

N89 - 18357

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FLUVIAL PROCESSES ON MARS: EROSION AND SEDIMENTATION; S.W. Squyres, Center for Radiophysics and Space Research, Cornell University, Ithaca, NY 14853

One of the most important discoveries of the Mariner 9 and Viking missions to Mars was widespread evidence for modification of the martian surface by the action of liquid water. From the standpoint of a Mars Rover/Sample Return mission, fluvial activity on Mars is important in two ways. First, channel formation has deeply eroded the martian crust, providing access to relatively undisturbed subsurface units. Second, much of the material eroded from channels may have been deposited in standing bodies of liquid water. The aqueous sediments that exist on Mars may preserve an excellent record of conditions when the planet was significantly warmer and wetter than it is at the present. In fact, there is probably a much better sedimentary record of the first billion years of martian history than there is of the first billion years of the Earth's history. This record may be read by locating and returning samples of ancient water-lain martian sediments.

The most striking fluvial erosion features on Mars are the outflow channels. These are most common in the equatorial regions of Mars, and are concentrated along the northern lowland/southern highland boundary. They generally arise from the highlands and debouch onto the lowland plains. The source regions usually show very complex topography that earns them the name chaotic terrain. The appearance of the chaotic terrain strongly suggests removal of subsurface material and widespread collapse of topography. The channels arise fully-born from these chaotic regions and may extend for many hundreds of kilometers. Although clearly the result of fluid flow, outflow channels bear only superficial similarity to terrestrial rivers. They are much more similar to the types of features formed by catastrophic floods on Earth. They were probably formed when subsurface fluid was released rapidly from a highly porous and permeable subsurface aquifer. Once released, the floods were apparently of sufficient size that they proceeded for enormous distances across the martian surface. They probably could have formed under the present climatic conditions. The density of impact craters superimposed on the outflow channels indicates that they date from fairly early in martian history.

A second type of channel apparently caused by flow of liquid water is the valley system. These are more similar to terrestrial drainage systems, consisting of narrow, often sinuous valleys with tributary systems. They are dissimilar to terrestrial stream systems in a number of ways, however, exhibiting irregular junction angles, high bifurcation ratios, and lack of stream competition for interfluves. They are more similar to terrestrial drainage systems formed by sapping, although formation by precipitation cannot be ruled out in a few cases. Valley systems are found in the ancient cratered highlands. The density of superimposed impact craters indicates that formation of valley systems was concentrated in the earliest part of martian history, probably more than 4 billion years ago. Because the fluid discharges implied by the valley systems are quite modest, it is unlikely that they could have formed under the present climatic conditions. They therefore provide evidence that the pressure and temperature of the atmosphere very early in Mars' history were higher than they are today. This more clement era apparently did not extend past the earliest part of martian history.

The sedimentary deposits of outflow channels are often difficult to identify. No obvious deposits such as deltaic accumulations are visible in Viking images. Instead, one merely observes the streamline and scour features characteristic of outflow channel erosion gradually giving way to a fairly nondescript plain. Similarly obscure sedimentary sink relationships are found for catastrophic flood features on the Earth. Significant fractions

of Mars' northern lowland plains may indeed consist of sediments eroded from outflow channels. These plains contain a variety of enigmatic features, some of which may be consistent with a sedimentary origin. For example, large-scale polygonal fracture patterns may have resulted from sediment dessication. However, the tentative identification of channel deposits on the northern plains is made primarily on the unsatisfying grounds of proximity to channel mouths, rather than on deposit morphology. There is somewhat more compelling evidence for deposition at some locations within the outflow channels that emanate from the eastern end of the Valles Marineris. In particular, areas of chaotic terrain in the upper reaches of Tiu and Simud Valles contain smooth interior deposits that may be sediments either generated locally or transported from still further upstream.

Another set of deposits that may be water-lain and that date approximately from the epoch of outflow channel formation are the layered deposits in the Valles Marineris. These deposits are widespread in the canyons, and exhibit fine rhythmic near-horizontal layering that is continuous over large areas. The deposits form erosional remnants that once may have covered larger areas of the valley floors. These remnants most commonly take the form of plateaus up to 5 km high with exposed layering on their steep faces. Individual layers range from ~ 70 to 300 m in thickness, and there may be finer layering below the resolution limit of Viking images. The layered deposits were emplaced during roughly the same period in which the Valles Marineris were enlarged by sapping, collapse, and weathering of the walls to form spur-and-gully topography. Further local canyon wall collapse and perhaps deep erosion of the deposits in some areas followed; the outflow channels emanating from the east end of the Valles Marineris may date from this epoch of erosion. The deposits predate the major episodes of landsliding in the canyons. One attractive hypothesis for the origin of these deposits is that they were laid down in large lakes that once occupied the Valles Marineris. The horizontality, lateral continuity, great thickness, and stratigraphic relationships of the layered deposits are consistent with deposition in standing bodies of water. Materials could have entered lakes by slumping from canyon walls, volcanic eruption on the canyon floor, or downward transport through an ice cover. However, there are other hypotheses that may also be consistent with the appearance of these deposits in Viking images. In particular, it is not possible to rule out with certainty the possibility that they are subaerial explosive volcanic deposits. These deposits are voluminous, well preserved, and well exposed, and should be considered an important possible target for a sample return. However, their identification as aqueous sediments must presently be considered equivocal.

From the standpoint of a Mars Rover/Sample Return mission, the problem with all of these possible water-lain sediments is their age, or rather the lack of it. All appear to date from the epoch of outflow channel formation. They postdate the early epoch of valley system formation, and hence probably postdate the warmest epoch of martian history. While a great deal of attention has been devoted to the morphologic details and climatological implications of valley systems, very little consideration has been given to their sediments. Within the ancient heavily cratered terrain, there are localized depressions that have acted as catchment basins for the water discharged from these valleys. They surely received sedimentary deposits of some sort. In a few instances, deposits can be identified within such depressions, often having a surface texture suggesting post-depositional freeze-thaw or subsidence. These materials may preserve the best record of the chemical and climatic environment on earliest Mars, and should also be considered important potential sites for returned samples.