CRYSTALLIZATION CONDITIONS OF APOLLO 16 IMPACT MELTS. A. L. Fagan[1] and C. R. Neal[2], [1,2]Dept of Civil Engineering and Geological Sciences, University of Notre Dame, Notre Dame, IN, 46556, USA (abacasto@nd.edu; neal.1@nd.edu).

Introduction: Basaltic samples from the Apollo 16 mission are considered to be impact melts from the lunar highlands due to their high alumina and calcium contents (~25-28 wt% Al_2O_3; 14-17 wt% CaO), which is reflected in high modal abundances of plagioclase. We examine Apollo 16 sample 60635 (Fig. 1) in a study of crystallization conditions for these highlands impact melts. 60635 is a coarse-grained, subophitic impact melt with anorthite laths and interstitial pyroxene [1]. Olivine is absent, but traces of ulvöspinel, troilite, and K-feldspar have been identified [3].

This study uses crystal stratigraphy in order to understand the petrogenesis of this impact melt. It focuses on individual mineral chemistry analyses of plagioclase and pyroxene crystals.

Fig. 1: Cross-Polar image of sample 60635,2 with Pyroxene (teal) and Plagioclase (red=-Eu; green=+Eu) analysis points.

Methods:

Major Elements: Major element mineral analyses were conducted on plagioclase and pyroxene crystals using a JEOL JXA-8200 electron microprobe (EMP) at Washington University in St. Louis, MO with a 5 µm spot size and a 30s on-peak counting time.

Trace Elements: Calcium abundances obtained by EMP were used as the internal standard for laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) analyses to determine trace element abundances in both plagioclase and pyroxene crystals; NIST SRM 612 glass was used as the external standard for both phases. LA-ICP-MS analyses were conducted at the University of Notre Dame using a New Wave UP 213 laser ablation system and a ThermoFinnigan Element2 ICP-MS, with a repetition rate of 5 Hz and a corresponding fluence of ~17-18 J/cm^2. All pyroxene crystals were ablated using a 40 µm spot size, while spot sizes for plagioclase crystals ranged 40-65 µm depending on crystal size. Elemental abundances were determined using *GLITTER©* software.

Whole Rock Analysis: Previous studies [1-2] have conducted whole rock analyses on 60635 using Instrumental Neutron Activation Analysis (INAA) that defined a slight negative Eu anomaly in the REE profile (Fig. 2). Given the prevalence of plagioclase in the sample, it is rather surprising that the whole rock analyses do not show a strong *positive* Eu anomaly. We have acquired a 481 mg aliquot (60635,19) with which to run an additional whole-rock analysis using Solution Mode ICP-MS; this analysis will be conducted in the upcoming months.

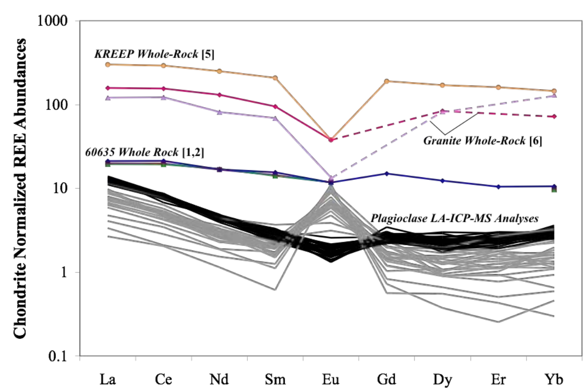

Fig. 2: REE abundances of plagioclase crystals from this study as well as 60635, KREEP, and granite whole rock analyses.

Results

Major Element Analysis: The average Anorthite content of the plagioclase crystals is 97.2% with a minimum of 94.4% and a maximum of 97.8%. Although some crystals display differences with regards to their trace element compositions, the major elements appear basically indistinguishable indicating crystallization from a relatively homogenous melt and/or cooling was slow enough to allow major element equilibration across crystals. Pyroxene crystals cluster as augite and pigeonite (MG#: 57.0-80.6, avg 69.4, Fig. 3).

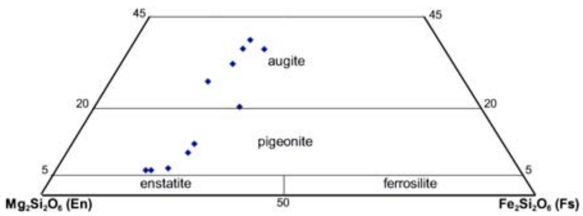

Fig. 3: Quad plot of pyroxene major elements.

Trace Element Analysis: Although lunar plagioclase REE profiles typically display a positive Eu anomaly, 20/24 crystals display a negative Eu anomaly for at least one datapoint (Fig. 2). Those datapoints with negative Eu anomalies are enriched in the light-REE and heavy- REE in comparison to the datapoints with more typical profiles. Pyroxene REE abundances span a wide range and the sub-parallel profiles are suggestive of closed system crystal fractionation (Fig. 4).

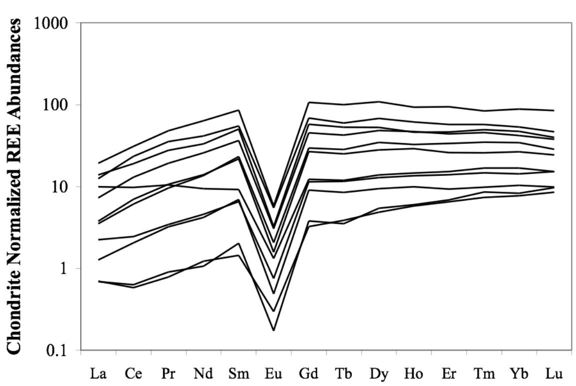

Fig. 4: REE abundances of 60635 pyroxenes.

Discussion: Plagioclase preferentially takes up Eu^{2+}, as it has the same charge and similar ionic radius as Ca^{2+}. Thus, in a REE profile we would expect to see a positive Eu anomaly rather than the negative one that is present in many of the crystals in this sample. Of particular interest is that a single crystal can contain both a negative and a positive Eu anomaly depending on the region analyzed; 9 plagioclase crystals have both positive and negative anomalies while 4 have only positive and 11 have only negative anomalies. Examination of individual crystals with cathodoluminescence does <u>not</u> suggest that crystals containing both anomalies are inherited and overgrown. In addition, it is possible to have a crystal with a negative Eu anomaly in the core and a positive anomaly at the rim or vice versa, which complicates any potential modeling.

Previous studies [1-2] have examined 60635 and the possibility that it has been influenced by KREEP; if this were true, the assimilation of KREEP may be used to explain the negative Eu anomaly as KREEP displays such a signature (Fig. 2). However, 60635 was found to be a highlands rock uncontaminated by KREEP due to differences in Rb-Sr isotopic work [1] as well as using whole rock Sm/Sc ratios [2], the latter being consistent with old, KREEP-free "Eastern" rocks [4]. As such, it appears that KREEP is not responsible for the negative Eu anomalies in the 60635 plagioclase crystals.

Another potential contaminant that could yield a negative Eu anomaly could be granite (Fig. 2). K-feldspar was identified in 60635 by [3], which could indicate the influence of granite.

Preliminary modeling of equilibrium liquids, based on the work of [7], indicates a magma with high heavy-REE abundances (Yb =445-7239 times chondrite) with the anomalous points having the highest abundances. However, the paucity of relevant Eu partition coefficients for plagioclase in the literature makes it difficult to model. Equilibrium liquids will be calculated for the pyroxenes in 60635 to determine if they have the same equilibrium liquid signature as the plagioclases.

It is possible that this sample was created via an impact into a mature regolith, generating water that would initially increase the fO_2 of the impact melt to push Eu^{2+} to Eu^{3+} thus making Eu incompatible in plagioclase. If correct, 60635 must have had a high fO_2 early on that subsequently dropped, as indicated by the presence of FeNi metal and troilite. However, generation of water to alter the Eu would only work with a small impact [8] and there does not appear to be any evidence of mature regolith now present at the Apollo 16 site [9]. The enigma presented by 60635 continues to be investigated.

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