The New Mars: Volcanism, Water, and a Debate over Its History

Mars has been studied for centuries with optical telescopes, and more recently with radar and with instrumented spacecraft on "flyby" trajectories. But the wealth of data obtained from the Mariner 9 spacecraft during nearly 700 orbits around the red planet has vastly improved knowledge of that body and has provided a third reference point—in addition to the moon and the earth—for understanding planetary physics. In the 14 months since the Mariner spacecraft first reached Mars, it has become clear as never before that the sun's fourth planet is a geologically active body with volcanic mountains and calderas larger than any on the earth. Interactions of wind, dust, and surface materials are now considered to account for the changes in the planet's appearance which have puzzled observers for so long. And there are strong indications that water, probably trapped in the polar caps, at one time flowed freely over part of the planet's surface, a possibility that has raised anew hopes that some form of life may exist on Mars.

Between 13 November 1971, when the Mariner spacecraft became the first man-made object to orbit another planet, and 27 October 1972, when depletion of the supply of gas used to keep the spacecraft positioned with its radio transmitter directed toward the earth caused it to be shut down, Mariner 9 took more than 7000 photographs in mapping the entire surface of the planet with its television cameras. Thermal and chemical maps of the surface, as well as studies of surface pressure, atmospheric composition, and the martian gravity field, were made with ultraviolet and infrared spectrometers, an infrared radiometer, and the telemetry signals from the spacecraft to Earth. Officials at the National Aeronautics and Space Administration count the mission a tremendous success, as do the scientists who are now digging into the vast amount of new information and offering the first tentative accounts of the planet's history.

Both atmospheric and surface features of the planet were studied. The planet-wide dust storm that obscured the surface in the early months of the mission proved a boon to those studying the martian atmosphere. Carl Sagan of Cornell University mapped streaks of dust extending from the leeward side of many craters and found that they formed a distinct global pattern. The streaks appear to have been laid down during the period of strongest winds and hence to give an indication of the surface winds during the dust storm. The circulation pattern, according to Conway Leovy of the University of Washington, agrees with theoretical models of meteorology at low martian latitudes and seems to be peculiar to its southern summer solstice—during which energy input from the sun is concentrated in a belt near 20° to 30° south of the equator. It appears likely that the coincidence of the summer solstice and the closest approach of Mars to the sun (perihelion) gave rise to the conditions that resulted in the dust storm. An initiating factor in the dust storm, according to Leovy, may have been the increased absorption of the sun's radiation due to dust particles raised by the strong winds that blow along the edges of the south polar cap during its yearly retreat.

Water in the Polar Caps

The polar caps had been thought to be carbon dioxide, which is the main component of the martian atmosphere. Measurements with the infrared spectrometer, however, showed the presence of water vapor in the atmosphere. At times, the atmosphere near the north pole was saturated with water vapor, although the total amount, because of the low temperatures, was small. Variations in the amount detected were correlated with the retreat of the northern polar cap, suggesting that it is the source of the water vapor. Other evidence is consistent with the idea that the residual polar caps are largely water.

Ozone was detected in the martian atmosphere with the ultraviolet spectrometer. The observed variations in ozone may add to the understanding of the stability of the protective ozone layer in the earth's stratosphere. The Mariner results show that ozone concentrations decreased in the summer when more water vapor was present in the atmosphere, presumably because of photochemical reactions involving water and ozone.

Several cloud systems were observed in the martian atmosphere. Among the most spectacular, according to Leovy, were those observed during summer on the slopes of the large volcanoes. The clouds were composed of water-ice crystals and had a cellular structure indicating convective activity, possibly the result of being heated from the surface, although the possibility that the clouds arise from vapors emitted by the volcanos is also being studied.

Wind speeds during the dust storm are believed to have averaged at least 30 meters per second in the equatorial region, and some investigators believe that velocities twice that high may have prevailed at the beginning of the storm. These high winds seem consistent with a martian surface marked by widespread erosion. Indeed, according to Hal Mazursky of the U.S. Geological Survey laboratory in Flagstaff, Arizona, eolian erosion is a dominant feature of Mars and is apparently so intense in some areas as to have completely eroded away preexisting volcanos. The edge of the largest existing volcano on Mars, Nix Olympica, is apparently being rapidly eaten away, exposing a 1- to 2-kilometer cliff around its base.

Nix Olympica and the three volcanos along the Tharsis ridge area are huge by any scale. One of the latter rises some 26 kilometers above the surrounding floor. As indicated by the relative scarcity of craters, these volcanic structures are also geologically recent. One estimate by William Hartmann of Science Applications Incorporated in Tucson, Arizona, puts the age of Nix Olympica at 100 million years and that of the Tharsis area at 300 million. But volcanic activity on Mars is not just a recent phenomenon. The Mariner photographs show many older volcanic structures, ranging from small calderas and volcanic vents to volcanic flows reminiscent of the lunar maria, and including at least one large primitive volcano. Many of these older structures are heavily cratered and severely eroded, and they appear to date back as far as 3 billion years, if crater counts are any indication.

East of the Tharsis volcanos is found a high plateau, and still further to the east, a large rift system that stretches nearly 5000 kilometers along the equator. The plateau is broken by faults that appear to indicate vertical movement of the crust. The faults coalesce to form the rift valley, a feature that presumably resulted from tensional forces in the crust whose cause is still unknown. Whatever its origin, the rift valley is the most dramatic evidence of tectonic activity on Mars. On a smaller scale, however, there appears to be evidence of faulting and other tectonic activity over much of the planet.

Perhaps the most startling finding of the Mariner effort has been the discovery of channels in the martian surface which appear to have been cut by running water. Three types of channels have been observed, all of them quite distinct from the lava channels seen on the moon and also on Mars. The largest of the putative stream beds emerge from the foot of landslide areas north of the rift valley and may have originated in the melting of permafrost uncovered in the slide debris. Smaller sinuous channels that originate nowhere in particular and run downhill, coalescing with other channels and becoming broader, have also been found. A third type is composed of a complex, interwoven pattern of channels that, according to Mazursky, is characteristic of intermittent stream flow (Fig. 1). All except the first type of channel originate in flat terrain and seem to imply rainfall runoff as the source of the water.

The channels appear to be geologically very recent but not all of the same age, so that their formation could not have been due to a one-time event, and they occur largely in the warmer equatorial regions of Mars. That they exist at all is quite remarkable, because under present conditions water could not exist on the martian surface in liquid form—the liquid phase is unstable at the prevailing temperatures and pressures and would immediately freeze or evaporate. The consensus of those who have examined the evidence, however, is that other explanations for the channels are even less likely; liquid carbon dioxide, for example, would require nearly 1000 times the existing atmospheric pressure on Mars. Hence the evidence is suggestive that the past environment of Mars must at some time have differed considerably from present conditions.

Another peculiar feature of the martian terrain is the laminated structures exposed by the retreating polar caps. What appears to be a series of overlapping plates, each composed of dozens of continuous layers of alternately dark and light material, presents a banded appearance (Fig. 2). A convincing hypothesis to many investigators is that the alternating layers represent deposits of dust and ice or frozen carbon dioxide, although what formed the intricate pattern of the plates is a subject of considerable debate. The number and uniformity of the layers, however, suggests a regular pattern of dusty and dust-free epochs in the planet's recent history.

There is a great deal of dust on Mars. Shifting dust seems to have been confirmed as the agent responsible for

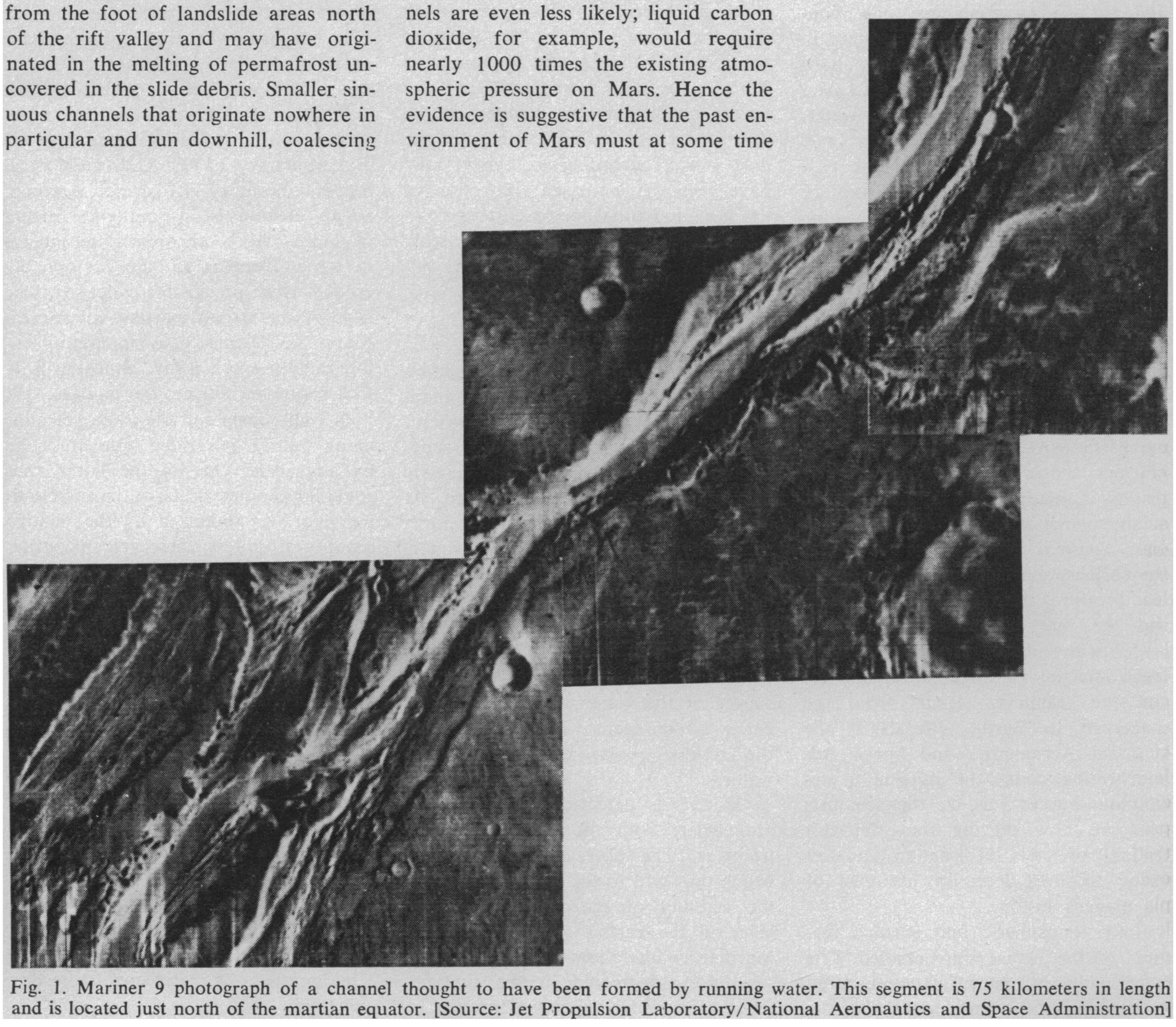

Fig. 1. Mariner 9 photograph of a channel thought to have been formed by running water. This segment is 75 kilometers in length and is located just north of the martian equator. [Source: Jet Propulsion Laboratory/National Aeronautics and Space Administration]

changes in the dark spots visible on the martian surface as well as for other variable surface features. The source of the dust, which seems to be composed of grains comparable in size to sand, is thought to be the continuing erosion of rocks. Erosion may be most intense in the equatorial regions. From there, dust may be carried poleward, deposited, and gradually redistributed over the planet.

The largest portion of the planet's surface is old, heavily cratered rock that some investigators believe to be the ancient crust. The incidence of craters that can be discerned is considerably less, however, than on the martian moon Phobus. Exactly how far back martian geologic history can be traced, if intense erosive processes have always been present, is uncertain.

Bruce Murray of the California Institute of Technology has proposed that the planet was without any significant atmosphere until recently. He believes that the planet is just beginning to be geologically active and that it created its present atmosphere volcanically during the formation of the Tharsis and Nix Olympica structures. Murray is correspondingly pessimistic that life could have evolved under the harsh, moonlike conditions that in his view prevailed over most of martian history.

Murray offers no explanation for the formation of the channels, but he does propose that the regular pattern of the polar laminated terrain is associated with periodic alteration in the martian climate. He finds that the planet's orbit changes shape from nearly circular to more elliptical with a period of about every 2 million years, perturbations caused by the influence of other planets, primarily Jupiter and Saturn. The resultant variation in the sun's radiant energy reaching the poles could under some circumstances, Murray speculates, lead to changes in the growth and sublimation of the polar caps. If dust is laid down alternately with layers of frost, thin laminae of the type observed could be formed.

On the question of the planet's ancient history, other investigators are less inclined to agree with Murray and cite evidence of volcanism and erosive processes stretching back over much of the planet's lifetime. Hartmann, for example, believes that in the past the planet must have had more rather than less atmosphere than it now has. Hartmann agrees, however, that tectonic activity of the type well known on the earth may just be getting started. Mars

Fig. 2. Mariner 9 photograph of the south polar cap region. The alternating black and white bands exposed there may represent layers of dust and frost. [Jet Propulsion Laboratory/National Aeronautics and Space Administration]

thus contrasts strongly with the moon, whose evolution shows no evidence of horizontal movement by crustal plates, and the earth, where convection currents in the mantle have been vigorous enough to completely remodel the surface over much of its history. Hartmann believes that the martian crust in the Tharsis region has been pushed upward in the last few hundred million years, possibly by a mantle convection current.

Others have suggested more explicit analogies with tectonic patterns on earth. Mazursky, for example, believes that the high plateau adjacent to the Tharsis ridge represents light, continental-type rock that overlies heavier materials found in nearby low-lying areas. The heavier material, Mazursky suggests, may be comparable to the basaltic rock of the earth's ocean basin floors. In this admittedly speculative view, the line of volcanos along the Tharsis ridge may represent the incipient stages of a tectonic process in which a plate of the heavier basaltic material is being thrust under the lighter continental plate. Others, such as John McCauley of the U.S. Geological Survey laboratory in Flagstaff, Arizona, do not see any evidence in the martian photographs of the compressional movements that such a process would entail. He points out that the density of Mars is less than that of the earth, that the tectonic activity on Mars happened late in its history, and that its apparent lack of vigor may indicate that no further crustal movements are in prospect.

In regard to the more recent evolution of the planet, the most puzzling problem appears to be the climatic changes that could have led to the formation of the channels by liquid water. Sagan has proposed that the climatic instability responsible for this is not inconsistent with that suggested by Murray for the formation of the polar laminae. If the polar caps were to entirely evaporate, Sagan calculates, the atmospheric pressure on Mars would be about 1 bar, the same as on the earth. Only about one-tenth this much atmosphere, assuming it was 1 percent water vapor, would be sufficient to permit liquid water as a stable phase at the daytime temperatures characteristic of the martian equatorial region. Hence Sagan proposes that rainfall and rivers may be recurring phenomena on Mars during each successive "interglacial" period.

Sagan believes that an advective instability in the martian atmosphere is the most probable cause of the drastic climatic changes he envisions. Changes in the absorption of sunlight at the poles—for example, by a layer of dust deposited in a major storm—would cause the pole to heat up and the total atmospheric pressure to increase slightly. With a more dense atmosphere, the normal circulation patterns that carry heat poleward from the equator would operate more efficiently, heating the poles still further. Continuation of the process would eventually lead to conversion of the polar caps to atmosphere and rivers. The process is also reversible, Sagan believes, because liquid water could serve as a trap for dust, cleaning the atmosphere and allowing it to recondense at the poles.

If indeed the environment on Mars alternates between wet and dry, at least in the tropics, then speculations about life on the planet become more interesting. Life forms that could go into extended repose while awaiting the availability of liquid water, for example, would seem well within the realm of possibility, if such forms exist. Experiments that expose martian soil to liquid water and test for biological activity might therefore be of particular interest. As it happens, two such experiments are planned for the Viking spacecraft that will attempt to land on Mars, in 1976.—Allen L. Hammond