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Early Solar System Records Preserved in Lunar Palaeoregolith Deposits

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Abstract

One of the principal scientific reasons for wanting to resume *in situ* exploration of the lunar surface is to access the record it contains of early Solar System history [1-3]. We argue that this record will be best preserved in ancient, buried regolith ('palaeoregolith') deposits, and that locating and sampling such deposits would be an important objective of future lunar exploration activities.

1. The Lunar Record

Studies of Apollo samples have revealed that solar wind particles are efficiently implanted in the lunar regolith, which may therefore contain a record of the composition and evolution of the Sun [4,5]. In addition, samples of Earth's early atmosphere may also be found in lunar regolith [6], as well as samples of Earth's early crust in the form of terrestrial meteorites [7]. In addition, the regolith has been discovered to contain fragments of ancient asteroid populations that can inform our knowledge of early Solar System processes [8].

Moreover, the lunar regolith may contain a record of galactic events, by preserving the signatures of ancient galactic cosmic ray (GCR) fluxes (deriving from the production of stable and radioactive nuclides, and tracks of radiation damage within crystal lattices [4,9]), and the possible accumulation of interstellar dust particles during passages of the Sun through dense interstellar clouds. All these records would potentially yield valuable astronomical information concerning the evolution of the Sun and its changing galactic environment, with implications for the conditions under which life arose and evolved on Earth.

2. Palaeoregoliths

The present surficial regolith has been subject to comminution and overturning by meteorite impacts for the last three to four billion years, and the record it contains is therefore an average over most of solar system history. From the point of view of accessing ancient records of solar system and galactic history, it will be most desirable to find ancient regoliths (*palaeoregoliths*) which have been undisturbed since formation.

2.1 Formation

A regolith forms when a fresh lunar surface is exposed to the flux of micrometeorites. Most exposed mare surfaces date from between about 3.8 to 3.1 Ga, with small-scale, geographically restricted volcanism continuing to perhaps as recently as 1 Ga. For example, the study by Hiesinger et al. [10] reveals a patchwork of discrete lava flow units in Oceanus Procellarum with individual ages ranging from about 3.5 to 1.2 Ga. As younger lava flows are superimposed on older ones, we may expect to find layers of palaeoregoliths sandwiched between lava flows dating from within this age range. Support for the existence of such palaeoregolith layers is provided by results from the Kaguya radar sounder [11] and high-resolution LROC images (e.g. [12,13]). The archival value of palaeoregoliths will be enhanced by the fact that the under- and overlying basalt layers will lend themselves to radiometric dating, thereby defining the age of the geological record sandwiched between them.

2.2 Preserving a Record

A worthwhile geochemical record will only be preserved within a palaeoregolith layer if it survives the thermal consequences of burial by the initially molten overlying lava flow. In previous work [14,15] we have shown that, for lava flows ranging from 1 to 10 m thickness, implanted solar wind particles should be preserved in palaeoregoliths at depths of greater than 0.2 to 2 m beneath an overlying lava flow, depending on the thickness of the latter and the molecular species of interest. Given estimated regolith accumulation rates [16], individual lava flows would have to remain exposed for tens to hundreds of Ma to accumulate regoliths in this thickness range. The ages of basalt surfaces mapped by Hiesinger et al. [10] indicate that this not unreasonable. GCR records, meteoritic debris, and geochemical evidence for interstellar dust particles, will presumably be more robust against thermal disruption, and thus potentially preserved in shallower palaeoregolith deposits.

3. Conclusions

Lunar palaeoregolith deposits potentially contain important records of the evolution of the Sun, and its galactic environment, throughout most of solar system history. Sampling such palaeoregolith deposits would be an important objective of future lunar exploration [1,2,17].

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