Reports

Mariner IV: Analysis of Preliminary Photographs

Abstract. *Comparison of the distributions of Martian and lunar crater diameters indicates that the visible surface of Mars is 2.2 to 3 × 10⁹ years old. This result implies that in the early history of Mars large-scale subaerial erosion occurred. Of 69 Martian craters with diameters greater than 10 kilometers, 13 percent have central peaks. This compares favorably with the frequency (11.7 percent) of central peaks among lunar craters and may indicate that the central peaks are a direct result of the impact mechanism rather than post-impact volcanism. A well-defined system of lineaments is shown in the Mariner photographs. The presence of these lineaments may indicate that Mars has lost appreciable angular momentum during its history.*

The photographs of Mars taken by Mariner IV allow a fairly detailed comparison of the surface structure of three terrestrial-type bodies: the earth, the moon, and Mars. Although the Mariner IV photographs now available are the unrefined first-transmission sequence, their quality is high and they warrant considerable study. This report gives the preliminary results of such a study; it is concerned with crater, central-peak, and lineament statistics and some of their implications.

On frames 7 to 14, 89 craters were identified and measured to determine the diameter distribution of the Martian craters. The area covered by these frames is 5.1×10^5 km^2, and the crater diameters range from 6 to 170 km. Only reasonably well-defined craters were counted, so the diameter distribution curves obtained should be considered a lower limit. However, the loss of ill-defined craters is probably not too serious for craters with diameters greater than 20 km, that is, about 10 times the resolution of the Mariner TV system; thus, it is unlikely that the counts are in error by more than 30 percent in this size range. The resulting diameter distribution, curve *M*, is given in Fig. 1.

For craters larger than 40 km, the slope of the Martian crater curve is almost equal to that of similar curves for the moon. The change of slope at 40 km is probably due to loss of craters by erosional processes rather than to lack of resolution; the diameters of craters in this range are still more than an order of magnitude greater than the resolution of the photographs. However, the great deficiency of craters with diameters less than 12 km is certainly partially due to lack of resolution.

Included in Fig. 1 for comparison are curves showing the diameter distribution for both pre-mare and post-mare lunar craters. The lunar data are those of Hartmann (in press) which were derived from "The System of Lunar Craters, Quadrants I, II, III" (*2, 3*). Curve *a* represents the diameter distribution of post-mare craters, which are thought to be mainly due to impacts of asteroidal bodies (*4*). Curve *b* represents the diameter distribution of pre-mare craters, whose origin may be different from that of the post-mare craters (*1*).

Because of the proximity of Mars to the asteroid belt, it is thought that the Martian craters are the result of asteroidal impacts. Anders and Arnold (*5*) have calculated that the flux of asteroidal bodies in the vicinity of Mars is 20 to 25 times that found in the earth-moon system. Similarly, Witting *et al.* (*6*) found the difference in the fluxes to be a factor of 15. For this paper, it is assumed that the flux difference is about a factor of 20.

In Fig. 1, the difference between curves *a* and *M* is only a factor of 10, rather than the factor of 20 mentioned above. Thus, about 50 percent of the craters on Mars have been removed, presumably by erosional processes. If the cratering rates have been nearly constant since the formation of lunar maria, and if lunar post-mare craters are almost completely due to asteroidal impacts, then the Martian surface is about 50 percent as old as the lunar maria ($\sim 4.5 \times 10^9$ years) or 2.2×10^9 years. As above, curve *M* may be a lower limit, so the age of the surface may lie between 2.2 and 3×10^9 years. However, in view of the present uncertainties in these calculations, it seems reasonable to estimate the age of the surface as a large fraction of the age of Mars.

This result for the age of the surface is consistent with the 2 to 5×10^9 years estimated by Leighton *et al.* (*7*), but the agreement is fortuitous. (i) There is a systematic scaling error in Leighton's crater count that has shifted his curve to the left by a factor of about 1.6. This shift has the effect of making Leighton's estimated age of the surface low by a factor of 2. (ii) Leighton included frames 5 and 6 in his count; these two frames cover about 25 percent of the area he included, but, probably because of their poor definition, show only a few craters. Exclusion of these frames from the count increases the number of craters per square kilometer, and therefore the age, by 30 percent. (iii) Leighton *et al.*

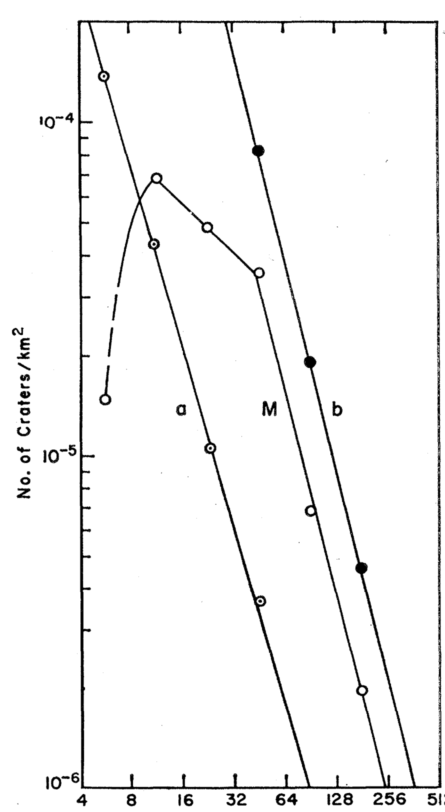

Fig. 1. Comparison of the diameter distribution of Martian craters (curve *M*) and lunar post- and pre-mare craters (curves *a* and *b*, respectively).

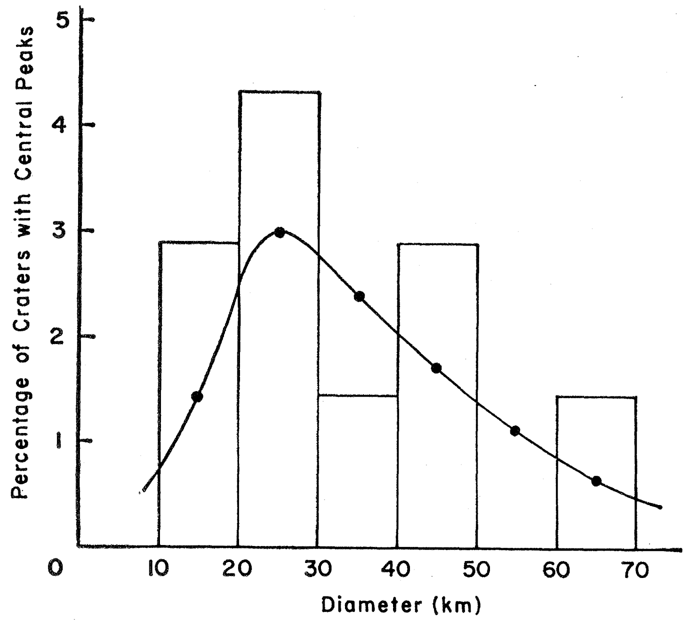

Fig. 2. Comparison of the frequency of central-peak craters of Mars and the moon. The histogram represents the Martian central-peak data and the smooth curve represents the lunar central-peak data.

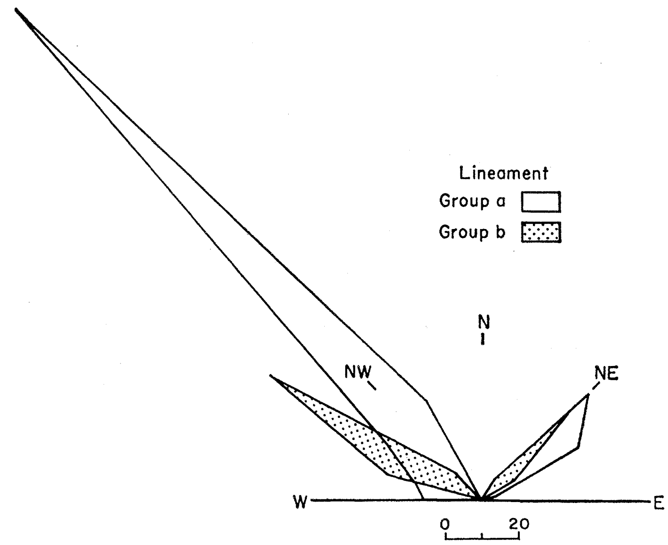

Fig. 3. The azimuth frequency of the Martian lineaments. Group *a* are those lineaments north of latitude 36°S (frames 7 to 12) and group *b* are those lineaments south of latitude 36°S (frames 13 to 15).

compared their Martian crater count to lunar crater counts that did not differentiate between maria and uplands. As the lunar data contain a large fraction of pre-mare craters, the crater density per unit area is much too high. (iv) As pointed out by Anders and others, Leighton did not consider the different cratering rates of the moon and Mars.

In an attempt to correct Leighton's results by considering the differences in cratering rates, Anders and others, using Leighton's Martian crater statistics, obtained ages for the Martian craters between 3 and 8×10^8 years. On the basis of the foregoing discussion these ages should be increased by a factor of about 2.6.

As mentioned above, the calculated age of 2.2 to 3×10^9 years for the Martian surface implies considerable erosion of the surface in the early history of the planet. Admittedly, owing to uncertainties in the age determination, the surface age may equal that of Mars, and consequently relatively little erosion would have occurred. However, if the first conclusion is valid, it is reasonable to assume that in the early history of Mars the atmosphere was dense enough to promote large-scale subaerial erosion. A similar conclusion regarding past atmospheric conditions on Mars has been reached by Binder and Cruikshank (*8*). These investigators found that the deserts of Mars seem to consist of detritus stained with weather-produced limonite ($Fe_2O_3 \cdot nH_2O$); since limonite cannot readily, if at all, form in the present Martian atmospheric environment, more suitable atmospheric conditions for chemical weathering must have existed in the past.

Of 69 craters with diameters greater than 10 km found on frames 7 to 14, nine have recognizable central peaks (for craters less than 10 km in diameter, a central peak would probably not be detected owing to a lack of resolution). Thus, 13 percent of the Martian craters observed have central peaks. This compares favorably with the 11.7 percent central peak frequency for lunar post-mare craters found by Wood (private communication), who used "The System of Lunar Craters, Quadrants I, II, III" (*1*). Figure 2 shows the distribution of central peaks for the Martian craters and lunar post-mare craters. If the slight apparent excess of Martian central-peak craters for craters with diameters less than 25 km is neglected, the lunar and Martian data are quite similar, considering the limited information concerning the latter. This similarity suggests that the central-peak formation mechanism is similar for Martian craters and lunar post-mare craters and may be the result of initial impact rather than of post-impact volcanism. It seems unlikely that volcanic activity would have the same intensity on two bodies with such different physical parameters and presumably different thermal histories.

Over 480 lineaments were found on frames 7 to 15; however, it is likely that some of these are due to instrumental effects (see below). A feature was considered a lineament if it was sensibly straight and narrow; for example, a long narrow ridge or a graben. Figure 3 shows the azimuth frequencies for frames 7 to 12, which were taken north of latitude 36°S (group *a*), and for frames 13 to 15, which were taken south of latitude 36°S (group *b*). In general there seems to be a complete absence of NS striking lineaments and nearly a complete absence of those striking EW. There is a predominance of lineaments that strike NW and a large number that strike NE. Since the lighting in all the photographs either favors the detection of those lineaments that are ridges or depressions with NE trends over those with NW trends, or makes the detection of these trends equally probable, the difference in the number of lineaments in these directions appears real. Strom and Hartmann (private communications) have each noted a similar predominance of NW over NE lineaments in lunar mare basin sculpture. Strom (*9*) and others have described the lineament system on the moon, and geologists have long been aware of the earth's lineament system. Thus, Mars is the third terrestrial body found to have a strong lineament system that is oriented with respect to the axis of rotation. It is generally thought that such a lineament system is caused by stresses in the planet's crust produced by changes in the planet's rotational equilibrium figure. The NS and EW lineaments are then the tensional and compressional features, and the NE and NW lineaments, the complementary shear directions.

Unfortunately, in the Mariner IV frames studied, north is always within 10° of being perpendicular to the scan direction; thus, the major lineament directions, that is, NW and NE, always nearly cut diagonally across the checkerboard pattern produced by the TV digital system. Similarly the EW lineament direction is always nearly parallel to the scan lines. Consequently, a number of the lineaments may well be instrumental in origin.

Two differences between "low-latitude" and "high-latitude" lineaments are noted. First, in the low-latitude group (group *a*) the NW direction contains over three times as many lineaments as the NE direction, while for the high-latitude group (group *b*) the difference is a factor of 2. It is possible that the reduction in disparity in the latter group is due to lighting effects, since on the high-latitude frames the lighting favors the detection of features with a NE trend. Secondly, the angle between the shear directions is 90° to 95° for the low-latitude group and 105° for the high-latitude group. Although this difference may be accounted for by projection, or other distortions, Vening Meinesz (*10*) has indicated that in the case of the earth the angle between shear lineaments should increase in high latitudes.

Since the lineament systems of the earth and moon are probably a result of the decrease in the rotational angular velocity that the two bodies have experienced throughout their histories, it seems likely that the Martian lineament system had a similar origin. The changes in angular velocity caused by tidal interactions of Mars with Phobos and Deimos are completely negligible and that caused by the sun is a few percent at most (MacDonald, *11*); thus other mechanisms must be sought. Wise (*12*) has postulated that the earth lost a considerable amount of angular momentum by an interaction of the geomagnetic field with strong solar winds in the early history of the solar system. To apply this mechanism to Mars, it is necessary to postulate that Mars once had a magnetic field but lost it, since the Mariner IV results indicate that the Martian magnetic field is no greater than 3×10^{-4} that of the earth (*13*). According to the widely held dynamo theory, a liquid iron core is necessary for a geomagnetic-type field. Though the dynamical oblateness of Mars indicates that it is more homogeneous than the earth (*14*), studies of the internal structure by MacDonald (*15*) and many others indicate that Mars may have at least a small iron core. This core would probably have been liquid during at least some time after its formation, so the dynamo requirements may have been fulfilled for an early aeromagnetic field.

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References and Notes

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X-Ray Diffraction Study of Minerals from Shocked Iron Meteorites

Abstract. *Diffraction analysis of minerals from iron meteorites indicates a pronounced shock-induced alteration in the minerals' crystallographic character. The extent of alteration seems to be dependent on the degree of shock and can therefore serve as a measure of shock intensity. The changes appear to be due to the minerals' direct recrystallization during passage of the shock wave.*

Recent metallographic studies have shown that natural and artificial shock waves cause a number of microstructural changes in iron meteorites (*1, 2*). These changes have been used in a qualitative manner to categorize such meteorites into lightly (< 130 kb), moderately (130 to 750 kb), and heavily (> 750 kb) shocked groups (*2*). However, most of these changes can be produced either by shock or by heat-treatment in the 1-atmosphere region (*2*). Thus, in the absence of unequivocal indicators of shock, it may be difficult to decide whether a meteorite has been shocked or has been artificially heated at atmospheric pressure. Since the meteorites' shock histories can be related to other parameters, it would be very desirable to establish unambiguous shock criteria.

It occurred to us that these shock-induced microstructural changes in iron meteorites might also be accompanied by crystallographic alterations in the meteorites' constituent minerals. Ideally, such alterations would not be reproduced by simple heating and thus they would serve as unequivocal indicators that shock had occurred. In order to investigate this possibility we have studied, by x-ray diffraction techniques, a number of minerals common to iron meteorites. These minerals, which include kamacite (α-Fe), taenite (γ-Fe), troilite (FeS), cohenite (Fe_3C), and schreibersite (Fe_3P), were removed as undeformed single grains and were x-rayed without rotation in a 57.3-mm powder camera; manganese-filtered $FeK\alpha$ radiation was used. The meteorites include a suite of Canyon Diablo specimens studied metallographically by Heymann *et al.* (*2*) and natural and artificially shocked Odessa specimens (*3*). We found that shock does indeed affect the crystallographic character of minerals from iron meteorites (*4*).

For taenite and troilite our preliminary results were not conclusive. However, grains of kamacite, schreibersite, and cohenite show definite evidence of shock-induced crystallographic alteration. Figure 1 shows typical diffraction patterns for cohenite from lightly (*A*),