THE MOON AS AN ARCHIVE OF SMALL BODY MIGRATION IN THE SOLAR SYSTEM.

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Overview: Constraining the sources and temporal flux of impactors delivered to the Moon helps to address key questions about the causes of impact bombardment in the inner Solar System [1-7]. Some evidence for the lunar impact record comes from surface morphology and geophysical characteristics of craters and basins (e.g., the number, size, and relative ages of structures [1,2]). Additional information is preserved in the lunar sample collection, recording the timing of impact events (i.e., isotopic resetting of rocks and impact melt crystallisation events [3]) and evidence of the sources of the projectile populations [4-7].

The impact melt breccia and igneous rock archive: Chemical signatures of material accreting to the lunar crust and mantle have been identified from the budgets of highly siderophile elements (HSEs) and volatile elements in impact melt [5,6] and endogenous igneous samples [8-10]. HSE analyses of different lunar impact melt breccias imply that projectiles in the basin-forming epoch (~3.8-4.2 Ga) originated from primitive asteroids (i.e., ordinary and carbonaceous chondritic), differentiated asteroids (i.e., iron meteorite sampled from planetary embryo cores), and bodies that are compositionally dissimilar from those that we find in the current meteorite collection [5,6].

The regolith archive: The lunar regolith is a time capsule of small body migration in the Solar System.

Chemical signatures: Nitrogen isotope analysis of lunar soils and agglutinates indicate a common exogenously contributed ‘planetary’ chemical component in the lunar regolith [11]. Inorganic gas release measurements have shown that some soils have exogenously implanted volatile elements from cometary or carbonaceous chondrite impactors [12]. HSE chemistry of mature lunar regoliths suggest an addition of between ~1.6 to ~3.4 % primitive CI/CM-like chondritic meteorite material during space exposure intervals of tens to hundreds of millions of years [13,14]. It is important to note that this regolith ‘meteoritic component’ is a chemical signature, originating from the contribution of vaporised impactor material bound up in microscale metals and sulphides within comminuted impact melt breccias and glassy agglutinate structures.

Projectile debris: Survivability of projectiles to the Moon’s surface is facilitated by low impacting velocities (<10 km/s) and by oblique (<10°) impact angles [15]. Examples of surviving projectile debris have been located in soils and regolith breccias, where impactor types include iron meteorites, chondrule fragment debris, carbonaceous chondrite silicate mineral debris, and an enstatite chondrite (see [7] for a review). All these fragments are very small (i.e., a few microns to few mm) and *to date* no cometary silicate debris has been directly identified in lunar regolith samples.

Constraining timing of projectile delivery to the regolith: Constraining regolith ages can be challenging, but it is critical for understanding the temporal variation of sources of small bodies delivered to the Moon [7,16]. The duration of a regolith’s space exposure can be determined by measuring abundances of cosmogenic nuclides, however, this does not tell us *when* in the past that exposure occurred. Regolith antiquity records are preserved in fused regolith breccias collected as hand specimens and rock fragments in the lunar soil [16]. Most accurate temporal records are likely preserved in trapped (ancient) palaeoregolith horizons found sandwiched between layers of radiometrically datable geological units, examples of which are now being identified from orbit using ground penetrating radar techniques or high-resolution images of layered bedrock exposures [17].

Conclusions: In the last decade new and improved analytical techniques have facilitated both the detection and characterisation of impactor species in Apollo samples and lunar meteorites [5-13,16]. New exploration methods should consider identification and the characterisation of impactor debris in different lunar terrains [17], as they may be associated with deposits that have a resource potential. Coupling these datasets with temporal constraints on impactor delivery will help to provide better geochemical and chronological constraints for models of Solar System dynamics, as well as identify the causes of impact spikes to the Earth-Moon system through time [1,4-7,16,17].

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