Mapping the moons of Mars: Phobos and Deimos

by Philip Corneille

Since antiquity, the planet Mars has always been an object of great interest to observers of the night sky. However, the two tiny moons of the red planet weren't discovered until the 1877 Mars opposition and it took another century to get some good photographs of these enigmatic satellites. Moreover, mapping both Martian moons proved very difficult due to their potato-shaped surfaces.

The satellites of Mars

Since Galileo Galilei (1564-1642) made the first telescopic observations of the planets in the solar system in 1610, astronomers started to speculate about the moons of Mars. Galileo's observations revealed that Jupiter, the next planet beyond Mars, had four satellites. Johannes Kepler (1571-1630), a believer in the harmonic numerology of the solar system, argumented that in order out of the Sun, Venus had no moons, Earth had one, Mars was uncertain and Jupiter was thought to have four. Two moons for Mars seemed the proper assumption to fit the mathematical progression.

Remarkably, the idea that Mars might have two satellites was also introduced in the books, *Gulliver's Travels* by Jonathan Swift (1726), *Die Geschwinde Reise auf dem Luft-Schiff nach obern Welt* by Eberhard Kindermann (1744) and *Micromégas* by Voltaire (1750).

During the 19th century, astronomers started the careful search for Martian moons but both William Herschel (1738-1822) and H.L. d'Arrest (1822-1875) were not successful. Observations of the red planet revealed the obvious features such as the polar caps, bright and dark areas but detecting the moons proved to be a challenge, due to their proximity to the high surface brightness of Mars. Moreover, both moons are dark objects, reflecting only five percent of the sunlight falling upon them. The best way to find these small objects was to catch the planet near opposition with both moons at greatest elongation and moving Mars just out of the scopefield. The actual discovery of the two Martian satellites was finally made in August 1877 by Asaph Hall (1829-1907) at the US Naval Observatory. The planet was in a favourable opposition and Hall was using the 26 inch 'Great Equatorial' refracting telescope, then the largest of its kind in the world. He first discovered the outer moon and later the larger inner moon. Further observations on 18 August 1877 put beyond doubt the character of these objects and the discovery was publicly announced by US Navy Admiral Rodgers. Of the various names that were proposed, Hall chose the suggestion by Henry Madan (1838-1901) of Eton college; Deimos for the outer moon and Phobos for the inner moon. In Greek mythology, Phobos and Deimos were the horses drawing the chariot of Mars, the god of war. The Romans called Phobos 'Pavor' and Deimos 'Pallor'. In 1879, Hall was presented with the Gold Medal of the Royal Astronomical Society of Great Britain for his important find. The origin of the two Martian satellites became a subject of speculation; either these were formed at the same time as the planet or they were captured asteroids.

Spacecraft exploration

The first spacecraft sent to Mars were mere flyby missions that attempted to photograph surface details.

Nevertheless, NASA scientists of the 1969 Mariner 6 mission hoped to detect Phobos in TV pictures, as its shadow on the Mars surface photos would have a sufficient photometric depth. In this way the shadow could be measured from the projected area and hence the diameter of the satellite. But it was Mariner 7 which imaged the inner moon for the first time. The featureless silhouette of Phobos in transit over Mars was only a few pixels across but the photo allowed a rough estimate of the moon's size. Phobos was found to have an unusually dark surface and to be irregular in shape.

Observations of the Martian satellites were an important science objective for Mariner 9, which became the first spacecraft to orbit another planet in 1971. Pre-orbital science pictures were taken while the spacecraft was several hundred thousand kilometres from Mars in order to refine orbit parameters and to permit accurate camera pointing at closer encounters. A search for any new satellites was made on 19 pictures of Phobos and Deimos acquired before Mars Orbit Insertion (MOI). After 349 days in orbit, Mariner 9 extensively covered the largest moon Phobos and obtained the first resolved images of Deimos covering about 60 percent of the outer moon. These first telephoto images showed the moons to be heavily cratered dark bodies and covered with regolith (loose grained material overlaying sediments). The largest craters found on these moons suggested that both satellites survived impact energies capable of disintegrating these 'flying mountains' of Mars. Scientists at the Jet Propulsion Laboratory (JPL) concluded that the moons might be composed of a mixture of carbon-rich rock and ice similar to the C-type asteroids in the belt between Mars and Jupiter. The JPL-team gave reliable measurements of the satellites' intermediate diameters: Phobos 22 km and Deimos 12 km. The orbital parameters for both moons were refined; Phobos orbited at 9380 km with a period of seven hours 39 min and Deimos orbited at 23,460 km with a period of 30 hours 18 min. Moreover, continuous observations over a 100 day period revealed that both satellites keep one side toward Mars at all times.

As part of the centennial celebration commemorating the discovery of Phobos and Deimos in 1877, an extensive exploration of the two Martian moons was

In August 2004, Mars Express' High Resolution Stereo Camera imaged the Mars-facing side of Phobos from a distance of less than 200 kilometers. ESA

conducted with the Viking orbiters in 1977 and 1978. Previous to the encounters, the orbital motions were precisely determined which allowed trimming manoeuvres in order to harmonise the orbital periods of both the Viking orbiters with the two satellites. By this means an 88 km flyby of Phobos and a 28 km flyby of Deimos were achieved. The spectacular high-resolution imaging data obtained have rivalled in resolution any previous flyby or orbiter imaging data on any body in the solar system. The silhouette of Phobos was dominated by three 'Phobian' craters, Stickney (10 km diameter), Hall (5 km) and Roche (5 km). The only named ridge on the inner moon is Kepler Dorsum. The outer moon's 'Deimian' craters were named after writers who mentioned the moons before their discovery; Swift (2.3 km) and Voltaire. Deimos appeared to have a significantly thicker cover of blanketing material (regolith) than Phobos. The encounters were so close that the masses of the satellites could be determined from their perturbing effects on the spacecraft motions; Phobos (1.1 X 10 power 16 kg) and Deimos (1.8 X 10 power 15 kg). The largest moon Phobos was confirmed to be in the Roche limit (2.44 times the radius of the planet) where internal gravity was too weak to hold the inner moon together. Phobos could crash onto the surface or be torn apart to become a ring plane around Mars. In contrast, Deimos could be decelerating and move away from the red planet.

The unmanned Soviet spacecraft Phobos 1 and Phobos 2 were dedicated missions to study the inner Martian moon. Both vehicles were launched in July 1988 but communication was lost with Phobos 1 in September of that year. Phobos 2 arrived at Mars in January 1989 and returned 37 quality photos of Phobos's surface. The spacecraft detected a faint outgassing from the largest moon during its approach to within 50 metres of Phobos' surface. During this final phase of its mission, Phobos 2 had to release two landers, one mobile hopper and a stationary platform, but contact with the craft was lost. The mission officially ended when the spacecraft signal failed to be reacquired on 27 March 1989. The nature of the outgassing was never determined but it was most likely water.

NASA's Mars Global Surveyor arrived at the red planet in September 1997. Its high-resolution photos of Phobos indicated that the surface of this small body had been pounded into powder by eons of meteoroid impacts, some of which started landslides that left dark trails marking the steep slopes of giant craters.

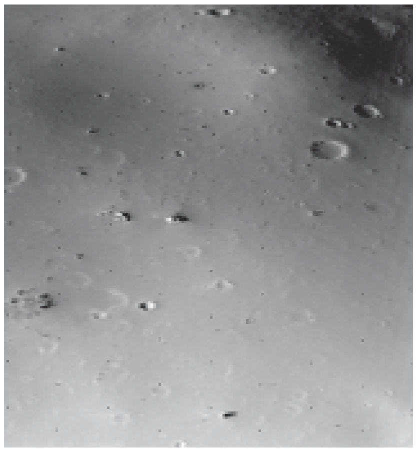
More recently, the 2004 Mars Exploration Rover 'Opportunity' observed the transit of Deimos (4 March 2004) and Phobos (7 March 2004) across the surface of the Sun. The moons were seen as black spots moving rapidly across the face of the distant Sun.

The European Space Agency's (ESA) Mars Express orbiter arrived in Mars orbit at Christmas 2003. This spacecraft returned unprecedented high-resolution images of Phobos' surface, enabling the moon's shape, topography, colour, 'regolith' light-scattering properties, and rotational state to be further determined.

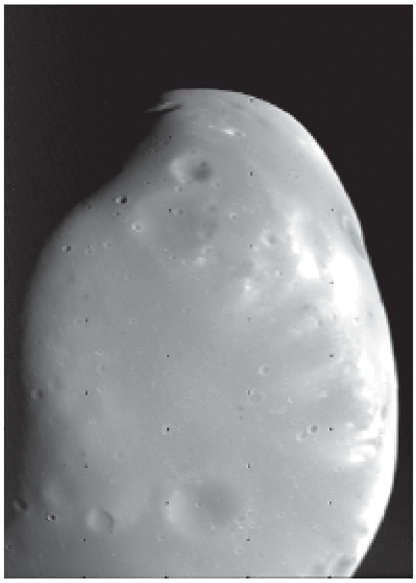
Last but not least, NASA's Mars Reconnaissance Orbiter (MRO), which arrived at the red planet in March 2006, will use images of the Martian moons for navigation. MRO's High Resolution Imaging science Experiment (HiRISE) has a one metre per pixel resolution and could unravel the scientific mystery of the Martian moons' origin: natural satellites, remnants of a moon or captured asteroids?

Targets for future colonisation

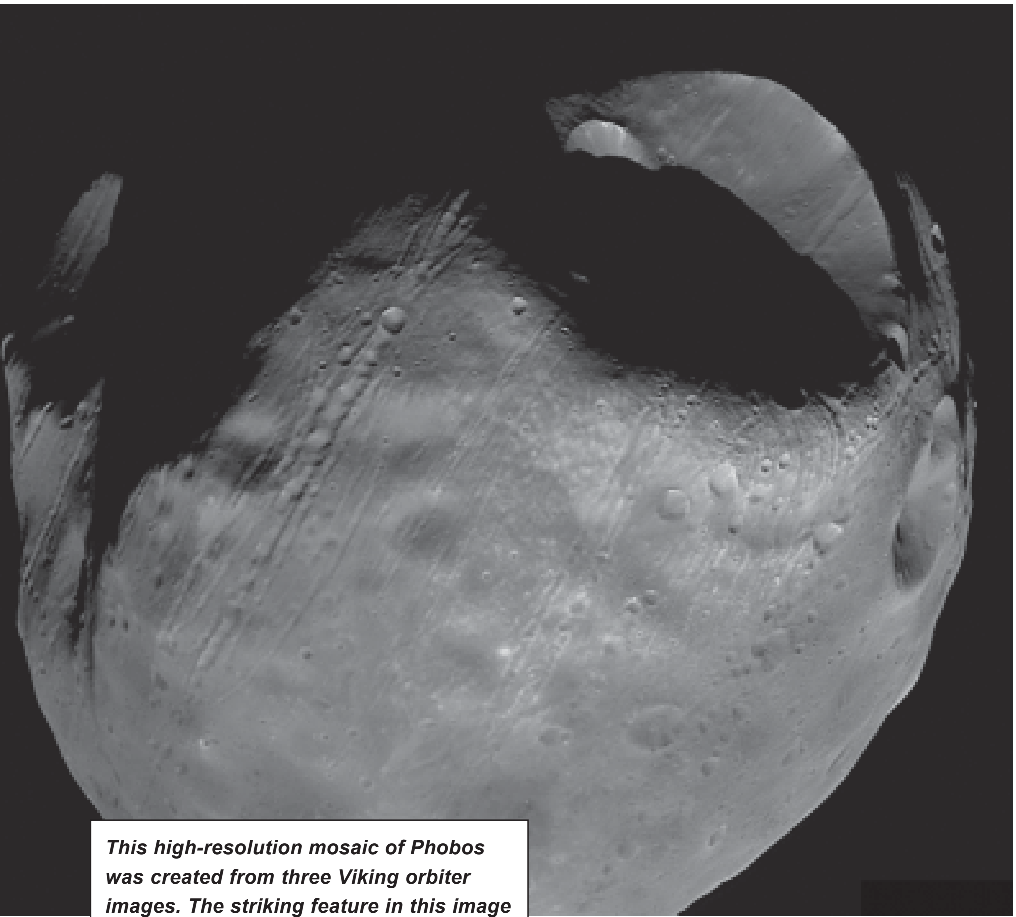
In the 1960s, Dr Ernst Steinhoff and Dr Fred Singer stated the potential of the Martian moons as subjects for space exploration. An examination of the Martian satellites could



This Viking 2 Orbiter image shows the surface of Mars' moon Deimos from a distance of 30 km. The image covers an area 1.2 km by 1.5 km and features as small as 3 meters across can be seen. Note many of the craters are covered over by a layer of regolith estimated to be about 50 meters thick. (NASA-JPL)



Morphographic projection of the surface features on Mars' smallest moon Deimos. The large craters Voltaire and Swift are clearly visible in the middle of the map. Dr P.J.Stooke



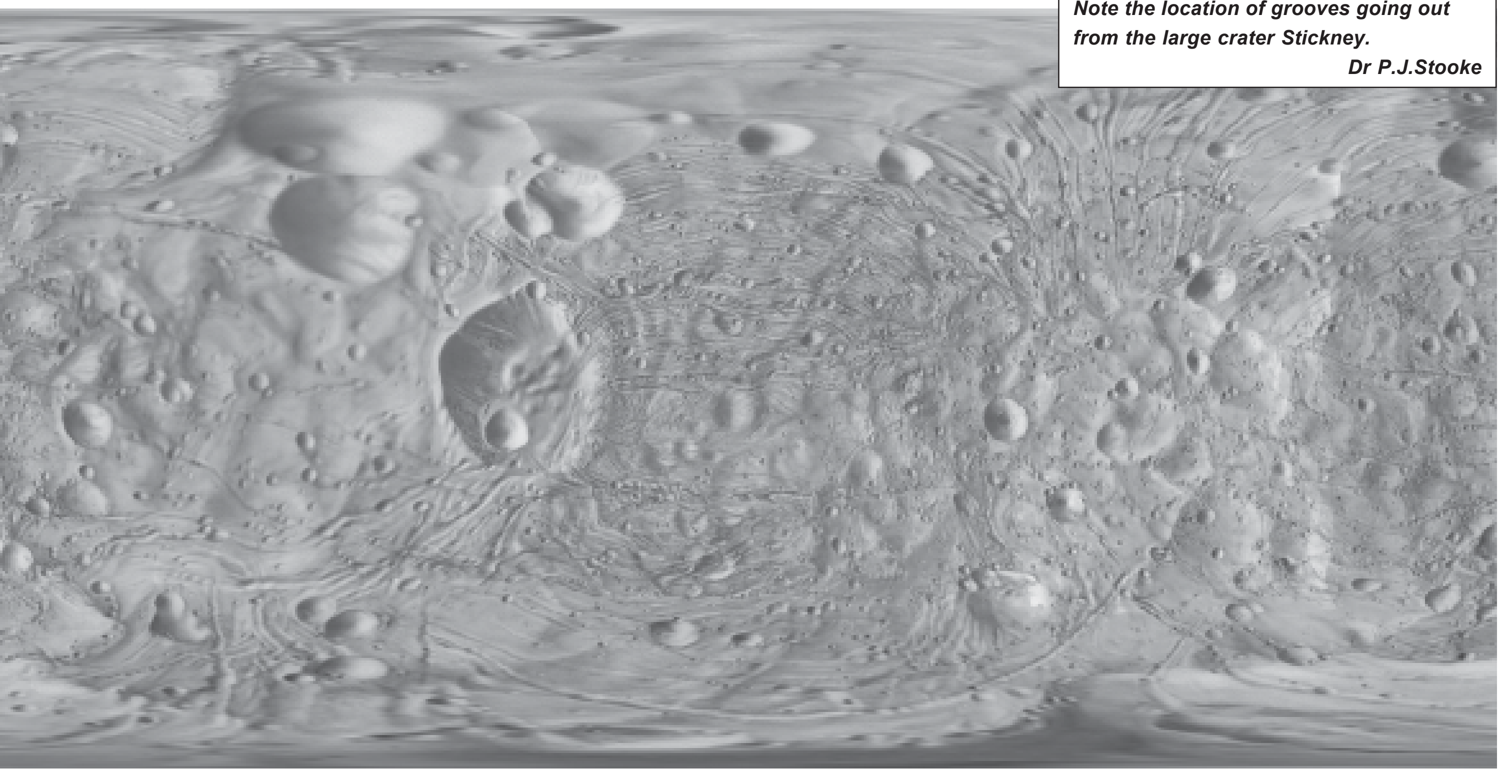
This high-resolution mosaic of Phobos was created from three Viking orbiter images. The striking feature in this image is the giant Stickney crater. Grooved fractures caused from the impact that created Stickney extend away from the crater. ***NASA-JPL***

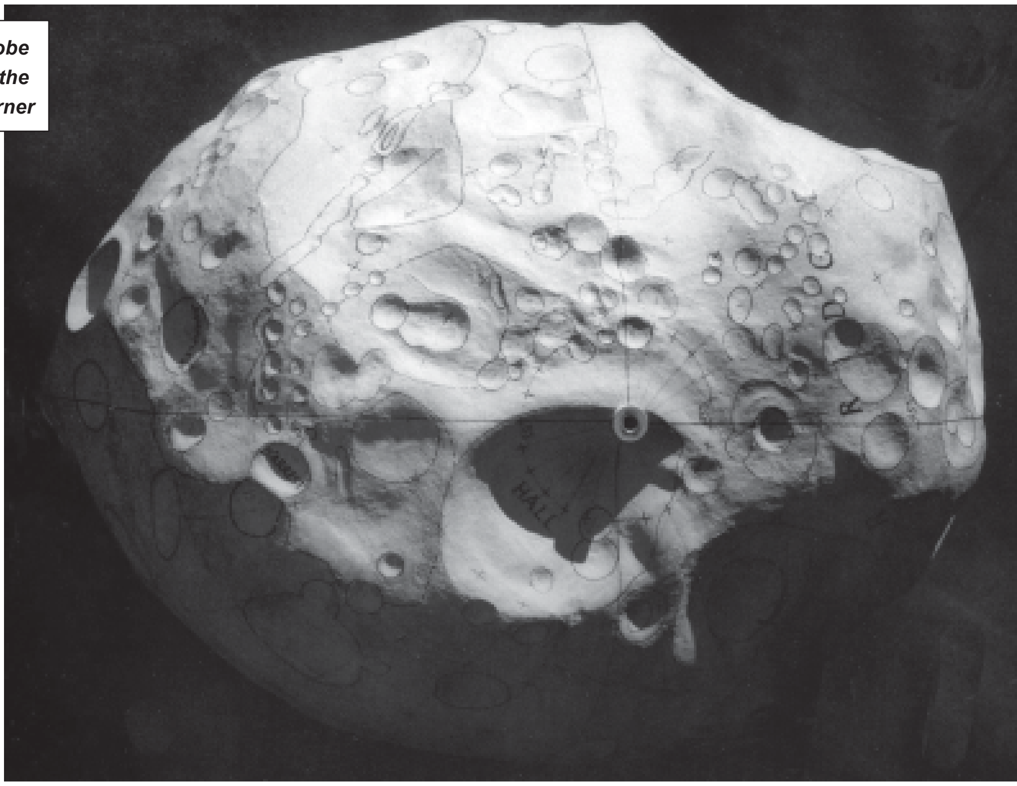
not only provide clues on the origin of the solar system but could also reveal if Phobos and/or Deimos were suitable as gateways to extensive Mars exploration. Singer envisioned an encampment of astronauts on Deimos from where down-to-the-surface sorties could be undertaken to selected areas on Mars. He argued that this was the best way for humans to get around on the red planet as a surface trip from the equator to a pole would be dangerous and would take too long. Spacecraft could examine the resource potential of the Martian moons.

However, delivering spacecraft onto Mars or its satellites required detailed maps in order to locate the most interesting places. The 1971 Mariner 9 pictures were the basis for three-dimensional photomosaic globes of Mars (*Spaceflight,* July 2005, page 270) and the first two-dimensional maps of the Martian moons produced by US Geological Survey. However, producing good maps of the satellites proved difficult due to the non-spherical shape of both moons. Three types of map projections were considered; orthographic, simple cylindrical and morphographic. The latter projection (triaxial ellipsoid model) resulted in map sheets, which made the production of a Phobos globe feasible. In 1975, a rubber mould for globes of the Martian moon Phobos was constructed by scientific modeller Ralph J. Turner, Rock Creek Experimental Station – Oregon, at a scale of 1:60,000 using 25 Mariner 9 photo records. The triaxial spheroid proposed by T.C. Duxbury was taken as the general form of the satellite. A total of 10 casts were made in plaster, among which were two for NASA JPL, one for Smithsonian Institute, one for Cornell University and some to private persons (eg Dr Carl Sagan). Each of these globes measured 44 cm on its longest axis.

The successful Viking missions to Mars in 1976 provided unprecedented data for mapping of Martian features. Moreover, the

Morphographic projection of the surface features on Mars' largest moon Phobos. Note the location of grooves going out from the large crater Stickney. ***Dr P.J.Stooke***





South Polar view on a 1:60000 scale Phobos globe showing the large Hall crater in the middle and the Kepler Ridge on the upper rightside. Ralp Turner

spectacular surface panoramas taken by the Viking landers encouraged astronomers and sci-fi writers alike to imagine how the moons would occur for an observer on Mars. Both Martian satellites revolve in the same direction as the rotation of their parent planet. However, Phobos, orbiting below the synchronous orbit radius (faster than Mars' rotation), would rise in the west, passing overhead in four hours and would set in the East approximately twice a day. The outer moon Deimos would move slowly across the pink sky, rising in the east and setting some two days later in the west. After the 1977 Viking Orbiter 1 and the 1989 Phobos 2 spacecraft encounters, new mapping accuracies became available and Ralph Turner created another Phobos globe and a Deimos globe on scale 1/100,000. Other Phobos and Deimos globe at scale 1/50,000 were made by the Astrophysics departments of the Martin Luther University (Wittenberg, Germany) and the Max Planck Institute (Munchen, Germany).

The Viking orbiters' new image data enabled the creation of digital shape models of both Martian moons. By projecting spacecraft images onto a digital radius model, the creation of photomosaics was possible. Map projections of Phobos and Deimos consisted of 14 sheets each. Nowadays, the digital shape models of Dr Peter Thomas (Planetary Sciences – Cornell University) and Dr Philip Stooke (Geography - University Western Ontario) are available online at the Planetary Data System websites (http://pds.jpl.nasa.gov) (www.psi.edu/pds/maps.html). Image-processing software can be used to extract data on size and distributions of surface features. Dr Stooke also produced precise 1/50,000 Atlases of Phobos and Deimos. Recently, some of the Phobos and Deimos globes mentioned above were put on display during the September 2005 international astronomical meeting in Norway.

Single return missions

About 120 years of Earth-based observations and 25 years of spacecraft exploration of Phobos and Deimos have revealed a relationship of the moons to carbonaceous asteroids. The non-spherical, irregularly shaped Martian moons provided insights into the processes that affected the evolution of small bodies in the solar system. In the near future, both Mars and its satellites will become targets of unmanned sample return missions in order to verify the potential of indigenous resources. Moreover, both Phobos and Deimos are candidate gateways for future manned missions. The Martian moons could provide energy-efficient access to Mars and minimum-energy return to Earth.

Mars will inevitably become the first planet, beyond the Earth to be explored by humans. The Martian moons might play an important role in Mars space operations as outposts for such an adventure.

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