DETERMINING THE REGOLITH HISTORIES OF LUNAR METEORITES. N. M. Curran[1], K. H. Joy[1], and R. Burgess[1]. [1]School of Earth, Atmospheric and Environmental Sciences, University of Manchester, Oxford Road, Manchester, M13 9PL, UK (natalie.curran@manchester.ac.uk).

Overview: We have selected twelve lunar meteorites to determine their cosmic ray exposure age and regolith history. Our goal is to assess the impact flux at the lunar surface through time. The maturity of the regolith in different lunar rock types will be analysed and then compared to the data from Apollo samples. Our sample suite includes samples of feldspathic highland breccias, mare basalts and mixed feldspathic-basaltic breccias.

Cosmic Ray Exposure Ages and Regolith Maturity: Cosmogenic isotopes are produced during the interaction of both galactic and solar cosmic rays with surfaced exposed regolith material. The exposure age is defined as the duration the regolith has been exposed to cosmic rays. This calculation requires the production rates for each cosmogenic nuclide to be known and depends on the depth and chemistry of the target rock [1, 2]. Also, it is known from Apollo and Luna soils that, when at the immediate surface (top few mm of the regolith), direct implantation of solar wind results in the maturation of the lunar soil [3]. Both the solar wind content and the exposure age of a sample can be measured to understand the history of the rock during its lifetime in the lunar regolith. The regolith, therefore, contains a wealth of knowledge regarding the types of processes that have helped to modify the lunar crust through time and preserves a record of the Solar System environment [4, 5, 6]. Understanding this temporal archive is vital for probing the crustal evolution of the Moon.

Lunar Meteorite Regolith Record: Lunar regolith meteorites are ejected from random localities across the Moon, by asteroidal and cometary impacts [7, 8]. All lunar meteorites have experienced some exposure to cosmic rays, either while in the top few meters of the lunar surface (2π irradiation), during transit to Earth (4π irradiation) or both [7, 9].

Many of these meteorites are regolith breccias, which are fragmental rocks containing regolith components including agglutinates, glass spherules and impact melts. Often these rocks were closed to further surface modification processes at the time they were assembled from a soil into a rock (closure age) [10]. These meteorites are sourced from a number of geological terrains including the lunar farside and polar regions [7]. As such, they provide a more complete record of the global diversity of the lunar crust, compared with Apollo and Luna samples [11].

Apollo Regolith Record: Regolith breccias collected at different Apollo landing site have different exposure histories and closure ages. For Example, the most ancient regolith breccias collected at Apollo 16 have closure ages of >3.5 Ga and are classed as immature, with exposure ages of only a few million years [12]. Younger regolith breccias typically exhibit greater degrees of maturity and implanted solar wind [6,12]. The difference in maturity between the young and ancient breccias is associated with the impact flux and turnover rate of the regolith. Low maturity of the ancient breccias has been linked to rapid overturn in a megaregolith by basin and large-scale crater formation prior to 3.5 Ga [6, 12]. The submature to mature young regolith breccias have been reprocessed over a longer periods of time by less energetic impacts and micrometeorite bombardment during a 'gardening' processes.

We seek to understand if lunar meteorites display the same or a similar link between their closure age and their maturity.

Analytical Procedure: Cosmogenic noble gas isotopes will be measured in each meteorite using a VG5400 mass spectrometer, coupled to a resistance filament furnace. We will analyse both powders and solid chips of the samples (<1-10 mg). Data will be used to determine (i) the cosmic ray exposure age, (ii) the shielding depth, (iii) the closure age and (iv) the surface exposure (maturity) of each meteorite.

To determine the geological context of each meteorite and to test their consistency with their reported bulk rock chemistry, we have assessed the petrography and mineral chemistry of polished blocks made from sub-splits of each sample (~3-6 mg). We used a Phillips FEG-SEM with EDAX Genesis EDS system to produce back-scatter electron images and false colour element maps (Fig. 1) and a Cameca SX 100 EMPA to determine mineral chemistry.

Sample Petrography and Mineral Chemistry Results: So far, we have analysed 5 meteorites from our study suite:

MET 01210,38: MET is a polymict anorthosite-bearing basaltic regolith breccia containing coarse and fine grained basaltic fragments (up to 1 mm), symplectites, granulites and clast free/poor/rich impact melts. Mineral fragments (up to 200 μm) are mainly plagioclase, pyroxene, olivine and ilmenite (Fig. 1a). Extensive zoning from Mg-rich cores to Fe-rich rims occurs in some pyroxene grains (Fig. 2a). Minor apatite (~100 μm) and K-feldspar (~100 μm) are also present. Basaltic clasts in MET have olivine (Fo_{9-14}), plagioclase (An_{94-96}) and pyroxene ($En_{11-46}Wo_{14-36}Fs_{32-71}$).

MIL 05035,34: MIL is a crystalline gabbro. Mineral fragments are coarser than MET containing mostly pyroxene (3-6 mm), plagioclase (2-4 mm) and areas of symplectites and ilmenite (<1 mm). Compositions of these minerals have been reported previously [13, 14] where olivine are Fo_{1-11}, plagioclase are An_{76-95} and pyroxene are $En_{2-68}Wo_{13-43}Fs_{29-68}$ (Fig. 2).

EET 96008,70: EET is a basaltic breccia with mineral fragments of pyroxene ($En_{37-62}Wo_{7-37}Fs_{21-49}$), plagioclase ($An_{96-97}$) and olivine ($Fo_{29-51}$) (Fig. 2). Minor Ti-bearing oxides and phosphate-bearing phases are also present. Major bulk chemistry, trace element and rare-earth element content of EET are reported to be similar to very low Ti basalts of the Apollo suite which is supported by the composition of pyroxenes in our sample [15].

MAC 88105,175: MAC is an anorthositic regolith breccia dominated by feldspathic clast-bearing and clast-free impact melt breccias (up to 1 mm). Granulites and some minor isolated mineral fragments (up to 100 μm) are present, including fragments of plagioclase (An_{97-98}), pyroxene ($En_{31-56}Wo_{10-42}Fs_{20-48}$) and olivine ($Fo_{58-64}$) (Fig. 2).

ALH 81005,99: ALH is a polymict anorthositic regolith breccia containing clasts up to 0.5 mm (Fig. 1b). Clasts are basaltic, feldspathic clast-bearing and clast-poor impact melts, and coarse and fine-grained granulites. These are held in a shock-welded glassy matrix. Minerals within clasts and the matrix include plagioclase (An_{94-98}), pyroxene ($En_{44-79}Wo_{1-41}Fs_{7-47}$) and olivine ($Fo_{45-90}$) (Fig. 2), with minor Ti-bearing oxides.

Summary: Sample petrology and mineral chemistry for the meteorites analysed here are consistent with previous studies of these meteorites [13-18]. We are, therefore, confident that the reported literature bulk compositions of these meteorites can be used to calculate the cosmogenic nuclide production rates for our exposure age calculations.

Future Work: Understanding the impact flux and regolith maturity at different times in lunar history can provide an archive of regolith processes through time. We hypothesise that ancient breccias (those with older closure ages) will generally be more immature than younger regolith breccias as seen in the maturity vs. closure ages of Apollo 15 and 16 regolith breccia samples [6, 12]. The initial results of our noble gas studies will be presented here. Our new lunar meteorite exposure age calculation will be added to the current growing data-set from lunar meteorites to provide new constraints on the global context of the lunar regolith and crust, as well as confirming source pairing relationships between meteorites.

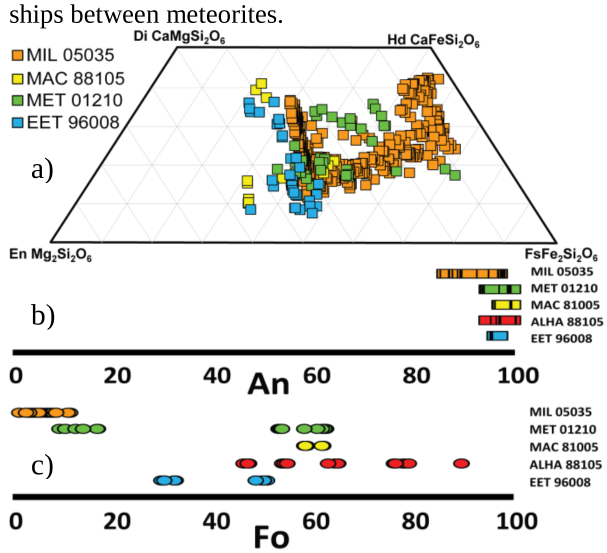

Figure 2: Summary of compositions of minerals in lunar meteorites: MIL 05035, MET 01210, MAC 81005, ALHA 88105 and EET 96008. a) Pyroxene are plotted on a pyroxene quadrilateral. b) An number (atomic 100 × Ca / Ca+K+Na) in plagioclase. c) Fo number (atomic 100 × Mg/Mg+Fe) in olivine.

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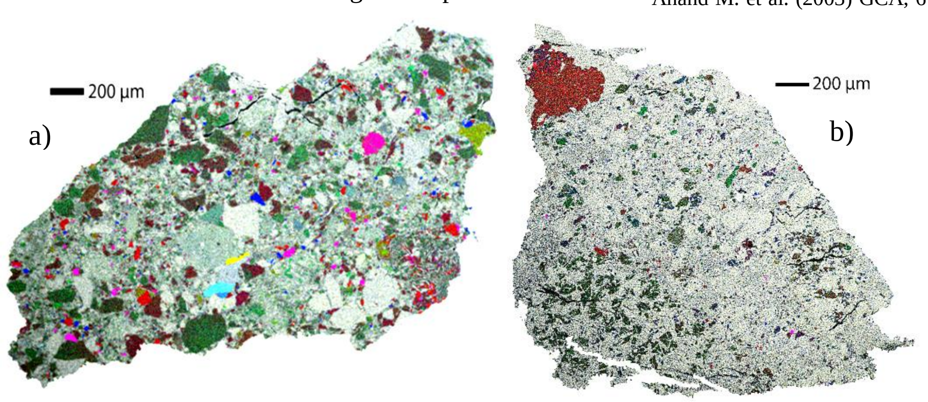

Figure 1: Petrographic and compositional characterisation of a) MET 01210,38 and b) EET 96008,50: two of the lunar meteorites under study. Maps have been colour-coded to show chemical variation with mineral association: in this colour scheme Ca = yellow, Mg = green, Si = blue, Fe = red, Al = white, Ti = pink and K = cyan.