LUNAR METEORITES: NEW INSIGHTS INTO THE GEOLOGICAL HISTORY OF THE MOON

K. H. Joy[1] (katherine.joy@manchester.ac.uk), N. A. Curran[1], J. F. Pernet-Fisher[1], T. Arai[2]. [1]SEAES, University of Manchester, Manchester, UK. [2]Planetary Exploration Research Center, Chiba Institute of Technology, Chiba, Japan.

Overview. Studies of lunar meteorites have brought unique insights to the Moon in time and space, helping us to better understand lunar lithological diversity and geological history [1,2].

Understanding the global compositional diversity of the lunar surface. Rock and mineral fragments within lunar meteorite regolith breccias have revealed new types of lunar lithologies, and the existence of new minerals providing insights into the diversity of magmatic [3] and space weathering processes [4] across the Moon. Importantly, the compositions of lunar meteorite regolith breccia have been used to calibrate remote sensing geochemical datasets, providing a more accurate global perspective of the chemical diversity of the lunar surface [5].

Understanding the formation of the ancient lunar primary crust. Feldspathic lunar meteorites have provided the first samples from the Feldspathic Highlands Terrane on the farside of the Moon, offering new perspectives to the compositional diversity of the lunar primary crust [6-8] and the history of its formation [8, 9]. Recent studies of anorthositic material in feldspathic lunar meteorites [6-8, 10] further indicate that it is possible that the crust may not have formed in a simplistic single magma ocean floatation event, and that more complex geological processes may account for crustal compositional heterogeneity [8-10]. This debate is controversial because of the small sample sizes of rock fragments in lunar meteorites [9, 11], however, as additional samples are investigated with innovative geochemical and isotopic techniques, together with studies of high-spatial-resolution remote sensing data, new ideas are emerging about the diversity and evolution of the lunar crust.

Understanding the diversity and timing of mantle melting, and secondary crust formation. Basaltic lunar meteorites are compositionally more diverse than Apollo and Luna samples, with many very-low-Ti (VLT <1 wt% TiO_2) and intermediate TiO_2 (6-10 wt% TiO_2) types found as small rock fragments in brecciated meteorites [12]. These offer new insights to the heterogeneity of the lunar mantle in regions both within and outside of the nearside PKT.

Basaltic lunar meteorites have also provided new insights about the temporal history of mare basalt eruption. Apollo mare basalts were typically erupted between 3.2 and 3.8 Ga, whereby older basalts have higher-Ti contents relative to the younger low-Ti basalts. In contrast, basaltic lunar meteorites represent both the youngest 2.93 Ga (NWA 032: [13]) and the oldest 4.35 Ga (Kalahari 009 [14]) sampled mare basalt lava flows. The lunar meteorites show no relationship between age and bulk rock Ti-composition [2], suggesting that the Apollo mare basalt dataset age-Ti correlation was an artefact of site sampling, and that secular melting in the lunar mantle is not coupled to the Ti-chemistry of the mare basalt source regions.

Understanding the impact bombardment history of the Moon and the inner Solar System. Lunar meteorite impact ages [15] and regolith breccia antiquity records provide a vital insight into studying the lunar cratering record and impact flux in regions distal to the Imbrium basin-forming event, which likely dominates the Apollo rock records. Lunar meteorite impact age data show no noticeable spikes prior to 4.2 Ga that would be consistent with ancient widespread basin formation caused by early Solar System accretionary debris [16]. Instead, like the Apollo samples, they show an enhanced late bombardment episode (peaking at ~3.7 Ga). However, this enhanced record appears to have a longer duration than witnessed by the Apollo samples and may reflect sampling of smaller and/or more localised impact cratering episodes [17]. In addition, regolith breccias with different formation ages offer temporal snapshots of regolith processing of the lunar highlands [18].

Future perspectives: The number of lunar meteorites is growing each year. Laboratory chemical, mineralogical, isotopic and chronological analysis of these samples has revealed important similarities and differences to samples in the Apollo and Luna sample collection, helping to test and constrain key models of the Moon's geological evolution and its archive of impact bombardment in the inner Solar System [1, 2].

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