EPSC Abstracts
Vol. 9, EPSC2014-764, 2014
European Planetary Science Congress 2014

Evolution of the presence of impact melt at the near-surface of the Moon

G.G. Michael[1], A.T. Basilevsky[2], T. Kneissl[1], G. Neukum[1]. [1]Planetary Sciences and Remote Sensing, Institute of Geological Sciences, Freie Universitaet Berlin, Malteser Strasse 74-100, Haus D, Berlin 12249, Germany. [2]Vernadsky Institute of Geochemistry and Analytical Chemistry, RAS, Kosygin str. 19, 119991 Moscow, Russia

1. Introduction

The purpose of the work is to understand the long-term effect of the impact gardening process on the presence of impact melt of different ages at the near-surface of the Moon. It is possible to make reasonable estimates of the amount of melt produced by impact events of differing scales, and likewise the depth of excavation and the quantity of unheated material which is redistributed at the surface. However, the cumulative effect of a long sequence of impacts melting, excavating, burying and re-excavating material produces a megaregolith which is complex in its melt distribution with depth. The characteristics of the distribution depend on the size–frequency distribution of craters forming on the surface, commonly called the crater production function. Further, if we wish to trace back the presence of melt specifically for the Moon, we also need to know the history of the crater formation rate.

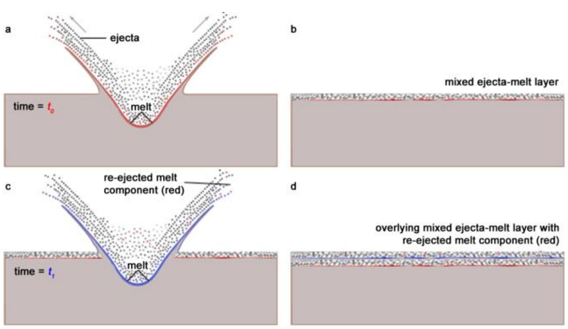

Figure 1. a) Impact event causing ejection of unheated and melted material, b) the deposition of a mixed layer of unheated ejecta and melt, c) a subsequent impact event, ejecting material from both the previous layer and beneath, melting a fraction of both, and d) depositing a new layer containing both new melt and a component of re-excavated melt from the previous event.

2. Method

The essence of the model is the following:

1. An initial volume, with a surface area equivalent to that of the Moon is denoted with a nominal starting age of T_0 (typically 4.5 Ga), and a minimum crater size for the simulation is chosen, $D_{\min}$.
2. From the lunar chronology function [5], an impact rate is found for the current model time, T, which corresponds to craters of 1 km in diameter. By means of the crater production function (PF), the equivalent rate for craters of size $D_{\min}$ is found.
3. The rate gives the average time to the next impact event producing a crater larger than $D_{\min}$. With a Monte Carlo approach, we can use a Poisson function to find realistically distributed time intervals, although for the large number of events being simulated, it can be sufficient to employ an averaged interval.
4. The diameter of the crater formed is generated using the Monte Carlo method in such a way that the size–frequency distribution statistically conforms to the portion of the production function larger than $D_{\min}$. Diameters above the defined range of the PF are drawn from a table of lunar impact basins [1].
5. For each crater produced, the penetration depth is taken as $D/3$ [2,4] and the depth of excavation taken as $D/10$ [3], around a third of the volume of the transient crater.
6. A portion of this excavated volume is considered to have been melted (or heated above the point required to reset the Ar-Ar clock): $\mathrm{r_{melt}} = \mathrm{cD_{tc}^{d}/V_{tc}}$, where D_{tc} and $\mathrm{V_{tc}}$ are the diameter and volume of the transient crater, and c and d are taken as 2×10^{-4} and 3.85, respectively (after [4]). The melted material is marked in the simulation with the current clock time, T.

7. The excavated material, together with the new melt, is redistributed evenly over the entire surface of the body. This is a simplification of the real situation, but in an average sense—because of the relative frequency of smaller impacts whose ejecta do not travel so far—it provides a reasonable reflection of the amount of ejecta sourced from craters of differing sizes at any point of the surface.

3. Results

Results for an impact rate scenario as described by [5], with the rate being constant back to 3 Ga, and exponentially increasing before then are shown in Fig. 2. The figure shows the prominence of melt from the most recent impacts in the uppermost surface, with progressively older melt occurring at greater depths. Occasional particularly large impact events are seen to leave a signature which rises all the way to the surface. By 'particularly large' we mean impacts which are larger in scale than any that follow. This is clearly a criterion which changes as you go back in time, so that a series of such events of increasing scale are observed. After such an event, subsequent impacts serve to repeatedly recycle its melt up to the surface, without ever burying it under material untainted by the event. The signature of early basin-forming events should also be found at the surface.

We aim to compare the results of this simulation, and others with differing early impact rate scenarios, with the histogram of observed melt ages from surface samples, both those returned from the Moon by manned and unmanned spacecraft and those delivered to the Earth in the form of meteorites, and thus to constrain the early bombardment history of the Moon.

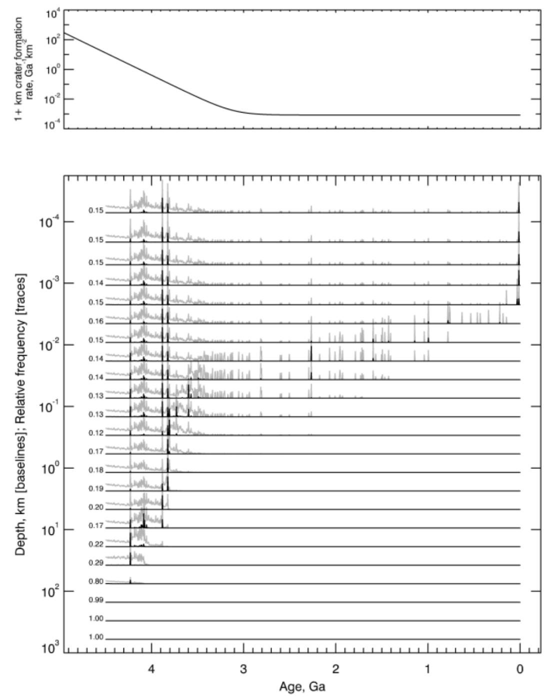

Figure 2. Simulation using craters of random size larger 30 km conforming to the size–frequency distribution described by the Neukum (1983) production function over a period of 4.5 Ga using a realistic impact rate function (plotted above) and incorporating basin-forming events. The horizontal axis indicates the age of the melt. Each trace in the plot represents a histogram of the presence of differing melt ages, the baseline of the trace being plotted at the layer's depth below the surface according to the vertical axis scale. The histograms are plotted twice: in black – with all traces using the same normalisation; in grey – with exaggerated small values. The numbers at the left side of each trace show the fraction of material of age T_0 that has never been melted during the simulation (this fraction is excluded from the histogram, since it would plot much higher). The four prominent peaks represent South-Pole–Aitken at 4.23 Ga, Crisium at 4.08 Ga, Imbrium at 3.88 Ga and Orientale at 3.82 Ga.

Acknowledgement

The work was supported by the German Space Agency (DLR Bonn), grant 50QM1301 (HRSC on Mars Express), on behalf of the German Federal Ministry of Economics and Technology.

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