Non-basaltic fragments in the Apollo soil sample 12003

NON-BASALTIC FRAGMENTS IN THE APOLLO SOIL SAMPLE 12003. J. F. Snape[1,2,3], R. Burgess[4], K. H. Joy[1,4], L. Ruzie[4], and I. A. Crawford[1,5], [1]Centre for Planetary Sciences at UCL-Birkbeck, London, UK (j.snape@ucl.ac.uk). [2]Department of Earth Sciences, University College London, UK. [3]Planetary and Space Sciences, The Open University, Milton Keynes, U.K. [4]SEAES, University of Manchester, UK. [5]Department of Earth and Planetary Science, Birkbeck College, University of London, UK.

Introduction: As part of an investigation into basaltic diversity at the Apollo 12 landing site, multiple small (1-10 mm) rock fragments were selected from the regolith sample 12003 at Johnson Space Center for petrologic investigation and isotopic dating [1,2]. Among the particles selected were two breccias (12003,308_9 and ,308_10) and one fine grained impactite (12003,308_6). The details of these three non-basaltic lithologies will be discussed here.

Analytical Techniques: The fragments were split into A and B samples. The A samples were analysed with a JEOL JXA-8100 electron microprobe. Back scattered electron (BSE) images (Fig. 1), elemental maps and bulk sample composition were obtained with an accompanying Oxford Instruments EDS probe and INCA software package (see [1] for details). Major and minor element mineral chemistries were measured with an integrated WDS system. Minor and trace element mineral chemistries were determined by laser ablation ICP-MS (see [1,3] for details).

Ar-isotopes of the B samples were measured at the University of Manchester. Samples 12003,308_9B (3.0 mg) and ,308_10B (1.7 mg) were step heated using an IR laser and analysed using the MS1 noble gas mass spectrometer [4]. Two subsplits of sample 12003,308_6B with masses of 2.1 mg and 1.5 mg were analysed using a Thermo Argus VI multicollector mass spectrometer at the University of Manchester. Each temperature step was achieved by firing a CO_2 laser Data are corrected for background and system blanks.

Results:

Impactite (12003,308_6). This sample exhibits a fine grained (50-100 µm phase size) poikilitic-granoblastic [5] texture unlike any of the other 12003,308 samples (Fig. 1; [1]). It is composed of nearly equal amounts of plagioclase (50%) and pyroxene (47%), with minor amounts of ilmenite (2%) and the phosphate phase merrillite (<1%). Pyroxene includes discrete grains of both high-Ca ($Wo_{32-44}En_{41-46}Fs_{14-23}$) and low-Ca ($Wo_{2-6}En_{61-69}Fs_{28-35}$) types. Plagioclase and pyroxene have significantly higher concentrations of REE (up to ~100 ×CI abundances) than those found in any of the other 12003 basaltic samples.

The two subsplits of ,308_6B show similar shaped argon age spectra. The trapped $^{40}Ar/^{36}Ar$ ratio is 0.5, and the samples have low concentrations of solar implanted ^{36}Ar. Low apparent ages are obtained from argon released at low temperature indicate minor ^{40}Ar loss, this is followed by an age plateau at about 4.1 Ga corresponding to ~60% of the ^{39}Ar release. Finally, there is a decrease in apparent ages from argon released at high temperatures. This ^{40}Ar-^{39}Ar age pattern is characteristic of many lunar samples and is usually interpreted as resulting from ^{39}Ar recoil between K-richer (feldspar) and K-poorer (pyroxene) phases, the latter releasing argon at high temperature. For this reason we prefer to use an average 4.083±0.029 Ga (2σ weighted mean) of the summed ages (4.093±0.020 2σ and 4.073±0.020 2σ) for the age of 12003,308,6B.

Brecciated samples (12003,308_9; and _10). These samples are both composed predominantly of pyroxene (68%) and plagioclase (24-27%). Although both samples have similar modal mineralogies and bulk compositions, they exhibit very different textures (Fig. 1).

12003,308_9A is a clast-supported lithic breccia with a variable clast grainsize (~10-400 µm). The clasts include fragments of impact melt, crystalline igneous materials and individual large (>100 µm) mineral grains. The bulk argon age spectra of ,308_9B is disturbed at the low and high temperature steps and has a relatively high trapped $^{40}Ar/^{36}Ar$ value of ~5, implying surface regolith exposure and closure of the breccia by about 2.7 Ga (using the calibration of [3]). A mid-temperature plateau comprising ~70% of ^{39}Ar release has a corrected mean age of 3.299±0.016 Ga (2σ). The cosmic ray duration exposure age is 194.4±4.0 Ma, based on 83% release of the Ca-derived ^{37}Ar.

12003,308_10A is more coarsely grained (~0.1-1.0 mm) than ,308_9A and is composed of a less varied range of lithic fragments. A wide range of pyroxene compositions are observed throughout both samples ($Wo_{3-42}En_{1-66}Fs_{18-85}$). The argon spectra of ,308_10B is highly disturbed with a total gas release corrected age of 2.96±0.64 Ga (2σ). The sample has a trapped $^{40}Ar/^{36}Ar$ value of ~4.2, implying that it underwent surface regolith exposure and the breccia was closed by about 2.45 Ga (using the calibration of [3]).

Discussion: 12003,308_6A has a poikilitic-granoblastic texture similar to several granulitic impactites collected at the Apollo 17 landing site (e.g., 72559 and 78527 [5,6]) and in at least two lunar meteorite (e.g., Northwest Africa 3163 and Sayh al Uhaymir (SaU) 169 [7,8]). The sample has a relatively fine grain size (~50 µm) compared to its overall size (~1.6×1.4 mm). The modal mineralogy and bulk composition obtained are, therefore, considered to be representative of the parent rock from which the sample originated. It is more aluminous (Al_2O_3 = 16.7±0.1 wt%) than most of the 12003 samples (Al_2O_3 = 9.7±6.4 wt%) and significantly more aluminous than most of the materials collected by the Apollo 12 mission [1]. High REE contents in the plagioclase (between ~10-50 ×CI abundances) and clinopyroxene (~100 ×CI abundances) phases in this sample as well as the high modal abundance of merrillites imply that it has high concentrations of incompatible trace elements (i.e., KREEP).

This 4.1 Ga age impactite is ~1 Ga older than the mare basalt lava flows at the Apollo 12 landing site (3.2-2.3 Ga [9]), and has presumably been introduced to the area as impact ejecta from an older terrain. It is also older than several other Apollo 12 impact-melt breccia samples and SaU 169 (~3.9 Ga; [10]). These younger impactites are likely the products of the Imbrium basin formation. As such, ,308_6 and other, previously identified, older Apollo 12 impactites (e.g., 12013 and 12034; 3.9-4.4 Ga [11-15]) may represent the ejecta of older impact events into KREEPy lithologies. Alternatively, these older ages may be inherited from the parent lithologies that were reworked into the impactite sample, though as the sample does not have a significant younger reset age this seems unlikely.

The bulk composition of ,308_6A is similar to that obtained for the typical and high-Th impact melt breccias found at the Apollo 12 site, as well as the KREEPy meteorite SaU 169. Previous studies have attempted to identify the provenance of the KREEP component found at the Apollo 12 site [16-19]. These suggest the most likely sources to be the Copernicus, Reinhold or Lansberg craters [19]. However, these craters are younger than the Imbrium basin [19,20], making them an unlikely cause of the impact event that generated ,308_6.

The modal mineralogies and bulk compositions of the two brecciated samples (12003,308_9A and ,308_10A) are more similar to those of the Apollo 12 basaltic suites [1], indicating that they may both contain material from similar bedrock sources (e.g., low-Ti lava flows). The bulk composition of ,308_9A is closer to that of the typical Apollo 12 soil composition, whereas ,308_10A has lower concentrations of Al, K and Mg more similar to the Apollo 12 pigeonite and ilmenite basalts [1].

The ,308_9A chip contains a diverse range of materials from individual mineral grains, to clasts with textures typical of Apollo 12 basalts and others with impact melt-like textures. Its Ar-Ar age of 3.3 Ga is also similar to the ages of Apollo 12 mare basalts, suggesting that it is dominated by local Apollo 12 basaltic material. The ,308_10A chip is composed of a less varied range of materials which resemble some of the most coarsely grained pigeonite basalts (e.g., 12007 and 12039; [20,21]).

Acknowledgments: We thank Drs. Andrew Beard and Andrew Carter for their assistance with electron microprobe and laser ablation ICP-MS analyses, and Dr. John Cowpe for technical advice in Manchester.

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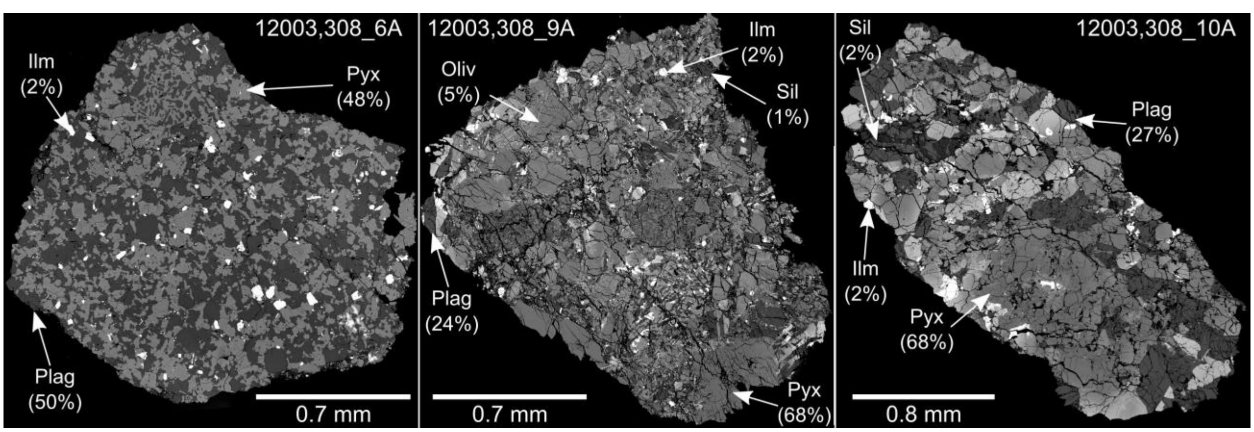

Figure 1 - Backscattered electron (BSE) images of the three 12003 "A" samples discussed here. Examples of main phases present and their modal mineralogies have been indicated.