PETROLOGY AND CHEMICAL COMPOSITION OF A SUITE OF APOLLO 16 IMPACT-MELT BRECCIAS **Jeremy N. Mitchell, Gregory A. Snyder, Lawrence A. Taylor, and Brian L. Beard,** Planetary Geosciences Institute, Department of Geological Sciences, University of Tennessee, Knoxville, TN 37966-1410.

Impact-melt breccias collected during the Apollo 16 mission provide important, albeit cryptic, information about the composition of the lunar highlands. We have studied the mineralogy, trace element composition [1], and Sr and Nd isotopic composition of a suite of nine previously undescribed impact-melt breccia samples. Compositions of plagioclase, olivine, and low-Ca pyroxene in clasts and the matrix of samples range from An_{70-97}, Fo_{62-95}, and XMg_{73-82}. Trace element compositions of a subset of samples are characterized by high Cr, Ni, K, Zr, Hf, and REE concentrations, with values typical for group 1 and 2 breccias [2, 3]. The isotopic composition of a group 1 sample is characterized by higher $^{87}Sr/^{86}Sr_{3.9\ Ga}$ and lower $\varepsilon_{Nd\ 3.9\ Ga}$ than group 2 and 3 breccias. The overlap of impact melt-breccia matrix and clast mineral compositions with samples of pristine highlands ferroan anorthosite and magnesian suite rocks suggests that the latter two are important components of the breccias. The high incompatible trace element concentrations of all samples and the presence of a relatively sodic plagioclase (An_{70}) fragment in one sample indicate contributions from KREEP-like material and possibly the alkali suite. Comparison between the isotopic composition of a group 1 breccia and Apollo 15 KREEP basalts indicates that the KREEP-like component present in breccias from the Apollo 16 vicinity is characterized by higher $^{87}Sr/^{86}Sr$ and lower ε_{Nd}.

MINERALOGY AND PETROGRAPHY. The petrography and mineral chemistry of the nine samples are described in the following section. **61225,5 -** microcrystalline to fine-grained intergranular matrix; plagioclase crystal fragments (An_{96}); clasts of brecciated anorthosite (An_{96}) and a troctolite (An_{92}; Fo_{76}); matrix of plagioclase (An_{95}), olivine (Fo_{76}), and pigeonite ($Wo_{19}En_{59}Fs_{22}$); FeNi metal occurs in trace amounts. **61249,6** - poikilitic matrix with oikocrystic pyroxenes ($Wo_5En_{74}Fs_{21}$) that enclose plagioclase chadacrysts (An_{94}); clast of olivine norite (An_{96}; Fo_{75}; $Wo_4En_{75}Fs_{21}$); plagioclase fragments (An_{93}); ilmenite, troilite, FeNi metal, and schreibersite in the matrix. **62245,10 -** poikilitic rock consisting of pigeonite oikocrysts ($Wo_{10}En_{71}Fs_{19}$) that surround plagioclase chadacrysts (An_{94}) and small olivine grains (Fo_{80}); plagioclase crystal fragments (An_{97}); opaque minerals include FeNi metal, troilite, and ilmenite. **64515,8** - poikilitic, with pigeonite oikocrysts ($Wo_{9-15}En_{66-71}Fs_{19}$) that contain plagioclase chadacrysts (An_{93}) and small olivine grains (Fo_{76}); crystal fragments of plagioclase (An_{95}) and olivine (Fo_{79}); FeNi metal, troilite, and schreibersite are also present. **65905,17** - fine-grained poikilitic matrix of plagioclase (An_{95}), low- and high-Ca pyroxene ($Wo_{4-27}En_{45-74}Fs_{22-27}$), and olivine ($Fo_{70}$); anorthosite fragment (An_{95}) and plagioclase crystal fragments; several pockets of ilmenite form poikilitic enclosures around euhedral (<100 mm) plagioclase crystals; other opaques are FeNi metal and schreibersite. **67487,8 -** intersertal texture with plagioclase microlites (An_{95}) in a matrix of mesostasis and fine-grained olivine, pyroxene, and opaques; leucotroctolite clast (An_{94}; Fo_{81}); crystal fragments of plagioclase (An_{97}) and olivine (Fo_{95}); one plagioclase fragment has three distinct compositional zones - An_{70} at the core, an intermediate An_{82} region, and a thin An_{93} rim (the outermost zone forms a complete rim around the fragment and possibly represents plagioclase growth on an old clast in impact-formed melt); ilmenite, FeNi metal, and troilite are also present. **67489,6** - microcrystalline matrix lacks the distinctive textures of many of the other samples; crystal fragments of plagioclase are numerous (An_{96}); granular lithic fragments of troctolite (An_{95}; Fo_{75}), olivine norite (An_{95}; Fo_{62}; $Wo_{4-14}En_{64-78}Fs_{18-22}$), and anorthosite ($An_{93}$); matrix mineral compositions are An_{94}, Fo_{80}, and $Wo_4En_{75}Fs_{21}$; opaque minerals include ilmenite, troilite, Cr-rich spinel, schreibersite, and FeNi metal. **68845,7** - intergranular, fine grained, plagioclase-rich matrix (An_{96}); evenly scattered plagioclase crystal fragments (An_{97}); one anorthosite fragment (An_{96}); mafic phases restricted to the matrix, where small grains (<0.05 mm) of olivine (Fo_{67}), pyroxene, troilite, FeNi metal, and ilmenite are present. **68846,5** - consists of plagioclase microlites (An_{95}) in a microcrystalline matrix (~Fo_{74} olivine and pyroxene); plagioclase crystal fragments (An_{96}); opaque minerals include FeNi metal and troilite.

GEOCHEMISTRY. The trace- and rare-earth element compositions of 61249, 62245, 64515, and 65905 were reported in [1]. Each of these samples are characterized by high Cr, Ni, K, Zr, Hf, and REE concentrations, with values typical for group 1 and 2 melt breccias [2]. The Sc and REE concentrations of samples 61249, 62245, and 64515 are consistent with group 2 breccias, whereas the even higher concentrations of these elements in 65905 suggest that it is from group 1 [1, 2, 3]. The chondrite-normalized REE patterns of these four samples are similar to patterns for their respective impact-melt breccia groups (Fig. 1). The three group 2 samples plot at the high end of the group 2 compositional range. The single group 1 sample plots at the high end of the group 1 compositional range. In general, increasing REE contents correspond with a larger negative Eu anomaly and an increase in K, Ba, Zr, and Hf concentrations. The substantial isotopic variability of impact-melt breccias is shown in Fig. 2. This diagram includes data from this study and [5]. The single group 1 rock (65905,8) plots at high $^{87}Sr/^{86}Sr_{3.9\ Ga}$ (0.70091) and low $\varepsilon_{Nd\ 3.9\ Ga}$ (-3.3). The group 2 rocks form a small trend from relatively low $^{87}Sr/^{86}Sr_{3.9}$ (0.69944) and high $\varepsilon_{Nd\ 3.9}$ (-0.2) to higher $^{87}Sr/^{86}Sr_{3.9}$ (0.69985) and lower $\varepsilon_{Nd\ 3.9}$ (-1.9).

DISCUSSION - Compositional Variations. The compositions of impact-melt breccias can provide important information on the average crustal composition of their respective regions. Anorthosite is certainly a component in these rocks, particularly samples from groups 3 and 4. The consistent problem with many breccia samples is that they are considerably richer in MgO than most well-documented highlands lithology. The range of plagioclase matrix and clast compositions in breccias falls within the fields for ferroan anorthosites and the magnesian suite. However, the majority of olivines and low-Ca pyroxenes in both the matrix and the clasts are more magnesian than ferroan anorthosites, suggesting a magnesian suite component. The core of the zoned plagioclase grain from 67487 has a composition that is similar to the lone Apollo 16 alkali suite sample for which there is mineral-chemical data [5], indicating a third possible component. It has been suggested numerous times that the samples with the highest REE contents, the group 1 breccias, have REE patterns that are virtually identical to Apollo 15 KREEP basalts [e.g. 6]. In Fig. 1, the dashed REE patterns were produced by mixing a ferroan anorthosite with low REE contents [7] and the most REE-rich Apollo 15 KREEPy basalt [8] in the percentages shown to the right of the patterns. These calculations demonstrate qualitatively that, assuming the same starting ferroan anorthosite composition, all impact melt breccias contain some amount of KREEP-like material. A factor that has not been assessed is that rocks of the alkali suite [9] and many samples from the magnesian suite [10] have very high REE contents and therefore may also have made an important contribution to the REE contents of the breccias.

Isotopic Evolution. Group 1 and 2 rocks form a trend that starts with group 2 samples that are intermediate between ferroan anorthosite [11] and Apollo 15 KREEP basalt fields [12,13]; this trend is directed down towards the group 1 sample at higher $^{87}Sr/^{86}Sr$ and lower ε_{Nd} (Fig. 2). Sample 65905 has the largest KREEP-like component of any Apollo 16 sample analyzed, yet it has an isotopic composition which is significantly different from Apollo 15 KREEP basalts. This suggests that the Apollo 16 KREEP-like component is characterized by relatively higher $^{87}Rb/^{86}Sr$ and lower $^{147}Sm/^{144}Nd$ compared to KREEP basalts, or that 65905 is significantly older than the group 2 rocks, or both. The age factor is shown in Fig 2, where we have calculated the composition of rock 65905 as if it was 300 million years older than the other samples. It still plots at lower ε_{Nd} than KREEP basalts, however, and there is no reason to believe that this sample is significantly older than the others. Thus, we feel that the unique isotopic characteristics of 65905 are a function of the isotopic composition of the KREEP-like component in the Apollo 16 vicinity.

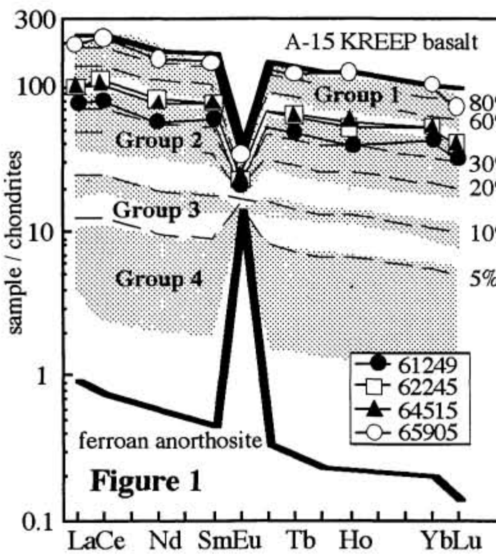

Figure 1

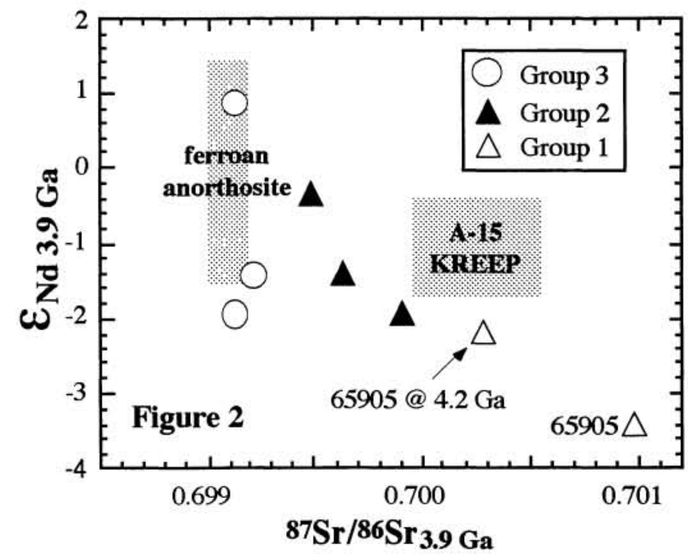

Figure 2

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