

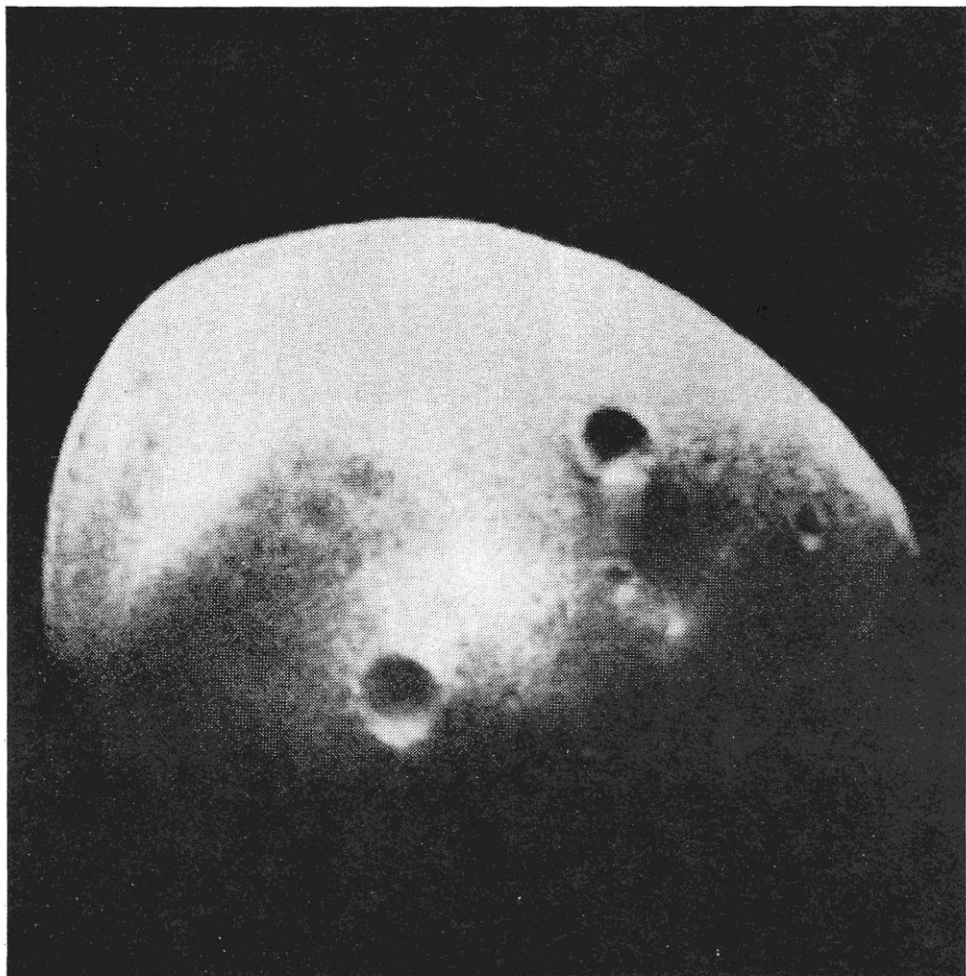
VESPA

Latin, for WASP



No.4

Vol.1



THE MOONS OF MARS

THE JOURNAL OF THE WARREN
ASTRONOMICAL SOCIETY

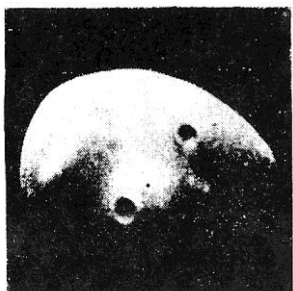
APRIL 1977



The Warren Astronomical Society (W.A.S.) is a local nonprofit organization of amateur astronomers. Membership is open, to all interested persons. Annual dues are as follows: Students, K-12 \$9.00- College \$11.00, Senior Citizen \$13.50, Individual \$16.00, Family \$21.00, the membership fees listed here include a one year subscription to Sky & Telescope Magazine.

Meetings are held on the first Thursday at Cranbrook, and the third Thursday of each month at Macomb County Comm. College, in the student union bldg.

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Roseville, Michigan 48066 776-8735



THE COVER

The picture on the cover is a computer-generated color image of Deimos, the smaller of the two moons of Mars (see "Phobos and Deimos," by Joseph Veverka. A pair of images of Deimos obtained by the *Viking 1* orbiter, one at the wavelength of violet light and one at the wavelength of orange, was combined in a single image in search of color differences on the moon's surface. The image is shown here oriented so that the illumination is from top to bottom. This prevents the apparent relief of surface features from reversing so' that

depressions such as craters seem to be elevations. The test image showed that, at least down to a resolution fine enough to register any object 200 meters or more in diameter, the surface of Deimos is a uniform gray in color.

OBSERVATORY SCHEDULE

Lectures for the coming month are listed below.

April •• 1/2 ••••• Ray Bullock ••••• 879-9458
April •• 8/9 ••••• Larry Kalinowski ••••• 776-9720
April •• 15/16 ••••• John Root ••••• 464-7908
April •• 22/23 ••••• Kim Dyer ••••• 835-2037
April •• 29/30 ••••• Carl NOBEL ••••• 573-0937

The lecturer may select either the Friday or Saturday depending on the weather and their personal schedule. If the Lecturer wishes, they may call upon the four new assistant lecturers. They are Bob Dennington 779-6395, Dave Locke 335-8429, Doug Holmes 776-8797, and Joe Tocco 573-8547. If you want help, Call.

MINUTES OF THE WARREN ASTRONOMICAL SOCIETY

February 17, 1977

The meeting was called to order by -President Pete Kwentus at 8 P.M. Treasurer Don Misson presented the treasurer's report.

Ken Kelly distributed ephemerides for minor planets in 1977. Kim Dyer also asked members interested in occultation timings to contact him.

Doug Bock announced the first Annual Astronomy Invitational at Michigan state University April 16. A star bowl and Messier contest will be held for which a small fee will be charged. He asked each club to submit names for a four-man star bowl team, potential questions and judges.

Carl Noble described an eclipse "flight" to the Hawaiian Islands in October. Bishop Museum is studying various locations at this time. For more information on the tour contact Carl Noble.

Larry Kalinowski plans to aid a group at DAS to assemble a variable drive unit. The meeting will be held March 4 at 7: 30 at Mercy College. Contact Larry or Kim Dyer for more information.

Dolores Hill distributed announcements of the U of M Astronomical Film Festival held by astronomer Jim Loudon each weekend beginning March 18. For more information contact Dolores Hill or call U of M at (313) 764-0478.

It was announced by Dolores Hill that the Chagrin Valley Astronomical Society plans to hold a Telescope Fair in May. Members interested in attending should contact Dolores Hill.

Louis Faix announced intentions to hold an "Amateur's Night". At the meeting members would give a ten minute "talk" on some area of their interest such as telescope making, astrophotography, observing, etc. Those interested should contact Louis Faix, program director.

The evening's program included a talk by Dave Harrington on Satellites of the Solar System and Eclipses and a talk on Bodes Law by Ray Bullock.

The meeting was adjourned by P. Kwentus at 10:30.

Minutes respectfully submitted,

Dolores H. Hill Secretary.



IMAGE OF PHOBOS, the larger of the two moons of Mars, is one of 27 obtained by *Mariner 9* as it orbited Mars in 1971-1972. Prominent in this view is the crater named for Asaph Hall, discoverer of

the moons; it is six kilometers in diameter. The image is oriented so that the illumination is from top to bottom; otherwise the apparent relief of craters and other surface features would tend to reverse.



IMAGE OF DEIMOS, the smaller and more distant of the moons, is one of nine obtained by *Mariner 9*. The distinct circular crater near

the center is named Swift; it is one kilometer in diameter. The subdued crater just to the right, two kilometers in diameter, is Voltaire.

Phobos and Deimos

The tiny moons of the planet Mars.

The pictures sent back from Mars by *Mariner 7* in 1969, by *Mariner 9* in 1971-1972 and by the two Viking spacecraft beginning last summer have revolutionized our knowledge of the planet and have enriched our understanding of the solar system in general. Among the most revealing of the pictures were those that showed not Mars itself but its two lumpy moons Phobos and Deimos. These tiny bodies have had a special charm ever since Johannes Kepler invented them nearly three centuries before anyone knew they existed. Kepler firmly believed the universe was an intricate puzzle that included certain symmetries contrived by the Creator to compel man to exercise his ingenuity in order to understand them. Regarding the moons of Mars, Kepler reasoned as follows. The earth has one moon; Jupiter has four. (The other nine Jovian satellites were of course still unknown.) How many moons should the planet between the earth and Jupiter have? The doubling series, 1, 2, 4 ... evidently appealed to Kepler's keen sense of mathematical regularity, and so he assigned Mars two moons. It is doubtful that in the absence of any observational evidence anyone really believed him. But the notion became well enough known to be echoed by both Swift and Voltaire in the century that followed.

Late in the 18th century Sir William Herschel found two new moons of Saturn with his 48-inch reflecting telescope, but he could not detect any satellites around Mars. Heinrich Ludwig d'Arrest, who helped to discover Neptune in 1846, also failed in the search for Martian moons. Not until 1877 did Asaph Hall, working at the U.S. Naval Observatory in Washington, succeeded in observing two faint moving specks of light in the vicinity of the red planet. He named them Phobos (fear) and Deimos (terror), after the two sons of Ares (Mars in the Roman pantheon) who according to Greek myth drive the war god's chariot.

Why did Hall succeed where others had failed? In part it was because he was observing during a very favorable opposition, when the distance between the

earth and Mars is at a minimum. In part it was because the Naval Observatory's 26-inch refractor was one of the best telescopes in the world at the time. Most of the credit must nonetheless go to Hall's skill and perseverance as an observer. Phobos and Deimos are notoriously difficult objects to detect from the earth. They are not only faint but also never very far away from Mars; it takes great skill to pick them out of the flood of scattered light that surrounds any telescopic image of the planet.

It was soon established that Phobos and Deimos move in almost perfectly circular orbits in a plane that virtually coincides with that of Mars's equator. The motion of both satellites is direct, that is, they revolve around Mars in the direction of its rotation, which would be counterclockwise in the view of an imaginary observer stationed above the planet's North Pole.

The orbit of Phobos, the innermost moon, lies just outside the Roche limit of Mars: the critical distance inside which tidal disruption would keep any swarm of interplanetary debris from accreting into a single body. The orbit of Deimos lies just outside what is known as the stationary orbit position: the point where a satellite's period of revolution exactly equals the planet's period of rotation, so that from the surface of the planet the satellite appears to hang motionless in the sky.

The orbital period of Phobos, 7.7 hours, is much shorter than the rotation period of Mars, which is an earthlike 24.6 hours. Thus Phobos, unlike the earth's moon, would be seen by an observer on the surface of the planet to rise in the west, move quickly across the sky and set in the east. The same observer would see Deimos creep across the sky from east to west, taking some 60 hours to move from one horizon to the other. Neither passage would be particularly dramatic. Deimos would be about as bright as Venus is in the earth's sky. Phobos, being the nearer and larger satellite, would be several magnitudes brighter but would still be much less of a spectacle than the thinnest crescent of the earth's moon. Moreover, since the orbits of Phobos and

Deimos, are in the plane of the Martian equator and are so close to the surface of the planet, neither satellite could be seen from the poles. The observer would have to be closer to the equator than a latitude of 82 degrees to see Deimos, and closer than 69 degrees to see Phobos.

Observations over the past few decades indicate that the orbital velocity of Phobos is slowly increasing. The phenomenon, termed secular acceleration, was first noted in 1945 by A. B. Sharpless of the Naval Observatory. Until recently the reality of the acceleration was a subject of controversy. Now, however, Phobos observations made during the *Mariner 9* mission of 1971-1972 have been thoroughly analyzed by Thomas C. Duxbury and G. H. Born of the Jet Propulsion Laboratory of the California Institute of Technology. They indicate that Phobos is indeed accelerating at a rate of about .001 degree per year per year. V. A. Shor of the Institute for Theoretical Astronomy in Leningrad, reexamining a series of telescopic observations, has independently arrived at a similar figure. The acceleration appears to be attributable to tidal drag. This may seem paradoxical, since drag would be expected to slow something down rather than speed it up. The drag would indeed cause Phobos to lose energy, but that would bring the satellite closer to Mars. Then the satellite would move faster on its smaller orbit. Assuming that the secular acceleration continues at its present rate, Phobos should crash onto the Martian surface in about 100 million years.

Phobos and Deimos are so small that it has not been possible to directly measure their size with telescopes on the earth. Early estimates of their diameter were informed guesses based on their observed brightness. The first photometric observations of the two moons were made by Oliver C. Wendell and Edward C. Pickering at the Harvard College Observatory, between 1877 and 1882. The observations were crude, but they did show that Phobos was brighter than Deimos. Perhaps more significant was Pickering's conclusion that the two moons were not the same color as Mars: where the planet was reddish, they were grayish. This suggested that the surface of the satellites could not be composed of the same stuff that composed the surface of Mars.

The first modern photometric observations of Phobos and Deimos

were not made until G. P. Kuiper undertook the task during a favorable opposition in 1956. Kuiper found Phobos to be some three times brighter than Deimos. Assuming that the two bodies were spherical and that their surfaces reflected roughly the same 11 percent of sunlight that the surface of the earth's moon does, he calculated that Phobos was 12 kilometers in diameter and Deimos six kilometers.

The first direct measurement of the size of Phobos came 13 years later. In 1969 the high-resolution camera aboard *Mariner 7* captured the silhouette of Phobos outlined against the disk of the planet. The image was scarcely seven picture elements wide, but it showed that Phobos was irregular in shape and much larger than Kuiper had estimated. Working with *Mariner 7* data, B. A. Smith of New Mexico State University calculated that Phobos was some 17 kilometers long and 23 kilometers wide. The fact that the size was greater than Kuiper had calculated on the basis of a surface material with the reflectivity of the earth's moon indicated that the material was actually only half as reflective as the earth's moon.

Detailed reconnaissance of both Martian satellites began on November 14, 1971, when *Mariner 9* went into orbit around Mars. In its observing lifetime *Mariner 9* obtained 27 views of Phobos and nine views of Deimos. On the average the resolution was good enough to show any feature more than 200 meters in diameter. The imagery of Phobos was sufficiently complete to make it possible to map most of the satellite's surface and to determine its shape with considerable precision. As the glimpse from *Mariner 7* had indicated, Phobos is irregular. Analyses of *Mariner 9* data by Duxbury, however, show that it is a tri-axial ellipsoid if one allows for a few missing chunks. Its principal diameters are 27, 21 and 19 kilometers.

The *Mariner 9* coverage of Deimos was less complete because only the side of the satellite facing Mars could be photographed. Nevertheless, analyses of the limited imagery suggest that Deimos too is roughly ellipsoidal, with principal diameters of 15, 12 and 11 kilometers. There are slight irregularities in the ellipsoid, as there are in that of Phobos, but the peculiar fact remains that the two moons of Mars are almost identical in shape.

By tracking individual surface features on each satellite analysts of the *Mariner 9* imagery were able to determine that both Phobos and Deimos rotate synchronously with their revolution around Mars. That is, one side of each satellite always faces the planet, as one side of the earth's moon always faces the earth. If a small, irregular body is set spinning rapidly in the vicinity of a larger body, tidal friction eventually brakes the rotation rate of the smaller body until that rate is synchronous with the rotation rate of the larger body. The time required to achieve the synchronous rotation is related to, among other things, the distance between the two bodies: the closer a satellite is to a planet, the shorter the spin-down time is. In addition, the more irregular the satellite's shape and the more eccentric its orbit, the shorter the spin-down time. For Deimos a rotation rate synchronous with that of Mars should have been achieved within a million to 100 million years. For Phobos, much closer to Mars, it should have been achieved within 10,000 to a million years. Such calculations put a lower limit on the length of time that has elapsed since the satellites were last set spinning. That spin may have been imparted by the violent impact of a large piece of interplanetary debris.

Before the *Mariner 9* imagery existed the probable appearance of the surface of small bodies such as Phobos and Deimos was a subject of debate. For an object to escape from the earth's moon it must have a velocity of 2,380 meters per second, but for one to escape from Phobos it needs a velocity of only about 15 meters per second. This low escape velocity means that when a piece of interplanetary debris hits Phobos, most of the collision products are blasted out into space. One question was therefore whether or not recognizable craters would be formed on bodies this small. Would the collisions leave mere pockmarks or would they make craters with raised rims, like those on larger bodies such as the earth's moon?

The *Mariner 9* imagery answered the question: both Phobos and Deimos showed a profusion of rimmed craters that were easily recognizable down to the limit of image resolution. Moreover, the craters on Phobos have all possible shapes, from one elongated crater shaped like a keyhole to others that are perfectly circular. There is also a wide range in the freshness of the craters, from

what appear to be young craters with a conspicuously raised rim to eroded depressions that are so shallow they are barely visible. Notably absent are features prominent on the surface of the earth's moon, such as blankets of ejecta and craters with a central peak. Given the negligible gravity of Phobos, their absence is understandable. The two largest craters on the satellite are named Hall and Stickney, the first after the discoverer of the moons of Mars and the second after his wife, born Angeline Stickney, who is said to have encouraged him in his long search. They are respectively six and 10 kilometers in diameter; the diameter of Stickney is thus about 40 percent of the maximum diameter of Phobos itself.

In addition to calculating the ellipsoidal shape of Phobos, Duxbury has made a surface map of Phobos from the *Mariner 9* imagery

Since the coverage of Deimos was limited, no map of the outer satellite has yet been produced. Detailed coverage of Deimos is a major objective of the current Viking orbiter missions to Mars. The surface of Deimos is much like that of Phobos, although it is perhaps a little less rugged. The largest crater on Deimos scanned by *Mariner 9* is an eroded structure; two kilometers in diameter that has been named Voltaire. Close to it is a one-kilometer crater with a conspicuous rim that has been named for the other 18th-century literary personage who publicized Kepler's fictional moons, Swift. The contrast between the soft outlines of Voltaire and the sharp ones of Swift demonstrates the effectiveness of erosion processes even on such small bodies as this one. The principal forces responsible for crater obliteration on Deimos must be the pitting caused by low-velocity impacts and the blasting caused by high-velocity ones.

The impacts responsible for the largest craters on the moons of Mars have doubtless modified the shape of both satellites. For example, the collision that gave rise to Stickney must have generated severe shock waves throughout Phobos and probably even knocked off large chunks of it. The effects of such high-velocity impacts on small bodies have been simulated in the laboratory by Donald E. Gault and his co-workers at the Ames Research Center of the National Aeronautics and Space Administration. Working with spherical targets, they are studying the effects of

impacts of various energies. Low-energy impacts leave a crater like scar on the target, with the damage concentrated in the contact area. High-energy impacts cause large pieces of the target to spall off. The spalling is concentrated on the face of the sphere opposite the point of impact, and often the entire outer layer of the target is removed, leaving only the inner core. The shape of these inner cores is surprisingly like that of Phobos and Deimos. Both moons have sharp projecting edges, suggesting that their present form is the result of high-energy impacts.

In view of the likelihood that spallation accompanied the formation of the largest craters on Deimos and Phobos, it will be interesting to study the crater densities in the regions of the satellites that are opposite some large craters. The *Mariner 9* coverage is not adequate for this purpose, but some suitable data are beginning to come in from the Viking orbiters. For example, we now know that an area of abundant secondary cratering visible on a Viking Image of Phobos lies on the side of the satellite opposite the major impact represented by Stickney.

The surfaces of both Martian moons, like the surface of the highlands of the earth's moon, are saturated with craters. On the basis of this observation James B. Pollack of the Ames Research Center has argued that Phobos and Deimos are at least 1.5 billion years old and may in fact date back to the birth of the solar system some 4.5 billion years ago. The sharp edges apparent on both moons suggest that on the whole they have the consistency of solid rock. Agglomerations of loose rubble, bound together only by small gravitational forces, would surely not shatter in this fashion.

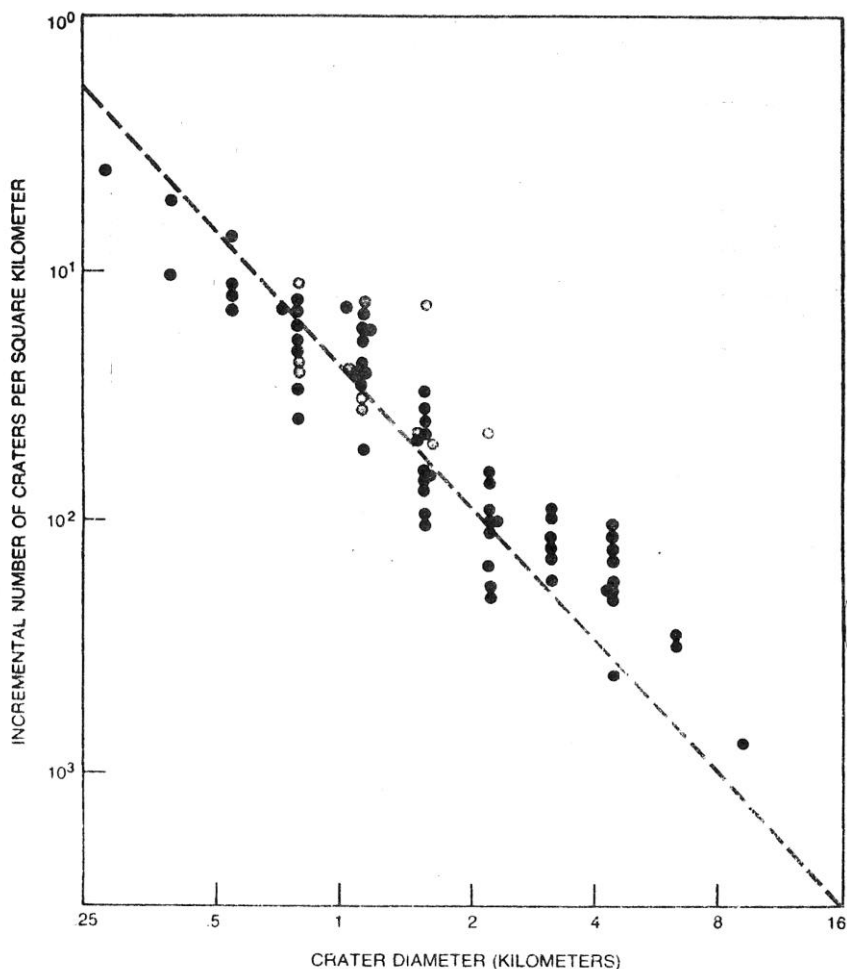
At least the surface of the satellites, however, consists of the kind of impact-produced layer of rubble known as a regolith. Two kinds of evidence support such an interpretation. The first is optical evidence: how sunlight is scattered by the surface. The second is thermal evidence: how the surface heats up.

It was Benjamin H. Zellner of the University of Arizona who managed, in 1971, to measure the degree of polarization of the sunlight scattered from the surface of Deimos: the flood of scattered light from Mars itself makes this an extremely difficult telescopic measurement. Zellner found that the surface of Deimos polarized sunlight in a

way that was quite uncharacteristic of solid rock. Instead the polarization was like that of a surface composed of some dark powder.

At about the same time that Zellner made his observations known, instruments aboard *Mariner 9* recorded complementary evidence. One of the *Mariner 9* experiments was the measurement of the infrared radiation from Phobos before and after the satellite passed through the shadow of Mars in its quick journey around the planet. The question was: How would Phobos heat up after cooling off' in the shadow? Would it do so slowly? Slow heating would be indicative of a compacted surface or perhaps even a solid one, characterized by high thermal conductivity. Would it heat up rapidly? Quick heating' would suggest some kind of porous surface with low thermal conductivity. The infrared observations showed that the surface of Phobos heated up with remarkable rapidity after the satellite emerged from the shadow of Mars, indicating a surface layer with the extremely low thermal conductivity characteristic of a powder. The experiment was sensitive to the temperature of the uppermost millimeter or so of the surface; thus at least that much of the surface is evidently a powdery regolith.

Still further evidence from *Mariner 9* supports Zellner's telescopic observations. At Cornell University, Michael Noland and I have made use of *Mariner 9* data to analyze the light-scattering properties of the surface of Phobos and Deimos. Both surfaces scatter sunlight in a manner characteristic of a dark surface with an intricate structure. For example, when such a surface is observed at an angle equal to the angle of illumination, there is no gloss or increase in brightness. The light-scattering properties of Phobos and Deimos resemble those of certain areas on the earth's moon. In these areas the surface not only is dark enough to prevent the scattering of most of the impinging photons but also is so intricate in texture that each surface element has numerous nooks and crannies that trap most of the photons that do get scattered. Our study of the *Mariner 9* data suggests that both satellites of Mars are covered with a homogeneous layer of regolith possessing these light-absorbing properties. We have searched carefully for patches of exposed rock but so far have found none. It is probably unrealistic, however, to think of the regolith on small bodies such as the moons of Mars as being exactly like the regolith of the



CRATERING of the moons of Mars is compared with cratering of the earth's moon. The straight line shows the trend for the most heavily cratered uplands of the earth's moon, which are "saturated": the number of craters cannot increase because new craters only obliterate older ones. *Mariner 9* images indicate that Phobos and Deimos are also saturated. They show 62 craters on Phobos (black) and 11 on Deimos. Only one side of Deimos has been seen, however.

earth's moon. Until we have sampled the surface layers of a few small bodies, however, we shall not know what the differences between the two classes of regoliths are.

How does a body as small as Phobos retain a regolith? No one is really sure. The most popular explanation involves what is called the low-velocity tail of the debris that is formed by impacts. Typically the impacting object imparts a wide range of velocities to the particles of the debris. If the

velocity required for escape from the parent body is low, most of the flying particles will be lost to space. Some fraction of the debris, however, will not achieve escape velocity and will remain imprisoned by the gravity of the parent body. The captured fraction need not be large in order to cover the parent body with a layer of fine dust. Estimates of the precise fraction needed to form such a layer are being derived from the laboratory experiments with high-velocity impacts, but they remain uncertain. Nevertheless, the

Viking-orbiter observations indicate that many of the craters on Phobos are secondary, that is, they were made by objects that were thrown up by primary impacts. These craters provide direct proof that some impact debris has indeed fallen back to the surface of the satellite.

It has been suggested that the reason Deimos and Phobos have a surface covering of regolith is that they are close to Mars. The argument goes on to conclude that similar small bodies in the asteroid belt between Mars and Jupiter would not have a regolith surface. In the case of the moons of Mars it is reasoned that if a particle of debris is to escape into space, it must have sufficient velocity to escape the gravitational influence not only of the parent satellite but also of Mars. If it lacks sufficient energy to escape Mars, the particle may go into orbit around the planet and eventually be captured by one moon or the other. Thus the moons of Mars have a chance to retrieve some of their own escaped debris. In the asteroid belt there would be no such opportunity for recapture.

The argument neglects the low-velocity-tail effect, which would hold some of the debris blasted from the surface of an asteroid as it presumably does on Phobos and Deimos. What is perhaps more important is observational evidence with respect to the asteroids themselves. For example, during the close approach to the earth in 1975 of the asteroid Eros, a body comparable to Phobos in size, several independent telescopic observations suggested the presence of a regolith surface. Such dust layers may in fact be an essential feature of all the solid surfaces in the solar system. Recent experiments conducted by Gault and his co-workers at the Ames Research Center show that for an impact of a given energy it is more difficult for debris to be ejected from a regolith-like layer of loose particles than it is for it to be ejected from a surface of solid rock. This suggests that once regolith forms it tends to remain and to be self-perpetuating.

I have indicated that at the wavelengths of visible light the reflectance of Phobos and Deimos is about 6 percent, compared with a reflectance of 11 percent for the earth's moon. As far as reflectance is concerned the surface of Phobos appears to be homogeneous. On Deimos, however, there are some areas that are brighter than the rest. On the basis of Mariner 9 data Noland and I have estimated that the brightness of one

such patch is some 30 percent above average. This puts its reflectance somewhere around 8 percent rather than 6 percent, which would make it a very dark surface.

It is usually assumed that Phobos and Deimos have a common origin. No conclusive evidence supports this assumption, but one argument cited in favor of it is the similarity in the orientation of the orbits of the two moons. The similarity of their photometric characteristics is possibly even stronger evidence in favor of a common origin. Hypotheses of the Martian moons' origin fall into two main schools: capture and accretion.

Those who favor accretion hypotheses regard the two satellites as collections of material left over from the formation of Mars. One plausible capture hypothesis visualizes a large asteroid passing close to Mars and breaking up during its passage, after which at least two of its larger fragments are captured by the planet and remain in orbit around it. This hypothesis has simplicity in its favor, but it leaves certain technical questions unanswered. For example, how would the orbits of the two fragments end up in the equatorial plane of the planet?

The truth is that not enough evidence is available for definitive theorizing about the origin of Phobos and Deimos. For example, the composition of the satellites' surfaces could provide important clues regarding their origin, but at this point no one knows what the surfaces are made of. The usual astronomical means of determining the composition of a solid object is to discover how the object reflects various wavelengths of electromagnetic radiation, including light. Adequate spectral reflectance measurements for Phobos and Deimos simply do not exist; at this stage all our arguments about their composition are indirect.

Since both moons are very dark, it is often stated that this fact alone makes it likely that the surface material is similar either to basalt, a dark igneous rock, or to the material of the class of crumbling meteorites known as carbonaceous chondrites. This kind of reasoning cannot be conclusive, since darkness by itself is not a diagnostic property of a surface. For example, the reflectance of a slate blackboard is about the same as that of Phobos and Deimos. Since slate is not known to exist in space, however, no one has suggested that the satellites are made of it.

To settle the question of origin we must find out what Phobos and Deimos are made of. If the material should prove to be basaltic, then the satellites are almost certainly fragments of a much larger body or bodies. The formation of basalt requires melting and mineral differentiation in a parent body and it is unlikely that such processes could take place in objects as small as the moons of Mars. If Phobos and Deimos are indeed basaltic, this fact would favor their being fragments of a large (and therefore differentiated) moon of Mars, shattered long ago in some catastrophic collision. That they could be fragments of some other large and similarly shattered basaltic body of bodies, perhaps from the asteroid belt, is less likely because of the low probability that Mars would capture such fragments.

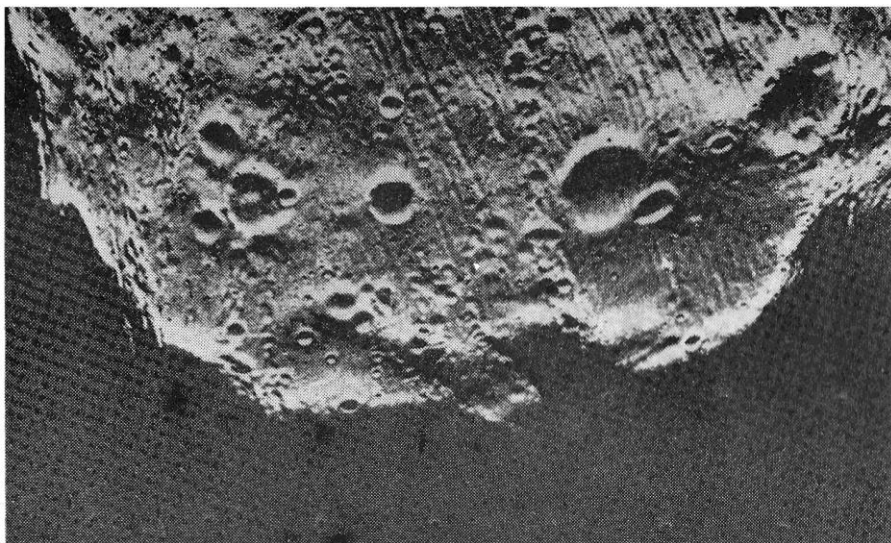
If the material should prove to be similar to that of the carbonaceous chondrites, then Phobos and Deimos need not be fragments of larger bodies. They could instead represent material left over from the formation of Mars itself. There is, however, some debate about whether or not Mars accreted much material of this kind during its formation. Some theorists maintain that such material could form only in the asteroid belt and not as close to the sun as the orbit of Mars. This seems to be almost certainly true of at least the carbonaceous chondrites classified as Type I, which are the richest in volatile components. If Phobos and Deimos should prove to be made of Type I material, then the two satellites are almost certain to be bodies captured from the outer half of the asteroid belt.

Whatever their origin, Phobos and Deimos have given us our best glimpse of the kind of body that populates the asteroid belt in uncounted numbers. We have yet to study the topography of any asteroid in detail, but we now have a relative wealth of information on two bodies that surely resemble asteroids very closely. Like asteroids, the moons of Mars are small and their gravitational fields are almost insignificant. Bodies with weak gravitational fields share three important characteristics. First, they lack an atmosphere. Second, they continually lose mass as a result of the high-velocity impacts of interplanetary debris. Third, they tend to be irregular in shape because large impacts are likely to knock off large chunks of their surface. Because such

bodies are too small to have the kind of internal pressure forces that would enable gravity and rotation to readjust their components into spherical form, they retain the irregular shapes they acquire.

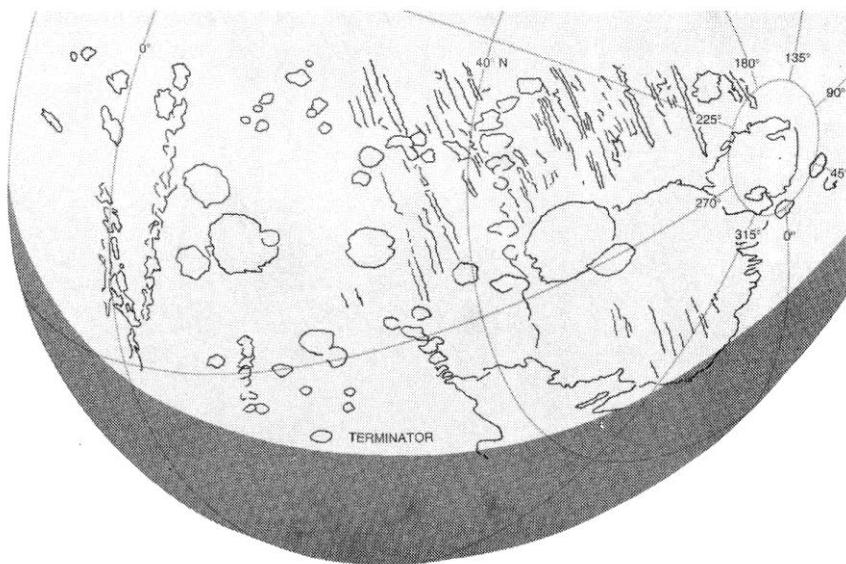
The two Viking orbiters have been circling Mars since last summer. Among their most important tasks have been extending the picture coverage of Phobos and Deimos and making more refined measurements of the decaying orbit of Phobos. One of the orbiters is now making close approaches to Phobos. Imagery with a resolution that will record features only 10 meters in diameter should be possible allowing a detailed study of many of the satellite's smaller craters. The same orbiter should also pass close enough to both moons to "feel" their gravitational pull. This, it is hoped, will make it possible to calculate their mass with an accuracy of plus or minus 10 percent. Knowledge of the satellites' mass will enable us to determine their mean density, and that in turn should narrow the range of guesswork about their possible constitution. For example, knowledge of the satellites' mean density may make it possible to eliminate from the running either carbonaceous-chondrite material of Type I, with a mean density of about 2.3 grams per cubic-centimeter, or basalt, with a mean density of 2.9 grams.

The, Viking-orbiter images have already led to better counts of crater-density on both Phobos and Deimos and also to the discovery of enigmatic grooves on the surface of Phobos *[see illustrations on page 34]*. The nature and origin of these peculiar parallel markings remain to be explained. but one exciting possibility is that they reflect layering, perhaps representing successive lava flows on the surface of a much larger parent body of which Phobos is merely a fragment.



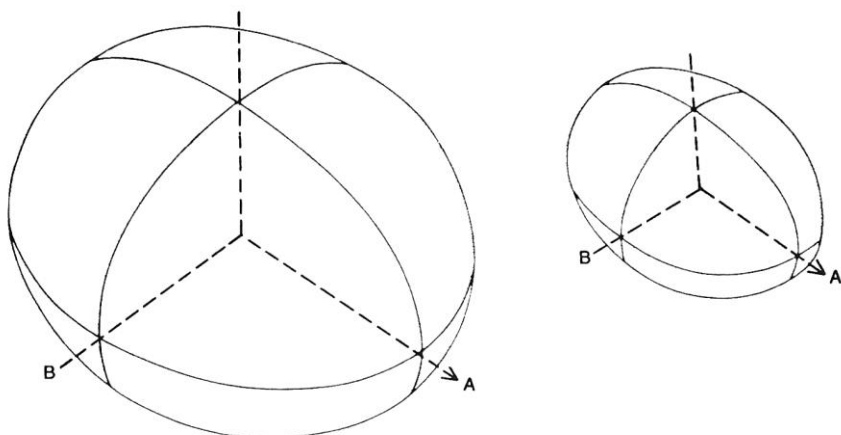
CLOSE-UP OF PHOBOS shows a portion of the satellite's surface extending from the north-polar region (*right*) to a little below the equator (*left*) and covering 70 degrees of longitude at its widest. The total area is nine by 18 kilometers. The image was obtained by the

Viking 2 orbiter in September, 1976, when less than 900 kilometers away. A series of prominent parallel grooves is evident at this resolution, which makes visible objects 40 meters or more in diameter. The cause of these curiously regular markings is uncertain at present.

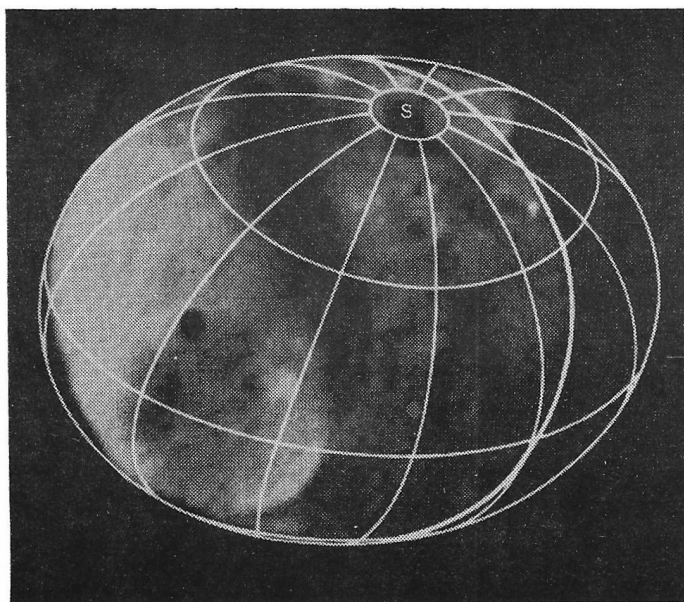


SKETCH MAP, based on the system of coordinates devised for Duxbury's model of Phobos, relates the *Viking 2* orbiter imagery to

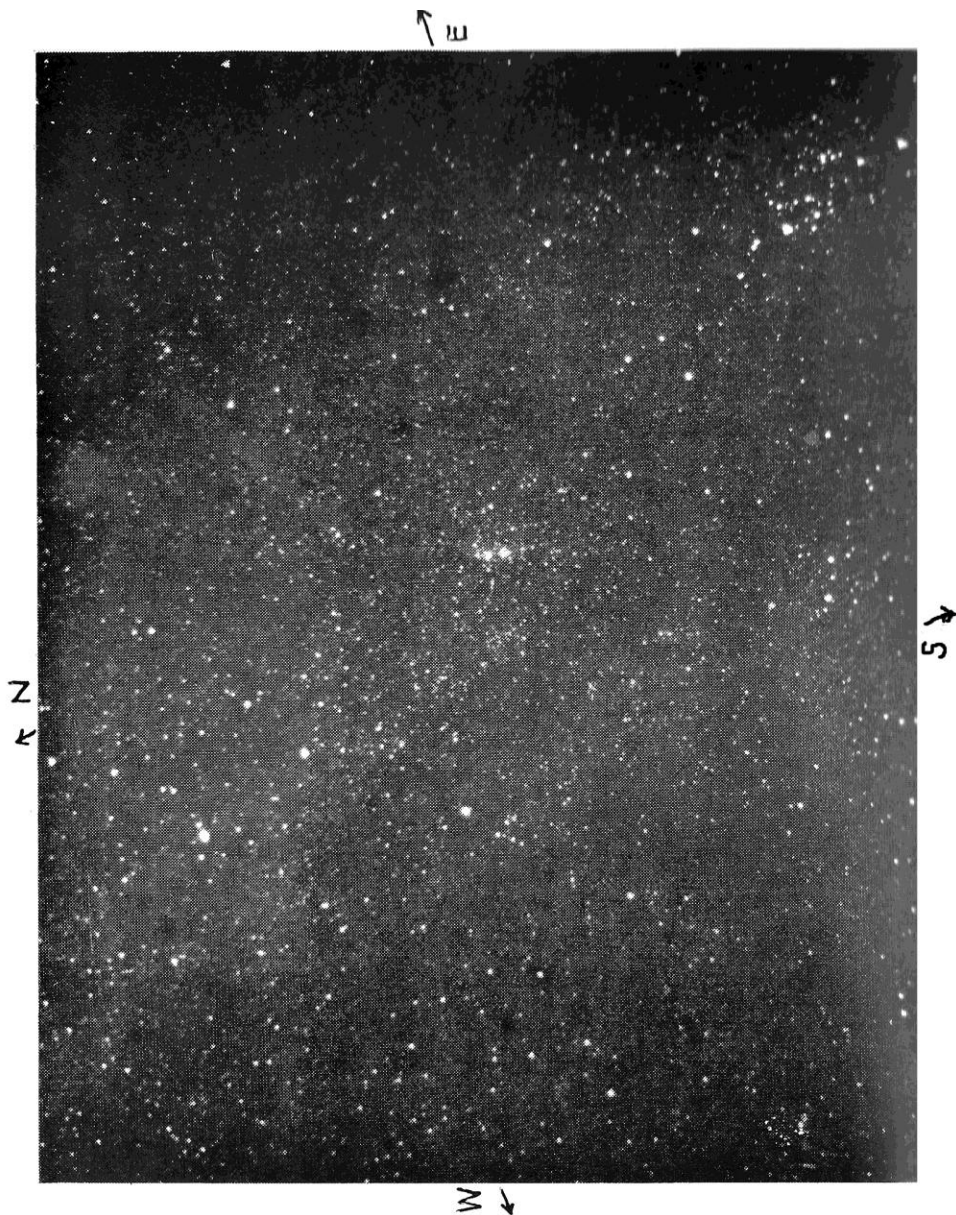
the map of the satellite's surface on the preceding page. Area in shadow lies east of boundary between light and dark hemispheres.



RELATIVE SIZES of the two Martian moons are apparent in this comparison of Duxbury's two models. The principal diameters of the Phobos ellipsoid are 27, 21 and 19 kilometers; those of Deimos are 15, 12 and 11 kilometers. The *A*-axis arrows label the side facing Mars; the *B* axes label the orbital plane. The similarity between the two moons' shapes is unexplained.



SYSTEM OF COORDINATES for Phobos is imposed on images of the satellite in two orientations obtained 22 days apart by *Mariner 9*. The geometry of the coordinates is based on a triaxial ellipsoidal model of the satellite developed by Thomas C. Duxbury of the Jet Propulsion Laboratory of the California Institute of Technology. As the separate superpositions indicate, after allowance is made for some missing chunks of the moon the model gives a good fit.



Double Cluster in PERSEUS. Taken by Roger Civic on
 Sept. 6 1976. Film, Tri-X, 400ASA, Exposed for 5 Min.,
 guided, using a 35mm Lens.