data from the Lunar Prospector and Clementine spacecraft show that, relative to the Apollo and Luna landing sites, most of the lunar surface has low abundances of FeO and incompatible elements [3; 4], with an average composition more like that of the feldspathic lunar meteorites [5]. We have started a re-investigation ALHA81005 to improve our understanding of unsampled areas of the Moon and enlarge our knowledge of lunar highland rock types and the Moon's early history.

Sample and Method: Antarctic meteorite Allan Hills A81005 is a ploymict, anorthositic regolith breccia from the lunar highlands [6,7]. Its clasts include granulites, FAN, mare basalts, impact melts, and impact glasses. Clasts described here were analyzed from the polished thin section ALHA81005,9.

Mineral analyses were performed using an electron microprobe (Cameca SX100) at NASA JSC. Operating conditions were 15kV accelerating voltage, 20nA, focused beam and a measuretime of 20-40s per element. Standards included well characterized natural and synthetic materials.

Lithic and Mineral Clasts: ALHA 81005 contains a wide range of rock and mineral fragments, most of which are granulites and anorthosites [13,7]. Other rock types are rare, and some mineral fragments must represent other lithologies.

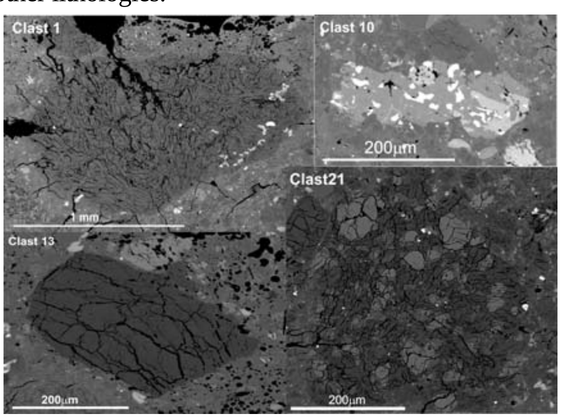

Figure 1: *BSE image of: a granulite clast (21); ferroan anorthosite clast (1); possible plutonic clast (13) and an unusual clast (10).*

Granulites: Granulitic lithologies are fine-grained equigranular rocks, typically ~60% plagioclase with olivine and pyroxene (Fig. 1). Some also contain a few spinel grains. They are inferred to be impact metamorphites [8], possibly compact ejecta or devitrified melts.

Granulite clasts are abundant in many feldspathic lunar meteorites and seem to be an important and widespread part of the lunar crust. Their chemical composition is consistent with remotely sensed data on the Farside Lunar Highlands Terrane [9].

Granulites in ALHA81005,9 have a wide range of Mg# (Mg/[Mg+Fe]) from hyperferroan to highly magnesian (Fig. 2 brown diamonds and triangles). The magnesian granulites are not related to and did not form from the Apollo Mg-suit rocks [1]. The formation of intermediate-Mg# granulites can not be explained from a simple mixing between the magnesian granulites and a single anorthosite composition [6].

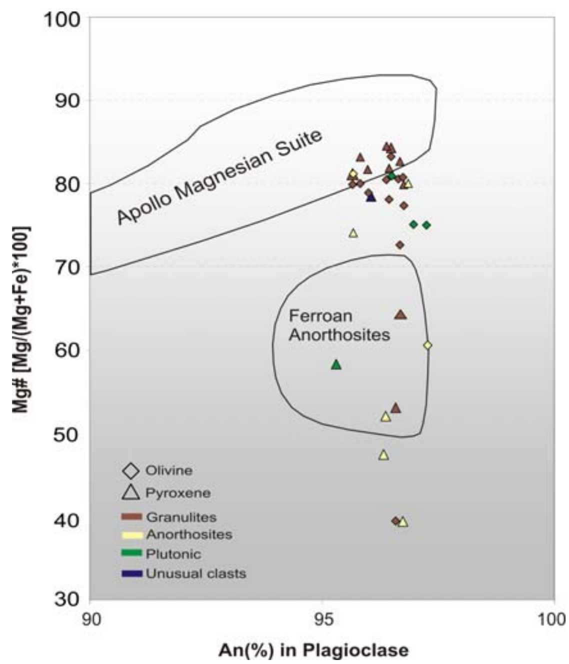

Figure 2: *An (anorthite) content of plagioclase and Mg# of co-existing mafic minerals for clasts in ALHA 81005,9.*

Ferroan granulites are known from the Apollo collection [10], and are probably related to ferroan anorthosites. We have found a clast of 'hyperferroan' granulite (Mg# = 39; Fig. 2), which may be related to the 'hyperferroan anorthosites' described by [7,14].

Anorthosites: Ferroan anorthosite (FAN) is a dominant rock type in the lunar highlands and is thought to be a product of the lunar magma ocean [e.g. 3,11-12]. Anorthosites are primarily composed of plagioclase with minor pyroxene and or olivine (Fig.1). The most abundant anorthosites (in the Apollo and Luna collections) have plagioclase of An_{94-97}, and mafic minerals (olivine & pyroxene) with Mg# of 50-70 (Fig. 2). Anorthosite clasts in ALHA 81005,9 fit the same plagioclase compositions but have a broader range in Mg# (Fig. 2): from highly magnesian (Mg# = 81) to hyperferroan (Mg# = 39). Such magnesian anorthosites are known from both the Apollo collection and lunar meteorites [15,16]; hyperferroan anorthosites are reported only from ALHA 81005 [14,7].

The Mg# of the plagioclase grains themselves appears to mirror the Mg# trend of assosiated mafic minerals [7]. For instance, plagioclase in hyperferron anorthosites have low Mg# of 0-20, while plagioclase in magnesium anorthosites have Mg# between 64-73. We are investigating this correlation and may be able to infer to the origin of plagioclase grains without any mafic minerals (as commonly found in meteorites like ALHA 81005).

Possible Plutonic Rocks: ALHA 81005,9 contains many isolated olivine and pyroxene fragments (Fig. 1) that have compositions unlike those of the granulites or anorthosites (Fig. 1) by having Mg# as high as 95. The existence of highly magnesian (93) olivine grain was first noticed by [14]. These grains attest the existence of magnesian protoliths [14] and could represent magnesian plutonic rocks, which are no longer preserved.

Exotic and Unusual Clasts: Some clasts in ALHA 81005,9 are outside the chemical, textural and mineral proportion range normally found in lunar materials. Among these clasts are: (1) a clast of olivine, pyroxene and glass with Mn/Fe ratios more like those of martian meteorties (Fig. 3); (2) a spinel-granulite clast (Cr-Al Spinel) with up to 30vol% spinel; (3) an olivine-pyroxene-FeS clast (Fig.1) with Ti-rich pyroxenes and (4) clasts rich in phosphates reported by [17].

Implications: The lithic and mineral clasts in ALHA 81005 have a wide range of mineral compositions, mineral proportion, and textures. This variety of fragments suggests that the meteorite formed in a complex area in the lunar highlands.

The abundant granulites range from magnesian to highly ferroan. Most are intermediate in composition but can not have formed as simple mixtures of magnesian granulites and FAN [6]. The highly magnesian olivine fragments suggest the presence of Mg-rich plutonic rocks, as magnesian or more than those of the Apollo Mg-Suite rocks; these could serve as a possible constituent of the granulites.

FAN are common in ALHA 81005, as are the unusual magnesian and hyperferroan anorthosites [7,14-16]. In fact, ALHA 81005 contains the widest range of anorthosite compositions of all lunar samples, and a larger range than the anorthosites of the Stillwater intrusion [18]. It is not clear if the anorthosites in ALHA 81005 are genetically related (formed from a single igneous body, e.g., magma ocean), or if they represent different sources and mechanisms of anorthosite formation (e.g., Stillwater vs. Nain).

The Fe/Mn ratios of rocks and minerals appear to follow planet-body specific trends and thus have been used as characteristic fingerprints of a sample's origin [19-21]. However, rocks from the Moon appear to fit several trends, not a single one. Karner [20] noted that olivines in mare basalts fell on two distinct trends, which were averaged by [19] to a single trend (Fig. 3). Olivines in anorthosite and granulite clasts in ALHA 81005 deviate from the average Mn-Fe trend (Fig. 3), and are close to the trend of high-Ti basalts [20] although none are rich in Ti. This variety of Mn-Fe trends is under study. It could suggest that the source regions of the samples (i.e., nearside vs. farside) have different compositions or oxidation states, and thus different geochemical histories.

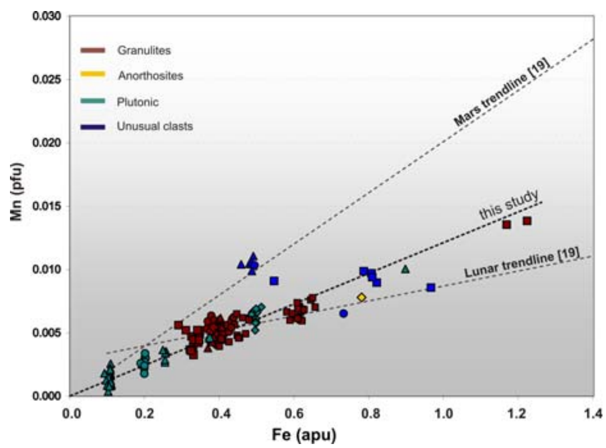

Figure 2: *Mn (pfu) vs. Fe (pfu) for olivines in ALHA81005,9.*

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