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INVESTIGATIONS OF MARTIAN HISTORY

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FINAL REPORT
September 1975

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TASK 1: GEOLOGIC AND STRATIGRAPHIC ANALYSIS OF "CHANNELS"
(Principal Investigator: William K. Hartmann)
Final Report prepared September 1975

I. BASIC WORK ON CONTRACT

The funded proposal leading to this work called for:

(1) New crater counts on channels
(2) Limited crater counts in provinces where channels are found
(3) Study of channel interaction with craters
(4) Structural studies on episodic histories of channels
(5) Photographic comparisons with terrestrial channels

This has been carried out in the following way. A number of Mariner frames were surveyed to pick out high resolution images of major channels and related areas of chaotic terrain. Stratigraphic studies were then made, both in the form of crater counts to determine what units had the least relative age, and in the form of comparison of geologic form (apparent degree of erosive smoothing, infilling, etc.). This work included items (1), (2) and (3).

Crater counts and stratigraphic studies were made for about a dozen channel systems, represented on forty Mariner photos and mosaics. Additionally, about eight frames of chaotic terrain have been analyzed.

Results of this investigation were generally compatible with results of my earlier study, of which this became an extension (Hartmann, 1974) "Geologic Observations of Martian Arroyos," JGR 79, 3951). In general, these results indicated that major channel and chaotic systems, grouped together, were relatively young, post-dating the old cratered terrain and probably forming shortly before the volcanic units such as the Tharsis plain. (Crater counts averaged among the major channels were nearly indistinguishable from those on the volcanic regions, but because major do not cross the volcanic units, the channels must pre-date them.)

These preliminary results were presented at the February 1975 meeting of the Division of Planetary Sciences, American Astronomical Society in Columbia, Maryland. At this meeting, and at another invited presentation of the results at Cornell University (October, 1974), I discussed the results with David Pieri, who has made a similar study of the smaller channels scattered through upland cratered terrains. Pieri has made an excellent investigation including crater counts and structural comparisons. Comparison of our two results shows that his finer channels have more craters than the major channels I studied, and are hence older. Pieri presented his results and comparison with mine at the 1975 Planetology Principal Investigators Meeting, Pasadena (March, 1975), where I also made remarks from the floor on the subject.

Taken together, the projects suggest exciting clues about Martian history. At the present state of our knowledge, all workers (Hartmann, 1973; Soderblom, 1974; Chapman, 1974; Jones, 1974; Arvidson, 1974) agree that Mars experienced some period or episode(s) of enhanced erosive activity, initially discovered through analysis of total numbers of craters of all classes and recognizable sizes. Mutch et al (1976, in press, The Geology of Mars, Princeton University Press) hypothesizes that this was a period of early dense atmospheric activity in which rain fell. The current work on channels indicates that much of the oldest, cratered terrain on Mars was rilled with apparent stream channels of kilometer-scale width -- the channels studied by Pieri. In many areas of Mars, as pointed out by J. Cutts and M. Malin (independent papers at PPPI meeting), massive sedimentary blankets are being stripped away, revealing older terrain; there is some suggestion that some small channels of Pieri's studies have been revealed in this way. Fluvial activity in larger channels apparently occurred or persisted at later times, mostly prior to the formation of the major volcanic provinces such as Tharsis. Some of this may have been related to flooding from water released in thermokarst terrain. At this point in the research, it has become important to distinguish the stratigraphy of channels in chaotic terrain and possible thermokarst topography from the other channels, and search for relations.

The final stages of the project have seen work in that area; items (2), (3) and (4) of the list in the first paragraph. A few major channels emerging from chaotic units have been studied. Crater counts were made in chaotic units and their backgrounds. In general, the chaotic regions have some of the lowest counts of craters, as shown in Fig. 1 (although the polar plains have the lowest crater densities of any large unit so far found on any planet except earth). This alone suggests collapse events (melting in permafrost regions?) in relatively recent times. In one area, the Tiu-Simud channel complex, there was some evidence of several stages of formation, with an old, cratered background unit and possible two chaotic units, one more eroded and cratered than the other (Fig. 2).

Photographic comparisons with earth-analog features, Item (5) in the first paragraph, have also been carried out. Figure 3 shows a photo of an arroyo near Tucson displaying braided sedimentary deposits very similar to those of Martian channels. A much larger selection of the author's photos from the Tucson area, SW Arizona, and Peru has been assembled . Two sets of comparative photos will be published in an article prepared independent of the contract and now in press in Smithsonian magazine. It is hoped that other examples can be published in later reports. All these materials strengthen the view that the main Martian channels have been formed by running water. The floor deposits, sinuosities, and stubby tributaries are very similar to those found in terrestrial arid regions where rainfall or other water sources are very infrequent, but occasionally very large. This comparison supports the hypothesis or episodic fluvial activity on Mars.

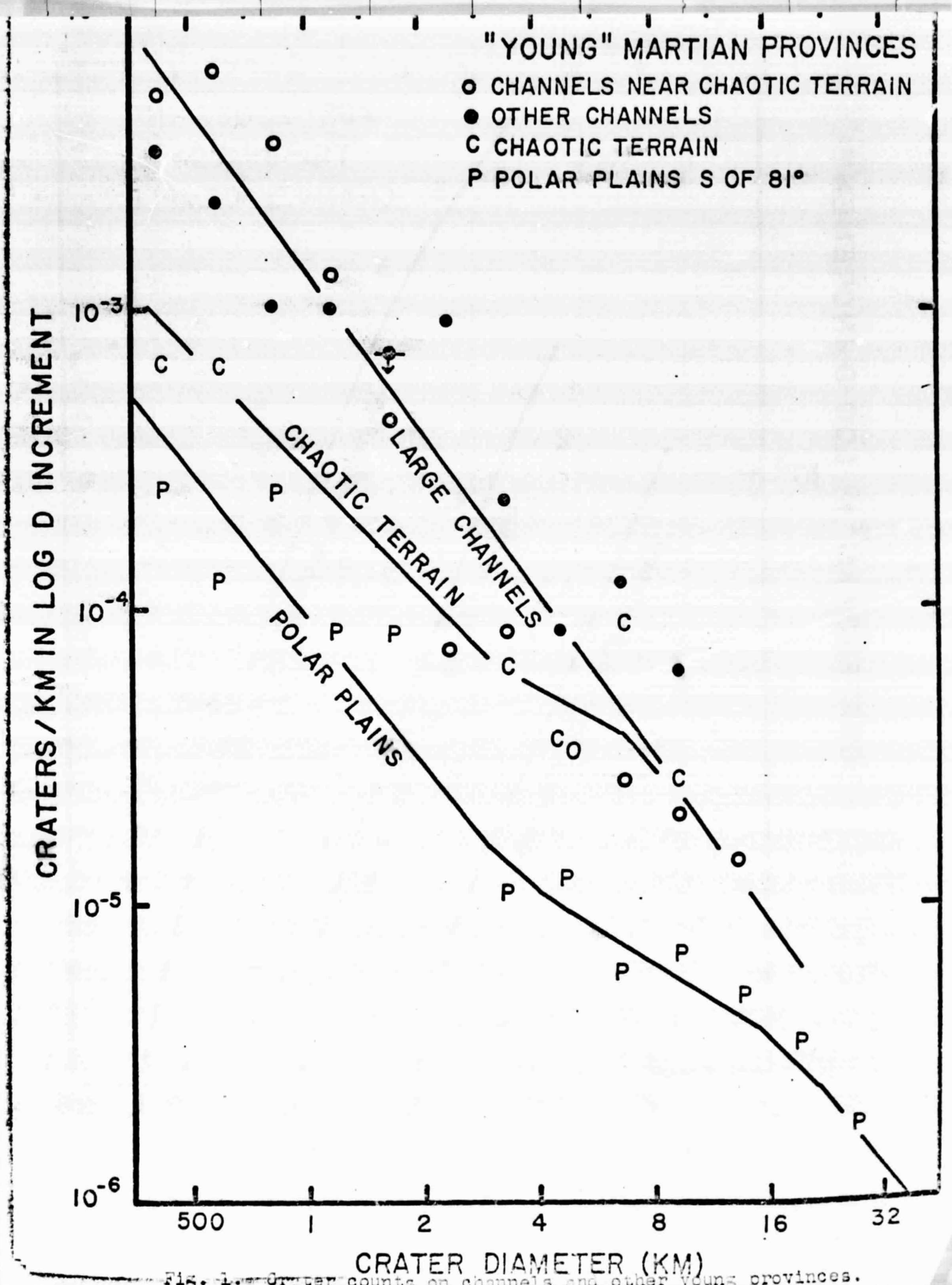

Fig. 1.—Crater counts on channels and other young provinces.

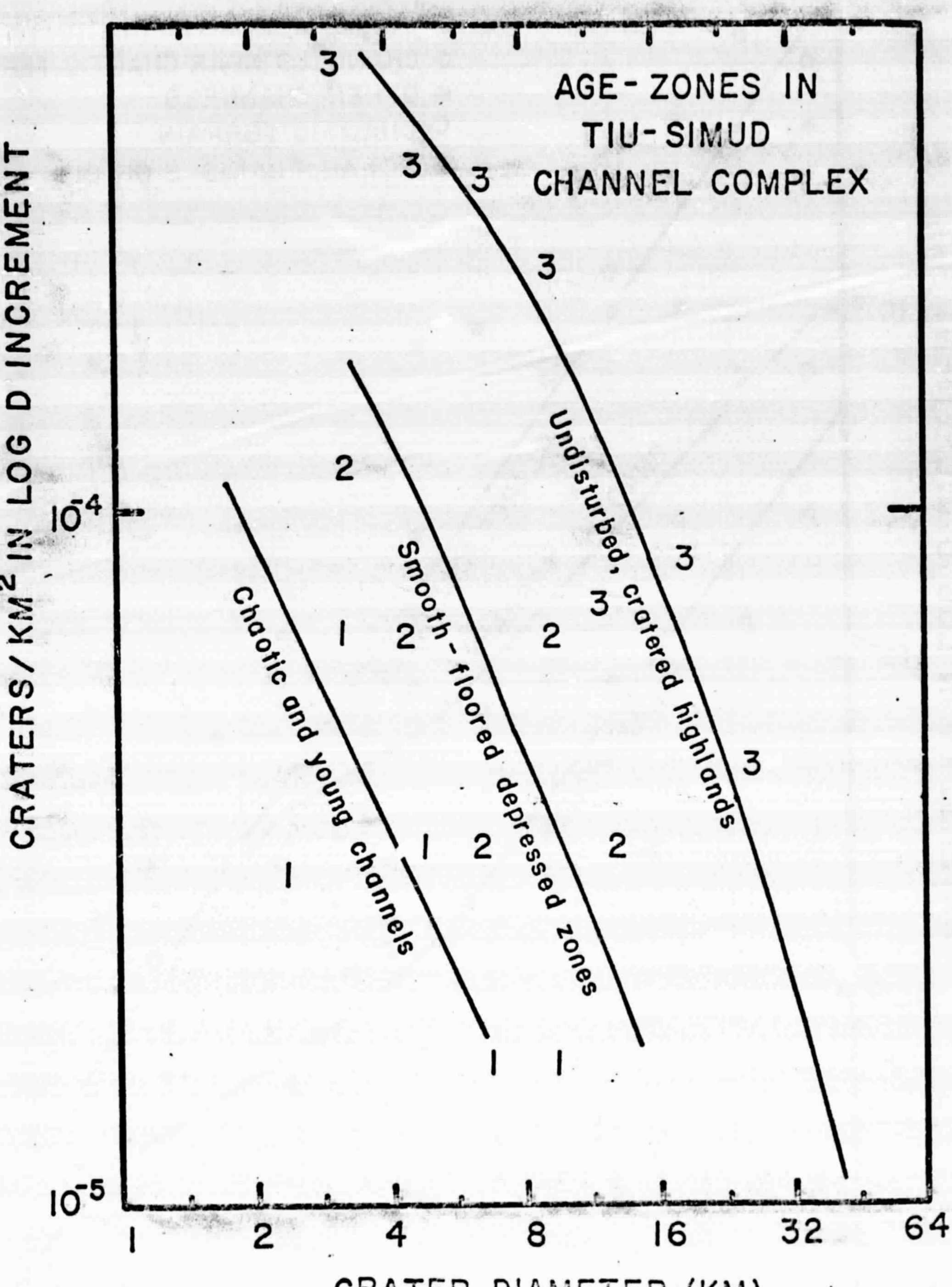

Fig. 2. Crater counts illustrating stratigraphy in a chaotic complex.

Fig. 3. Arroyo near Tucson, showing examples of braided and truncated deposits similar to those found on Mars. Note pattern at entry of side channel into main stream (arrow).

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In summary, the portions of this work related to relative stratigraphy of channels indicate that some major channels may have been fluvially active after the network of fine channels studied by Pieri, and that major channels from chaotic regions may have been independently active at similar later times. Channels having tributaries and isolated from chaotic units, continue to suggest atmospheric water sources or sources unrelated to permafrost and thermokarst activity. This has significance for Martian history, discussed in Part III.

II. THE PROBLEM OF ABSOLUTE AGES

The significance of this relative stratigraphy could be greatly enhanced if even the most crude absolute ages could be specified. For example, one theory of the channels (in conflict with Mutch et al, mentioned above) is that they formed temperate phases caused by oscillations in the orbital elements and obliquity of Mars. The longest-term cycles known are obliquity periodicities of 1.2 million year period studied by W. Ward (1973). I have pointed out that the number of craters superimposed on Martian channels are far too great to allow the hypothesis that they formed during episodes as recent as these cycles under any plausible cratering rate (Hartmann, 1974, JGR, in press; Hartmann, 1974, Icarus 19, 550) and the present work confirms this.

This shows the importance of combining these studies with critical studies of the Martian cratering rate . As shown by the above example, even a crude determination of Martian cratering rates with a factor 10 uncertainty allows us to separate "10^6 - year theories" from "10^9-year theories," thus narrowing the present wide range of Mars geologic theories. As of the last two years, this has become a tractable problem, since calculations of orbital lifetimes of interplanetary particles by Wetherill and others allow scaling of known lunar crater production rates to Martian rates. Although I have made some efforts toward such studies under this contract, I was discouraged from further work as part of this contract by directives from the Planetology Program office. Therefore, I have embarked on a critical review of the crater production rates from data of Wetherill and others, in a parallel program of my own . The whole problem is one of intense discussion at recent planetary meetings, including the International Mercury Colloquium, June 1975. My own critical review is complete and a manuscript has been prepared; it was referred to by Chapman and myself at the Mercury meeting, where problems of Martian chronology related to this contract were peripherally discussed. The study appears to give fairly firm limits of Martian cratering at about 1 to 10 times the lunar production rate, with most likely values being 1 to 3. Such values make the channels of the order 10^9 years in age, and rule out values such as 10^6 years.

Based on my own work, discussions and interest by various researchers at meetings including the DPS, PPPI, Lunar Science, and Mercury Colloquia, I still regard the relative crater production rates on terrestrial planets as an absolutely fundamental research area for planetology; it is tractable and will see progress in the next few years if further Wetherill-type calculations are supported.

III. SIGNIFICANCE OF THIS WORK

As I pointed out in my 1974 Icarus paper, the existence of Martian channels and their evidence for fluvial episodes has been one of the major unexpected discoveries of the space program and is perhaps the most striking unsolved problem. I believe this contract has been of considerable importance in bringing this problem to the attention of other scientists. For example:

(1) Carl Sagan has pointed out to me a recent article describing intense interest of Soviet scientists in the channels. Figure 4 is an excerpt from an article on the Soviet work, which probably reflects knowledge of our work.

(2) A recent article based on a pre-launch Viking press conference, carried in Tucson papers, quoted a discussion of the crater counts in Martian channels as evidence of fluvial periods in the past on Mars. This discussion, attributed in part to Dr. Sagan, reflects this work, and constituted a major fraction of the article as carried in the Tucson press.

(3) Independent of this contract, I have prepared an article for Smithsonian Magazine on the existence and implications of the channels. A hypothesis is that the fluvial episodes on Mars were caused by solar increases in luminosity which caused simultaneous warm periods on earth. Such periods are known from geological records, e.g. 120 million years ago. Editors at Smithsonian reviewed this hypothesis with workers in several areas including biology and geology. Rather than the skepticism I had considered likely, they reported to me that the general reaction was "Why didn't I think of that."

This last hypothesis, that solar variations may have occurred and may be evidenced in analysis of planetary imagery has many exciting ramifications, including a new explanation of certain geological cycles and explanation of evolutionary changes in terrestrial biology. The article referred to above is in press at this writing. Unfortunately, (in my opinion) I was directed by the Planetology Programs Office not to investigate this subject as part of the contract. My work on this implication of the contract research has thus been severely restricted, but I anticipate that there may be future interest in the whole subject of simultaneous planetary climatic fluctuations, and their effects on geology and biology.

THE PAST AND PRESENT OF MARS*

The possibility that Mars may become another Earth for our remote descendants is regarded as a distinct possibility by Professor Vasily Moroz. Writing in *Izvestia*, he develops a hypothesis supported by a number of Soviet scientists, who believe that some millions of years or even only some hundreds of thousands of years ago, Mars had an atmosphere the density of which was close to that of the Earth.

In support of this view Professor Moroz cites some of the latest information obtained with the help of the Soviet space probes Mars 4, 5, 6 and 7 (*Spaceflight*, June 1974, pp. 213-214).

"Mars has had surface water and may have surface water again," he says, "for changes of this kind have repeatedly taken place during the planet's geological history, with a definite periodicity." Evidence of this, he claims, are the traces of river beds which can be seen in photographs of the planet's surface. These river beds, he writes, are not more than a few million years old and can be seen on photographs taken by Mariner 9 two years ago and on others taken quite recently by Mars 5.

Frozen Atmosphere

It is suggested that 99 per cent of the Martian atmosphere is frozen in the polar caps, which consist of condensed carbon dioxide and water.

In order to corroborate this hypothesis, writes the scientist, it is important to establish that the amount of argon in the atmosphere of Mars amounts to at least 20 or 30 per cent.

Among the instruments carried by the landing module of Mars 6 was one which indicated that the planet's atmosphere contained about this proportion of an inert gas, which is probably argon.

Experiments designed to analyse directly the chemical

Photograph received from the Soviet spacecraft Mars 5 which became an artificial satellite of Mars on 12 February. The picture, which covers an area of about 62 x 62 miles (100 x 100 km), shows a flat-bottomed crater about 15.5 miles (25 km) across. On the crater wall is a small crater and on the inner slope many radial depressions.

Novosti Press Agency

... is not ruled out." Professor

FIGURE 4. This excerpt, based on an article in Izvestia, indicates strong Soviet interest in Martian channels, their ages, and implications. The Soviet suggestions on atmospheric argon suggest that a more massive atmosphere may have once existed.

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I anticipate publication of various portions of this research in papers planned during the next year. In my opinion, my independent work on crater production rates of the different planets must be completed before further publication makes sense, so that there will be some basis for commentary on absolute ages, rather than the relative ages discussed above. The Planetology Programs Office has discouraged my work on this subject as part of the contract, so that my paper on that subject has been prepared independently and is only now being completed. Papers involving the Martian research will then follow, utilizing the cratering chronology. In addition, the work has been described at the DPS meeting in a research paper, and discussed informally at the Planetology Programs Principal Investigators' meeting and at the International Colloquium on Mercury.

TASK 2: GEOMORPHOLOGICAL STUDIES OF SELECTED LOCAL MARTIAN REGIONS (Principal Investigator: Clark R. Chapman)

INTRODUCTION

A picture of Martian history has been developing over the past several years as a result of photogeological interpretation of the Mariner 9 photography. Involved in these interpretations are episodes or periods during Martian history during which a wide variety of geomorphological processes have been operating on Mars. Some of these are quite localized (e.g. to the polar regions) while others are more global in extent (aeolian deposition). One technique of quantitative geomorphological analysis has not been applied previously to elucidation of these processes: interpretation of diameter-frequency relations of different morphological classes of small craters. A comprehensive study has been made of the distributions of large craters by class as measured from the A-frames of Mariner 9 (Jones, 1974).

The present study was conceived as a preliminary attempt to study regional differences in small-crater morphologies on a variety of different Martian terrains, directed towards revealing the different characteristics of the locally dominant geomorphological processes. A thorough analysis of B-frame imagery may ultimately be desired, but the present study was quite limited in both scope and cost. Another task that had been proposed was to have included incorporation of the results of these cratering studies in a general synthesis of Martian geological history; but inasmuch as that task was not funded, we provide here only the narrower results of small crater studies and first-order interpretations of the resulting frequency curves.

This final report is intended to summarize the approach and implementation of the studies and to present examples of the regional crater studies and first-order geomorphological interpretation. A lengthier, more complete report on this work is being prepared for publication in a professional journal, probably Icarus, and will constitute the third installment of Chapman's "Cratering on Mars" series.

THE METHOD

Chapman (1968), Chapman et al (1968) (see also Chapman et al, 1969), Chapman et al (1970), and Chapman (1974a) have discussed the use of diameter-frequency relations of different morphological classes of craters. The craters are classified in one of four morphological classes based on over-all degradation of fresh-crater morphology. The same criteria have been used in the present study for classifying the craters, but it should be emphasized that due to differences in solar illumination angle and other factors between, for instance, the Mariner imagery and earlier lunar imagery, there is necessarily less of a one-to-one correspondence between the crater classifications used earlier than there is a uniformity throughout the present study.

Crater diameters have been sorted into diameter increment "bins" chosen to provide, where possible, adequate statistics to specify the crater frequency. The frequencies are the same as defined by Chapman and Haefner (1967): Incremental frequencies are the number of craters per square kilometer per kilometer diameter increment. The scales of the pictures in both vertical and horizontal dimensions have been determined from unpublished computer output giving the geometrical characteristics of the pictures. Portions of frames of poor quality have been excluded, as well as regions outside designated terrain types.

All identified craters are encircled on plastic overlay sheets with colors coded to the crater class. Subsequently the craters are measured and placed in a diameter bin. Typical bins are of width D to D+(D/2) or D to D+(D/3). Craters of fresh morphology are counted at smaller diameters than the more poorly resolved degraded classes. Care is taken to exclude from the final frequency curves any counts deemed to be incomplete. Typically, the freshest craters (class 1) are complete to about 0.3 km diameter.

Most emphasis has been directed toward B-frame analysis, but in order to place these counts in the context of the distributions of larger craters some counts have been done on A-frames and the crater distributions of Jones (1974) have been used to indicate the frequency of largest craters in specified terrain types, when possible. There is some degradation in quality of the counts near 1 to 2 km diameter for which the counting statistics are poor on B-frames and the resolution of A-frames is inadequate; however, these problems are not serious except for classes of craters that are already very rare at such sizes.

RESULTS EXEMPLIFIED

The figures show the detailed counts and averaged crater frequency distributions for important basal units: pm and pc. The pm unit near (90°, -25°) is represented by B-frames DAS 05923402 and DAS 05995293, as well as A-frame DAS 05923438 which contains part of the first B-frame. Jones (1974) pm 10 fresh crater population is also depicted. Raw counts are depicted, with those encircled being given high weight due both to quality and number of craters counted in that interval. Upper limits are given for increments in which no craters of the specified class exist; these are shown by numbers subscripted with carets. Smooth fits to the data are shown on a scale off-shifted from the raw data by one order of magnitude in diameter. Arrows indicate where frequency relations are indeterminate because crater density is too sparse for adequate counting statistics.

The pc unit near (70°, -25°) is also illustrated. It is based on B-frame DAS 06067323 and A-frame DAS 06139248, supplemented by relevant counts by Jones (1974) at largest diameters.

Raw data have been assembled for numerous other regions of fundamental importance or interest, including cratered terrain in areas for which the large crater populations have been especially carefully studied, and numerous terrain types in the Ismenius Lacus area. Final drafted illustrations of similar format to those illustrated here will appear in the paper currently being prepared for publication.

INTERPRETATION

An important trait of Mariner 9 B-frames is that the crater distributions and morphologies tend to be roughly similar everywhere on Mars by contrast with the very great differences in large-crater densities say between the cratered terrains and the plains units. This characteristic is not a surprising one in the context of crater-obliteration models that have been proposed in the past. It has been widely argued that the large craters on the cratered units were degraded and obliterated at some time before or concurrent with the formation of the plains-forming units on part of the planet. Chapman (1974) and Jones (1974) have argued more explicitly that this was a major episode in Martian history that was indeed roughly contemporaneous with the plains formation. It is not surprising that the same obliterative episode which so grossly degraded large craters, totally wiped out the small B-frame craters. There has been recratering of all units subsequent to the formation of the plains and very little concurrent obliteration, as indicated by the predominant fresh morphology of 1 to 10 km diameter craters. The degree to which small-crater distributions are similar in most Martian units means that since the obliterative episode, there has been rather similar subsequent obliterative processes, generally on a small scale, on all such units.

The evident duststorms and perhaps other obliterative processes have generally degraded the oldest of the smallest B-frame craters subsequent to the obliterative episode. Fig. 13 of Chapman (1974) illustrates expectations for B-frame morphology frequencies based on an erosion rate (relative to cratering rate) 1/7th of the rate preceding the episode. If anything, the B-frame results show that on many Martian units, the obliteration rate has been even slower. Nevertheless the reappearance of substantial numbers of class 2 craters below 1 km diameter, and class 3 craters below about 0.4 km (e.g. see pm and pc units illustrated herein) indicates that obliteration has been affecting these smallest craters. The vertical relief filled in, or eroded, by the cumulative effects of this obliteration since the formation of the plains unit is surprisingly little, perhaps 10 or 20 meters, at a maximum. If the episode is interpreted to have ended as long ago as 3 b.y. or more (e.g. Soderblom et al, 1974), then it is especially surprising that the erosion rate has been so low.

The generalities just discussed are not applicable to a number of localized regions on Mars, and it is for these regions that studies of differences from normality can be especially revealing and diagnostic of important processes, including much heavier cratering and/or obliteration activity than average. It is evident in certain few regions where small-crater spatial densities are much higher than average that either secondary cratering or multiple implacts have been occurring. In several cases, proximity to prominent large fresh craters, and morphological relationships (such as radial alignment) conclusively argue for secondary crater formation. But there are also cases of isolated groupings of small, circular craters, of similar morphology (sometimes very fresh, but occasionally quite subdued), that bear no obvious relationship to other large features and seem to be of exogenic origin. It seems likely that these swarms must represent nearly simultaneous impact by swarms of bodies, perhaps comet heads or tidally disrupted asteroids. An alternative explanation to tidal disruption may be disintegration in the Martian atmosphere at a time when it was appreciably denser than today.

The Ismenius Lacus area (Quad MC-5) displays many different terrain types indicating a variety of geomorphological processes. Cratered terrains to the south grade through dissected terrain to sparsely cratered plains to the north. There is extensive channelization. The diverse crater morphology distributions throughout this region reveal prominent local differences in both the relative efficacies of the degradational processes and in their temporal sequences. There are locally variable evidences of episodic deposition, episodic cratering, and possible exhumation of craters by dissection of the plateaus to the south. The presence of exhumed craters in a locality presents a complication to the interpretation of erosion processes which are most simply modelled as one-way processes. Nevertheless to the degree that a well-preserved ancient surface is cleanly revealed by exhumation, we can establish interpretations of cratering and obliterative processes in more ancient times. More refined interpretation of the episodic processes indicated by the crater morphology distributions may constrain the fluvial and aeolian erosional history.

Certain terrains are virtually devoid of craters. In some cases the few craters that are observed are very tiny fresh craters, consistent with very recent re-cratering -- in the absence of significant concurrent obliteration -- following a period of very great obliteration. When the few craters are rather large and of highly degraded morphology, we can then calculate the magnitude of the obliteration that has destroyed all smaller craters.

Elucidation of the extremely complex geomorphology in several regions of Mars will require synthesis of standard photogeological analysis with quantitative assessment of spatial and morphological parameters. The regional analyses performed in this small project exemplify the utility of the statistical analytical technique and point to the need for more systematic analysis of Mariner 9 B-frame imagery.

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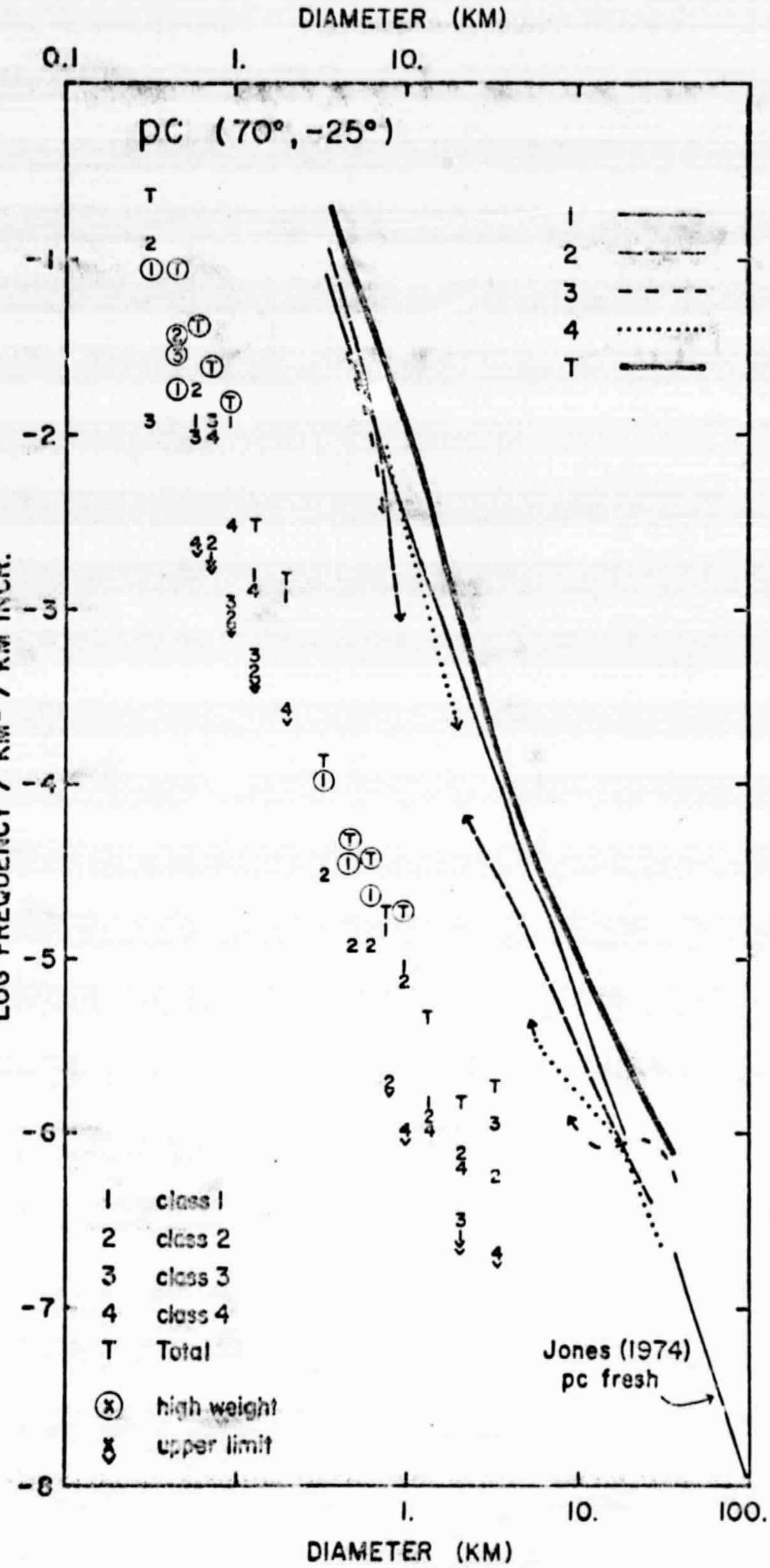
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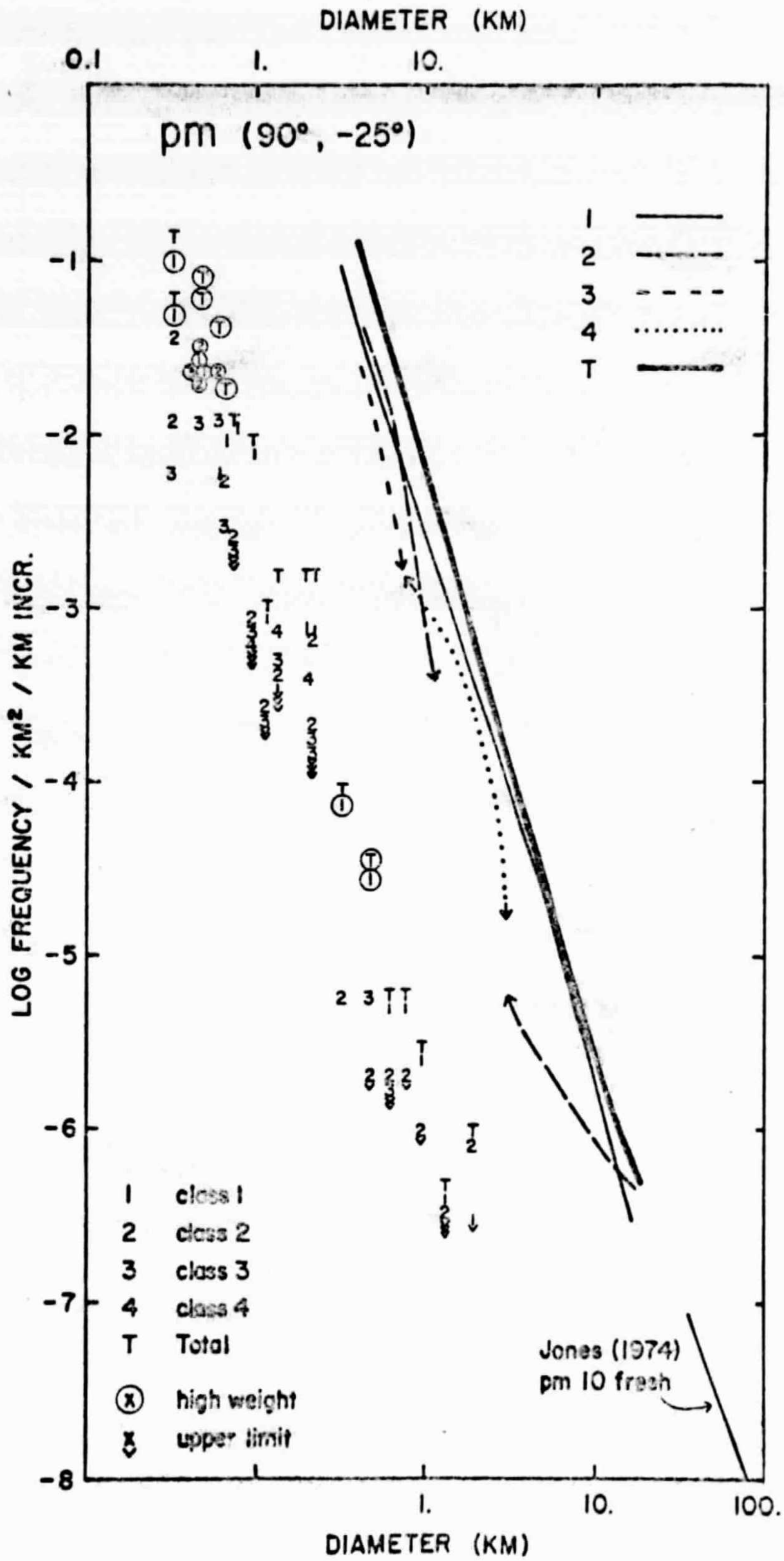
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