GLOBAL DIVERSITY OF THE LUNAR CRUST: SCIENCE AND CHALLENGES OF LUNAR SAMPLE RETURN. K. H. Joy[1], J. Gross[2], T. Arai[3], S. A. Russell[4] [1]School of Earth, Atmospheric and Environmental Sciences, University of Manchester, Oxford Road, Manchester, M13 9PL, UK, [2]The American Museum of Natural History, Dept. of Earth and Planetary Sciences, New York, NY 10024, USA, [3]Planetary Exploration Research Centre, Chiba Institute of Technology, Japan, [4]The Natural History Museum, Cromwell Road, London SW7 5BD, UK (katherine.joy@manchester.ac.uk).

Introduction: The lunar crust preserves an archive of planetary differentiation and early evolution, which is not easily accessible on other rocky planetary bodies.

Early history of the Moon: After its formation, the Moon had a well-mixed global lunar magma ocean (LMO) that initially crystallised at equilibrium [1-3]. This first phases precipitated were Mg-rich mafic minerals that, after ~50% total crystallisation, sank to form the lunar deep mantle [4-6]. The final stages of LMO formation were likely controlled by fractional crystallisation of a constantly changing and instantaneously homogenous residual magma [5]. After about 80% of LMO crystallisation, plagioclase was precipitated and floated to form a primary crust made of ferroan anorthosites [2-5]. In the classic LMO model all the plagioclase solidified would have originated from a chemically homogenous parent melt.

After the lunar highlands crust was formed, the lunar interior was still hot and partially melted. These melts intruded the crust and a formd suite of magmatic rocks (Mg-Suite and High Alkali Suite) and extrusive lava flows (KREEP basalts, high-Al basalts).

New insights from Apollo samples: Isotopic and chemical studies create complexities for FAN origin as primary crust formed from the primordial LMO. For example, variation in εNd values [7-8] and REE [9] suggest that FANs originated from a range source regions. Additionally some FANs have younger ages (~4.2 Ga [8]), that overlap with Magnesian Suite and High Alkali Suite intrusive magmatic rocks, suggesting that they formed through a similar period of lunar history.

New insights from lunar meteorites: Lunar meteorites are sourced from random localities on the surface and, thus, provide a global understanding of the geological diversity of the Moon, although their precise provenance is unknown [10,11]. Major element mineral compositions of anorthositic material in feldspathic lunar meteorites [12-14] do not fit well with the fields of Apollo highland rock suites [15]. Notably, anorthositic clasts in lunar meteorites are often more magnesian than their Apollo equivalents, suggesting unique parent melts [12-14]. Plagioclase mineral chemistry trace element data provide further evidence for compositional differences between the lunar nearside highlands, as sampled by Apollo 15 and 16 [9,16], and regions remote sampled by the lunar meteorites [17-19].

These critical observations potentially present complications for the proposed formation mechanisms of the lunar crust, and may support the view that the anorthositic highlands may have formed from different parent melts (e.g., asymmetric crystallisation or multiple magma oceans, serial magmatism, differentiated impact melt sheets [13]).

However, lunar meteorites are typically highly impact processed, and deconvolving the chemical and physical effects of impact from primordial signatures is a challenge [20]. It is unclear if all clasts in lunar meteorites are representative of large-scale lunar lithologies as their petrographic context has often been lost, including indication of true pristinity.

Sample return opportunities: Future exploration of the lunar surface [21] should seek to test models of lunar crust formation (e.g., [13, 22]). Any regolith / core drill samples returned from the lunar surface will likely contain small fragments of ancient crust, providing key insights to the chemical and chronological history of lunar differentiation. Direct sampling of crust within the farside Feldspathic Highlands Terrane will provide direct access of material with known geological context, helping to test models of crust formation [22]. It would be highly desirable to directly sample outcrops of pure anorthosite layers to compare their isotopic and petrological evolution compared with nearside FANs [23-25]. However, many of these sites are located in potentially technologically challenging landing sites (e.g., steep slopes, mountains), so roving capabilities from safer landing sites to collect material would enable bedrock sample access. Sampling floor materials in the South Pole-Aitken basin will help to investigate the products of differentiated impact melt ponds [22, 26], helping to test impact modification crust formation models.

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