Viking (II): Water, Ice, and Argon—Three Puzzles Resolved

The search for life was the foremost purpose of the Viking mission to Mars. After 3 months of operation, the Viking biology experiments are still ambiguous and probably negative (*Science*, 19 November). During the first phase of the 2-year Viking mission the physical science experiments have returned three definitive verdicts.

The general scientific consensus is that Viking has made conclusive discoveries about the cause of the martian channels, the nature of the polar ice caps, and the size of the ancient atmosphere. All three of these topics were vigorously debated after the previous Mars mission, Mariner 9, was completed in 1973. That so much has been firmly established so soon in the Viking mission is an unusual testament to the scientific value of the project.

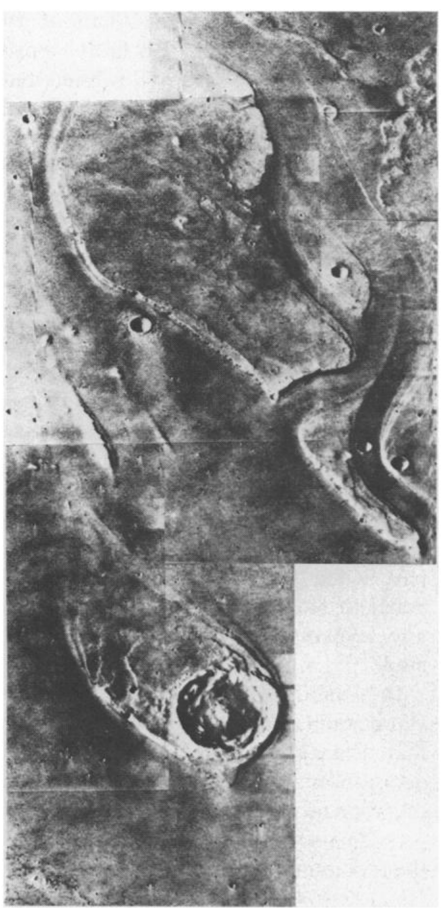

Fig. 1. Two islands in a channel at the mouth of the Chryse outwash, where Viking 1 was originally intended to land. The upstream end of one island is marked by an old crater whose ramparts resisted erosion. The downstream ends of both islands show the tails characteristic of fluvial action.

The hottest issue debated about Mars was whether running water ever existed on the surface of the planet. Although erosion by a flowing liquid seemed to be a natural explanation of many of the large and braided channel patterns observed by Mariner 9, the present atmosphere is much too thin (about 6 millibars) to permit liquid water. All the water presently on Mars must therefore be in the form of ice or vapor.

The Viking cameras looked in greater detail at the wide channels observed by Mariner 9 and they found teardrop-shaped features that are unmistakably ancient islands in dry stream beds (Fig. 1). Other examples of water-sculpted terrain have also been recorded, and some pictures show hints of water lines along the shores of the channels. The geomorphology clearly indicates that a fluid was the agent that cut many of the channels, and the only conceivable fluid is water.

Other images show channels that seem to emerge from the headwalls of box canyons just below regions of collapsed terrain (Fig. 2). These channels could be caused by slow seepage of underground water or wholesale melting of subsurface ice, causing collapse of the region where the water originated. Harold Masursky, of the U.S. Geological Survey at Flagstaff, Arizona, suggests that there are three types of channels. Complex tributary systems caused by rainfall, large channels caused by flooding of geothermally generated underground lakes, and smaller channels cut by slow water seepage are all visible on Mars according to Masursky, who is a member of the Viking orbiter imaging team. Rainfall is perhaps the most popular putative cause of channels, but Robert Sharp of Caltech is skeptical of the view that most water came from the atmosphere, suggesting instead that ground "sapping," a common process whereby water seeps from the base of a hillside, was more prevalent. There is no consensus on classification of channel types, as only a few percent of the surface area has been photographed at high resolution.

Volcanic activity is one natural explanation of the melting of ground ice that apparently occurred during the period of channeling. At least a dozen large volcanoes are quite prominent on Mars, and the age of these volcanoes is disputed. Some geologists think they may be as young as 100 million years, while others estimate their age at 1 billion years. There is even less agreement on the ages of the channels. The best measure of channel ages expected from Viking will be crater counts in the channeled regions—the areas that are older will be more heavily cratered. But the method is statistical and may not be reliable until a large number of regions are analyzed.

Some scientists are already cautiously concluding that the channels are correlated with the rise of the volcanoes. Carl Sagan, of Cornell University, suggests that the largest channels were carved during the last major period of volcanic activity, which he estimates was 1 billion years ago. Harold Masursky thinks the data already show that there have been several episodes of channeling. Multiple episodes of channeling are difficult to exclude, according to Sagan, but he is hesitant to estimate how frequently channeling occurred.

Before Viking, the central point debated about the aqueous environment of Mars was whether there was evidence for more than a trace of water. The atmosphere was known to contain a small component (up to 0.1 percent) of water vapor, but whether there was evidence for water permanently frozen into place at the poles was disputed. The answer returned by Viking, for poles as well as the mid-latitude channels, was water in abundance.

Using two different infrared instruments on the orbiter, Crofton Farmer of JPL, heading the water vapor mapping team, and Hugh Kieffer of the Uni-

Fig. 2. Channel found near the Viking 2 landing site which appears to have been caused by the melting of subsurface ice. The area of collapsed terrain to the right of the headwall probably indicates the extent of the collapse.

versity of California at Los Angeles, heading the thermal mapping team, established that the permanent ice cap at the north martian pole is made of water ice. Farmer's team found that the water vapor concentration increased with latitude to a maximum over the pole (indicating a source of water at the pole), and Kieffer's team found that the temperature of the ice there (205°K) was more than enough to make carbon dioxide evaporate, thus ruling it out as a constituent.

During their respective winters, both poles of Mars acquire large caps of carbon dioxide, which are laid down when the major component of the atmosphere freezes. That the seasonal caps were made of carbon dioxide was well known before Viking, but this mission was the first chance for an orbiting spacecraft to get a detailed view of a cap in summer, when it had shrunk to its minimum size (Fig. 3). Mariner 9 had stayed in rather equatorial orbits affording poor views of the poles, but after the first Viking lander completed the most active phase of its program, one of the Viking orbiters was freed from the task of relaying data so it could be shifted into a polar orbit. Thus Viking has obtained infrared and photographic surveys at much better resolution than obtained before.

How much water is represented by the polar ice caps is still in doubt. Pre-Viking estimates that the caps were very thin seem to be discounted, but both teams are cautious. Farmer estimates that the thickness of the caps is some hundreds of meters, sufficient to cover the planet with about 0.5 meter of water if it were all released at once. Subsequent observations, using such techniques as stereographic imaging, may clarify the size of the water reservoir locked in the polar caps.

Water could also be stored in the broken surface rubble of Mars, in the form of ice or permafrost. It would only penetrate to the extent that the fractured crust, called the regolith, had been cracked by meteoritic impacts and thus been made permeable.

Water and carbon dioxide are the principal volatile compounds associated with Mars, and the thrust of the Viking data is that—much as has been found—more must be awaiting discovery. In the case of water, this is a particularly ironic shift in viewpoint, since so little was postulated previously. In the case of carbon dioxide, large amounts of the gas are necessary to make up the denser atmosphere that has long been suspected, and Viking is giving the data necessary to specify how much there must have been.

Table 1. The gases in the atmosphere of Mars as measured at the surface by Viking. Traces of krypton and xenon are also present.

Gas	Abundance
Carbon dioxide (CO_2)	~ 95 percent
Nitrogen (N_2)	2 to 3 percent
Argon (^{40}Ar)	1 to 2 percent
Oxygen (O_2)	0.1 to 0.4 percent
Water (H_2O)	0.01 to 0.1 percent
$^{36}Ar/^{40}Ar$	1:2750 ± 500
$^{15}N/^{14}N$	1:160 to 1:200

The channels have stood for 5 years as indirect evidence for a dense past atmosphere, since 5 to 50 times the present atmospheric pressure would be needed for liquid water. Viking has now provided direct evidence (Table 1).

Noble gases and nitrogen discovered in the martian atmosphere lead by independent lines of reasoning to a much heavier carbon dioxide atmosphere in the past. The noble gases, particularly argon, lead to an estimated primitive atmosphere with a pressure of about 100 millibars, according to Tobias Owen at the State University of New York at Stoney Brook, who is a member of the Viking molecular analysis team. The nitrogen measurements suggest a pressure ranging from slightly below that value to

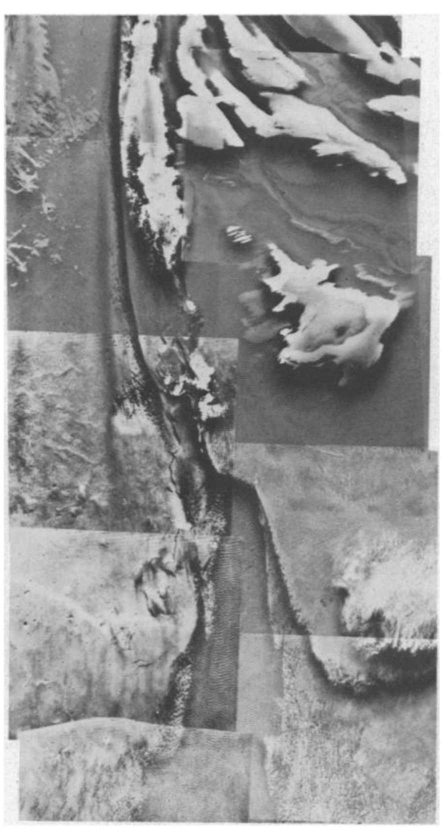

Fig. 3. View of the north pole of Mars, showing outlying fragments of the polar ice cap at the top, areas of layered terrain between segments of the ice sheet, and dune fields in the valley in the lower part of the picture.

a value about ten times higher than it.

Noble gases are particularly good markers of the quantity of volatile compounds released from a planet during the evolution of its atmosphere because, being chemically inert, they are not removed from the atmosphere through chemical reactions. Thus the common wisdom is that the quantity of noble gases is an indicator of the total quantity of gases cycled into the atmosphere since a planet's accretion. Chemically reactive gases, such as water, carbon dioxide, and, to a lesser extent, nitrogen, are less reliable indicators since they can be trapped in the surface through the formation of nitrates and carbonates.

All these gases are presumed to have been present in the material that formed the planets (adsorbed in the case of the noble gases rather than chemically bonded or frozen). The evolution of the atmosphere was a process of warming the primitive planetary material so that the gases were released (outgassing). Outgassing could have occurred at the beginning of martian history as a result of heating of the Mars-forming material by the process of accretion. Alternatively, throughout Mars' history, volcanism caused by radioactive decay in the interior could have supplied most of the volatiles. In either case, the broken material of the regolith could have trapped some of the volatiles and released them at a later time. Heavy gases could have been removed from the atmosphere at any time by chemical reactions with the material in the crust, by freezing or condensing, or by adsorption. Lighter gases could have slowly escaped into space from the top of the atmosphere.

The Soviet space probe, Mars 6, had radioed back some indications that as much as 35 percent of the atmosphere might be argon. This proved to be a substantial overestimate, when Viking measured 2 percent argon at the surface of the planet. Most is argon-40, produced from the radioactive decay of potassium-40 in potassium-rich minerals. A tiny fraction is argon-36, a nonradiogenic isotope, which can be traced more directly to the inventory of volatile compounds in the material that formed the planet.

The bulk composition of the material that formed Mars is not known, so some assumption must be made about the relative proportions of the various volatile compounds in each gram of the stuff from which Mars accreted, in order to relate the small amounts of argon to large amounts of nitrogen, carbon dioxide, and water. Assuming the composition was similar to that of the earth, the argon-36 measurement leads to a low estimate of the amount of volatiles released from the planet—only enough to triple the present atmospheric pressure even with the unlikely assumption that all the carbon dioxide would be in the atmosphere at once, according to Fraser Fanale at JPL. Such a small amount of outgassing would barely raise the pressure enough for liquid water to exist and probably not provide enough of it to cut the large channels.

The measured amount of argon-36 leads Owen of the Viking team to a larger estimate of the volatile inventory on Mars than Fanale suggests, but nevertheless a modest estimate. Using a different published value for the ratio of argon-36 to carbon dioxide outgassed from the earth, Owen concludes that the martian atmosphere was "never much more than ten times as massive as it is now, producing a maximum surface pressure of 100 millibar."

The early newspaper reports of a thick ancient atmosphere were probably based on the amount of argon-40 found in Mars' atmosphere, which does indeed lead to a generous estimate of volatiles outgassed. But most scientists studying the question now caution that because it has a different genesis, the production of argon-40 may be decoupled from the evolution of the rest of the atmosphere. (The moon, for instance, is still giving off argon-40 billions of years after the other volatiles.) Two other noble gases, krypton and xenon, have also been discovered on Mars. The concentrations are parts per million or less, and krypton is more abundant than xenon. In the view of Owen, a member of the molecular analysis team, the noble gases together tend to corroborate the outgassing indicated by argon-36 alone, which is about 1/100 that of the earth.

Speaking of Science

Irrational Drug Prescribing and Birth Defects

One of the weakest links in the chain connecting the drug company and the consumer is the physician. Few physicians receive formal training in the correct use of drugs, but the average practitioner writes 7934 prescriptions each year. Many of these prescriptions are irrational in the sense that the drug has not been shown to be effective for the purpose for which it has been prescribed; many are completely inappropriate because they represent a substantial hazard to the patient without any compensating benefits. The classic example of the first situation is the widespread use of antibiotics in the treatment of viral infections—an inappropriate use that many scientists feel is responsible for the increasing antibiotic resistance of many pathogenic bacteria. A good example of the second situation was the widespread use in the 1950's of diethylstilbestrol to prevent miscarriages—despite evidence (i) that the drug is not effective for this purpose and (ii) that it is carcinogenic in animals.

A current example of the second situation involves combinations of estrogen and progestagens, progesterone-like hormones that are used in birth control pills and that are widely prescribed for prevention of miscarriages, pregnancy testing, and for treatment of other complications of pregnancy. The evidence indicates that physicians have continued to prescribe these hormones for use during pregnancy despite evidence that they may produce birth defects.

The occurrence of an unusual number of birth defects among children of women exposed to the hormone combination during the first trimester of pregnancy has been documented by several investigators, most notably James J. Nora and Audrey H. Nora of the University of Colorado Medical Center and Dwight T. Janerich of the New York State Department of Health. They have found that the incidence of birth defects among such children is from two to five times higher than the incidence among children whose mothers were not exposed to the drugs. The most commonly observed defects are limb reductions (the absence of an arm or leg or of part of the limb, such as one or more fingers or toes) and congenital heart defects. The increased incidence has been observed both in retrospective studies and in preliminary results from prospective studies. Despite the increased incidence, however, the total incidence of birth defects among the exposed population is still less than 1 percent, suggesting that only part of the population is susceptible to the deleterious effects of the hormones.

In light of this preliminary evidence and other evidence that the suspected drugs* are not effective in preventing miscarriages, the Food and Drug Administration (FDA) in December 1973 and February 1974 withdrew approval of the drugs for use during pregnancy. At the start of 1975, furthermore, FDA warned against use of the drugs during pregnancy in a bulletin mailed to physicians and other health professionals.

The change in legal status of the drugs and the warning have apparently been ignored by physicians, however. Evidence obtained by International Marketing Service of Ambler, Pennsylvania, indicates that, in 1975, physicians wrote 533,000 prescriptions for use of the hormones during pregnancy—only about 10 percent less than the number written in 1972, when such uses were approved.

Prodded by Sidney M. Wolfe of the Public Citizen Health Research Group in Washington, D.C., FDA announced last month that it is preparing further regulations about the hormones. The new rules will require manufacturers to print and distribute to users a brochure emphasizing that the drugs should never be used during pregnancy. They will also require manufacturers to revise physician labeling for the hormones to incorporate a warning against use in early pregnancy, to say that no studies show the drugs to be effective in preventing miscarriages, and to say that the drugs should never be used to test for pregnancy. The regulations would thus not only discourage the physician from describing the drugs, but would also warn the patient so that, even if the drugs should be prescribed, she will be alerted to the potential hazard and will thus retain the option to avoid the drugs.

—Thomas H. Maugh II

*Provera and Depo-Provera, manufactured by the Upjohn Company; Delalutin, manufactured by E. R. Squibb & Sons; Duphaston, manufactured by Philips Roxane Laboratories; Norlutin and Norlutate, manufactured by Parke, Davis & Company; and Progesterone, manufactured by Eli Lilly and Company.

In the view of most observers, the nitrogen measurement gives a more abundant primitive atmosphere. The Viking lander measured an enrichment of nitrogen-15 over nitrogen-14 that appears to be due to differential escape of the lighter isotope, caused by a photochemical process suggested 4 years ago by Michael McElroy at Harvard University. When the preferential escape of nitrogen-14 is related to the total amount of nitrogen outgassed, it points to a dense early atmosphere—especially if much of the nitrogen released long ago was trapped in nitrite and nitrate minerals. At a maximum, the nitrogen measurement indicates that the carbon dioxide atmosphere could have reached a pressure as great as the earth's (1 bar), and the water could have covered the planet to a depth of 200 meters, if all of both volatiles were released at once.

Thus, where the presumed water might be found and where the extra carbon dioxide is hidden are not idle questions. "It is clear that Mars must have an inventory of volatiles at least 20 times greater than what is presently observed in the atmosphere and the polar caps," says Fanale. The discovery of a large deposit of frozen carbon dioxide somewhere on the planet cannot yet be ruled out, but Fanale proposes that the most likely place to find the extra carbon dioxide is in the regolith, which may extend down to 1 km below the surface in his view. Carbon dioxide could be absorbed onto this material, which at present martian temperatures could function as a cold trap. In such a repository, the carbon dioxide could participate in a cycle of atmospheric changes that would increase the pressure during warm periods by a sort of feedback mechanism—warmth would release carbon dioxide, which would increase both pressure and temperature. The principal evidence for such a fluctuating climate on Mars is the layered appearance of the permanent polar cap.

A regolith model of bimodal climate oscillation would change more sluggishly than if the balance of the carbon dioxide were stored during cold periods in a solid chunk somewhere near the poles—as most often discussed before Viking. But a climate oscillation based on the regolith could nevertheless be operative if surface temperature increases persisted over a 100,000-year period, according to Fanale. This period is typical for the sources of heating that have been suggested as drivers for the postulated atmospheric instability. Among the heating phenomena that have been proposed are changes in the inclination of the planetary axis of rotation (obliquity) and changes of the intrinsic dynamics of the sun. Periodic tilting of the rotation axis, followed by a return to the "normal" position, would effectively increase the solar flux on Mars, particularly in polar regions. Periodic fluctuations of the intrinsic brightness of the sun, predicted by some solar models, would of course change the amount of heating by sunlight on all the planets.

The atmospheric evolution of a planet is a very complex process, and apparently one that only yields to careful, subtle analysis. Prior to Viking, the earth was the only example. Now geochemists have two planets to test atmospheric evolution, and dynamicists have two planets to test models of weather and climate. All observers agree that the Viking measurements have given atmospheric modelers exactly the levers they need for a consistent formulation of the outgassing of the planet. In a few months or a year, predicts Ichtiaque Rasool of NASA, the measurements of argon, krypton, xenon, and nitrogen will make the theories on the size of the primitive atmosphere converge to a consensus.

—William D. Metz

The 1976 Nobel Prize for Physiology or Medicine

During the week of 11 October the World Health Organization convened in Geneva a committee on viral hepatitis for the third time in 4 years. The rapid succession of meetings and reports is indicative of the progress being made in an important field of public health which had lain fallow for many years. In spite of intensive research efforts since World War II on the part of a few investigators supported almost totally by the U.S. Army Medical Research and Development Command through its committee on liver diseases, significant advances in hepatitis began only after the revelation that a recently discovered antigenic substance in blood, named Australia antigen, was specifically related to one form of liver infection, so-called serum hepatitis. Those of us in Geneva preparing the third WHO Technical Report on Viral Hepatitis were deeply pleased to learn that Baruch Blumberg had been awarded a share of the Nobel Prize for Physiology or Medicine for his discovery of the Australia antigen. Without knowledge of this antigen, productive meetings such as ours could not be taking place.

Baruch Blumberg, of the Institute for Cancer Research in Philadelphia, was awarded the prize "for his discovery concerning new mechanisms for the origin and dissemination of infectious diseases." His discovery of the Australia antigen ultimately became a major breakthrough in hepatitis research, for it permitted intensive study of the disease and of the nature of the viral agent, even though the virus itself has yet to be grown in culture in significant amounts.

Blumberg's work leading to this discovery began as a consequence of his interest in inherited polymorphisms of blood. He and a co-worker, A. C. Allison, hypothesized that patients receiving multiple transfusions would receive some serum proteins of a phenotype different from their own and would respond by producing antibodies. With the simple two-dimensional micro-Ouchterlony immunodiffusion technique, serums from multiply transfused patients were tested against a panel of serums from donors living in different geographic areas. One serum from a transfused patient possessed a precipitin (antibody) for some of the serums in the panel. This antiserum reacted with substances that seemed to comprise a system of inherited antigenic low-density β-lipoproteins.

Blumberg then began a search for additional antigen systems, and in 1963 two serums from multiply transfused American hemophiliac patients yielded a single precipitin line with only 1 of 24 serums in a test panel. The antigen in this one serum contained at most only a relatively small amount of lipid, which distinguished it from the serum β-lipoproteins. Since the reacting serum was obtained from an Australian aborigine, Blumberg named it Australia antigen. Subsequent studies by him and others revealed that it was relatively rare in healthy persons living in North American and West European communities but that it was frequently present in the blood of those living in many parts of Africa and Asia.

Since the Australia antigen was often found in the blood of leukemic patients, Blumberg first suggested that its presence might be of value in the early diagnosis of their disease. However, while studying a number of serums Blumberg and his colleagues found evidence that linked the antigen to viral hepatitis. Other investigators, notably A. M. Prince at