LUNAR REGOLITH BRECCIAS MET 01210, PCA 02007 AND DAG 400: THEIR IMPORTANCE IN UNDERSTANDING THE LUNAR SURFACE AND IMPLICATIONS FOR THE SCIENTIFIC ANALYSIS OF D-CIXS DATA. K. H. Joy[1, 2, 3], I. A. Crawford[1], S. S. Russell[2], B. Swinyard[3], B. Kellett[3] and M.Grande[3]. [1]The Joint UCL / Birkbeck Research School of Earth Sciences, Gower Street, London, WC1E 6BT, UK. [2]The Natural History Museum London, Cromwell Road, London, SW7 5BD, UK. [3]The Rutherford Appleton Laboratory, Chilton, Oxfordshire, OX11 0QX, UK. (K.Joy@ucl.ac.uk).

Introduction: Lunar regolith breccias provide direct samples of the complicated, highly mixed nature of the Moon's near-surface environment. By understanding their makeup it is hoped to be able to extrapolate to how large-scale remote-sensing datasets will detect geochemical information from a mixture of different lunar lithological terranes. Discussed here is an investigation into three lunar meteorite regolith breccias: Meteorite Hills 01210 (MET 01210), found in Antarctica in 2001; Pecora Escarpment 02007 (PCA 02007), found in Antarctica in 2002; and Dar al Gani 400 (DaG 400), found in the Libyan hot desert in 1998. We briefly consider the implications for interpreting data from D-CIXS, an innovative planetary X-ray spectrometer which is part of ESA's SMART-1 mission to the Moon [1,2,3].

Samples and Method: A polished thin section of PCA 02007 and two thin sections of MET 01210(21, 27) were kindly provided by the Meteorite Working Group. A polished thick section sample of DaG 400 was kindly loaned to the Natural History Museum London (NHM) by the Vatican Observatory Collection. Mineralogical analysis was done at the NHM using a WDS Cameca SX-50A and elemental mapping was achieved using a LEO 1455VP EDS SEM fitted with Oxford Instrument's INCA analysis software. Bulk rock geochemistry was determined for major, minor and trace elements using the NHM's ICP-AES and ICP-MS facilities. Trace element clast and mineral chemistry was determined by LA-ICP-MS. Analysis of D-CIXS data was performed using software developed at the Rutherford Appleton Laboratory (RAL) and D-CIXS team members [1].

Meteorite Analysis:

MET 01210: is a polymict regolith breccia [4] that is rich in mare basalt material (Fig. 1). It is therefore likely to represent regolith that was consolidated on the near-side of the Moon. It contains large mineral fragments (≤1mm) of pyroxene, plagioclase (heavily shocked), olivine and ilmenite, and clasts (≤4mm) of low-Ti mare basalt, feldspathic impact melt breccia, symplectites and feldspathic granulites (Mg-rich minerals). Both MET 01210 thin sections (21 and 27) have a vesicular fusion crust with melt similar in composition to the sample bulk rock chemistry (Table 1). Pyroxenes (Fig. 2a) fit within the range measured in Apollo and meteoritic low-Ti basalt samples [5], and zone to extreme evolved Fe-rich varieties. Olivines (Fo_{3-59}) are more fayalitic (Fig. 2c) and plagioclases (An_{86-96}) are more sodic in MET 01210 than in PCA 02007 and DaG 400 (Fig. 2b); suggesting source material that is more typical of basaltic terranes than of highland lithologies.

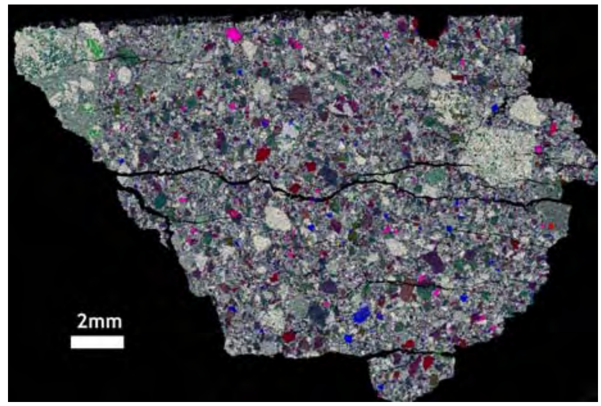

Fig. 1. Montaged elemental map of MET 01210(27). A specific colour scheme has been used to easily identity the elemental ratios in different minerals and clasts. Si = blue, Al = white, Mg = green, Fe = red, Ca = yellow and Ti = pink.

PCA 02007: is a finer-grained mixed polymict regolith breccia [6, 7] with a 'frothy' irregular fusion crust and several small (<20μm) glass beads. It is more mafic than most of the other lunar feldspathic meteorites [6] and yet has a similar bulk rock REE to DaG 400. It contains mostly feldspathic impact melt material with FAN clasts, cataclastic anorthosites, feldspathic breccia lithic clasts and granulites. A few small mare basalt clasts (see pyroxene compositions in Fig. 2a) and norite clasts are present, although they are often heavily shocked and/or partially remelted. Olivine compositions (Fig. 2c; mostly Fo_{63-83}), and Ca-rich plagioclases (An_{92-98}), indicate material of a more primitive/feldspathic nature than in MET 01210.

DaG 400: is an immature polymict regolith breccia [8,9 and 10] that is feldspathic (Table 1) with a high content of impact melt breccia clasts (52% of our sample; 20-500μm size fraction by mode). It is well-consolidated and many of the clasts have glassy rims that appear to merge into the sample matrix, indicating partial remelting by the pervasive shock process that welded the original regolith together. Lithic clasts (non-impact melt) include FAN varieties with anorthosites, gabbroic and noritic anorthosites and mafic-FAN clasts inlcuding anorthositic troctolites, norites and troctolites. Mineral compositions (Fig. 2) are generally more primitive than in MET 01210 and PCA 02007; pyroxenes: $En_{35-81}Fs_{8-50}Wo_{2-43}$, olivines mostly Fo_{68-86}; and plagioclases: mostly An_{99-90}. There is no evidence of mare basalt material in the section we have studied. Its feldspathic nature and bulk chemistry differ from Apollo 16 regolith breccia material (DaG 400 has a lower-Th content [Table 1], minimal/no mare material and a lower Mg/Fe ratio) suggesting that is may be a sample of the Moon's far-side highland material, and thus an important sample of typical FAN crustal material[10].

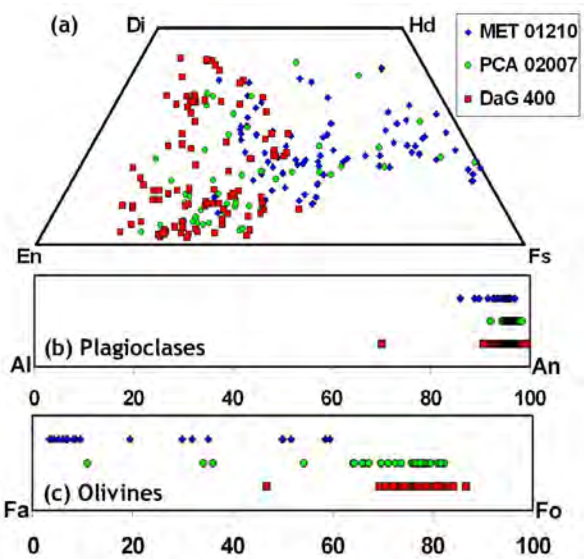

Fig. 2. Comparison of (a) pyroxene compositions, (b) the anorthite content of plagioclases and (c) the forsterite content of olivines in the three meteorites.

Remote Sensing Implications: Using the three lunar meteorite's bulk chemistry as a broad guide to chemical variations between different geochemical terranes on the lunar surface (mare, mixed and highland), we can start to use these (and other relevant) lunar rock samples to help to calibrate data taken by D-CIXS from lunar orbit [3]. By using theoretical models generated to predict the D-CIXS spectra from given absolute elemental weight% (converted from data in Table 1), we can predict the spectra that we would expect to see from our known regolith compositions, at different solar flare conditions, energy resolutions and viewing geometries (Fig. 3).

Conclusions: Our understanding of remotely sensed datasets like that of D-CIXS will be greatly helped by understanding the variability and geochemistry of lunar rock samples such as those provided by lunar meteorites. Remote sensing provides a Moon-wide view of geochemical variations that in return, can be useful for mapping lithological diversity of the lunar surface and understanding the planetary scale of lunar evolution.

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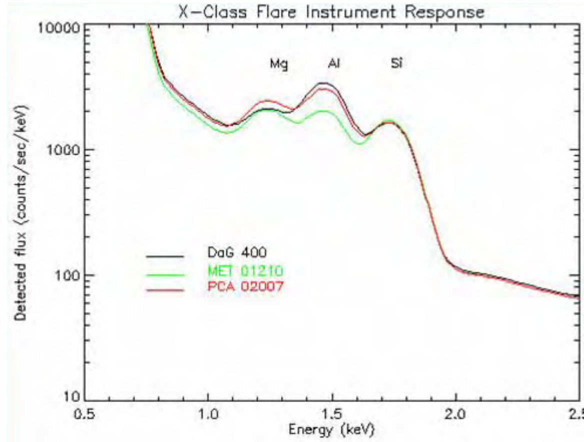

Fig. 3. D-CIXS predictive spectra showing a comparison of the theoretical low-elemental line energies generated from the bulk chemical compositions of MET 01210 (Green), PCA 02007 (Red) and DaG 400 (black). MET 01210, the most mafic of the three meteorites has a noticeably lower Al-energy peak than the two more feldspathic samples. The model was run for a nominal energy resolution of 180eV, and assuming an X-class solar flare.

Wt.%	MET01210	PCA02007	DAG400
SiO_2	44.03	43.41	41.42
Al_2O_3	16.60	25.71	27.76
FeO	16.46	6.30	3.61
MgO	6.20	6.80	4.84
CaO	12.96	15.19	17.24
Na_2O	0.32	0.36	0.39
K_2O	0.06	0.03	0.08
TiO_2	1.55	0.28	0.17
P_2O_5	0.05	0.03	0.42
MnO	0.22	0.09	0.07
Total	98.44	98.20	95.99
Mg #	37.69	63.41	68.24

ppm	MET	PCA	DaG	ppm	MET	PCA	DaG
Cr	1881	1168	527	**La**	6.69	2.52	3.52
Ba	81	70	1203	**Ce**	13.8	6.21	7.62
Zr	103	58	40	**Pr**	2.12	0.888	1.07
Co	32	27	15	**Nd**	10.7	4.19	4.85
Cu	23	11	16	**Sm**	3.58	1.22	1.33
Li	8	4	6	**Eu**	1.11	0.880	1.02
Ni	212	324	143	**Gd**	4.54	1.44	1.48
Sc	56	13	7	**Tb**	0.905	0.287	0.266
Rb	1.34	0.588	0.882	**Dy**	5.85	1.81	1.62
Sr	163	144	451	**Ho**	1.26	0.393	0.342
V	60	32	18	**Er**	3.63	1.16	1.00
Y	37	11	10	**Tm**	0.532	0.164	0.141
Zn	37	17	5	**Yb**	3.54	1.11	0.903
Be	1.72	0.257	0.294	**Lu**	0.519	0.164	0.129
Cs	0.089	0.047	0.022				
Ga	19.1	3.14	3.66	**U**	0.321	0.107	0.472
Hf	2.37	0.83	0.691	**Th**	0.855	0.370	0.393
Mo	12.8	0.413	0.945				
Nb	1.07	2.64	2.26				
Pb	0.551	0.835	1.35				
Ta	0.103	0.176	0.195				
Tl	0.009	0.051	0.105				

Table 1. Bulk Chemistry of MET 01210, PCA 02207 and DaG 400 as measured by ICP-AES and ICP-MS. Results are shown in oxide Wt. % for the major elements and ppm for minors and traces.

References: [1] Grande et al. (2006) LPSC 37, this volume. [2]Dunkin et al. (2003) PSS, Vol. 51. pp. 435-442. [3] Grande et al. (2006) PSS *in review.* [4] Arai et al. (2005) LPSC 36, abstract# 2361. [5] Heiken et al. (1991) The Lunar Sourcebook, *Cambridge Uni. Press.* [6] Zeigler et al. (2004) LPSC, 35, abstract# 1978. [7] Taylor et al. (2004) LPSC 35, abstract# 1755. [8] Cahill et al. (2004) MAPS, Vol. 39. pp 503-530. [9] Zipfel et al. (1998) MAPS 33. abstract# A171 [10] Warren et al. (2005) MAPS, Vol. 40. pp 989-1014.