been that dry alluvium is only rarely found in sufficient depth to conceal the effects of explosions of significant size. It must be deep enough not only to contain radioactive materials, but also to prevent the formation of collapse craters of the type that usually occur at the test ground in Nevada.

ARPA has funded studies to examine the extent to which sufficiently deep and dry alluvium might be found in Russia. As recently as the July Senate hearings, it had been implied that tests of up to 45 kilotons could be concealed by testing in this material. But in October, the testimony was that it would probably not be useful for tests above 1 or 2 kilotons, which happens to be the yield below which explosions in any kind of earth materials might have a good chance of escaping detection. The implication was that dry alluvium of sufficient depth for greater-yield tests probably does not exist in Russia.

The testimony also addressed other possibilities for concealing tests. One method was to test in large, approximately spherical holes. It was suggested that it would be technically feasible to conceal an explosion of as much as 50 kilotons by this method. According to the decoupling theory, 50 kilotons detonated in a cavity 475 feet in diameter and about 4000 feet below the earth's surface would produce approximately the same size seismic signals as a 0.5-kiloton explosion detonated in the conventional manner in hard rock. It was also implied that signals from 50- to 100-kiloton explosions could be concealed in seismic waves generated by a large earthquake. Another hypothesized evasion technique involves setting off in rapid succession a series of explosions; thus the composite seismic signal would have the character of earthquake signals.

There is little basis for determining the amount of credence that should be given such evasion possibilities. All assertions about what might be done to conceal explosions are based on little or no experimental data at explosion yields that might be significant.

The Pentagon's backing and filling as to whether anything new has happened with regard to the ability to detect violations was indicative of a mood within the Pentagon. Advances in seismological research are not welcomed by officials who believe continued testing is more important than the treaty. Defense Department scientists, who manage test detection research, are thus subjected to conflicting pressures. Senator Pastore took note of the problem and suggested that the management of test detection research be transferred from the Pentagon to the Office of Science and Technology in the White House.

In noting the flurry of talk about the test ban, Stephen Rosenfeld suggested recently in the Washington *Post* that the interest was not shared by those in government who were in a position to make test ban policy. And indeed it may be that the matter has come full circle—that doubts have been raised about the need for tests and that the verification problem had been eased—but there has been no essential change. However, it is more likely that things are not the same. The Woods Hole conference and the Cannikin episode have probably triggered a permanent movement to new ground.

The most significant changes of 1971 appeared to be the rather widespread willingness to cast a skeptical eye upon such sacred cows as the relevance of any nuclear tests, the ease of concealing violations, the dangers inherent in undetected clandestine activity, and the need for on-site inspections. Such changes will probably assure a more rational dialog, if not a treaty banning all nuclear weapons tests.

—HENRY R. MYERS

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RESEARCH TOPICS

Mars as an Active Planet: The View from Mariner 9

Only in recent years have ground-based optical and radar studies of Mars, and now spacecraft observations, made available pictures and maps of sufficient clarity to rule out some of the scientific speculations and popular fantasies of the past. The new evidence, however, is only slightly less interesting than the old stories of canals and dying civilizations. Far from being a dying planet, Mars turns out to have many features that appear to be, on geological time scales, of recent origin. The preliminary reports of the Mariner 9 findings on pages 293–320 of this issue of *Science* provide evidence of past volcanic activity, of faulting and other indications of major tectonic zones, and of geochemical differentiation. Observations of the dust storm that initially obscured most of the Martian surface have led to the conviction that the dust is more prevalent than had been expected and that dust, rather than biological phenomena, may be the cause of the seasonal and secular changes in the appearance of the planet as seen through telescopes.

When the Mariner 9 spacecraft went into orbit around Mars last 13 November, the dust storm was still so intense that only the south polar cap and the tops of a few high mountains could be seen. During December, however, visibility improved noticeably, and, by 29 December, when the spacecraft's orbit was adjusted slightly to prepare for photographic mapping of the planet, the dust had cleared enough to reveal many additional features. The dust settled first around Mars's south pole, and is gradually clearing in more northernly regions, fortuitously the same sequence as the mapping pattern decreed by the Mariner orbit.

Mapping of the Martian surface is now under way, and the Mariner scientists expect to complete most of the observations originally planned for the mission. The spacecraft carries two television cameras, ultraviolet and infrared spectrometers, and an infrared radiometer, and the telemetry signals from the spacecraft to Earth are being used for an occultation experiment and a celestial mechanics experiment. The most dramatic findings have come from the television pictures, but all experiments are working well and are returning large amounts of data. The two Soviet spacecraft in orbit around Mars are also apparently returning useful data, although the U.S.S.R. has not released much information from them or from the short-lived instrument capsule that landed on the Martian surface.

Among the first visible features of the Martian surface were the huge craters in Nix Olympica and in North, Middle, and South spots, that appear to be the highest points on Mars. Additional pictures of these craters and the surrounding terrain show what appears to be a large volcanic plateau, extending outward from the peaks where the craters are located. The craters are almost certainly volcanic, Mariner scientists now believe, and look somewhat like the collapsed volcanic craters or calderas seen on Earth. The plateau is crisscrossed by an intricate pattern of what appear to be fault valleys and stretches eastward to an extremely deep rift of the size and extent of the African rift valley.

Although mapping of this area is not complete, both the overall arrangement of the features and the details which have been studied so far appear to be characteristic of large-scale tectonic activity not unlike that found on Earth. The orientation of the trench-like rift valley is parallel to the line of volcanic craters, for example, and the type of faulting in the plateau appears to be that caused by movement of blocks of volcanic material. Moreover, the sharp edges visible on the large craters and fragmented blocks, and the virtual absence of meteoroid craters, which are common in other areas of Mars, are evidence that the volcanic eruptions which presumably formed the plateau are geologically recent.

Additional evidence that Mars is a geologically active plant comes from the infrared spectrometer data, which show that the dust in the atmosphere, and hence probably the surface materials, have a relatively high content of silicon dioxide. Mariner 9 scientists regard this finding as an indication that the planet has undergone substantial geochemical differentiation, in that enrichment of the surface with lighter materials such as silicates, and correspondingly lower amounts of chondritic materials in the surface composition, implies that some separation of the elements has taken place.

Still other Martian features, many different from those observed by the 1969 Mariner mission, are being photographed and studied. Some peculiar, light and dark markings have been discovered, whose nature is unknown, although they appear to be the result of surface processes—possibly, according to one speculation, the result of wind-carried dust that partially covers the surface to produce the unusual markings.

In any event, wind-blown dust now seems to be the most likely explanation for many of the observable changes in the appearance of Mars. Strong winds that periodically shift loose dust and uncover surface materials whose reflective properties are different from those of dust have been proposed as the cause of the Martian seasonal changes observed on Earth. Earth-based photographs of Mars may themselves have to be reinterpreted as a result of the unexpected amount of dust found by Mariner 9. Although the current dust storm as viewed from telescopes on Earth appears to have ceased, the satellite instruments show that the remnants of the storm are still present and that dust still obscures much of the planet. The apparent lack of craters in Hellas, a large basin about 1000 kilometers across, had puzzled geologists during the earlier Mariner mission; but it is now thought that local dust storms occur very frequently in Hellas, so that the surface and any craters that may be present are obscured from view.

High Winds and Mountains

The Martian atmosphere itself is composed mostly of carbon dioxide, although Mariner 9 has found, as did earlier spacecraft, traces of water vapor and its dissociation products atomic oxygen and hydrogen. Observations with the infrared spectrometer indicate that the largest concentrations of atmospheric water vapor occur above the south polar cap region. No measurements have been made of wind velocities, but one estimate suggests that winds greater than 170 miles per hour, a velocity about half of the speed of sound on Mars, are not uncommon. Martian meteorology is expected to differ from atmospheric processes on Earth in other ways too; the characteristic thickness of the Martian atmosphere as indicated from temperature measurements is about 10 kilometers, less than the 13-kilometer differences between the high and low points of the Martian topography. Surface temperatures are more extreme, and temperature gradients larger than on Earth.

Early in the mission before the dust had begun to clear, Mariner instruments indicated that the lower atmosphere was surprisingly isothermal in its vertical structure. Whether the effect was caused by the dust is still uncertain, but temperature profiles obtained in the last few weeks with both the infrared spectrometer and the occultation experiment show a more normal pattern. The ultraviolet spectrometer is also finding less interference from the dust, and mapping of the surface pressure with this instrument has begun. Ultraviolet spectra from the upper atmosphere continue to show that the upper atmosphere responds to variations in the solar energy flux, but whether the coupling is similar to that between the sun and the earth's upper air is not yet known. Initial looks at the surface temperature data from the infrared radiometer experiments indicate a few areas that are warmer than their surroundings, but there is no evidence, for example, of any active volcanos; reduction of the data is still continuing.

The most well-studied features of the Martian surface in the early days of the Mariner 9 mission was the south polar cap, which is known to be composed of frozen carbon dioxide. Significant changes in the extent of the cap occurred within a 2-week period, during which only a few centimeters of carbon dioxide could have sublimed, thus implying that the cap is extremely thin—at least along some of its edges. Shrinking of the cap also uncovered some unusual topographic features that appear to be low ridges or troughs and that might, some geologists have speculated, be related to thicker accumulations of ice in the past, like the glacial moraines found on Earth.

Observations of Mars's satellites (its moons) have also proved interesting. The moons are heavily cratered, and hence probably old, bodies of irregular shape, with indentations suggesting that pieces may have been broken off in earlier impacts. One large crater on Phobos appears to have been the result of an impact nearly as large as this moon could have sustained without fracturing. The crater density on these satellites is much higher than that on Mars itself, implying the presence of erosive processes on the planet.

Analysis of the Mariner 9 data is just beginning. But it is already clear that information from Mariner 9 and from the forthcoming Viking spacecraft which, hopefully, will land on Mars should provide new perspectives for geologists, meteorologists, and perhaps eventually even for biologists.

—ALLEN L. HAMMOND