Distribution of Small Channels on the Martian Surface

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The distribution of small channels on Mars has been mapped from Mariner 9 images, at the 1:5 000 000 scale, by the author. The small channels referred to here are small valleys ranging in width from the resolution limit of the Mariner 9 wide-angle images (~1 km) to about 10 km. The greatest density of small channels occurs in dark cratered terrain. This dark zone forms a broad subequatorial band around the planet. The observed distribution may be the result of decreased small-channel visibility in bright areas due to obscuration by a high albedo dust or sediment mantle. Crater densities within two small-channel segments show crater size-frequency distributions consistent with those of the oldest of the heavily cratered plains units. Such crater densities coupled with the almost exclusive occurrence of small channels in old cratered terrain and the generally degraded appearance of small channels in the high-resolution images (~100m) imply a major episode of small-channel formation early in Martian geologic history.

INTRODUCTION

Probably one of the most surprising features on Mars photographed during the Mariner 9 mission was the Martian channels (Masursky, 1973; Milton, 1973; Sharp, 1973; Sagan et al., 1973). There are many hundreds of channels on Mars visible in Mariner 9 photography displaying a wide range of morphology varying from the immense cliff-rimmed Kasei, Shalbatana, Simud, and Ares channels (1000-2000 km long and 100-200 km wide) to diminutive filamental channel networks, the smallest channels visible (a few hundred meters wide) being limited by the resolution of the narrow-angle images. Masursky (1973) categorized the Martian channels into four types: (1) broad and sinuous (~100-200 km wide), (2) narrow with braided floors and tributaries (25-50 km wide), (3) small and closely spaced, and (4) those associated with volcanic centers. Though the morphological varieties of channel systems on Mars may be much greater, this classification scheme will suffice for the purpose of this discussion.

By far the most abundant type of channel on Mars, and the subject of this paper, is the third type, the system of closely spaced small channels. These filamental channels are generally small in comparison to the other classes of channels, varying from 1 to 10 km in width and rarely extending more than 150 km in length. They exhibit both dendritic and reticulate patterns, both angular and sinuous, dissecting the surrounding terrain to varying degrees (Milton, 1973). The purpose of this study was (1) to map the global distribution of small channel systems on Mars; and (2) to establish any correlations between the distribution of small channels and terrain type, relative age of the terrain (based on density of small craters), albedo, population of large craters, and topography—in short, to determine the areal extent and period of small-channel formation and degradation and find any associations with other surface processes.

EXAMPLES OF SMALL CHANNELS

Several examples of small filamental channels are shown in Figs. 1a–Id. In
these wide-angle photographs, typical of occurrences in equatorial regions, the small channels often appear deeply incised. Narrow-angle photographs of these channels show extremely rough, ragged channel sides with numerous craters occurring in the channels (Figs. 2a–2c). Figure 3 is a wide-angle “A-camera” photograph of some relatively linear small channels. Figure 4 is a mosaic composed of three narrow-angle “B-camera” photographs centered on one of the small channels shown in Fig. 3. The channel in Fig. 4 is about 5 km in width, with about 150 km of its approximately 200 km length visible in this photograph. Although the channel sides are rather subdued, incipient dendritic tributaries are visible. Further indications of dissection of the terrain are evident in the morphology at scales down to the resolution limit of the narrow-angle frames. Figure 4 is one of the best high-resolution views of the small channels. Such frames are very rare at present. There are only about ten high-resolution frames in which small channels are clearly visible, representing about 1% high-resolution photograph coverage in the latitudes at which most small channels are seen. Assuming an essentially random photographic coverage with respect to the small channels, it is estimated that there are of

Fig. 1a. Wide-angle view (picture width about 400 km) of typical small channel, centered on 345.07 longitude, -10.06 latitude, in the dark equatorial region. The terrain appears to be heavily dissected, particularly around the north rim of the basin in the center of the picture. Most channels seem to be oriented NW SE. Widths of channels range from the resolution of the photo to about 10 km (DAS 6714788, processed at Center of Astrogeology, USGS, Flagstaff, Arizona).

Fig. 1b. Wide-angle view (picture width about 350 km) centered on 330.07 longitude, -10.43 latitude, of small-channel groupings in the dark equatorial region. Notice particularly the radial orientation of channels with respect to the two large craters in the upper center. A close-up of the channel network just below these two large craters is shown in Fig. 2. The largest channels in this picture are approximately 10 km in width (DAS 61620630, processed at Center of Astrogeology, USGS, Flagstaff, Arizona).

Fig. 1c. Wide-angle view (picture width about 400 km) centered on 317.27 longitude, -9.03 latitude, showing, again, small-channel groupings in the dark equatorial region. Note the banded, dissected appearance of the equatorial terrain. Compare Ic with Id (DAS 6930738).

Fig. 1d. Wide-angle view (picture width about 400 km) centered on 311.09 longitude, 8.95 latitude of cratered terrain with high albedo. Channels in this figure appear subdued, barely visible, without extreme contrast enhancement. Such subdued appearance is typical of the few channel networks visible in regions of high albedo (DAS 6931298, processed at Center of Astrogeology, USGS, Flagstaff, Arizona).

Fig. 2a. A mosaic of high-resolution B-frame photos of the small-channel system shown in Fig. 1b. The terrain is extremely rough. The view is downslope, with the high rim of the large crater doublet mentioned in Fig. 1b visible at the bottom of the photograph. The rims of large craters in the equatorial regions are heavily dissected by networks of small channels. This mosaic is a typical view of such terrain (DAS 9736794, 9736864, 9736934, processed at the Center of Astrogeology, USGS, Flagstaff, Arizona).

Fig. 2b. This photograph is a narrow-angle B-frame (photo width is approximately 40 km) of a small-channel segment located at about 0.87 longitude, -5.92 latitude. The terrain on either side of the channel is heavily eroded (DAS 13165294).

Fig. 2c. This figure is a high-contrast enhancement of DAS 6570763 (centered at 8° longitude, -22° latitude). A small channel spans the bottom of the photograph. Illumination is from the upper left corner. The terrain in this region appears to be extremely rough in this image; however, roughness in wide-angle images of this same region is not apparent. Drainage into channel on this terrain would occur from top to bottom of the image.

Fig. 3. Wide-angle view of a relatively subdued channel network located about 304.98 longitude, -19.30 latitude. The downslope direction is from upper left to lower right. Contrast enhancement is extreme in order to bring out the topography in areas of intermediate albedo. The relatively large sinuous channel just to the upper right of the two large elongated pits is shown in narrow-angle view in Fig. 4 (DAS 7074588).
the order of $10^3$ small channels (width >1 km) visible in the area studied.

**A Planetwide Survey**

A global survey of Mars was carried out to determine the distribution of the filamental channels. The distribution of small channels was mapped in the zone between 30° N latitude and 65° S latitude using all available Mariner 9 wide-angle images. The channel positions were then plotted on 1:5 000 000 series photomosaics. Examples of these data are shown in Figs. 5, 6, and 7. The small channels range in width from the resolution limit of the narrow-angle television images (~100 m) up to about 10 km. Narrow-angle images were used to confirm observations based on wide-angle images wherever overlapping coverage existed.

Using the 1:5 000 000 scale Mercator plots of channel distribution, a 1:25 000 000 global map of small-channel distribution was compiled (Fig. 8) on an airbrushed albedo and topography base (Inge, 1974). It would be virtually impossible to show at journal page size the position of each of over 2000 small channels mapped at the 1:5 000 000 scale in a journal format; hence, Fig. 8 represents only dominant channels and channel clusters.

**A Global Correlation**

Figure 8 shows that almost all small filamental channel systems are confined to latitudes from +90° to +30° and −65° to −90° were excluded from this survey due to the marginal quality of the resolution with respect to features <10 km in width.

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**Fig. 4.** This channel is about 5 km in width, and about 150 km of its length is visible in this three narrow-angle B-frame mosaic. Channel sides are rather subdued and incipient dendritic tributaries are visible along its length. (Again, extreme contrast enhancement brings out detail in the moderate albedo areas while saturating areas of high and low albedo.) Dissection of terrain on either side of the channel is visible down to the resolution limit of the photograph. Less than ten high-quality, high-resolution photographs of small channels exist, of which this mosaic is probably the best (DAS 9880159, 9880089, 9880019). (Centred at 305° longitude, −19° latitude.)
Fig. 5. A map of small-channel distribution in Sinus Sabaeus quadrangle, MC20. Map base is semicontrolled photomosaic, 1:5 000 000 scale, USGS, Center of Astrogeology, Flagstaff, Arizona.
Fig. 6. Map of small-channel distribution in Mare Tyrhenenum quadrangle. Map base is a semicontrolled photomosaic, MC22, 1:5 000 000 scale, USGS, Center of Astrogeology, Flagstaff, Arizona. Note the distinctly lower density of small channels in the Hesperia Planum region in the center of the photomosaic. Hesperia Planum is a young, dark plains unit with a prominent volcanic construct at about 252° longitude, -22° latitude. Note the radial distribution of small channels around the volcanic center. These channels are almost certainly volcanic in origin.
Fig. 7. Map of small-channel distribution in Acolis quadrangle. Map base is a semicontrolled photomosaic, 1:5 000 000 scale, MC23, compiled at USGS, Center of Astrogeology, Flagstaff, Arizona.
A comparison of the small-channel map of Sinus Sabaeus quadrangle (MC-20) (top), of Mars compiled by the author, and a sun elevation angle corrected photomosaic (Batson, 1973) showing the location of the classic dark feature Sinus Sabaeus and part of Sinus Meridiani (bottom). A comparison of the channel map and the photomosaic shows a strong correlation between small-channel density and low albedo. Note particularly the bright patch (at about $-5^\circ$ latitude, $350^\circ$ longitude) which is devoid of small channels. The bright patch presumably consists of high albedo mobile material which has been deposited by wind, and may have buried more rugged terrain.
dark, low albedo regions between 15° N and 30° S latitudes, centered at about 20° S latitude. This is perhaps the first time that the classical albedo features of Mars have been well correlated on a global scale with the occurrence of a geologic feature.

The correlation is particularly striking in the Meridiani Sinus and Sabaeus Sinus region. Figure 9 shows the small channel map of MC-20 drawn by the author and a sun angle controlled photomosaic (Batson, 1973) of the same quadrangle which includes Sabaeus Sinus and Meridiani Sinus. A comparison of the channel map and the albedo photomosaic shows that small channels are concentrated intensely in the dark area and are almost nonexistent to the south. Notice in both Figs. 8 and 9 the rapid increase in small-channel density crossing bright/dark area boundaries. The correlation is also particularly good in MC 23 (compare Fig. 7 with Fig. 8).

There are a few anomalies in the global correlation. Figure 6 (MC 22) and Fig. 10 (MC 23) show two of the major anomalies which violate the correlation between low albedo and high small channel density. These two anomalous regions, Hesperia Planum and Syrtis Major Planitia, are low albedo cratered plains units markedly devoid of small channels. In general, Martian plains units show very few small channels. High northern and southern latitudes are usually also devoid of small channels. Hence, a second condition must be added to the global correlation of high small-channel density and low albedo: Small channels are seen in regions of both low albedo and high density of large (> 20 km in diameter) craters. This double correlation, quite visible in Fig. 8, implies that small channels are most numerous in cratered uplands of low albedo.

**Relationships of Small Channels to Topography**

The relationship between the frequency of occurrence of small channels and regionally high and low areas within old cratered terrain was also investigated. The ultraviolet spectrometer (UVS) data from the Mariner 9 mission, revised as of August 1973 (Hord et al., 1972) was combined with Haystack and Goldstone Earth-based radar data (Goldstein et al., 1970; Pettengill et al., 1969), occultation point data (Kliore et al., 1973), and IRRIS data (Kieffer et al., 1973) to provide global topography. Local slopes, as one might expect, have an effect on the shapes of channel systems within a particular region. There is, however, no general trend which would suggest a correlation of the density of small channels with regional variation of altitude, globally.

**Other Correlations**

It has been pointed out (Soderblom et al., 1974) that several other phenomena correlate with the zone of high small-channel density. The region of highest small-crater (0.6-1.2 km in diameter) density and the Martian wind equator are coincident with the equatorial band of high small-channel density. They conclude that the small craters are easily obscured due to complete and partial burial by surface dust and debris mantling, and it seems probable that small channels are likewise affected, probably to a greater degree.

The decrease in spatial density of small craters and small channels with increasing latitude and the filling of crater interiors with bright material (Soderblom et al., 1973; Woronow and King, 1972; Sagan et al., 1973) indicates that burial is at least one mechanism which could account for the erasure of small channels in these same regions.

The dichotomy in small-channel distribution, then, has at least one major implication: Small channels may exist beneath bright mantles of varying thicknesses and become visible when prevailing winds are strong and steady enough to remove the obscuring layer of dust and/or poorly consolidated sediment.

2 With the exception of some volcanic channels associated with Tyrrhenum Patera.

3 Latitude of zero net colian transport north or south (Soderblom et al., 1974).
Map of small-channel distribution in Syrtis Major Quadrangle. Map base is a semicontrolled photomosaic, MC13, 1:5,000,000 scale.

Isolated linear features in the upper center of the picture are related to regional structure and are not true "small channels."
Deflation of surface materials effective to many tens of meters has been observed on the Earth in areas such as the Quattara depression and the Gobi Desert, even to the extent of excavating deflation hollows in granite terrain (Berkey and Morris, 1927). The removal of overburden by deflation, then, seems reasonable for Mars where planetwide dust storms are common and high abrasion rates are predicted. Such models invoking deflation as a mechanism for production of dark areas in general on Mars have been proposed previously (Sagan and Pollack, 1967; Sagan et al., 1973; Cutts et al., 1971). It seems, then, that though small channels are highly visible in the dark cratered uplands, they are by no means exclusive to these areas and may, in fact, be ubiquitous to all cratered uplands.

The inference that high concentrations of small channels in equatorial regions implies a formative mechanism working preferentially in these areas, as per Sagan et al. (1973), should be pursued with caution in the light of a burial hypothesis. One consequence of such burial of surface features may be that the so-called permanent dark markings of Mars which have been observed from the Earth are in reality only a migrating window (Soderblom, 1974) to the bedrock, a zone relatively deflated of dust (Sagan et al., 1971), coinciding with the steadiest winds, which moves north and south periodically over geologic time as the obliquity varies.

**Discussion of the Relative Age of Small Channels**

It appears that small-channel distribution and morphology, aside from implications regarding surface visibility, may yield information regarding their relative age. The inference that high concentrations of small channels in equatorial regions implies a formative mechanism working preferentially in these areas, as per Sagan et al. (1973), should be pursued with caution in the light of a burial hypothesis. One consequence of such burial of surface features may be that the so-called permanent dark markings of Mars which have been observed from the Earth are in reality only a migrating window (Soderblom, 1974) to the bedrock, a zone relatively deflated of dust (Sagan et al., 1971), coinciding with the steadiest winds, which moves north and south periodically over geologic time as the obliquity varies.

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**Fig. 11.** Cumulative crater counts in two small channels as seen in DAS 06570763 and in the mosaic consisting of DAS 09880159, DAS 09880089, and DAS 09880019. Both channels are located in old cratered terrain. There are very few B-frames which show small channels clearly and crater counts were performed utilizing two of the best image sets. The data presented here show that the small channels under consideration exhibit a small crater population similar to that surrounding the old cratered terrain, and differ markedly from the crater populations in the presumably younger volcanic and plains units. Caution must be used in drawing conclusions based on such scanty data alone. Such counts, however, coupled with the lack of small channels on fresher surfaces, may imply great age.
age. Particularly significant in this regard are the two regions of low albedo and very low small-channel density which have already been mentioned, Syrtis Major Planitia and Hesperia Planum (Fig. 8). There are at least two explanations of the occurrence of the channels in dark cratered terrain and not in dark cratered plains:

1. Most small channels were formed before cratered plains and younger plains existed.

2. Small channels cannot form on the plains materials because they are too resistant (e.g., basalt flows), topographically too low, or too pervious (e.g., pyroclastics).

The hypothesis that the formation of almost all small channels predates the formation of Martian cratered plains units can be tested by examining the size/frequency distributions of small craters within the channels themselves. Small channels as a group are morphologically distinct from the intermediate and large channels, and generally are older than both groups of larger channels (Masursky and Granata, 1974; Hartmann, 1974). Crater counts within the channels on 4 B-frames (Fig. 11) show a size/frequency distribution very similar to that of the cratered uplands, setting an upper limit for the ages of the small channels as a group (3–3.5 billion yr based on the flux model of Soderblom et al., 1974). This fact, along with the intensely degraded appearance of almost all of the smaller channels and the almost exclusive and extensive occurrences of these channels on old cratered terrain, suggests that a major episode of small-channel forming occurred extremely early in Martian geologic history (Soderblom et al., 1974) and that the process was probably widespread over the entire planet.

**DISCUSSION OF PROCESSES**

The ubiquity of small channels would certainly not rule out structural (Schumm, 1974), ground ice (Sharp, 1973), or ground water sapping (Sharp and Malin, 1975) origins for small channels. Volcanism is not ruled out as a mechanism (Carr, 1974), particularly if associated with the widespread final evolution of an anorthositic crust (Soderblom, 1974). However, the case for channel formation by precipitation of atmospheric water (Sagan et al., 1973; Milton, 1973; Masursky, 1973) would be strengthened, particularly if a real, rather than an apparent, equatorial anisotropy in channel distribution can eventually be substantiated (Sagan et al., 1973), despite problems of small-channel detection in nonequatorial regions discussed above.

If rainfall were the prime agent of small-channel formation on Mars, accompanying fluvial erosion at a smaller scale than can be seen from Mariner 9 images probably occurred, producing many gulleys. Relict forms of such original fluvial terrain hypothesized may still exist (Lucchitta, 1974) despite eolian erosion and deposition. Hints of erosional terrain dissection can be seen in Fig. 4 on either side of the channel in the center of the photo. Significant amounts of such small-scale terrain dissection could have occurred on Mars, implying a greater surface roughness than is appreciated at present, the magnitude of which will become vital in the selection of a Viking landing site.

The ubiquity of old degraded small channels within the old cratered terrain, with a possible concentration in distribution near the equator of Mars, argues for an ancient and abundant channel-forming agent. Rainfall is an attractive explanation in some respects and unattractive in others. It would explain the dendritic patterns observed on high ridges and crater rims (Fig. 12a) (Milton, 1973; Masursky, 1973; Masursky and Granata, 1974) and the local coalescence of some small-channel systems into locally low areas. Interior structure and form of some small channels (Fig. 13) would be difficult to explain other than by fluid flow/flowing water hypotheses.

The possibility that small channels are ancient is consistent with a scenario of an initially thick early atmosphere, in which, for a time, precipitation would be possible. Small river valleys would then have been
formed and an intense period of leveling by fluvial erosion and deposition, volcanic mantling, or other processes could have ensued. The concept of widespread leveling has been invoked for early Martian history by several authors (Soderblom, 1974; Chapman, 1974; Hartmann, 1971, 1973), to help explain the absence of crater saturation on heavily cratered terrains. Eventually the early atmosphere could have been depleted by chemical reaction with the surface (Siever, 1974) and also precipitated out at the poles. Eolian excavation and possible ground ice sapping would have modified the original small river valleys and may have initiated new small channels along developing lines of structural weakness. It is possible that many river valley systems could have formed contemporaneously with the end of the torrential meteoritic flux (Soderblom et al., 1974) and were themselves completely or partially obliterated by impacts. Figure 14 shows the remnant of what was perhaps a more extensive small-channel system which may have survived the early meteorite torrent. Disjointed channel systems, having been semiobliterated by impacts and subsequently sculpted by less violent surface processes over geologic time, may be likely precursors to the incoherent and ancient small-channel systems observed on Mars today. It must be remembered, however, that such a departure from present conditions would have required a climatic excursion of great proportions, as would relatively short-term (period ~10^6 yr) periodic climatic change models (Sagan et al., 1973: Ward, 1973: Murray et al., 1973).

**Summary and Conclusions**

1. Small channels exist in preponderance in low albedo regions of old upland cratered terrains, and themselves appear to be old and degraded. The regions of high small-channel density correspond strikingly to the classical Martian albedo features as observed from Earth. This is perhaps the first time that Martian surface topography has been well correlated with large-scale albedo.

2. The observation of small channels in the low albedo cratered terrains is probably due to the lack of obscuration by bright dust; small channels could exist beneath a bright dust and loose sediment mantle in other areas of old cratered terrain.

3. Small crater distributions, which are themselves affected by dust mantling, and global wind distribution correlate positively with the zones of high small-channel density.

4. More recent plains units, of both high and low albedo, have very few, if any, visible small channels.

5. Small channels seem to coalesce into local topographically low areas, which could be indicative of fluid flow.

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Fig. 12. (a) A high-resolution B-frame (DAS 09124579, approximately 54 × 42 km) centered on 248.0 longitude, −35.7 latitude. This image illustrates the type of dissection which has occurred on the rims of large old craters. Note the gullying on both sides of the crater rim. Also note the almost concentric deposits present in the crater interior. (b) An aerial photograph of Meteor Crater near Winslow, Arizona (Western State Aviation). Note the similarity in gullying between the Martian and the terrestrial examples.

Fig. 13. A high-resolution B-frame (DAS 0930773) centered at longitude 316.20, latitude −6.95. This image shows a small part of a more extensive system of small dendritic channels, barely visible at A-frame resolution. Note the junction of two “tributary” channels at the right center of the picture. The morphology of the feature in the tributary running N.W. S.E. across the lower right-hand corner of the image is reminiscent of a terrestrial channel bar. There may also be evidence in this image for discrete flow episodes, although this is certainly not a unique interpretation. Note the scarp connecting points A and B on the image (illumination is from the left) which could be interpreted as resulting from a final flow episode in the right tributary.

Fig. 14. An A-frame image of an area in the Margaritifer Sinus quadrangle (MC 19). A highly dendritic, semiobliterated small-channel system appears in this image (DAS 07901848). There are at least four instances of large craters apparently superimposed on the preexisting channel system. Such superposition is indicative of great age.
6. The small channels exhibit a small crater size–frequency distribution curve which is very similar to that of the cratered upland terrain. They occur extensively on old cratered terrain and are themselves old and degraded.

7. Observations point to the possibility of an early (3-3.5 billion yr BP), possibly fluvial, episode of small-channel formation in Martian geologic history.

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