CHARACTERISTICS OF FRESH MARTIAN CRATERS AS A FUNCTION OF DIAMETER: COMPARISON WITH THE MOON AND MERCURY

Mark J. Cintala
James W. Head
Thomas A. Mutch

Department of Geological Sciences
Brown University
Providence, Rhode Island 02912

Abstract. Martian craters defined as fresh on the basis of morphologic parameters have been analyzed for the presence and abundance of various morphologic features as a function of size. Bowl-shaped craters dominate the fresh crater population below about 15 km. The onset of central peaks occurs at about 5 km. Craters above about 15 km often have terraced walls, central peaks, and hummocky floors; at diameters of 40 km and greater, these features dominate fresh martian crater morphology. Central peak onset occurs at smaller diameters on Mars and the Moon than on Mercury, and terrace onset occurs at similar diameters on the Moon and Mars, but at larger diameters than on Mercury. Since Mars and Mercury have a similar surface gravitational acceleration (greater than twice that of the Moon), gravity-controlled crater features should appear at similar diameters on the two planets. However, the differences in onset and abundances of central peaks and terraces on Mars and Mercury indicate that processes other than gravitational effects may also be important.

Introduction

Recent space flights to Mars and Mercury have shown that cratering is a significant process on these planets, as well as on the Moon. While fresh craters on the three planetary bodies and the Earth show similarities, differences have also been noted. For instance, the first appearance of central peaks (Gault et al., 1975; Smith and Sanchez, 1973) occurs at smaller diameters on the Earth than on the Moon, Mars, or Mercury (Hartmann, 1973). Causes for variation in fresh crater morphology may be related to gravitational differences from planet to planet (Hartmann, 1972) and their effects during crater excavation and modification (Gault et al., 1975). Other variations, such as impact velocity (Wetherill, 1975) or substrate variations (Head, 1976), may also be important. Preliminary information on the morphology of fresh craters has been presented for the Moon (Smith and Sanchez, 1973) and Mercury (Gault et al., 1975), based on relatively small samples of the total fresh crater population. Preliminary observations have also been made on martian crater morphology and morphometry, but are also restricted to small samples of the total fresh crater population (Hartmann, 1972, 1973; Pike, 1971; Murray et al., 1971). The purpose of this paper is to present a more comprehensive analysis of the morphologies of fresh craters on Mars and to compare the characteristics and size distribution of morphologic features of martian craters with those on the Moon and Mercury.

Based on criteria presented below, 33,810 fresh craters were chosen from a population of 46,559 martian craters of all sizes and morphologies. The data base consists of a catalog of all craters visible on Mariner 9 A frames; crater location, rim crest diameter, and a series of morphologic features, as well as several other parameters, are recorded for each of the craters. The procedures for recording the data and the details of the morphologic classification scheme are presented elsewhere (Arvidson et al., 1974; Arvidson, 1974). Craters classified as volcanic on the basis of these morphologic parameters have not been included in this study.

Definition of Fresh Craters

Fresh lunar craters over several kilometers in diameter have a crisp appearance and are characterized by rays, satellitic craters, radial rim facies, a sharp rim crest, and terraces or a bowl shape depending on size (Pohn and Offield, 1970; Arthur et al., 1963; Wood, 1972; Smith and Sanchez, 1973; Head, 1974; Howard, 1974; Pike, 1974). Relative youth of craters is determined both by crispness and stratigraphic relationships. Fresh craters are of Copernican age (with rays) or Erathosthenian age (fresh morphologies without rays) (Wilhelms and McCauley, 1971) and span an age range of about the last 3 billion years (Head, 1974, Fig. 3). Large Imbrian-age craters show only slightly higher levels of degradation, but pre-Imbrian craters are usually heavily degraded (Head, 1974). The freshest lunar crater class of Arthur et al. (1963), Class I, is characterized by craters with sharp rim crests, while Class II craters have blurred or possibly broken rims. Class I craters correlate with craters of Copernican, Erathosthenian, and even Imbrian age (C. A. Wood, personal communication). Fresh craters on Mercury show similar characteristics and correspond to Class I lunar craters (Gault et al., 1975).

Using similar criteria, fresh martian craters are defined as unmodified or nearly unmodified structures which appear in one of three categories (Fig. 1): 1) deep, flat-floored, with terraced walls; 2) deep, bowl-shaped, with terraced walls; and 3) deep, bowl-shaped, with non-terraced walls.
The deep category is a qualitative expression for relative crater depth and compares to other categories such as shallow and extremely shallow. Details of modified martian craters are described elsewhere (Jones, 1974; Arvidson, 1974). Of the fresh crater population thus defined, over 98 percent have raised rims, while this feature is seen in less than 25 percent of the remaining population of non-fresh craters. In addition to the morphologic crispness of these craters, a relatively young age is supported by superposition relationships. Less than one percent of the fresh craters defined on morphologic grounds have breached rims or superposed craters, compared to 25 percent for the more highly degraded craters.

In a morphologic sense, the martian fresh crater class is approximately equal to Class I lunar craters of Arthur et al. (1963). Less than one percent of the population have the blurred and broken rims characteristic of Classes II and III. Detailed correlation with the Pohn and Offield (1970) lunar scale is more difficult because of the lack of information on the characteristics of the fine-textured exterior deposits on Mars. This is a result of resolution limitations of Mariner 9 A frames, and some eolian modification of exterior crater deposits as exhibited in B frames (Soderblom et al., 1973). However, fresh martian craters appear to be as fresh or fresher than about 4.2 to 4.4 on the Pohn and Offield scale, based on characteristics of the crater interiors. On the Moon, this value lies close to the beginning of the Imbrian Period (Head, 1974).

**Crater Morphologic Characteristics and Their Variation with Size**

**Bowl-Shaped Craters.** The vast majority of fresh martian craters are bowl shaped. The classification of craters as bowl shaped at small diameters is partly controlled by the resolution limits of Mariner A frames. Craters with diameters less than 1 km cannot be resolved. This same resolution effect accounts for a decrease in apparent abundance of bowl-shaped craters at diameters less than 3 km (Fig. 3). It is likely that many of the bowl-shaped craters here classified as fresh would show some effects of degradation in higher-resolution pictures, but a reclassification of some bowl-shaped craters from fresh to degraded would not influence our present conclusions. Fig. 2a shows the number of fresh bowl-shaped craters as a function of size and Fig. 2b shows the percentage of fresh craters which are bowl shaped, as a function of size. Almost 100 percent of all fresh craters less than 20 km in diameter are bowl shaped. Over 98 percent of the total bowl-shaped crater population are less than 20 km in diameter.

**Flat-floored craters.** Fig. 2c illustrates the percentage of the fresh crater population which has flat floors, as a function of crater size. Less than 1 percent of the fresh craters below 20 km diameter are characterized by flat-floors. The occurrence of flat floors increases markedly above about 20 km diameter. Between 20 and 30 km, about 20 percent of the fresh craters have flat floors, and above 50 km all fresh craters contain this feature.

**Central peaks.** Central peaks are seen in 685 fresh craters. No central peaks are observed in fresh craters less than 5 km in diameter, and an extremely small percentage of the total population between 5 and 10 km contain central peaks (Fig. 2d). Because of the large population, these are not visible in Fig. 2d. However, their presence is indicated in Fig. 4b. The percentage of fresh craters showing central peaks steadily increases above 10 km until over half of the fresh craters between 60 and 100 km contain central peaks.

**Wall terraces.** These features are seen in 483 fresh craters but are not found at diameters below 10 km (Fig. 2e). Less than 5 percent of the fresh craters between 10 and 20 km display terraces, but the proportion of terraced craters increases with increasing crater size until 100 percent of the craters over 50 km diameter have terraces.

**Floor hummocks.** In the lunar case floor hummocks are associated with fresh Copernican- and Eratosthenian-age craters and are seen predominantly in flat-floored craters over 15-20 km in diameter, although they do occur at lower diameters (Pohn and Offield, 1970; Smith and Sanchez, 1973; Head, 1974; Cintala and Head, 1976). Lunar floor hummocks are generally less than a kilometer in diameter, which is approximately the resolution of Mariner 9 A frames. On Mars, floor hummocks are seen in only a small percentage of fresh craters (Fig. 2f). This distribution may be due to resolution effects and small amounts of eolian infilling.

**Comparison with the Moon and Mercury**

A comparison of the frequency of occurrence...
Figure 2. Morphologic characteristics of the fresh martian crater population as a function of diameter; a) number of fresh bowl-shaped craters as a function of size; b-f) percentage of fresh craters with a particular feature as a function of crater size (e.g. ~ 98.5% of the fresh craters between 10-20 km diameter are bowl-shaped). b) bowl-shaped; c) flat-floored; d) central peaks; e) wall terraces; f) floor hummocks.

of terraces and central peaks as a function of diameter for Mars, Mercury, and the Moon is shown in Fig. 4a, b. The onset of terraces occurs at about the same diameter on the Moon and Mars. However, the percentage of martian craters with terraces in each size class falls consistently below values for both the Moon and Mercury below 50 km. A small percentage of central peaks are seen at diameters of less than 10 km on Mars. On the basis of data presented by Gault et al., (1975) and Smith and Sanchez (1973), central peaks do not occur until 10-20 km diameter on the Moon and Mercury (Fig. 4b). However, a recent compilation of lunar crater data shows that, within a 13 million square kilometer area on the nearside, 5 percent of the Class I craters between 5 and 10 km diameter have central peaks (C. A. Wood, personal communication). Martian central peaks show a slower rate of increase at higher diameters than do lunar and mercurian craters. Small amounts of eolian infilling on Mars may serve to obscure or bury the central peaks in many cases, while not changing the general fresh-crater appearance.

Previous investigators have attributed the differences in central peak and terrace frequencies between the Moon and Mars (Hartmann, 1972; 1973) and the Moon and Mercury (Gault et al., 1975) to dissimilar surface gravitational field strengths. The Moon and Mercury differ in surface gravitational acceleration by over a factor of 2 (Moon, 0.16 relative to Earth=1; Mercury, 0.37). The gravitational acceleration at the surface of Mercury is approximately the same (about 5 percent less) as that of Mars (0.38). Since Mars and Mercury have similar surface gravities, features such as terraces which are thought to be gravity-controlled (Gault et al., 1975) should appear at similar diameters if gravity is the dominant factor. However, terraces appear at smaller diameters on Mercury than on Mars and the Moon (Fig. 4a). The differences between these planets strongly suggest that, in addition to gravitational effects, other factors such as varying impact velocities and dissimilar substrate characteristics may also be important. Compilation of a complete data base for the Moon and Mercury will allow more detailed comparisons to be made.

Acknowledgements. This work was performed under NASA grants NGR-40-002-008 and NGR-40-002-116 which are gratefully acknowledged. Thanks
Figure 4. Comparison of Mars data with the Moon and Mercury for the frequency of occurrence of terraces (a) and central peaks (b) as a function of crater diameter (Mercury data from Gault et al., 1975; lunar data from Smith and Sanchez, 1973, as modified by Gault et al., 1975). In Gault et al. lunar wall terrace data below 10 km is incorrectly plotted but is corrected here. Martian central peak data below 10 km are enhanced for visibility.

are extended to Ray Arvidson and Ken Jones for the compilation of the Mars data bank, to R. Stockman, R. D’Alli, S. Grenander, and C. A. Wood for discussion and to J. Ralske for help in preparation of the manuscript, and to D. E. Gault and K. A. Howard for their critical reviews of the manuscript.

References


(Received February 5, 1976; accepted February 17, 1976.)