EVIDENCE FOR EARLY SOLAR SYSTEM HISTORY FROM LUNAR CRATERS AND IMPLIED PLANETARY COLLISIONS

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Lunar Rocks

Microcrater populations formed by the impact of interplanetary dust grains on lunar rocks have been studied extensively (1). It has been shown that:
1. on at least one face of almost all lunar rocks, the density of craters has reached an equilibrium with respect to crater superposition (2,3),
2. the largest craters observed on lunar rocks represent events slightly smaller than those required to catastrophically rupture the host rocks (3),
3. the most likely future for a rock exposed at the lunar surface is to suffer catastrophic rupture (4,5,6).

These results have led to the assertion that essentially all rocks remaining on the lunar surface represent survivors from an originally larger population (3,6). These findings may be generalized to yield the following rule.

If the impact crater population on a host object is in equilibrium with respect to superposition, and if the size distribution of the population is continuous up to craters only slightly smaller than required to catastrophically rupture the host object, then the host object is almost certain a surviving member of an originally larger population, and the most probable future for the host object is catastrophic rupture, assuming continuous size and time distributions of impacting objects.

The Moon

We now apply this rule to the moon itself, which may be considered just another lunar "rock" or a host object. The size distribution and areal density of impact-produced basins on the moon (7) are remarkably similar to size distributions and areal densities of microcraters on lunar rocks judged to be in equilibrium (2,3), the only difference being a factor of about 100,000,000 in the diameters of both the craters (basins) and host objects. We conclude, in agreement with others (8), that the crater or basin population is in equilibrium with respect to superposition up to the largest size basin observable on the moon. We further suggest that the largest basin observable on the moon, the diameter of which is about 1/3 that of the entire moon, is only slightly smaller than that corresponding to a moon-rupturing collision. Thus, if we are correct, the conditions required by the above-stated rule are satisfied, and we may conclude that the moon is almost certainly a surviving member of an originally larger population of similar objects and the future of the moon is catastrophic rupture...assuming continuous size and time distributions of impacting objects. This result, taken alone, lends support to the capture hypothesis for the origin of the moon. Capture has been considered unsatisfactory because the probability of such an event would have been extremely low. Clearly, if a large number of objects were available for capture, then the probability of capture of the moon would have been correspondingly higher.
The Solar System

If the moon and lunar rocks represent survivors of a continuing collisional destruction process, then other solar-system objects may be survivors also and reflect this process. We take the ratio of the diameter of the largest crater on an object to the diameter of the object to indicate the likelihood that an object is a survivor. Shown in the following table are ratios for a variety of objects exposed to impact in the inner part of the solar system.

<table>
<thead>
<tr>
<th>Object</th>
<th>Object Diameter (meters)</th>
<th>Largest Crater Diameter (meters)</th>
<th>Crater-to-Object-Diameter Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lunar spherule</td>
<td>0.0005</td>
<td>0.0002</td>
<td>0.40</td>
</tr>
<tr>
<td>Lunar rock I</td>
<td>0.038</td>
<td>0.012</td>
<td>0.31</td>
</tr>
<tr>
<td>Lunar rock II</td>
<td>0.097</td>
<td>0.032</td>
<td>0.33</td>
</tr>
<tr>
<td>Lunar rock III</td>
<td>0.19</td>
<td>0.049</td>
<td>0.26</td>
</tr>
<tr>
<td>Delmos</td>
<td>11,400</td>
<td>2,000</td>
<td>0.18</td>
</tr>
<tr>
<td>Phobos</td>
<td>21,800</td>
<td>5,000</td>
<td>0.23</td>
</tr>
<tr>
<td>Moon</td>
<td>3,480,000</td>
<td>1,300,000</td>
<td>0.37</td>
</tr>
<tr>
<td>Mars</td>
<td>6,750,000</td>
<td>1,500,000</td>
<td>0.22</td>
</tr>
<tr>
<td>Earth</td>
<td>12,700,000</td>
<td>200,000</td>
<td>0.016</td>
</tr>
</tbody>
</table>

Neglecting the earth, we find the largest-crater-to-object-diameter ratio is about 0.3 and, within a factor of about 1.5, constant for objects ranging over ten orders of magnitude in diameter. The earth may be excluded justifiably because of the strong likelihood that large craters or basins existing at one time on the earth have been destroyed subsequently by geological processes. This relatively large and reasonably constant ratio leads us to suggest that all objects in at least the inner part of the solar system are survivors and have been subject to destructive collisions and that other up-to-planet-sized objects must have existed in the inner solar system and have been destroyed by collisions.

Solar System History

We envision a stage in the early history of the solar system characterized by destructional collision processes. Observations of meteorites, especially of chondrules, fracturing, and evidence for mixing, all possibly the result of impact or collision, lend support to the idea of such a stage. Accretionary processes probably operated also during this stage, thus leading to an extended period of quasi-equilibrium between destructional collisions and constructional accretionary processes. We consider this time of competition between destruction and accretion processes a period of collisional decay. Because collision processes are dissipative, i.e. the sum of gravitational potential and kinetic energies for the proto-solar-system must decrease as a result of collisions, and because the material of the proto-solar-system must necessarily seek a minimum energy condition, the constructional accretionary processes have succeeded to form the planets, which are the natural products of collisional decay.
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The onset of collisional decay is not well-defined and may date back to the formation of early concentrations of solid material in the proto-solar-system. On the planetary scale we suggest the end of major effects of collisional decay coincided with the termination of basin-forming cratering events on the moon about 4 b.y. ago. On a scale of less than tens to hundreds of kilometers collisional decay remains an important process today. Solar system objects up to these dimensions are still being destroyed by impacts and collisions. Fragments produced by these events ultimately will be accreted by major planets having dimensions of thousands of kilometers. Thus, the processes of planetary construction and destruction continue today, and the concept of collisional decay is consistent with the geological principle of uniformitarianism.

Finally, we emphasize the importance of the observation that the largest-crater-to-object-diameter ratio is essentially a constant for all exposed inner-solar-system objects having simple geologic histories. Future accounts of solar system history must consider the significance of this observation and the related idea of collisional decay.

References