MARS CRATERING ISSUES: SECONDARY CRATERING AND END-NOACHIAN DEGRADATION. .
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Introduction: Since the formation of impact craters is a well characterized physical process (primary impacts form explosion craters with characteristic initial shapes, distributed at random across a planet's surface), they provide a baseline for many fundamental issues involving the geological evolution of the surface. I explore two of these issues here, both of which have important implications for understanding the early history of Martian geology:

The first issue concerns the possible importance, or even dominance, of crater populations by secondary craters. If many or most craters are secondaries, then the presumption of randomness (among other attributes of primary craters) is wrong, undercutting long used methods of relative and absolute age dating of geologic units on Mars.

The second issue concerns a long-standing question about the nature and duration of a major episode of crater obliteration (relative to the cratering rate) that occurred toward the end of the Noachian. The hypothesis, developed from crater morphology data measured from Mariner 9 images, was never re-evaluated in the post-Viking timeframe. With exquisite images now available from MOC and THEMIS, the time is overdue to evaluate the global obliteration episode in the context of our more recent, higher resolution understandings of Martian surface processes.

Secondary Cratering: Current understanding of Martian cratering, age-dating of units and features, and the entire evolution of Mars is based on a fundamental assumption [1-3]: cratering on the terrestrial planets, especially the Moon and Mars, is dominated by primary craters. But that assumption may be wrong, especially as applied to smaller units, which can be dated only by using more frequent, small craters. There is new, strong evidence that secondary cratering may be much more important, in comparison with primary cratering, than has been accepted during the past three decades. The first recognition of the importance of secondary cratering came from analysis of over 25,000 small craters on Galileo images of Europa by Bierhaus and his colleagues [4-9]; the vast majority of small craters on Europa are spatially clustered and must be secondaries. More recently, McEwen *et al.* [10] have shown that a single, recent 10 km crater may have produced ~10^7 – 10^8 secondary craters >10 m in size on Mars. Unless this particular crater formed in a very unusual manner, secondary craters dominate over primary craters on rocky Mars, as well as on icy Europa.

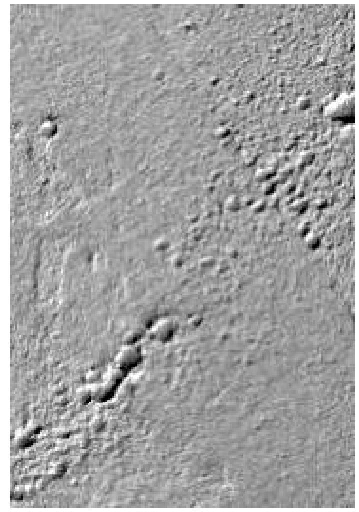
Fig. 1. Clustered craters in MOC image.

Shoemaker's [11] secondary crater branch (craters <3 km diameter) was interpreted to be an attribute of the primary production function by Neukum [12]. Vickery's [13,14] efforts to characterize secondary craters on the Moon were impeded by the crowding of small craters. At large distances from the primary, "background" secondaries strike at higher velocity and look like primary craters, blending in. The same problems affected Vickery's studies of Martian secondaries, which were restricted to the rarer, larger sizes due to resolution limits of the available images. Conversely, at very small diameters (less than several hundred meters on the Moon) it becomes especially difficult to study any morphological or statistical attributes of craters at all because they become saturated, crater-upon-crater. Thus far-field, distal, background secondaries have not been considered, since the 1970s, to contribute significantly to the small-crater populations on the Moon, Mars, or elsewhere. Bierhaus [9], however, finds that if the production of secondaries is as efficient on the Moon as on Europa, secondaries could fully account for the lunar steep branch.

Of course, small clusters of craters have been recognized on Mars over the years. Originally some were attributed to break-up of primary projectiles by the thin Martian atmosphere [15], but it is now recognized (cf. [16]) that such effects pertain only to craters a few meters across and smaller (unless the atmosphere was much thicker in the past). More recent studies [17, 18] properly attribute most of these clusters to secondary cratering. Secondary cratering has also long been theoretically considered as an inevitable process since Melosh's [19] explanation for the derivation of Martian SNC meteorites on the Earth: the same spallation process that accelerates fragments to escape the gravity of Mars surely contributes many more distant secondary craters, made by the fragments that fall somewhat short of escape velocity. Nevertheless, it has taken the McEwen work to posit that secondary cratering may be far more pervasive than supposed by researchers studying isolated clusters and production of SNC's.

Since secondary craters are produced in temporal bursts as well as in spatial clusters, they greatly degrade the possibility for inferring relative ages of units from crater frequencies (unless worse-than-order-of-magnitude accuracies are still useful). Many published relative and absolute ages for units on Mars are suspect if based on densities of craters <5 km diameter, and especially <2 km diameter, where the steep branch predominates over an extrapolation of the primary branch.

Late-Noachian Crater Degradation: Two end-member hypotheses frame our understanding of late Noachian landform degradation: (a) Degradation of early craters on Mars might have been temporally associated with impact processes themselves (either caused directly by the impacts, or due to some indirect but impact-triggered cause), which dominated the Noachian epoch and declined toward the end of the Noachian. Perhaps this decline in impacts coincided with the end of the LHB, recorded on the Moon as peaking near ~3.9 Ga and quickly ending by ~3.82 Ga ("early" in Martian history but "late" compared with the epochs of planetary accretion; the absolute Martian chronology is tied to the LHB through only a single rock age, ALH84001 [20,3]). (b) Alternatively, the landform degradation might have happened *after* the LHB ended, implicating specific endogenic – that is non-impact – processes (one example might be: an episode of volcanism, which began emplacing northern hemisphere plains and melted much of the cryosphere, thus giving rise to a thick, warmer atmosphere and resulting precipitation runoff). In end-member case (a), the evolution of the Noachian terrains might resemble what happened at similar epochs on the Moon and Mercury (even these two bodies, whose geology is dominated by impacts and early volcanism only, differ in the degree of inter-crater plains formation). Perhaps the additional flattening of Martian craters, beyond what is observed for lunar or Mercurian craters, is more superficial than it appears (e.g. a bit of filling of low spots on crater floors by windblown dust) rather than reflecting an epoch dominated by a hydrological cycle. In that case, it might be less likely that the late Noachian was a wetter era.

Chapman & Jones [21] argued that case (b) is closer to what happened. If the obliteration episode took place after the LHB (i.e, it was *decoupled* from it), then major landform modification must have been due to separate, endogenic causes and it may be more likely that there are profound implications for environmental conditions at the time, including a climate favoring the early evolution of life on Mars.

The technical basis for inferring a spike in obliteration rates toward the end of the Noachian is robust. (Carr has questioned whether limited resolution might be responsible for the statistics of crater morphologies interpreted by Chapman & Jones [21]; but the observed systematics vary in an opposite sense to resolution effects.) Unfortunately, the early work was never redone, even using Viking images. Now there is abundant evidence from high-resolution images obtained during the past decade concerning specific geological processes, ranging from gully processes to terrain softening, which need to be evaluated to see how their specific effects in degrading craters can be manifested in the much coarser, low-resolution degradation states employed in the early work. Whether it was one process or a combination, some endogenic process/es dramatically affected Mars during an episode in its comparatively early history that we need to understand.

References: [1] Neukum G. *et al.* (2001) *Space Sci. Revs. 96*, 55-86. [2] Ivanov B.A. (2001) *Space Sci. Revs. 96*, 87-104. [3] Hartmann W. & Neukum G. (2001) *Space Sci. Revs. 96*, 165-194. [4] Chapman C. (1997) *MAPS, 32,* A27. [5] Bierhaus E. *et al.* (2001) *Icarus, 153*, 264-276. [6] Bierhaus E. *et al.* (2001) *BAAS, 33,* 106. [7] Chapman C. *et al.* (2002) *LPS XXXIII* Abs. #2005. [8] Bierhaus E. *et al.* (2003) *DPS 35th*. [9] Bierhaus E. (2004) PhD thesis Univ. Colo. [10] McEwen A.S. *et al.* (2004) submitted to *Icarus*. [11] Shoemaker E. (1965) In *Ranger VII Rept* (JPL Rept. 32-700), 75-134. [12] Neukum G. (1983) Habs. Diss. Ludwig-Maximillians-Univ. Munich. [13] Vickery A. (1986) *Icarus, 67,* 224-236. [14] Vickery A. (1987) *Geophys. Res. Lett., 14,* 726-729. [15] Hartmann W. *et al.* (1994) *Meteoritics, 29*, 471-472. [16] Hörz F. *et al.* (1999) *Science, 285*, 2105-2107. [17] Barlow N. (1998) *BAAS, 30,* 1055. [18] Hartmann W. *et al.* (2003) *LPS XXXIV,* Abs. #1815. [19] Melosh H.J. (1984) *Icarus, 59*, 234-260 . [20] Chapman C. (1996) *Nature, 380, 23-4*. [21] Chapman C. & Jones K. (1977) *Ann. Rev. EPS, 5, 515-540.*