"Theoretical Researches into Planetary Atmospheres and their Influence upon Surface Features"

Grant Number: NGR 22-007-242

FINAL REPORT

Period: June 15, 1972 to October 1, 1974.

Submitted to: NASA Scientific and Technical Information Facility

P.O. Box 33

College Park, Maryland 20740

by: Richard Goody.

Richard Goody, Mallinckrodt Professor of Planetary Physics

Division of Engineering and Applied Physics

Harvard University

Cambridge, Massachusetts 02138

October 1, 1974

(NASA-CR-140188) THEORETICAL RESEARCHES INTO PLANETARY ATMOSPHERES AND THEIR INFLUENCE UPON SURFACE FEATURES Final Report, 15 Jun. 1972 - 1 Oct. 1974 (Harvard Univ.) 20 p HC $4.00 CSCL 03B

N74-35254

Unclas
G3/30 51538

The purpose of NGR 22-007-242 was to understand the interface between certain geological and atmospheric phenomena on Mars by investigating those geological features which could be associated with the presence of water in the liquid or solid phases. This research has been pursued by Alexander Woronow as a thesis project in the Dept. of Geological Sciences under the joint sponsorship of Professors Richard Goody and Richard O'Connell.

Alexander Woronow was slower in starting than was anticipated, and we requested a no-cost extension for the period June 15, 1973 to June 14, 1974. The aims of the investigation were unchanged.

On October 1, 1973 Woronow's work was incorporated into the objectives of another grant (NGL 22-007-228) in order to economize administration. From this point of time reporting has taken place under the combined grant.

A second objective of NGR 22-007-242 was to support 3 undergraduates who wished to work with Professor Michael McElroy. The success of this venture is described in Semi-Annual Status Report #1 for the period June 15, 1972 to January 14, 1973

Further reports describing the progress of Woronow's work are:

Semi-Annual Status Report #2 Jan. 15, 1973 to June 14, 1973.

Semi-Annual Status Report #3 June 15, 1973 to Jan. 14, 1974.

Continuation under NGL 22-007-228 is described in:

Semi-Annual Status Report #5 Sept. 30, 1973 to Jan. 14, 1974.

Since Woronow's work, is not yet completed an extensive discussion of its status is included in the report as an Appendix.

Publications under the grant are:

Gierasch, P.F. and Goody, R.M. 1973: A model of a Martian great dust storm, J. Atmos. Sci., 30, 169-179.

McElroy, M., Kong, D., Leverett, B. 1973: Photochemistry of the Martian atmosphere, in course of publication for Planet. Space. Sci.

APPENDIX I

Martian Flow Feature Morphologies

Summary:

We have examined several classes of martian surface features that may have had their origins in flow processes with the objective of determining what role ice may have played in their creations. Preliminary studies concerning the behavior of martian ice shelfs were conducted, with the conclusion that flow rates of martian and earth ice sheets are similar, and therefore, one should expect martian ice-carved landforms to display morphologies similar to their earth analogs.

Withdrawal of subsurface ice was found to be among the first explanations for the origins of the chaotic-terrains and drifted blocks. More detailed inquiries are being made into the effects of subsurface ice flowage on crater morphologies and crater population statistics.

The geologic and biologic evolution of Mars is closely tied to its atmospheric evolution. Since the discovery of river-like features on Mars, and the hypothesis that the chaotic terrains resulted from subterranean sapping, the possibility exists that Mars once possessed a more massive, and wet, atmosphere; but the precise physical nature of this atmosphere is completely unknown as is its meteorological behavior. But the apparent atmospheric saturation, or near saturation, with water at the present epoch suggests that a reservoir of water ice might be buffering the atmospheric water and that the atmosphere, if more massive, could be wet enough to produce rain. The depth of this ice reservoir and its thickness would depend on the thermal structure of the local subsurface and on the local water supply; this might cause the ice to be abundant in some locales and absent in others. The seemingly ubiquitous volcano-like structures on Mars may indicate a rather wide-spread degassing of the planet with the attendant possibility that some or much of the subsurface contains ice from juvenile waters.

Because of the important implications, that influence thought on the geologic, atmospheric and biologic evolution of Mars, attendant to free surface water, substantially more evidence for subsurface ice needs to be accumulated than is now available from the "looks like rivers" argument. Interestingly, there are considerable variations in the crater populations across Mars and these differences are being examined (as described later) to see if they could be attributable to the effects of subsurface ice. The mobility of ice, either moving down slope or spreading under its own weight, serves to distinguish ice behavior from that of a liquid or a solid. This intermediate mobility causes new landforms or modifications of pre-existing landforms, such as craters, on Mars.

The next section will examine the behavior of ice sheets under some simple assumptions so that an idea of the time constants of the motions of these bodies can be obtained, and their potential influence upon surface features can be evaluated.

Such studies could also serve as the foundation for examining what set of paleo-martian conditions would have made surface-glacier formation possible.

ICE SHEETS

This portion of the investigation consists of a parametric study of sheet glaciers to determine the effects of surface temperature (Ts), geothermal flux (F) and ice sheet thickness (H) on the behavior of a martian ice cap. The model employed is the steady state model where the temperature at any depth is not changing with time. Using an accumulation rate of 0.1 cm of new ice per martian year (Leovy,6) or less, a parameterized plot of the internal temperature distribution of the ice sheet was constructed where Ts, H and F were allowed to vary. From this, the maximum thickness of a sheet of ice that is not melted at its base can be calculated as a function of the assumed values of F and Ts (which is a function of latitude). As an example of the results, if a mean annual temperature of 250°K (near 25°S) is assumed and F of Mars is taken to be 3/4ths that of the earth, then the maximum thickness of ice without melting at its base would be 400m.

Another calculation was made to produce a plot of the spreading rate of an ice sheet assuming it behaves plastically with a yield stress of 1 bar. In order to calculate a spreading rate, an assumption of a steady state was made, requiring any accumulation on the glacier to be removed by horizontal transport of the ice. As a representative result, with a mass bälance of 0.1 cm/yr and a central thickness of 3 km, at one-half the distance from the center to the edge, the horizontal velocity would be 3.6 cm/yr, which is an earthlike rate and would probably produce landforms similar to their earth analogs.

An alternative to the assumption of the plastic behavior of ice, yet simply handled, is the assumption that all of the deformational response to the stresses caused by the weight of the ice is concentrated near the base of the ice sheet, where the stresses are naturally the greatest. If a parabolic crossection, is assumed (which the Antarctic ice sheet approximates), and if the heating effects of the deformation can be ignored, then for any height and width of the ice sheet, and for any ice grain size, geothermal flux and surface temperature the spreading rate can be calculated. As representative of the results of this model, a height to width ratio of 0.006 is assumed (a rough value for the earth's Antarctic cap), with a height of 2 km, a thermal flux of ½ that of the earth, a grain size of 10 mm and a surface temperature of 240°K, this results in a 2 m/yr spreading rate at a distance half way from the center to the edge of the sheet.

If the size of the ice grains is reduced by a factor of 10, a slightly greater than factor of 10 increase in velocity is realized, if the geothermal flux is halved, the velocity is practically halved. If the temperature is reduced to 160°K, the velocity is reduced to 10^{-5} mm/yr and the velocity is also proportional to 1/log(half-width).

Another fact from the calculations is that a 4.5 km thick polar cap would be at the pressure melting point at its base if the surface temperature were 162°K and the geothermal flux were equal to that of the earth.

Both of these two models, though simple, show that one might expect martian glaciers to behave roughly as their earth counterparts do and therefore produce landforms of a similar nature.

VALLEY GLACIERS

Calculations of the velocities of valley glaciers can be made under similar assumptions to those of the ice sheets and are dependent upon their surface environment as are the ice sheets. The calculations for valley glaciers have not yet been done. (But they would doubtless show that indicaters of valley glaciation might be found almost anywhere on Mars, if not unreasonable past climatic conditions are assumed.)

Before going on to the studies of subsurface ice behavior, consider the paleo-evidence for free surface water that is represented by the stream-like channels.

STREAM CHANNELS

Stream-like channels occur in all size ranges from features that dwarf the largest rivers on earth to features just visible on the B-frames. Pieri (7) of the USGS has mapped more than a thousand such features and finds that they are preferentially located on the low albedo terrains that are also heavily cratered, and, therefore, probably older. Schumm (8) notes that the size of these features corresponds more with river valleys than with the actual river beds, and that a wholly tectonic origin should not be ruled out.

Comparisons have been made between a few of the small branching features on the edge of the Coprates Chasma with ephemeral streams of the Southwest as measured by Leopold and Miller (5). Characterizations that they employed that could also be employed for the Mars channels were plots of log (stream order) versus log (stream length) or log (stream order) versus log (number of streams of a given order).

Both of these characterizations were found to give straight line graphs for the Earth arroyos. When these plots were made for the Mars channels, straight lines were also obtained, thus making the interpretation of the martian channels as ephemeral streams not inconsistent with the observations. However, the only test for similarity is the linearity of the logarithmic plot; the slope is not constrained nor is the intercept value. The linearity of these plots is not a very strong constraint as the scatter of data points is large, even for the Earth arroyos. A more sensitive and meaningful description of the earth systems is needed, against which the martian channels can be compared.

Consider now the classes of features on Mars that may have been caused by the motion or withdrawal of subsurface ice. They fall under the following types, each of which will be discussed in its own section at some length:

a. Rifted Blocks

b. Chaotic Terrains

c. Filled Craters

Along with the possible role of subsurface ice in the creation of each of these features, possible origins and applicable tests of origins as well as possible earth and moon analogs will be discussed.

RIFTED BLOCKS

The rifted blocks occur at the borders between two terrain types that are at different elevations. The highlands materials are more densely cratered than are the lowlands, but even the highlands ajoining the rifted regions are relatively sparsely cratered compared with the older surfaces of Mars. The development of the rifted blocks is most prominent on the western edge of Lunas Planum, which borders the plains surrounding the volcanic complex of the Tharsis Montes.

The rifted blocks appear as flat-topped plates bounded on three sides by rifts and on the fourth by the lowlands. The upper surfaces of the plates may be slightly tilted toward the lowlands, but the features on their surfaces more closely resemble those of the highlands than those of the lowlands.

There are three primary methods by which landforms can be created: tectonic activity, erosion, and deposition. The elevated position of the rifted blocks precludes their being formed by deposition, but within the regimes of tectonics and erosion a number of possibilities exist, of which the most likely are listed below.

Possibility 1: The rifted blocks are of a wholly tectonic origin: they are horsts bounded by a fault system and the rifts are actually grabens (Figure 1).

Possibility 2: This is also a tectonically created landform. The rift blocks could be sheets in a detachment fault like the Hart Mountain detachment fault, and the rifts would be formed in the break away zone (Figure 2).

Possibility 3: This possibility is basically erosional in nature. The rifted blocks are erosional remnants, in a sense, where the highlands are being eroded

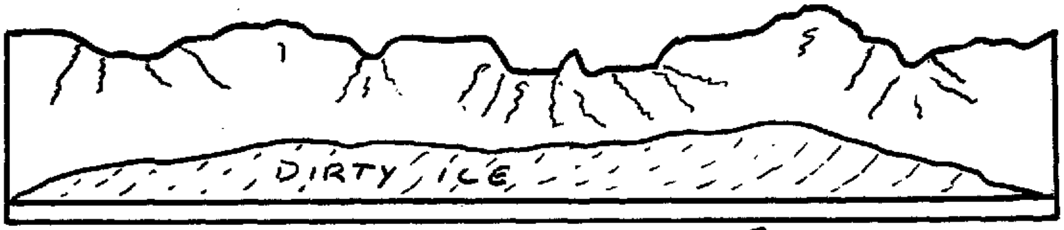

Figure 1

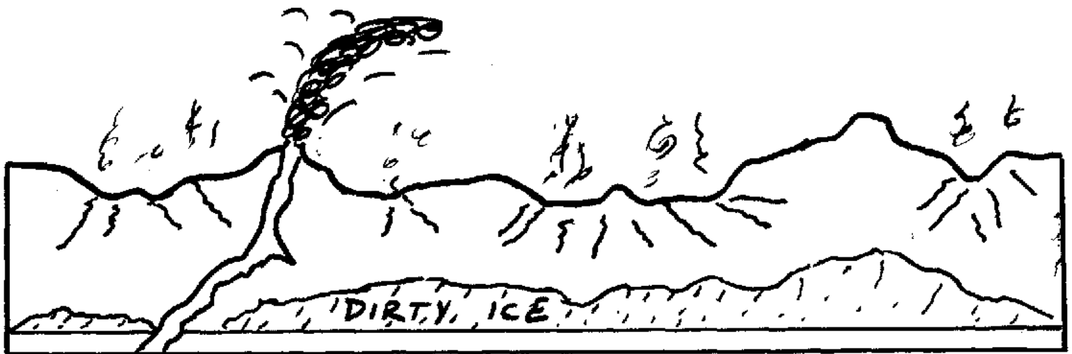

Figure 2

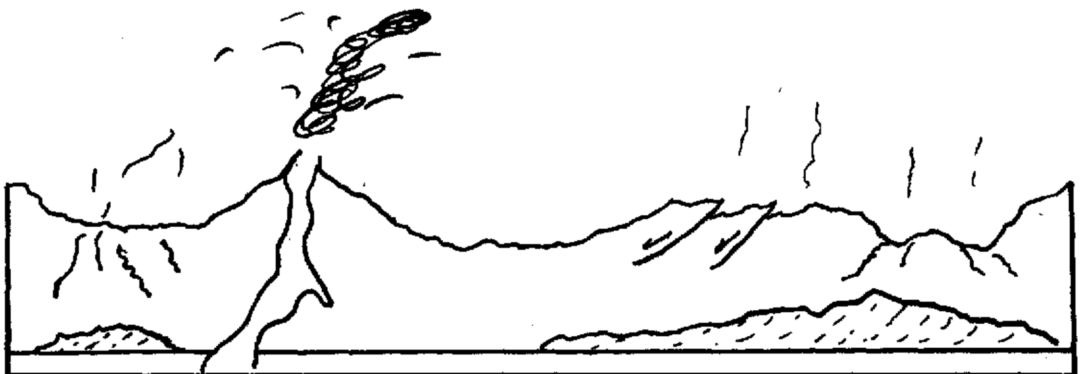

Figure 3

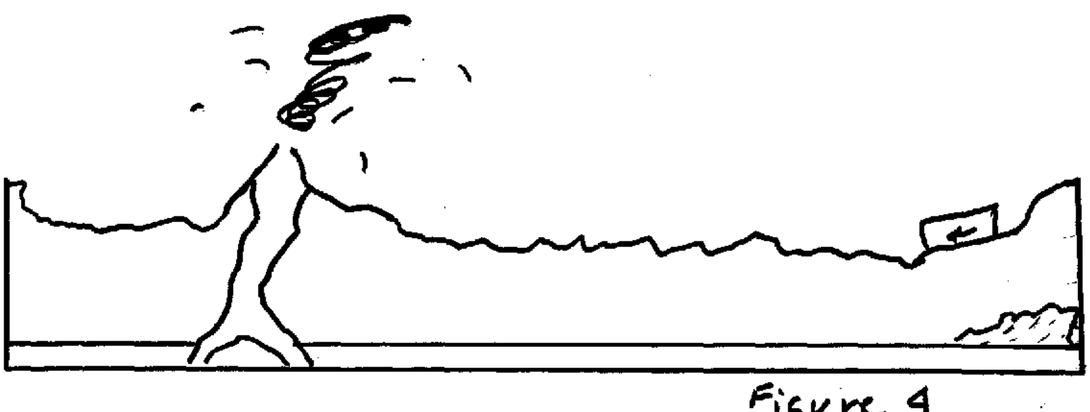

Figure 4

back and the rifts are actually regions of local deflation, possibly along joints, but no motion of the plates relative to the rifts has taken place. The erosion products, if removed by winds could be widely dispersed, if removed by water they should be found at the mouths where the rifts open onto the lowlands; no deposits are observed, but the photographic coverage of the rifted region may not be of sufficient resolution to show such deposits.

None of these first three possibilities, however, explain the paucity of craters on the highlands and only #2 accounts for the observed high degree of parallelism of the two walls of the rifts.

Possibility 4: The rifted blocks are underlain by a layer of ice that can either ablate from the exposed front or deform, essentially forming a glacier or rock glacier-like feature.

Imagine that once the lowlands were of the same elevation as the highlands, and that the entire region was underlain by ice of sufficient thickness that its removal would cause disintegration upon collapse of the overlying strata or crater rubble (Figure 3A). The sequence of events in the development of the rifts might be as follows: first a large ice layer exists under an extensive region of the surface. If a portion of this region becomes thermally active (perhaps leading to volcanic eruptions), the ice may be forced from the subsurface through fissures caused by the cratering events (Figure 3B). As the ice recedes from the warmer regions, collapse of the overlying strata also causes a receding slope (Figure 3C). As the edge of the once extensive ice lens is the only remaining ice, the last collapses are accompanied by rifting and gliding of blocks on the nonstable slopes (Figure 3D).

It is interesting to note that the atmosphere is being supplied water that must be removed at the poles if this last possibility is correct; this could aid in buffering the atmospheric water. Also, this last possibility is substantiated by the location of the rifted blocks on the border of the volcanically active

Tharsis Mones region. Additionally, a break-away fault requires that the two sides of the rift be parallel and nonre-enterant, a condition satisfied by observation; and craters on the highland could be filled by the process of ice flow described in the "Filled Craters" section.

CHAOTIC TERRAINS

The chaotic terrains occupy closed basins and are entirely surrounded by cratered or moderately cratered terrains (USGS terminology) (Carr, 3). As the name implies, the chaotic terrains have no uniform texture, but consist of blocks and ridges of varying size and no apparent preferred orientation. On the mariner A-frames the terrain has a somewhat blotchy appearance. There are indications that the chaotic terrains may be growing at the expense of the surrounding cratered terrains, as there are often small break-away faults near the borders and often the cratered terrain immediately adjacent to the chaotic terrain has craters with diminished sharpness and gives the impression that there has been some noncohesive movement toward the basin by the cratered terrains.

Nothing on the earth or moon is similar in morphology to the chaotic terrains while being of such substantial extent and occupying the basins. The material of the chaotic terrains looks like meteorite impact rubble, but its extent and position do not confirm this interpretation. It could be caldera-collapse features, were it not for its amorphous shape (one would expect nearly circular basins if caldera were the parent features). In fact, it appears that the search for earth or moon analogs will not be of assistance in the evaluation of these features.

The four possible origins listed below were all originally proposed by Sharp (9), and I believe that at this time there is still insufficient data to choose among them.

Possibility 1: The chaotic terrains were formed by down slope movements of the impact rubble (possibly containing an interstitial fluid) that covered the cratered terrains. Sharp originally suggested that a large impact(s) could cause the down slope movements, but our post Mariner 9 view of Mars makes possible tectonic tilting or quaking as an alternative driving mechanism.

Possibility 2: Winds have deflated the basins, carrying off the fine materials and leaving the larger blocks of rubble behind.

Possibility 3A: That the melting of segregated subsurface ice has led to roof caving.

Possibility 3B: That withdrawal of some other subsurface material has led to roof caving.

The possibilities are difficult to choose among on the basis of direct observations of the morphologies of the terrain. All of the possibilities satisfy all the details known at this time, although the need to generalize the withdrawn medium (3B) is doubtful: the only alternative to ice is magma. However, the only large volumes of surface flows lay far to the east of the chaotic terrains in the Tharsis region, and it is unlikely that the magma could be transported from as far away as the chaotic terrains while remaining close enough to the surface as to cause a collapse upon its withdrawal.

Possibility 3A's viability may lie in future developments in the field of the total water budgeted of Mars. The possibility that substantial water exists on Mars is real, but whether the quantities are sufficient to account for the chaotic terrains is uncertain. But the possibility that the chaotic terrains, in some way, correspond to the lowlands in Possibility 4 of the Rifted Block origins is very strong. Perhaps the only difference is the time since their formations; the rifted blocks are recently active and the collapsed material could have been largely removed from the older chaotic terrains.

FILLED CRATERS

There are very few craters on Mars that now retain their original sharpness of features. Ejecta blankets are scarce, secondaries are even more scarce and many craters obviously contain material of a different albedo than the host material. The issue to be addressed is the nature of the filling material and how it was inplaced. There are only two ways that any filling matter could come to rest in a crater; either it was carried in from above, or it arose from below. The first alternative implies either that winds have driven debris into the craters, and indeed, dune fields have been found in craters, or that ejecta from surrounding craters (exogenic or endogenic) came to rest in the adjoining craters. Both of these are certain to have taken place and may well have acted together to inundate a great many crater floors.

If filling was from below, the most likely medium is magma -- an event commonly observed on the moon. However, there is a more interesting possibility. If ice resides in the subsurface, its mobility under the laterally varying pressures around a crater could cause it to flow into the craters and gradually cause the floor of the crater to rise. Because the presence of ice is of prime interest in our study, this last alternative, with its characteristics and variations, will be the topic of the rest of this section.

The physical distribution of the ice beneath a crater depends on the history of the planet. If the ice predates the impacts, a geometry like those in Figure 4 is most likely, whereas, if the ice postdates the cratering, a geometry similar to those in Figure 5 is most likely.

Figure 4

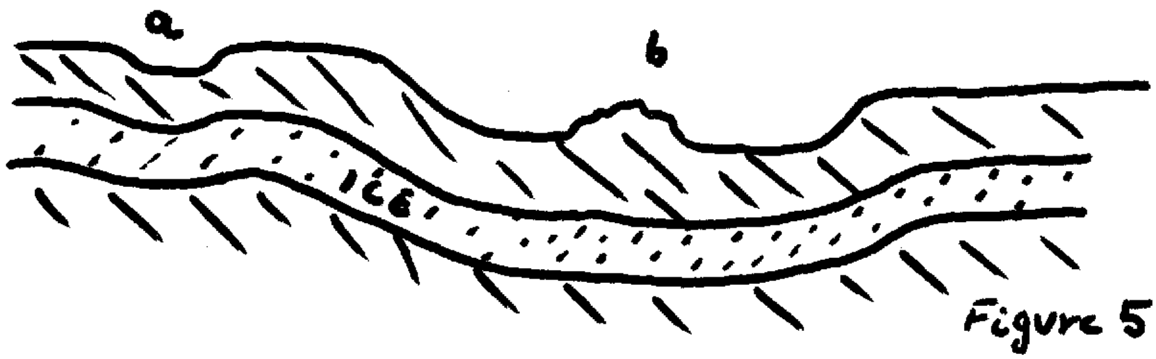

Figure 5

The mathematical treatment of the flow of ice differs for each geometry, and thus far only the simplest case, that of Figure 4a has been treated; however, one would not expect the other cases to vary from 4a by orders of magnitude since the processes involved in each are identical. The basic model used was that described by Jefferies (4); the outflow of an intermediate viscous layer. A theoretical crater profile with a depth to diameter ratio of 20:1 was used, and the geometry of the crater was chosen to be that of a square well. A sine-wave geometry for the crater would have been just as easy to model , but the square well has the advantage of providing a maximum relaxation time sotthat one might obtain an idea of the upper time limit of the infilling process. The strain rates used were taken from Ashby's data (2) on ice rheology with varying temperatures and pressures appropriate to the bottom of the craters. As the study now stands, only the depth of the crater's center has been monitored; however, the entire geometry of the crater would be easily followed with the addition of some computer time. The relaxation times reported in Table I are for pure ice: if the ice contains large amounts of debris, the relaxation times could increase by an order of magnitude. An ice crystal size of 1 mm was also used; if the crystal size varies, an order of magnitude could reasonably be added or subtracted from the times given below. Additionally, a more realistic model with better boundary conditions could change the times by an order of magnitude.

TABLE I

ICE ASSUMED TO BE 2 KM THICK.
CRATER ASPECT RATIO, 20.

INITIAL CRATER , DEPTH, KM	ICE TEMP. °K	TIME TO ½ DEPTH, YRS
1.5 (30 km dia)	150	1×10^7
1.0 (20 km dia)	150	2×10^6
0.5 (10 km dia)	150	8×10^5
1.5	180	8×10^5
1.0	180	3×10^4
0.5	180	1×10^4

Two things should be pointed out: 1) when a crater of any initial depth rises to a given fraction of its original depth, it will have the same slopes as any other crater of a different initial depth when that crater has risen to the same fraction of its initial depth (assuming similar depth to diameter ratios for all craters in the size range of interest) and therefore, be equally difficult to recognize. 2) Although the stress that drives the flow if ice into the craters is less for smaller craters, their half-lives are less because the ice that infills them has less far to be transported from the crater rim to the center.

Although the reality of the numbers in the above table could be challenged, the trends are well established (and probably not very model dependent): within any temperature range there is a wide variation in lifetimes depending on the initial depth; and, the lifetimes of similar size craters are extremely sensitive to temperature. Because all the lifetimes are substantially less than the age of the cratering, one could reject this model and go to those of Figure 5 with the hope of finding longer crater lifetimes, or one could suppose that Mars has undergone a history of environments substantially different from the one we now observe, and that ice infilling could have been delayed for a long time and only periodically activated. If the choice is to go to the Figure 5 model, there is no reason to believe that the ice was implaced immediately after the time of maximum crater formation. Indeed, the large expanses of volcanics of the Tharsis Mones postdate nearly all significant cratering, and it is not unreasonable to assume that degassing of Mars, allowing the formation of subsurface ice, also postdated the significant portion of the cratering. Hence, the short lifetimes need not mean that ice, if present, should have already filled all craters.

Although the filling times may be somewhat model dependent, the modifications to a population as infilling continues will trace a path that is not sensitive to the model assumed. The population modifications that are expected are as follows: in colder regions smaller craters will be eliminated more slowly than the same size crater in warmer subsurface regions (or craters in ice that was inplaced later will have suffered less modification than those in ice that was inplaced earlier). Therefore, one would expect to find crater populations in different regions of Mars corresponding to different "isochrons" derived from the models.

In order to examine the regional statistics for these predicted variations, size-frequency plots of the crater diameters were chosen. These plots display cumulative percent against crater diameter, enabling one to immediately read off the diameter of a 50 percentile crater, or conversely, immediately read off the percentile ranking of a 20 km crater. On these plots the changes in populations, because of selective elimination of smaller craters, is easily followed.

The theoretical changes in a population are easily standardized against the lunar highland crater population, or mare population. The lunar plots can be used as representative of the unfilled, original population, then at various later times the size-frequency distribution of the remaining craters could be calculated from the model. Arthur (1) has published a listing of lunar craters that would be ideal as the starting point for this project.

Thus far two regions have been examined for population variations: the region between Schiaparelli and Syrtis Major Planitia (centered on 320°E, 20°N), and the region between Argyre Planitia and Ares Vallis (centered on 20 E, 20 S). In the latter area 9 blocks of approximately 10x10 degree size were plotted on individual size-frequency plots, but no obvious latitude or surface feature correspondences with the population variations were found. The large size of the counting square did not provide the necessary resolution to easily recognize relationships between the statistics and the surface features. Therefore, when the other region was counted, the average counting square size was reduced to approximately 5x5 degrees. This gave enough points for regional variations to be studied. First the populations were standardized by assuming a cutoff value of 5 km diameter and adjusting the size-frequency distributions mathematically to this cutoff. Next the percentile ratings for each crater diameter from 10-50 km were read from the plots and those values assigned to the latitude and longitude of the counting square's center. The data was then smoothed and plotted by computer so as to yield a separate plot for each crater diameter of interest. The plots consist of contour lines representing the percentile rankings of various diameters over the planet's surface. Isopachs were also made in some intervals of interest so that regions having rapid or slow population changes with crater diameter could be identified.

In an attempt to find what parameters the spatial variations might correlate with, since latitude variations were immediately ruled out, several parameters were mapped. Two parameters of crater morphology were mapped, namely the state of the walls and the degree of floor covering. Nether of these parameters correlated with the observed population variations. A map was then made that displayed the surface distribution of various types of intercrater terrains; that is, the texture of the surfaces found between the craters. The units mapped were Smooth, Rough, Knobby, Mountainous and Striated. This map differs from the USGS geologic map in that crater density does not dictate the naming of units such as Moderately Cratered, Heavily Cratered and Lightly Cratered. A correlation between the crater population statistics and the terrain map was found. Craters upwards of 10 km tended very strongly to occupy lower percentile rankings on the Smooth intercrater terrains than on any other class of terrain, and the other terrains were not resolved from one another on the basis of crater statistics. This correlation is only of moderate value, because the quality of being smooth between craters probably results from a lack of small craters, which in turn causes larger craters to occupy lower percentile rankings. What is interesting is that this diminution of smaller craters extends at least beyond the 5 km cutoff used in this study. No correlations were found with the albedo markings, and elevation and slope have not yet been examined for possible correlations.

The crater statistics studies are continuing on a much larger scale. A deck of data on craters larger than 20 km for the entire surface of Mars was obtained from the USGS, but the reliability of that data was suspect, so the entire data set is being redone and extended down to 10 km diameter. In addition to recording the outside diameters of the craters, when a reliable measurement can be made, the inside diameter is also measured and codes are assigned to each crater specifying the presence or absence of various morphologies such as central peaks, ejecta blankets, crater filling material, and many other features. These data are recorded in 5 degree squares so that the population characteristics will have that resolution on the planet's surface. The results can be displayed optically through the facility at the USGS, as some preliminary data was done during my visit there. Any set of three parameters can be combined into one picture by the following false-color scheme: the values of the parameters within each 5 degree square are assigned a value from 0 to 64 -- the available gray scale -- and a black and white positive of the variation of each of the three parameters across the planet is made. The three are sucessively printed, one through a red light, one through a green and one through a blue, forming a color negative which is then printed to give a color positive. The areal changes in color indicate covariations in the three parameters. For example, if mean diameter is projected in red, standard deviation of crater depth in blue and crater density in green, one would expect of find flowing subsurface ice in regions that appeared quite red because the regions where ice is present would cause the elimination of the smaller craters driving up the mean diameter (causing a redder image), the ice would cause craters to be filled to a more uniform depth (causing little blue registration), and the selective elimination of smaller craters would drive down the total crater density (causing little green registration): therefore, the overall color would be toward the red.

To date 5/8ths of the surface has been recorded in the new data set.

REFERENCES

1. Arthur, D., 1966: Comm. Lunar Planet. Lab., V5, part 1, No. 70

2. Ashby, M.: Unpublished.

3. Carr, M., 1973: A generalized geologic map of Mars, J. Geophys. Res., Vol. 78, pp.4031.

4. Jefferies, H., 1929: The Earth, Second Edition, MacMillan Co.(New York)

5. Leopold, L. and Miller, J., 1953: The hydraulic geometry of stream channels and some physiographic implications, USGS Professional paper 252.

6. Leovy, C. et al.; 1972: The Martian atmosphere: Mariner 9 television experiment progress report, Icarus, 17, p. 373.

7. Pieri, D.:, 1974: Personal communication.

8. Schumm, S., 1974: International Conference on Mars in Pasadena, California.

9. Sharp, R. et al., 1971: The surface of Mars, , uncratered terrains, J. Geophys. Res., 76, p. 331.