CRATERING OF TERRESTRIAL PLANETS: BRIEF REVIEW

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ABSTRACT

Analysis of cratering on all terrestrial planets and satellites has produced tools to study (1) the past meteoroid and planetesimal environment, (2) the erosive environments of planetary surfaces, and (3) the relative and absolute ages of planetary surface units. Important findings include a decline in lunar crater production rate from a value 4×10^9 years ago that was thousands of times higher than the present, to present values which have been relatively constant for 2 to 3 x 10^9 years; evidence for an erosive period or periods on Mars that degraded many Martian craters but declined substantially at some time in the past; and the concept of destruction of primeval planetary surfaces by early intense cratering and production of a mega-regolith.

All seven planets and satellites in the inner solar system are known to have craters. Craters on Mercury, moon, Mars, Phobos and Deimos were revealed by spacecraft or telescopic imagery; those on Venus by radar; and those on earth are still being discovered by geologic exploration. Several arguments indicate that the majority of the multi-kilometer craters can be ascribed to impacts of asteroid-like bodies. Among these are patterns of ejecta and secondary pits; required energies surpassing known volcanic eruptions; and matches between observed size distribution of craters and asteroids (one being converted to the other by means of empirical relations between crater diameter and necessary energy).

The craters allow a number of practical applications to the study of the planets, illustrated and reviewed informally by Hartmann (1977a) The conversion between crater sizes and sizes of original planetesimals allows study of the planetesimal environment. Such studies on lightly-cratered plains of different planets reveal that the multikilometer craters are distributed with similar size distributions that can be approximated by power laws of form $N=kD^{-b}$, where N is the number of craters of size greater than diameter D. The constant b is the slope in commonly-used N - log D plots. Least squares fit of the author's crater counts, for example, give B = 1.96 for craters from 2 to 128 km diameter on both lunar frontside maria and Martian Tharsis volcanic plains (Hartmann, 1977b).

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This indicates similar planetesimal size distributions striking these two planets (probably within the last 3×10^9 years in both cases), for planetesimals ranging up to 16 km diameter in the Martin case (Hartmann, 1971).Whitaker and Strom (1976) have recently given evidence that the size distribution of pre-mare planetesimals striking the moon and Mercury probably around $4x10^9$ years ago) may have had a somewhat different size distribution. This might reveal interesting properties of the accretionary period of planetary history and bears further investigation.

Shoemaker (1965), prior to Apollo flights, analyzed the surface lunar sturcture as fine powdery layer created by rock pulverization during cratering. This he called the lunar regolith. There was speculation that the regolith might contain chips or rocks of some "primeval" lunar crust formed 4.6×10^9 years ago. Apollo and Luna sample-return missions showed that such rocks are extremely rare; few rocks older than 4.0×10^9 years old survive. Two explanations have been put forward that invoke the cratering of the planets. First, there may have been a "cataclysmic" episode of intense cratering that destroyed a pre-existing surface; this might have been cratering by some bodies that were perturbed from the outer solar system into the inner solar system, there breaking apart due to tidal interactions with terrestrial planets (Tera, Papanastassiou, and Wasserburg, 1974 ; Wetherill, 1974).

A second explanation of the lack of old rocks was based on the intense cratering rates in early lunar history. Analyses of crater densities in different lunar and terrestrial provinces of known age shows that while the cratering rate in the last 2 to 3×10^9 years has been relatively constant (probably within a factor 3 during most of this time), the rate prior to 3.5×10^9 years ago was markedly higher; 4×10^9 years ago it was thousands of times higher than at present (Shoemaker, 1970; Hartmann, 1970, 1972; Soderblom, et al., 1974). This could be analyzed as a smooth sweep-up of planetesimals left over after planet accretion, and therefore as an expected evolutionary process rather than as an unexpected or low-probability cataclysm.

Further study showed that a projection of the rate of bombardment back into time would indicate that the moon would have been saturated with impact craters during short time intervals during the intense bombardment prior to 4×10^9 years ago. The size distribution of fresh lunar and planetary craters has the interesting property that if the surface gets saturated by 2-km scale craters (or other small, multi-kilometer craters) it will simultaneously (or very soon) get saturated by craters as large as 100 km diameter or more. Thus, as craters accumulate, by the time the regolith reaches depths of a few hundred meters, the surface layers will begin to be churned to depths of roughly 2-3 km (Short and Forman, 1972; Hartmann, 1973). The churning would be done during very energetic impacts; rocks would be converted into shocked, heated, ejecta and buried in ejecta blankets. In this way a mega-regolith would form, the isotopic clocks of most near-surface materials would be reset, removing most primeval rocks, and seismic properties of the moon might be explained.

From the period of the first Martian close-up photos it was clear that older Martian craters in the more heavily cratered uplands of Mars had been degraded and perhaps partly filled by some mechanism not operative on the moon (Öpik, 1960; Hartmann, 1966; Chapman, Pollak, and Sagan, 1968). Analysis of Mariner 9 data confirmed this conclusion and suggested that an erosive period or periods earlier in Mars's history had a relatively sharp termination, leading to present less erosive conditions (Hartmann, 1973; Jones, 1974; Chapman, 1974; Soderblom et al., 1974; Arvidson, 1974). These results are of increasing interest in view of additional recent Martian research, from which it is concluded that (1) water ran freely in now-dry channels, probably formed in the last half of Martian history (Hartmann, 1974, 1977; Malin, 1976); (2) Mars had a much more massive atmosphere in the past (McElroy, Yung, and Nier, 1976); and (3) volatiles may have disappeared from that atmosphere during a short period when the Tharsis volcanic pile accumulated and changed the obliquity state of Mars from an earlier state where the summer water ice cap would melt to the present state where it doesn't (Toon, Ward, and Burns, 1977). Cratering and physical studies may thus be combining to clarify a picture of Mars which involves a climate change from ancient erosive, fluvial conditions to present dry conditions.

Measurements of crater density (crater/km^2) help reveal relative ages of various geologic ages of different provinces, under the assumption that more heavily cratered areas preserved craters from earlier eras, and are thus older. Absolute ages could be measured if we knew the crater production rates on the various planets; however, these are known only roughly (to perhaps a factor of 3 uncertainty). Further progress in this area can be made by better inventories of existing asteroids and comets in the inner solar system and by theoretical monte-carlo studies of the dispositions of those bodies from present orbits onto different planets' surfaces (Shoemaker and Helin, 1977; Hartmann, 1977a, b). To the extent that crater production rates on other planets can be confidently estimated, accurate chronologies of all planets can be estimated with minimal calibration from sample return missions.

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