TIME SCALE FOR THE MICROMETEORITE AND SOLAR FLARE MATURATION OF LUNAR SOILS, G. Poupeau and J. Johnson, McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130, USA.

We report here the results of a continuing study of the solar wind/solar flare/micrometeorite record in individual grains of lunar soils (1,2,3).

We showed last year that in several mature soils in which all grains (100-500 μm) had cosmic ray track densities in excess of 10⁸/cm², ▽25 to 40% of the crystals had impact microcraters (ξ₂ μm dia.). Nearly all (80 to 100%) also had glassy discs (ξ receptor dia.) indicating near-surface exposure. One surprising result was the absence of a correlation between microcraters and solar flare tracks in individual grains.

This work has now been extended to soils with different degrees of maturity. As before, individual crystals were studied with a SEM for characterization of the surface features, then mounted in epoxy and polished in an oriented position (perpendicular to the most cratered surface when microcraters were present). Results are presented in Table 1.

Although again no grain-to-grain correlation between track densities and microcrater densities was found, there is a tendency for the abundance of microcraters (as well as glassy discs) to decrease with a decrease in the range of track densities, i.e., with the duration of surface exposure. This confirms that glassy discs are related to surface microimpact processes. Larger glassy splashes on crystal surfaces as well as adhering particles are ubiquitous in crystals from all soils; these features thus give no indication of soil maturity.

Four soils in Table 1 present all the characteristics of mature soils, from the track and microcrater points of view. These include Apollo 16 drill core samples 60007,228, 60007,240, Luna 16 soil, and soil 67481. The results of the last two are particularly significant: the Luna 16 soil has the highest rare gas exposure age of all lunar soils analyzed so far (4) and presents extreme solar wind maturation effects (5). On the other hand, soil 67481 (rim of North Ray crater) is a rather young soil, brought to the vicinity of the lunar regolith no more than ▽50 x 10⁶ yrs ago. Its rare gas exposure age, similar to those of the rocks sampled at the same site, guarantees that there is not much contamination by nearby older regolith (6).

We therefore conclude that only 50 x 10⁶ yrs is required to thoroughly mix the lunar regolith to the depth of the sampling scoop, producing a set of crystals, most of which have glassy discs and high track densities (∽2 x 10⁹/cm²) and a sizable fraction of which have measurable impact features.

A possible lower limit for the establishment of these features can be set from sample 14141, from the vicinity of Cone Crater. The surface exposure of this sample has been variously estimated as 6 to 25 x 10⁶ yrs by track studies (7). It must be kept in mind that these are model ages, based on assumed simple exposure histories. The actual ages could be younger, but not older. Although soil 14141 shows evidence of contamination by older regolith, especially in the smaller grain sizes (8), it has a significantly lower fraction of crystals with glassy discs, microcraters, and lower track
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densities; it thus appears that the time span from \( \approx 5 \) to \( 50 \times 10^6 \) yrs marks
a critical period for transition of a several cm layer from a noticeably
immature soil to a mature one as measured by track and micrometeorites.

Although it is difficult to compare in detail, the results appear to be
roughly compatible with the SOLMIX Monte Carlo calculation of soil matura-
tion (9). The calculated track distribution for a single 3 cm layer exposed
for \( 25 \times 10^6 \) yrs shows a plateau between \( 10^7/\text{cm}^2 \) and \( 10^8/\text{cm}^2 \), followed by a
large peak with a maximum at \( \approx 10^9/\text{cm}^2 \). This corresponds to the average
lifetime of the "most probable" stratum thickness of 3 cm before burial by
another stratum. High track densities and impact microcraters result when
the grains find themselves in a lunar "skin" of 5 mm depth where there is a
large probability of recycling to the surface. Since the characteristic
depth for a \( 10^6 \) yrs exposure is 3 mm and 3 cm for a \( 25 \times 10^6 \) yrs exposure,
the time interval for transition between a mature and immature appearance
for a freshly deposited layer 3 cm in depth is \( \approx 10^6 \) to \( 25 \times 10^6 \) yrs.

In this context, it appears that soil 12033 (trench bottom), one of
the coarsest, most immature soils found, may have been exposed for \( <10^6 \) yrs
if it was deposited as a single layer on an ancient lunar surface.

The fact that the 50 my old sample 67481 is not significantly different
from soils with much larger rare gas exposure ages is somewhat surprising.
Crystals in very old soils have probably been recycled several times in
layers at the surface of the regolith. In the SOLMIX model, the material
in an "average" mature soil has been recycled at a rate of 2.5 times/\( 10^9 \) yrs
in a surface layer (10), resulting in a subtle displacement of the high track
density peak \( (>10^9/\text{cm}^2) \) toward higher densities. It might be expected also
that the abundance of micrometeor surface features on individual crystals
would increase correspondingly.

Possibly the explanation lies in the existence of processes such as sur-
fage erosion or grain-breakup which would produce an equilibrium state on
the surfaces of larger grains, independent of total exposure time.

REFERENCES
p. 3373-3390.
(3) Zinner, E., et al., this conference.
Hart, H. R., et al., 1972, ibid, p. 2831-2846; Phakey, P. P., et al.,
<table>
<thead>
<tr>
<th>Sample</th>
<th>Number of Crystals</th>
<th>Crystals with Glassy Discs No. (Percent)</th>
<th>Crystals with Microcraters†</th>
<th>Crystals with Microcrater Densities ( \times 10^6 ) cm(^{-2} )</th>
<th>Track Densities At the Center of the Grains</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical mature soil</td>
<td>( \approx 150 )</td>
<td>80-100%</td>
<td>25-40%</td>
<td>10-20%</td>
<td>( (0.5-3) \times 10^9 )</td>
<td>( (0.5-1.5) \times 10^9 )</td>
</tr>
<tr>
<td>60007, 240 (2.5-3 cm)</td>
<td>12</td>
<td>12 (100%)</td>
<td>8 (67%)</td>
<td>3 (25%)</td>
<td>( (1-4.6) \times 10^9 )</td>
<td>( (0.5-3) \times 10^9 )</td>
</tr>
<tr>
<td>60007, 228 (9.5-10 cm)</td>
<td>30</td>
<td>26 (86%)</td>
<td>15 (50%)</td>
<td>5±1 (13-20%)</td>
<td>( (0.5-3) \times 10^9 )</td>
<td>( (0.5-3) \times 10^9 )</td>
</tr>
<tr>
<td>Luna 16</td>
<td>22</td>
<td>21 (95%)</td>
<td>7 (32%)</td>
<td>3 (14%)</td>
<td>( (0.4-3.7) \times 10^9 )</td>
<td>( (0.1-2.5) \times 10^8 )</td>
</tr>
<tr>
<td>67481, 21 750 ( \mu )m</td>
<td>7</td>
<td>7</td>
<td>4</td>
<td>1</td>
<td>( (0.05-5) \times 10^7 )</td>
<td>( (0.05-5) \times 10^7 )</td>
</tr>
<tr>
<td>( \approx 100 \mu )m</td>
<td>15</td>
<td>14 (95%)</td>
<td>8 (54%)</td>
<td>2 (14%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14141</td>
<td>19</td>
<td>14 (74%)</td>
<td>3 (14%)</td>
<td>1 (5%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12033</td>
<td>14</td>
<td>1 (7%)</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Based on 10084 and 64421 data (1).
† SEM scanning at magnification 5K to 30K.
§ J. Borg (personal communication).