Non-basaltic fragments in the Apollo soil sample 12003

J. F. Snape[1,2,3], K. H. Joy[2,4], L. Ruzie[4], R. Burgess[4] and I. A. Crawford[2,5]

[1]Planetary and Space Sciences, The Open University, Milton Keynes, MK7 6AA, UK. [2]CPS at UCL-Birkbeck, London, UK. [3]Department of Earth Sciences, University College London, UK. [4]SEAES, University of Manchester, Manchester, UK. [5]Department of Earth and Planetary Science, Birkbeck College, University of London, UK. (j.snape@ucl.ac.uk)

LPSC XLV, abstract 1974

CEPSAR research centre for physical and environmental sciences

The Open University

1. 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.

2. Methods

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.

3. Results

Impactite (12003,308_6). This sample exhibits a fine grained (50-100 µm phase size) poikilitic-granoblastic [5] texture (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 ($Wo_{2-6}En_{61-69}Fs_{28-35}$; Figs. 2-3) types. Plagioclase and pyroxene have significantly higher concentrations of REE (up to ~100 ×CI abundances) than those found other Apollo 12 basalts, more similar to those identified in Mg-suite samples (Fig. 3). Two subsplits of ,308_6B show similar shaped argon age spectra and have an average age of 4.08±0.03 Ga corresponding to ~60% of the ^{39}Ar gas release (2σ weighted mean; Fig. 4a).

Brecciated samples (12003,308_9; and _10). These samples are both composed predominantly of pyroxene (68%) and plagioclase (24-27%; Fig. 1). 12003,308_9A is a clast-supported polymict lithic breccia with a variable clast grainsize (~10-400 µm). 12003,308_10A is more coarsely grained (~0.1-1.0 mm) and composed of a less varied range of lithic fragments.

The bulk argon age spectra of ,308_9B is disturbed at the low and high temperature steps (Fig. 4b) 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 3.30±0.02 Ga (2σ). The cosmic ray duration exposure age is 194.4±4.0 Ma, based on 83% release of the Ca-derived ^{37}Ar. The argon spectra of ,308_10B is highly disturbed (Fig. 4c) 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]).

4. Discussion

The texture of 12003,308_6A is similar to several granulitic impactites collected at the Apollo 17 landing site (e.g., 72559 and 78527 [5,11]) and in at least two lunar meteorites (e.g., Sayh al Uhaymir (SaU) 169 and Northwest Africa 3163 [6,12]). The bulk composition of ,308_6A is also 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 (Fig. 5). 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).

12003,308_6A is older than several other Apollo 12 impact-melt breccia samples and SaU 169 (~3.9 Ga; [14]). 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 [15-19]) may represent the ejecta of older impact events into KREEPy lithologies.

The modal mineralogies, bulk compositions and mineral chemistries of the two brecciated samples (12003,308_9A and ,308_10A) are more similar to those of the Apollo 12 basaltic suites (Figs. 1-3,5), indicating that they may both contain material from similar bedrock sources (e.g., low-Ti lava flows). The ,308_9A Ar-Ar age of 3.3 Ga is also similar to the ages of Apollo 12 mare basalts.

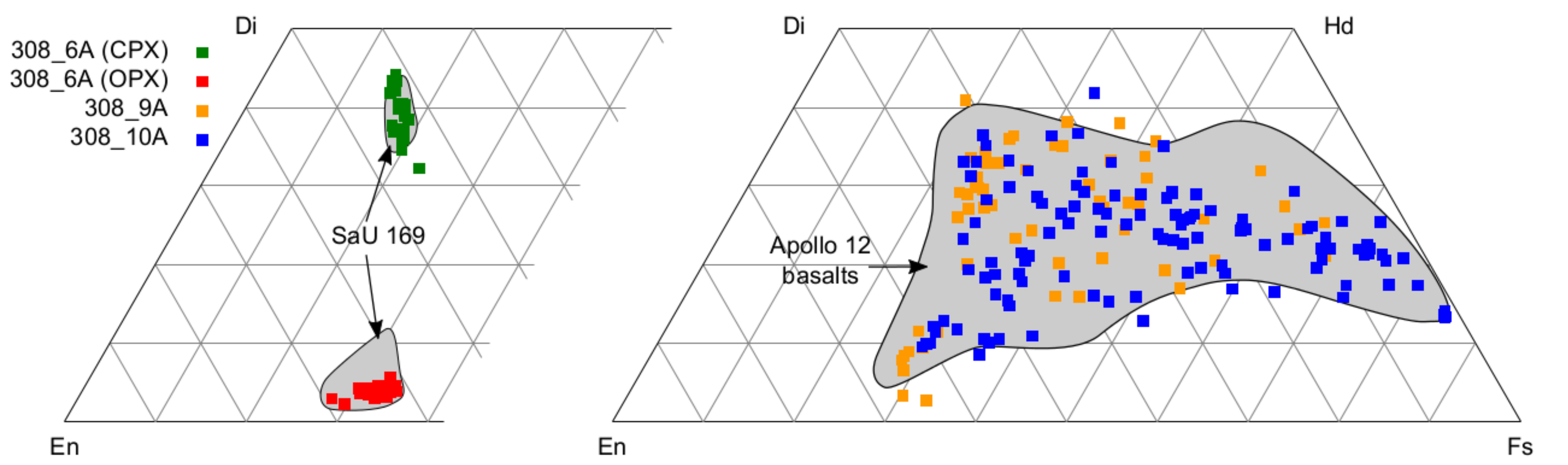

Figure 2: Pyroxene compositions within 12003,308_6A and 12003,308_9A and ,308_10A. 12003 data are compared with pyroxene analyses from the lunar meteorite SaU 169 [6] and Apollo 12 basalts ([1] and references therein). Di - diopside; Hd = hedenbergite; En = enstatite; Fs = ferrosilite.

References: [1] Snape J. F. (2012) UCL Doctoral Thesis http://discovery.ucl.ac.uk/1381931/. [2] Alexander L. et al. (2011) MAPS, 74, Abstract #5084. [3] Joy K. H. et al. (2011) GCA, 75, 2420-2452. [4] Burgess R. and Turner G. (1998) MAPS, 33, 921-935. [5] Cushing J. A. et al. (1999) MAPS, 34, 185-195. [6] Lin Y. et al. (2012) GCA, 85, 19-40. [7] Anders E. and Grevesse N. (1989) GCA, 53, 197-214. [8] Shearer C. K. (1989) GCA, 53, 1041-1054. [9] Papike J. J. et al. (1996) GCA, 60, 3967-3978. [10] Shervais J. W. and McGee J. J. (1999) Am. Min., 84, 806-820. [11] Nehru C. E. et al. (1978) LPS IX, 773-788. [12] Irving A. J. et al. (2006) LPS XXXVII, Abstract #1365. [13] Korotev R. L. et al. (2011) GCA, 75, 1540-1573. [14] Liu D. et al. (2012) EPSL, 319, 277-286. [15] Turner G. (1971) EPSL, 11, 169-191. [16] Tatsumoto M. et al. (1971) LPS II, 1521-1546. [17] Andersen C. A. and Hinthorne J. R. (1972) EPSL, 14, 195-200. [18] Lugmair G. W. and Carlson R. W. (1978) LPS IX, 689-704. [19] Zhang A.-C. et al. (2012) GCA, 95, 1-14.

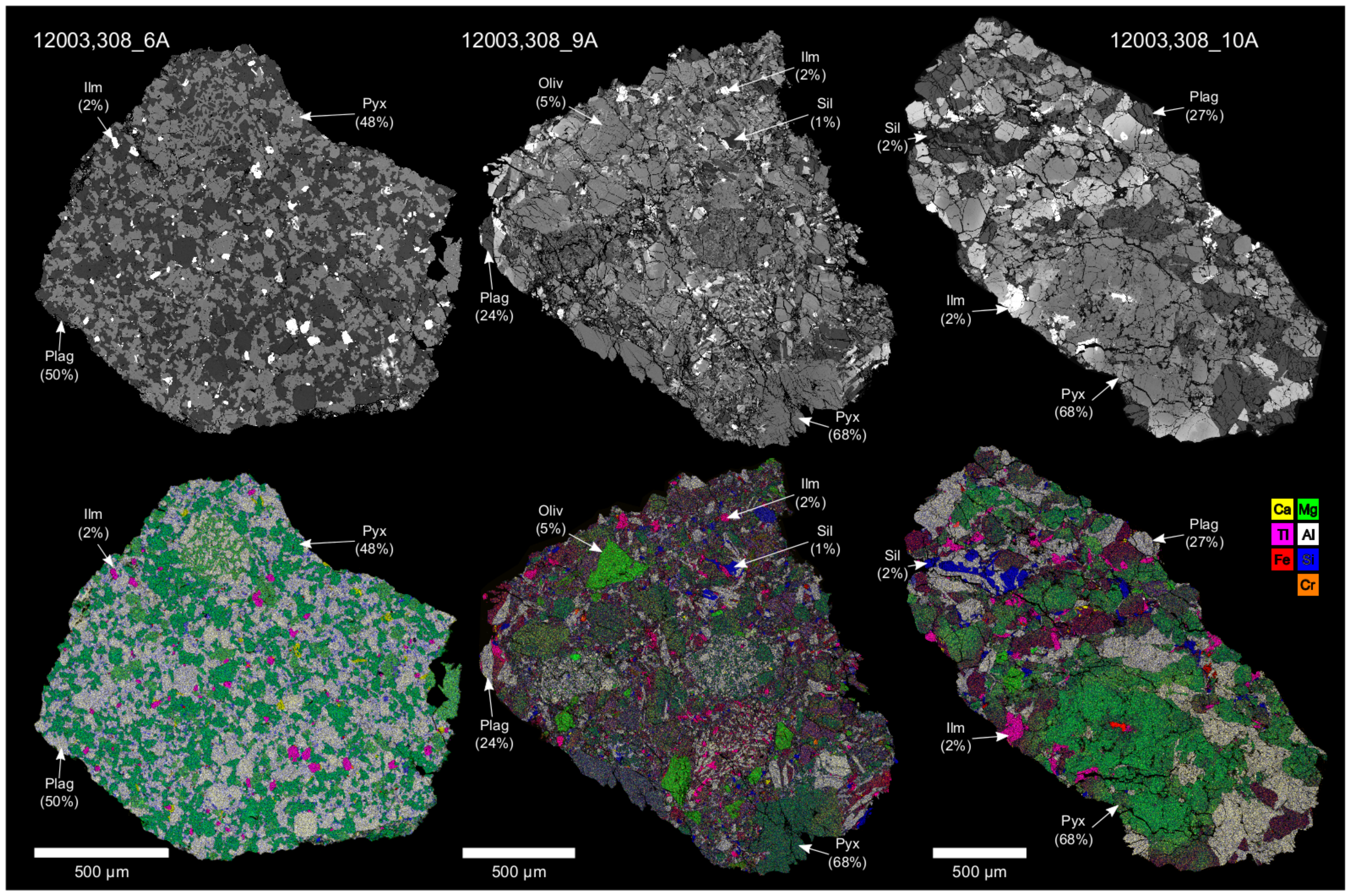

Figure 1: Backscattered electron (BSE) images (top) and false colour element maps (bottom) of the three 12003 "A" samples discussed here. Examples of main phases present and their modal mineralogies have been indicated. For the false colour element maps: Si = blue; Al = white; Mg = green; Fe = red; Ca = yellow; Ti = pink; Cr = orange.

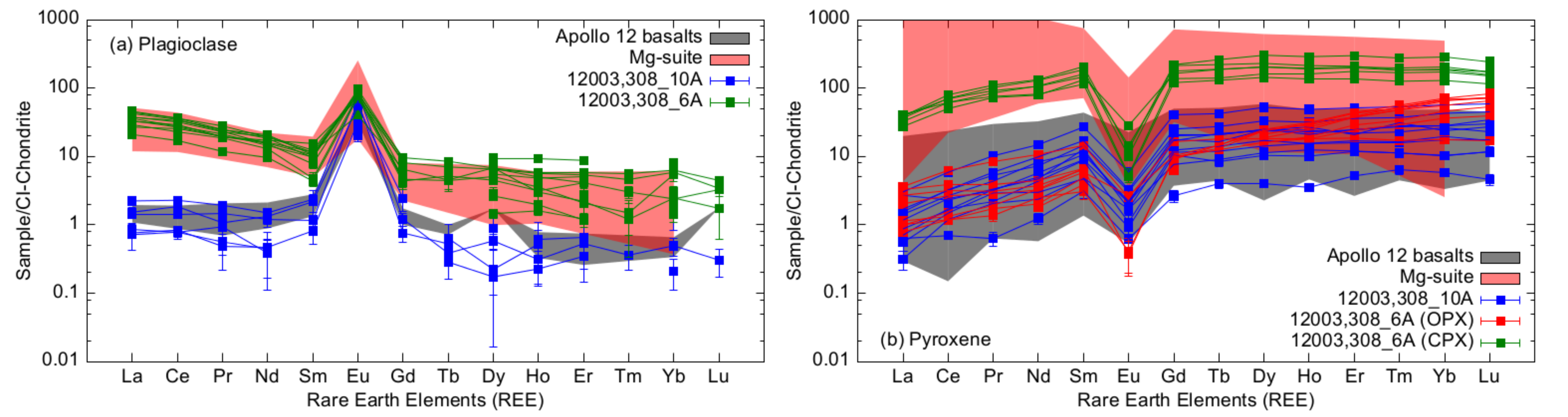

Figure 3: Chondrite normalised [7] REE patterns for (a) plagioclase and (b) pyroxene within ,308_6A and ,308_10A. Data are compared with those from other Apollo 12 basalts [8] and Mg-suite samples [9,10]. Error bars represent 1σ standard deviations.

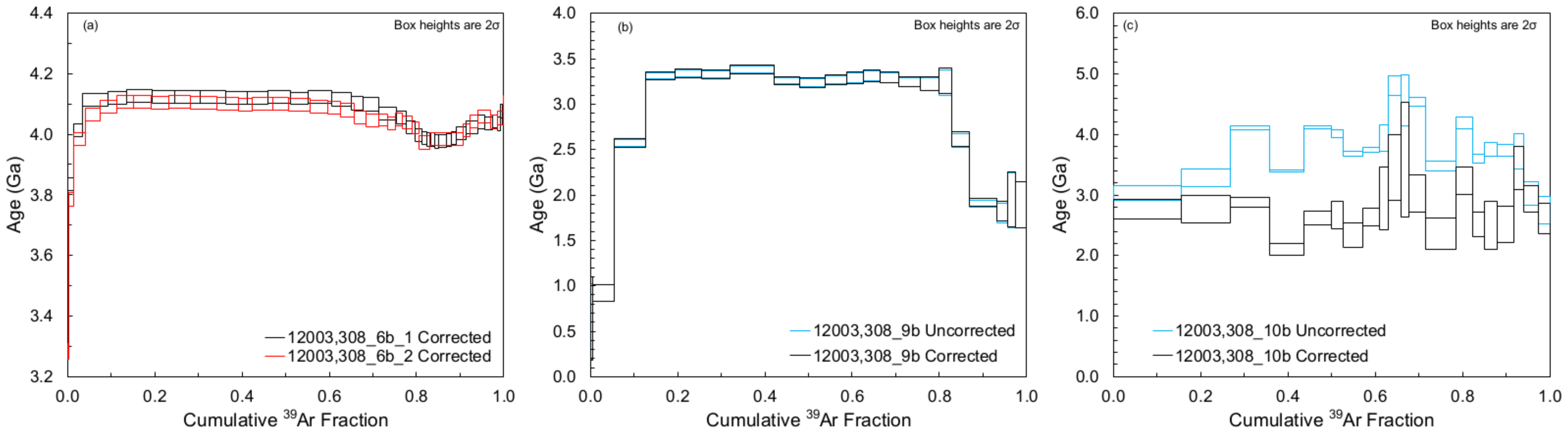

Figure 4: Cumulative ^{39}Ar release spectra for (a) two subsplits of 12003,308,6B, (b) 12003,308_9B, (c) 12003,308_10B. Uncorrected data for ,308_6B are not shown as they are very similar to the trapped argon corrected spectra. Note, there is good agreement between the two 12003,308_6B samples. Uncorrected and corrected data are shown for ,308_9B and ,308_10B (assuming a $^{40}Ar/^{36}Ar$ trapped ratio of 4.2 for ,308_9B and 5.0 for ,308_10B). Errors integrate the analytical errors and errors on J-value and monitors.

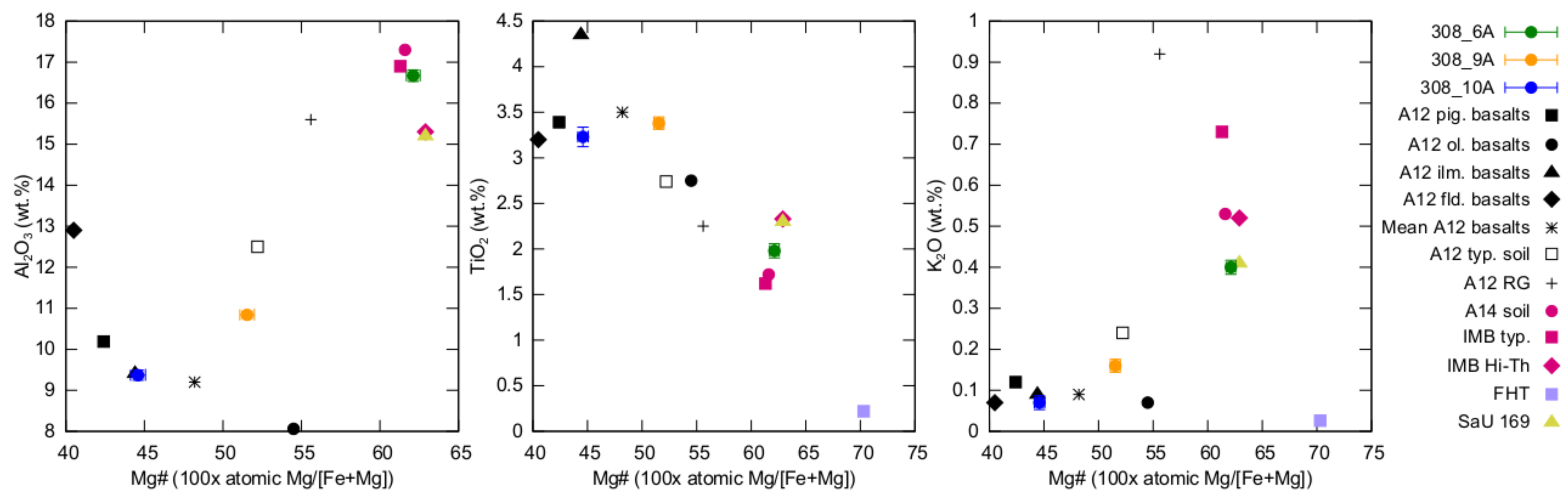

Figure 5: Bulk Mg# (100× atomic Mg/[Fe+Mg]) vs. Al_2O_3, TiO_2 and K_2O (wt%) for the 12003 samples. Data are compared with average values for Apollo 12 basalts, typical Apollo 12 soil, Apollo 12 ropy glass (RG), Apollo 14 soil, typical and high-Th impact melt breccias (IMB), feldspathic highland terrane (FHT) and the lunar meteorite Sayh al Uhaymir (SaU) 169 as calculated by [13] and references therein. Error bars on 12003 data represent 2σ standard deviations calculated from 10 repeat analyses of each sample.

UCL

Birkbeck UNIVERSITY OF LONDON

MANCHESTER 1824 The University of Manchester

CENTRE FOR PLANETARY SCIENCE