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Astronomical and Astrobiological 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]. Much of this record is astronomical in nature, some of it with clear astrobiological implications. 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. Introduction

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]. Recently, samples of the Earth's early atmosphere appear to have been retrieved from lunar regolith samples [6], and it has been suggested that samples of Earth's early crust may also be preserved there, in the form of terrestrial meteorites [7,8]. In addition to these local Solar System records, 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 astrobiological implications for the conditions under which life arose and evolved on Earth.

2. The Lunar Astronomical Record

Key astronomical events and processes which may be preserved in the lunar regolith, and which have astrobiological implications in that they may have influenced the astronomical conditions under which life arose and evolved on Earth (and possibly elsewhere in the Solar System), include:

- The strength of the early solar wind, and by extension the initial main-sequence mass of the Sun. Thus would test the suggestion that the so-called 'faint young Sun paradox', and the presence of liquid water on the surfaces of both early Earth and early Mars, could be explained by an initial solar mass several percent higher than its present mass [10,11].
- The variation of the GCR rate as a function of the Sun's position above and below the galactic plane, and its possible consequences for biological evolution on Earth [12]
- Occurrences of nearby supernova explosions, and their possible biological consequences.
- Passage(s) of the Solar System through dense interstellar clouds, with the attendant collapse of the heliosphere [13,14]. Such events will result in both enhanced GCR fluxes, and possible accretion of interstellar material onto exposed planetary surfaces (such as the lunar regolith). If remnants of the latter could be identified in lunar regolith deposits they would provide samples of dense interstellar cloud material not otherwise available for study (and perhaps help test models of interstellar panspermia [15]).

We note that, since the lunar geological record began, the Sun has revolved around the Galaxy approximately 20 times, so the lunar surface will have been exposed to a wide range of galactic environments. The only question is how well will such records have been preserved, and whether we will be able to access them.

3. 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.

3.1 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 [16]. For example, the study by Hiesinger et al. [16] 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 [17]. 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.

3.2 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 [18] 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 0.1 to 1 m beneath an overlying lava flow, depending on the thickness of the latter. Given estimated regolith accumulation rates [19], individual lava flows would have to remain exposed for between 20 and 200 Ma to accumulate regoliths in this thickness range. The ages of individual basalt flows mapped by Hiesinger et al. [10] indicate that this is likely to have been a common occurrence. GCR records, and geochemical evidence for interstellar dust particles, will presumably be more robust against thermal disruption, and thus potentially preserved in shallower palaeoregolith deposits (this will be a topic of future work).

4. Conclusions

Lunar palaeoregolith deposits potentially contain important records of the evolution of the Sun, and its galactic environment, throughout most of solar system history (approximately 20 revolutions of the Galaxy). Sampling such palaeoregolith deposits would be an important objective of future lunar exploration activities. As such sampling will require extensive field excursions, and/or sub-surface drilling, it would be greatly facilitated by a renewed human presence on the Moon [1,2,20].

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