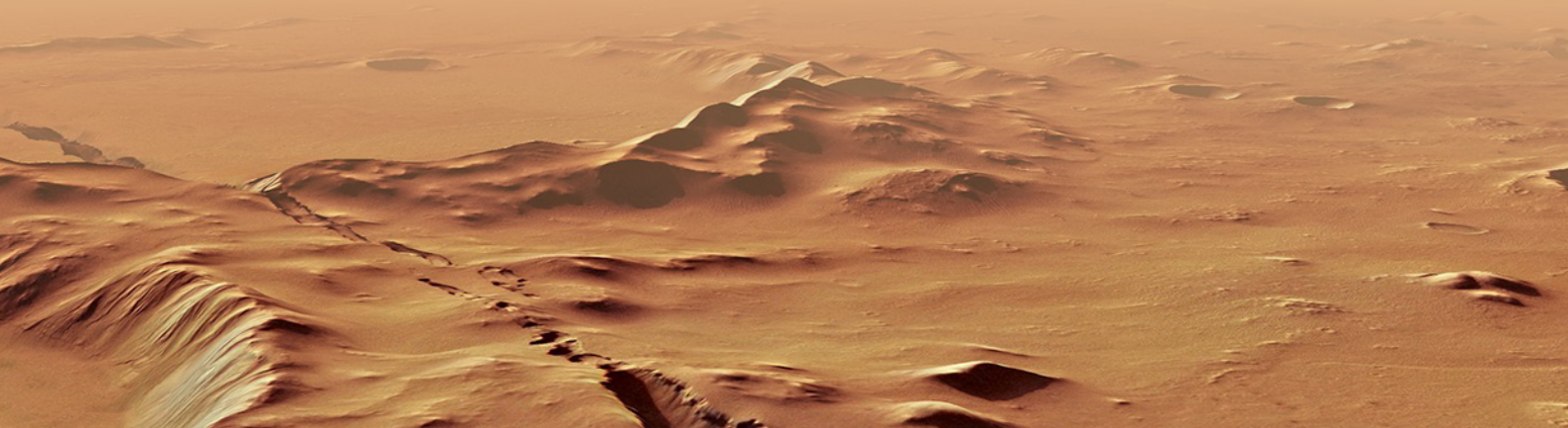
All About Space

25 AMAZING DISCOVERIES

By Laura Mears



MARS

25 amazing discoveries

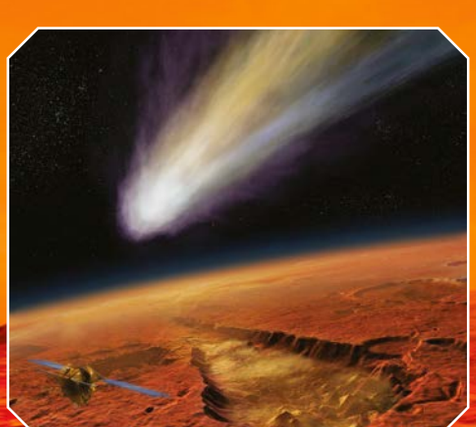
It is over 50 years since the first spacecraft flew past Mars and, in that time, we have learnt a huge amount about our mysterious red neighbour

Written by Laura Mears

A MASSIVE VOLCANO

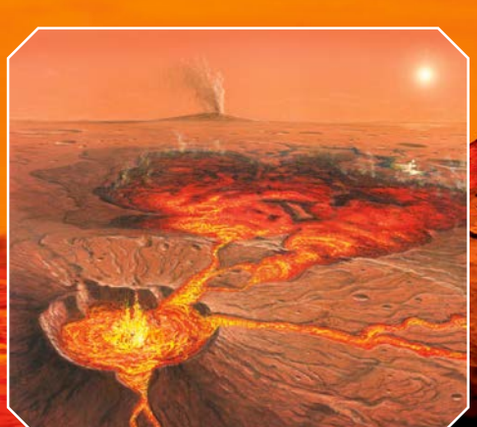
ITS ANCIENT WATERWAYS

THE MELTING POLAR ICE CAPS

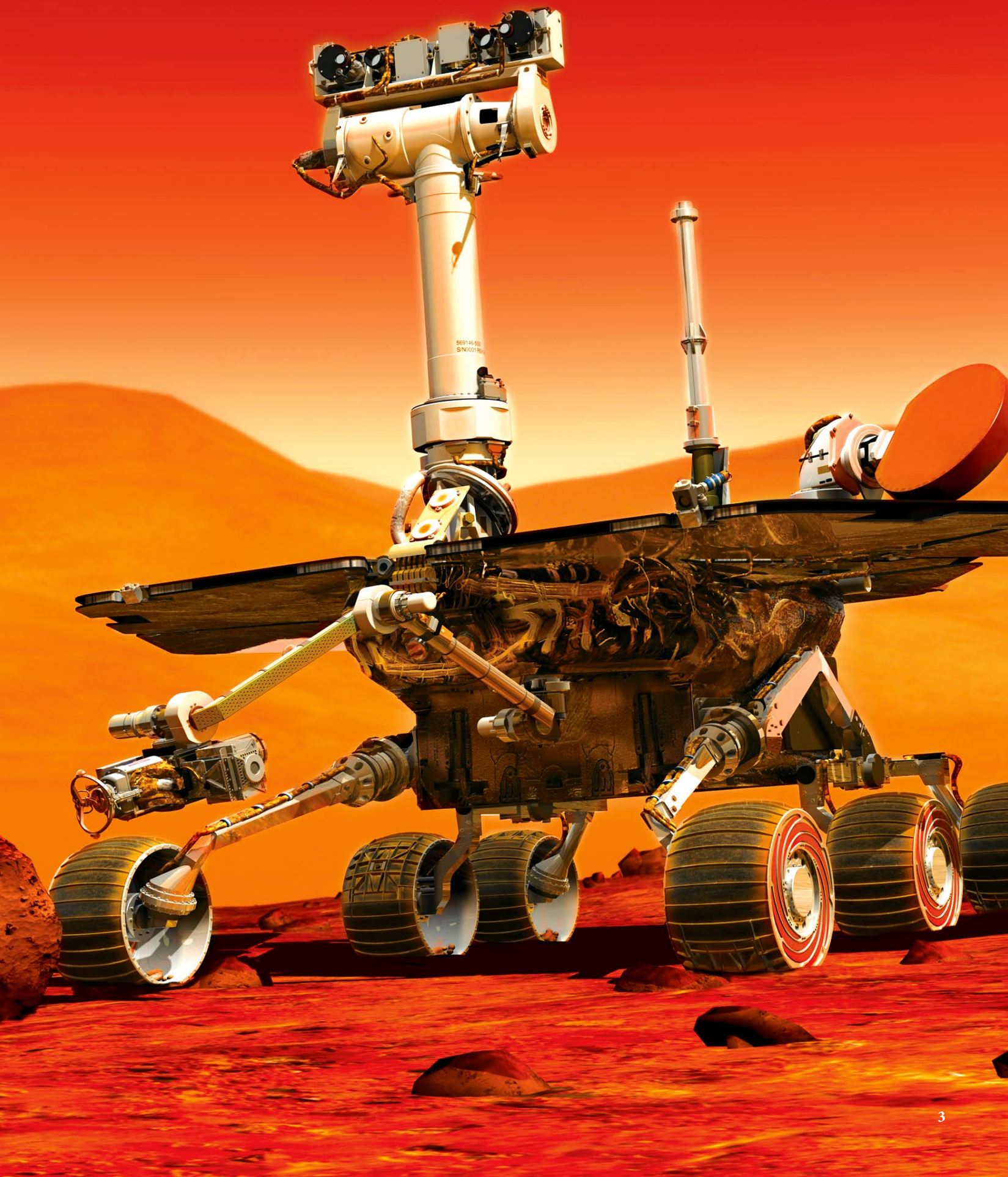


A NEAR-MISS

THE DANGERS OF EXPLORATION



ITS VIOLENT HISTORY



Astronomer Schiaparelli observed 'channels' on Mars

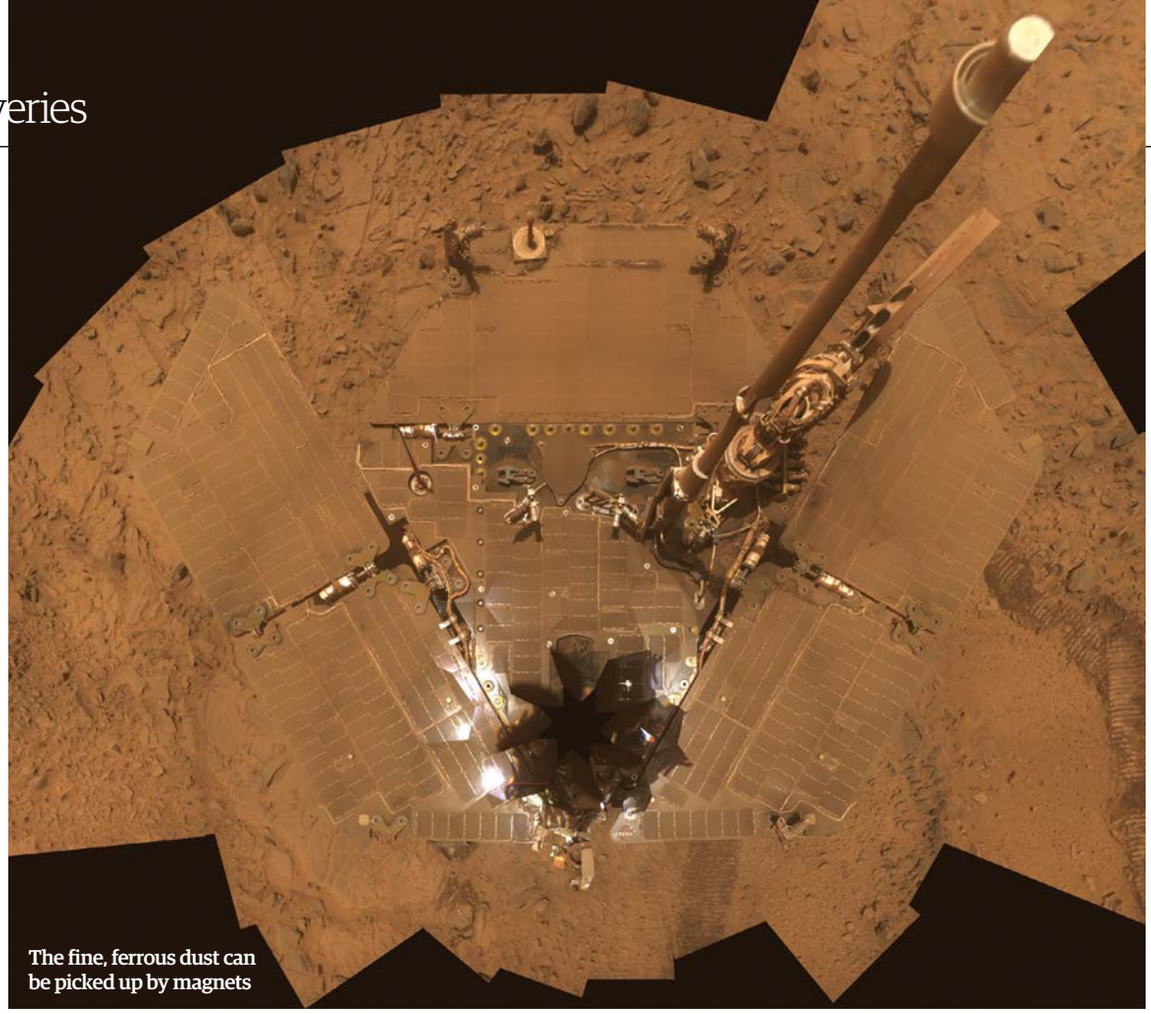
1 Mars looks like a dead planet

Since the invention of the telescope in the 1600s, astronomers have been fascinated by the surface of Mars. It is too far away to resolve from the Earth, and the atmospheres of both planets interfere with the passage of light, but they noticed dark and light patches that moved as the year passed, and speculated that they might belong to clouds, seas and even forests.

In the 19th century, Italian astronomer Giovanni Schiaparelli described a series of channels that he saw in the surface of the planet, imagining that there might be water on the surface, but a mistranslation of the Italian word 'canali' led American scientists, most notably Percival Lowell, to believe that the Red Planet was actually covered in canals, possibly built by an intelligent life form.

Hopes of an Earth-like planet were dashed when NASA's Mariner 4 captured the first ever close-up images of the surface during a flyby in 1965. The 22 stills showed craters, reminiscent of the scarred surface of the Moon, and revealed the planet to be a barren waste covered in red dust and rubble. Measurements taken by the onboard instruments detected no magnetic field, and barely any atmosphere.

For years after, scientists thought Mars was a dead planet, whose geological activity stopped billions of years ago. But subsequent missions revealed that there's much more to Mars than meets the eye.

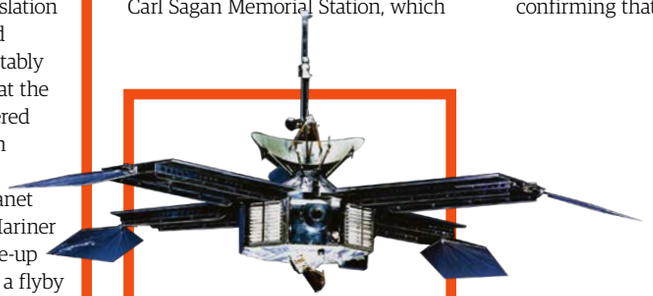


The fine, ferrous dust can be picked up by magnets

2 Martian dust is magnetic

The Red Planet owes its distinctive colouration to large amounts of iron, which was detected in high quantities in the soil by the Viking landers in 1976. Its surface is coated in a fine layer of dust, which after billions of years of winds and storms has been ground down to a consistency finer than talcum powder. The Imager for Mars Pathfinder (IMP), attached to the Carl Sagan Memorial Station, which landed in 1997, used the difference in atmospheric brightness throughout the day to measure the size of the airborne dust particles, revealing that on average, they measure about three microns in diameter: the perfect size to interfere with delicate equipment!

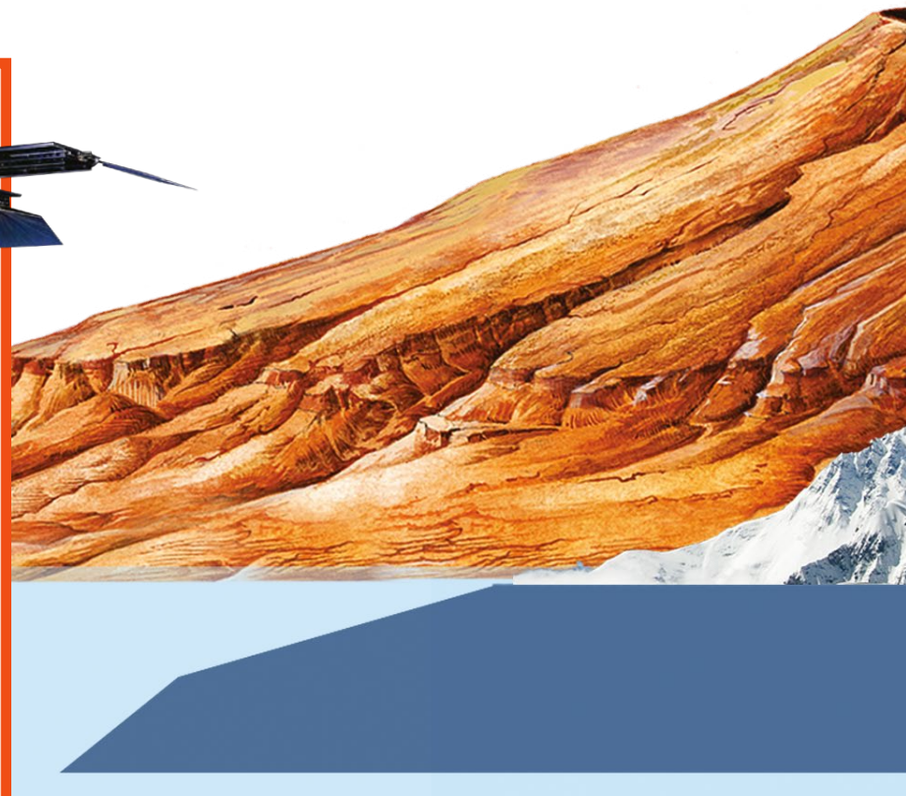
In 2004, NASA's Spirit rover carried permanent magnets to the surface of the planet to probe the dust further, confirming that almost all of the dust on Mars is magnetic, whether in the air or on the ground. Two angled magnets captured particles from the atmosphere, revealing different oxides of iron; strongly magnetic dark material that is either magnetite or maghemite, plus lighter, less magnetic haematite. The rover also carried a strong magnet near its panoramic camera that repelled the dust, protecting the equipment and ensuring the images remained clear.



Mission Profile

Mariner 4

Launched: 28 November 1964
Arrived at Mars: 14 July 1965
Weight: 260.68kg (574.70lb)
Number of days on/around Mars (in Martian days and Earth days): 1 day/1 day
Current status: Communications terminated in 1967



3 It is home to the tallest mountain in the Solar System

The biggest mountain we know of is nearly three times taller than Everest

The first orbiter to visit Mars was NASA's Mariner 9, tasked with mapping 70 per cent of the planet's surface. However, when it arrived in 1971, the planet was engulfed in a dust storm that completely obscured the view of the ground below, and the orbiter had to wait for several months for the dust to settle.

As the storm subsided, the highest points were revealed first, and four enormous volcanoes started to appear above the sinking clouds. They were large and domed in appearance, and the sides had gentle slopes, reminiscent of the shield volcanoes on Earth.

The lava in shield volcanoes is lower in silica than the lava in stratovolcanoes, making it runnier and more liquid. Instead of spraying outwards, as it escapes through the crust it moves in fluid sheets, and the lava flows travel for great distances across the ground. Over time, a gentle slope builds up as layer upon layer of lava are laid down, resulting in a wide, smooth volcano.

The tallest of the Martian shield volcanoes is Olympus Mons, measuring 624 kilometres (374 miles) across and extending nearly 26 kilometres (16 miles) above the ground. It easily dwarfs every other peak identified in the Solar System to date. For comparison, the tallest volcano on Earth, Mauna Kea in Hawaii, extends 10,000 metres (32,800 feet) above the floor of the Pacific Ocean.

4 Mars has two satellites

The two moons of Mars are named Phobos and Deimos, after the sons of the Greek god of war, Ares. Phobos has the closest orbit of any known moon, and passes within 6,000 kilometres (3,730 miles) of the surface of the Red Planet, completing a full circle three times every day. They have been photographed close up by several missions, but never visited.

5 Mars used to have lakes and streams

Mars wasn't always as dusty and desolate as it is today. Maps made of the surface by Mariner 9, the Viking orbiters, and the Mars Global Surveyor reveal networks of valleys across the southern hemisphere, and show evidence of streams running down the sides of the mountains.

The most convincing evidence for liquid water on Mars has been provided by NASA's rovers Spirit, Opportunity and, more recently, Curiosity. Within just a few months of landing in Gale Crater, Curiosity revealed an ancient streambed. On the ground are dunes made from sand and pebbles, too heavy to have been moved by the winds in the thin Martian atmosphere. The pebbles were smooth, like those you might find at the beach, and in the nearby rocks were veins of calcium sulphate, a mineral that would have been dissolved in the water that once flowed there. The rover also came across the site of an ancient lake, containing clay minerals formed in neutral water and mudstone, made from particles laid down over time.

In 2014, Opportunity discovered another fresh water source on Mars, 8,000 kilometres (4,970 miles) away from the Curiosity site and positioned in rocks from the earliest point in Martian history, when the surface was likely to have been more similar to Earth. The rocks in the area are smectite, a clay mineral formed in the presence of pH-neutral water.

3.5 billion years ago

Mars underwent a catastrophic change, and within the space of a few hundred million years, its core cooled, its magnetic field was lost, and over 95% of its atmosphere boiled away, preventing liquid water from existing on the surface. Over the next 3 billion years, volcanic activity periodically melted ice trapped beneath the surface, forming channels and gullies.

4 billion years ago

In the earliest history of Mars, the heavy bombardment was battering the inner planets of the Solar System, creating the craters now visible on Mars' southern hemisphere. The planet still had its atmosphere, and liquid water existed on the surface, possibly as a vast ocean that covered the northern hemisphere.

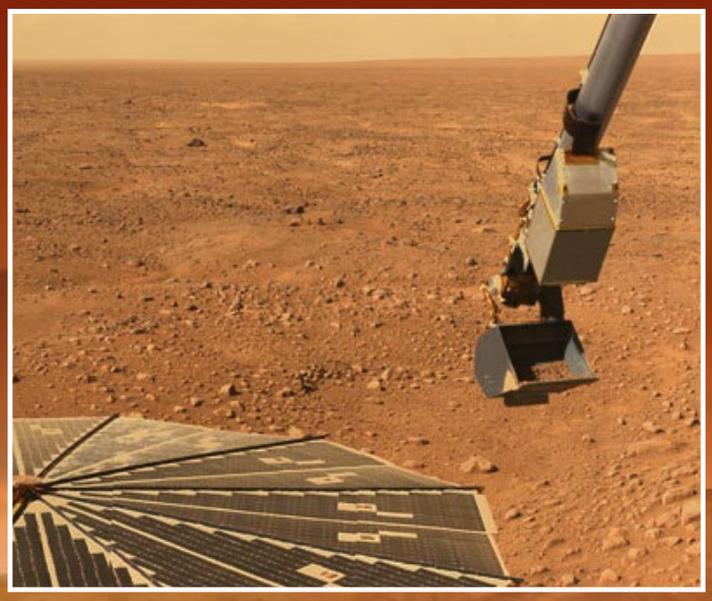
Mission Profile

Opportunity

Launched: 7 July 2003
Arrived at Mars: 25 January 2004
Weight: 185kg (407.9lb)
Mission type: Search for past water activity on Mars
Current status: Lost contact 10 June 2018

7 Mars isn't round

NASA's Mars Global Surveyor spent three years creating a topographical map of the entire Martian surface. It revealed that the northern hemisphere is low and flat, while the southern hemisphere is high, rugged and cratered, with a huge difference in elevation between the top and bottom of the planet.



6 It was once capable of supporting life

The sedimentary rocks laid down over millions of years on the surface of Mars are evidence that liquid water existed for prolonged periods, giving plenty of time for life to have evolved. Following the repeated discovery of water on Mars, NASA switched its focus to searching for signs of life, and the Curiosity rover has been hunting since it landed in 2012.

It has drilled into the sedimentary rocks in a location called Yellowknife Bay, revealing that the minerals beneath contain nitrogen, phosphorous, hydrogen, oxygen, carbon, and sulphur – the building blocks of the biological molecules that make up all life on Earth. On our own planet, microorganisms known as lithoautotrophs (rock eaters) can survive by using inorganic molecules to obtain their energy.

As the climate on Mars changed, the liquid water on the surface became trapped in the soil as permafrost, and today nothing can survive on the surface. The planet is bathed in radiation, battered by solar winds, and the atmosphere is painfully thin. However, on Earth bacteria can survive buried deep in Antarctic permafrost. Scientists are hopeful that if there was once life on Mars, traces will remain in the ice.

Present day

The atmosphere on Mars is thin, and the vapour pressure is low. Any water ice reaching the surface instantly sublimes into vapour and escapes. Much of the water that used to cover the planet is trapped beneath the ground as permafrost, and missions are ongoing to determine whether there is liquid water hidden below.

Mission Profile

Curiosity

Launched: 26 November 2011
Arrived at Mars: 5 August 2012
Weight: 899kg (1982lb)
Mission type: To determine whether Mars could have supported life in the past
Current status: Active

8 A day on Mars is 41 minutes longer than a day on Earth

Mars missions are planned and executed according to Mars time, where a day lasts for 24 hours and 37 minutes (compared to the 23 hours and 56 minutes of an Earth day). Amazingly, this number has been known since 1666, when Giovanni Cassini calculated the spin by watching surface features appear and disappear (he estimated the Martian day length to be 24 hours and 40 minutes).

9 Its gravity is about a third of Earth's

The orbital behaviour of satellites around Mars, both natural and artificial, have revealed that there is 62 per cent less gravity on Mars than there is on Earth. Mars is just half the size of the Earth, and is only around 11 per cent of the mass, dramatically reducing its gravitational pull.

10 A vast canyon opened up as the crust stretched

One of the most striking features on the surface of Mars is Valles Marineris, named after the Mariner 9 orbiter that discovered it. The vast canyon stretches across the equator and is over 4,000 kilometres (2,485 miles) in length, seven kilometres (four miles) deep and is thought to have been formed when the planet cracked as it cooled.

NASA's Gaylon McSmith, current project manager for Mars Odyssey Explorer, which revealed water ice beneath the Martian poles

11 The ground is filled with water ice

One of the major questions surrounding Mars was what had happened to its water. Today, there may be trickles of liquid on the surface but it instantly sublimes into vapour, before escaping the atmosphere into space. However, in the past the planet was covered with lakes, streams and possibly even oceans.

Between 2001 and 2002, the Mars Odyssey Explorer looked for hydrogen beneath the surface of Mars, evidence that there might be trapped water. The map it returned revealed that beneath the dry carbon dioxide ice at the poles there is a huge quantity of water ice. The radar sounder onboard ESA's Mars Express orbiter later revealed that there is enough potential water trapped under the Martian poles to cover the entire planet in an ocean 11 metres (36 feet) deep.

12 The core might still be molten

The lack of magnetic field around Mars indicates the core might have solidified, but the Mars Reconnaissance Orbiter revealed evidence of plate tectonics, with features some scientists say are reminiscent of the San Andreas fault in California, where two plates are moving horizontally past each other.

"In the past the planet was covered with lakes, streams and even oceans"

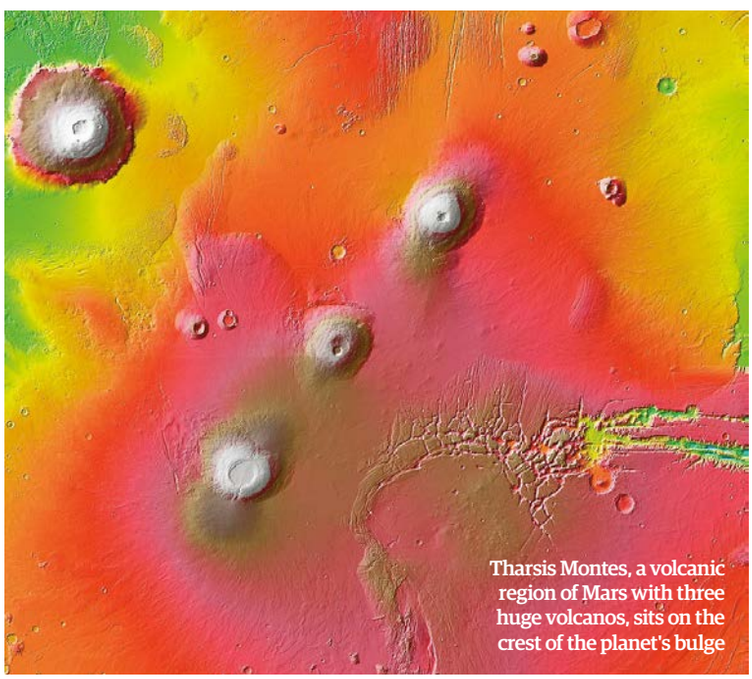
13 Mars has seasons

Seasons represent changes in day length and climate throughout the year, and are dependent upon a planet's distance to the Sun. If a planet is spinning straight up on its axis the equator always gets the same amount of sunshine every day, but if the planet is tilted the daylight hours vary slightly throughout the year. Earth is tilted on its axis by a little over 23 degrees, and Mars by 25 degrees, and both experience seasonal variations.

Mars differs from the Earth in that it has a more elliptical orbit and at certain times of the year is much closer to the Sun. As a result, spring and summer are longer in the northern hemisphere than they are in the southern, because when the north is tilted towards the Sun on the axis the entire planet is farther away in its orbit and so travels slower.

While the northern hemisphere enjoys a long summer, the winters at the southern hemisphere are harsh, and for much of the time the south pole is in complete darkness. The temperature drops so low that carbon dioxide solidifies out of the air, forming a permanent cap of dry ice over the region. NASA's first ever landers to reach the surface of the Red Planet, Viking 1 and Viking 2, showed that atmospheric pressure drops by as much as 25 per cent as the gas freezes in the winter.

At Mars' permanent south pole, winter temperatures plummet as low as -153C (-243F)



Tharsis Montes, a volcanic region of Mars with three huge volcanos, sits on the crest of the planet's bulge

14 It has shifted on its axis

NASA's Mars Global Surveyor completed a full map of the surface of Mars in 2001, but something didn't quite match up. The positions of the shorelines where regions of water might have been weren't level. A team at the University of California, Berkeley showed that the shoreline movement might be down to the change in the spin axis of Mars. The spin axis of Mars is not fixed like Earth's, but has changed over its lifetime, and crust has moved relative to the axis over a distance of around 3,000 kilometres (1,864 miles) along the surface in the last 2 to 3 billion years. As planets spin the motion causes them to bulge in the centre, and the group calculated that deformation in the crust would have changed the water level to match the patterns seen in the shorelines. It is even thought that floodwater might have contributed to the tilting of the planet, tipping the planet by 50 degrees, and then tilting it back again by 20 degrees as it dried out.

15 Its magnetic dynamo is not working

When Mariner 4 completed its flyby in 1965, it became apparent that something was wrong with Mars' magnetic field, and by 1989, a low-orbiting probe, Phobos 2, sent to Mars by the Soviet Union had revealed that it is 3,000 times weaker than the Earth's.

The direction and strength of the Martian magnetic field as it passes over the crust

Earth has a molten iron outer core, which circulates inside the planet, powering an internal magnetic dynamo. It acts like a giant bar magnet, generating magnetic field lines that spring out from the poles and encircle the Earth, deflecting solar winds and helping to protect the atmosphere. On Mars, these field lines are missing and, rather than circling the planet, weak magnetic fields are fixed in specific locations, mainly in the southern hemisphere. Earth's magnetic field periodically changes direction, and its magnetic history is written in to the rocks, with alternating bands of magnetic material deposited in opposite directions. NASA's Mars Global Surveyor found similar striped magnetic field lines in the ground of the southern highlands, indicating that at some point Mars had a functioning dynamo. These stripes are absent from the northern hemisphere, which formed much later in the history of the planet, suggesting the dynamo stopped functioning a few hundred million years after Mars formed.

16 Mars is still losing its atmosphere

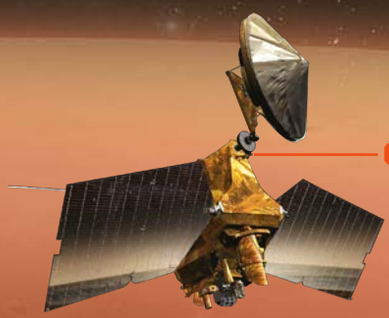
The atmospheric pressure on Mars ranges from around five to ten millibars (compared to 1,000 millibars here on Earth). The Red Planet is around 50 per cent smaller in diameter than Earth, and its lower gravity would have allowed the outer layers of the atmosphere to escape early in its life, particularly during energetic asteroid collisions. As the atmosphere started to thin, it would have provided less resistance to incoming asteroids, which would have resulted in even more collisions, beginning a vicious cycle of atmospheric loss. Without a functioning magnetic field, the Red Planet is also vulnerable to the effects of solar winds.

The Mars Express carries an imager capable of detecting the effects of solar winds, and showed that today, charged particles enter the Martian atmosphere, ionising the gases and allowing them to escape into space. NASA's Mars Atmosphere and Volatile Evolution (MAVEN) orbiter arrived on 21 September 2014, followed a few days later by India's Mars Orbiter Mission (Mangalyaan), and the two teams are collaborating to discover more about how Mars lost its protective sphere of gas.

Mission Profile

Mars Global Surveyor

Launched: 7 November 1996
Arrived at Mars: 12 September 1997
Mission goal: To characterise the surface features and geological processes on Mars
Current status: Contact ceased November 2006



Mars Reconnaissance Orbiter

Comet Siding Spring gave Mars a spectacular show as it passed nearby in October 2014

17 It had a near miss with a comet

The comet Siding Spring was discovered in January 2013 and in October 2014, it passed within 139,500 kilometres (86,680 miles) of the surface of Mars, just under a third of the distance from the Earth to the Moon. At the time there were two active rovers on the surface of the planet (Opportunity and Curiosity) and five active orbiters. All pointed their cameras in its direction.

The dust from the tail of the comet could easily have damaged the orbiting spacecraft, so the active orbiters, Mars Express, Mars Orbiter Mission, Mars Odyssey, Mars Reconnaissance Explorer and MAVEN waited on the opposite side of the planet. The comet passed without incident, and four orbiters managed to take pictures as it went.

18 Dust storms can shroud the entire planet

The dust that covers the surface of Mars is as fine as smoke and can float even in the painfully thin atmosphere. The biggest dust storm ever recorded on the Red Planet was seen by Mariner 9 when it arrived in 1971 and, since 1997, the Mars Global Surveyor has been in a polar orbit around Mars, tracking the weather.

As the ground heats up in the morning each spring, dust devils begin to form. Energy from the Sun is absorbed by the dust and rocks and in turn starts to heat the gases. They then rise up through the cold air, creating a spinning vortex. NASA says that the atmosphere is so thin that you wouldn't feel much wind on Mars, but that the fine dust whips through the air, building up static and releasing electrical arcs. As the day cools the storms subside, but the tiny dust particles can fly tens of kilometres into the air. In the low gravity, it takes a long time for them to fall back down to the surface again, with some remaining airborne for months.

The surface of Mars prior to (top) and during (above) the 2001 global dust storm as captured by Hubble

Upper
As you move up through the Martian atmosphere the pressure drops rapidly and the temperature rises. At altitudes of above around 200km (124mi), the gases begin to tail off into space, with no clear boundary between the atmosphere and the vacuum.

Middle
The combined effect of the spin of the planet, and the heating and cooling of the gases and dust in the atmosphere creates jetstreams between the lower and upper layers of the atmosphere. A similar effect can be seen on Earth.

Lower
In the lower atmosphere, dust particles absorb heat from the Sun, warming the air to around -63°C (-82°F). Clouds of water ice and carbon dioxide form in this layer, and dust storms regularly fill the air.

19 Mars has carbon dioxide weather

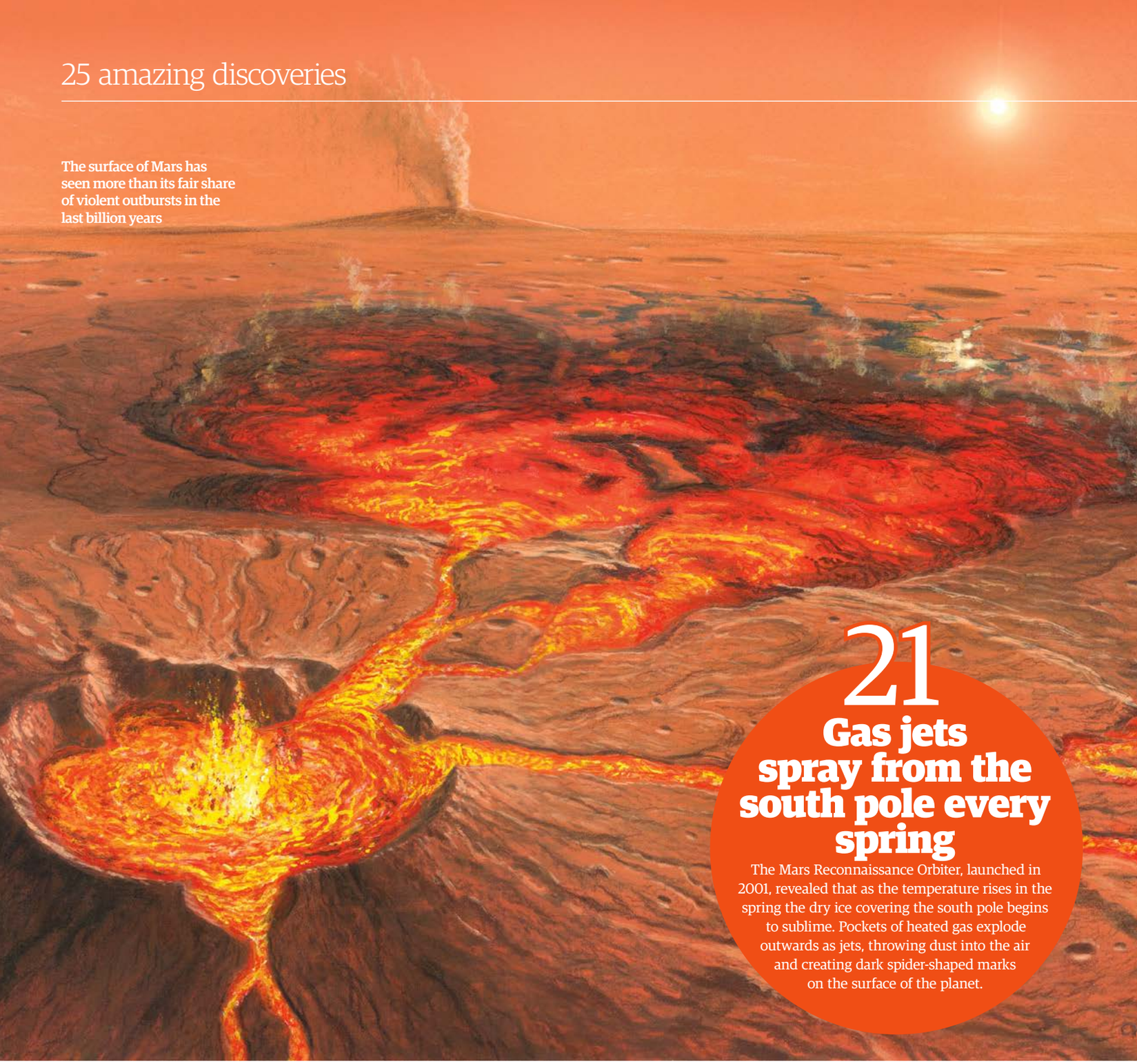
The atmosphere on Mars was first analysed during the Mariner 4 flyby, and has been tested by several orbiters since. The first accurate measurements of its composition were made by the Viking landers, revealing that the thin air is 95.32 per cent carbon dioxide, 2.7 per cent nitrogen, and 1.6 per cent argon. Just 0.13 per cent of the atmosphere is oxygen, and 0.03 per cent is water vapour. In contrast, the atmosphere on Earth is 78 per cent nitrogen, 21 per cent oxygen, and just 0.04 per cent carbon dioxide.

The European Space Agency launched its Mars Express orbiter in 2003, and has been monitoring the atmosphere ever since. It has observed carbon dioxide clouds forming around 80 kilometres (50 miles) in the air above the equator, and watched as it freezes down to cap the poles each winter. The orbiter also detected traces of methane gas alongside water vapour, sparking scientific interest in the potential for volcanic activity, or even life, beneath the surface.

Mission Profile

Mars Express

Launched: 2 June 2003
Arrived at Mars: 25 December 2003
Weight: 113kg (249lb)
Mission goal: To image the entire surface of Mars at super-high resolution
Current status: Active



The surface of Mars has seen more than its fair share of violent outbursts in the last billion years

21 Gas jets spray from the south pole every spring

The Mars Reconnaissance Orbiter, launched in 2001, revealed that as the temperature rises in the spring the dry ice covering the south pole begins to sublime. Pockets of heated gas explode outwards as jets, throwing dust into the air and creating dark spider-shaped marks on the surface of the planet.

20 There has been recent volcanic activity on Mars

The history of Mars is mapped out in the rocks that cover its surface and, using data gathered from orbiters and landers, scientists are beginning to piece together the planet's past. Over time, conditions on the surface have changed dramatically.

The Mariner 4 spacecraft observed some of the planet's oldest regions, craters made in the southern hemisphere during the heavy bombardment that battered the rocky planets around 4 billion years ago. Although this part of the surface has remained largely unchanged, the rest of the planet has since been remodelled. The northern hemisphere is much less cratered and has been covered with smooth lava plains, and the tops of the shield volcanoes at the equator indicate that they were recently active. Lava flows from the volcanoes repeatedly covered up impact craters, and by looking at the calderas at the top of the mountains it is possible to estimate when they last erupted. ESA's Mars Express has been examining the volcanoes, and scientists estimate that volcanic activity continued until 100 to 200 million years ago, with evidence of lava flows within the last few million years. It may be that the volcanoes are dormant, not extinct.

"Shield volcanoes at the equator were recently active"

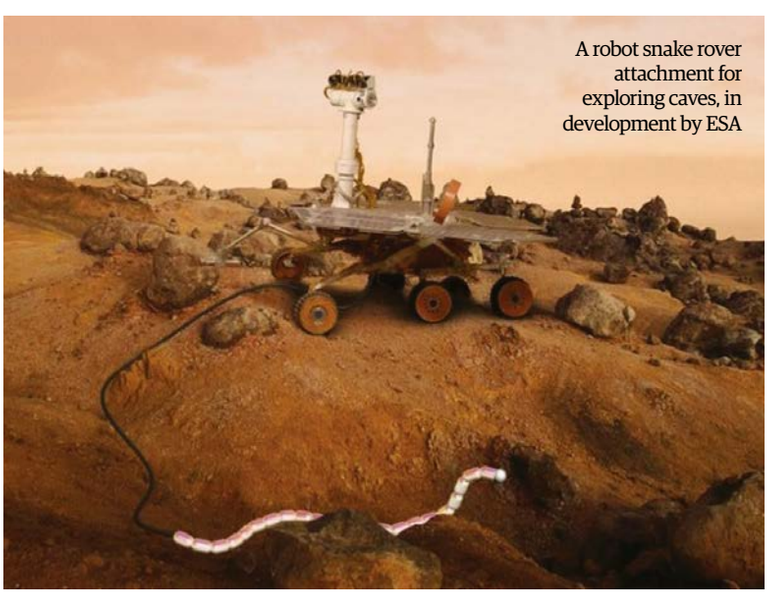
22 Travelling to Mars is extremely challenging

It will be far trickier to safely send astronauts to Mars than it was to send them to the Moon

If there is one thing that we have learnt about Mars over the last 50 years of space exploration, it is that travelling to the Red Planet is incredibly difficult. The first flyby in 1965 was the seventh attempt at reaching the planet and, since then, several more orbiters and landers have been lost. In the Nineties, four of NASA's six missions to the Red Planet failed. In 2003, the European Space Agency lost the Beagle 2 Lander launched alongside the successful Mars Express. And Russia and China's joint effort Phobos-Grunt/Yinghuo-1 was trapped in orbit around Earth in 2011.

Those that did reach the Red Planet had problems of their own. Although the Phoenix lander outlasted its three-month mission, its solar panels were eventually destroyed by the weight of many tens of kilograms of dry ice during the winter and, after six years on the surface, a wheel on NASA's Spirit rover stopped working, causing it to become irrevocably trapped in the Martian sands in 2009. More recently, NASA's Curiosity rover experienced unexpectedly quick damage to its aluminium wheels, forcing scientists to drive it in reverse.

But despite all these problems, we have learnt a huge amount about Mars and the combined information from both the successes and failures is being assembled and used to inform current and future missions. Using the information we have acquired, NASA intends to take humans to Mars in the 2030s.



A robot snake rover attachment for exploring caves, in development by ESA

23 There are caves on Mars

In 2007, the infrared cameras of the Mars Odyssey Orbiter spotted a set of caves on the surface of Mars, dubbed the Seven Sisters. They are located on the side of one of the shield volcanoes, Arsia Mons, and are visible as 'skylights', extending tens of metres downwards into lava tubes or sinkholes. Caves on Mars could provide easier access to buried layers of ancient rock without the need for heavy-duty drilling. These sheltered areas might be a good place to search for evidence of past life on the planet.

24 Sunsets are purple on Mars

The Viking 1 lander returned the first images of the Martian sunset in the Seventies. The fine red dust particles tint the sky a pinkish colour in the evening, but as the Sun starts to dip below the horizon, blue light is scattered, creating a purplish hue.

25 Mars has ozone layers

ESA's Mars Express orbiter has been circling the planet since 2003, and is equipped with a UV spectrometer called SPICAM. It's shown that Mars has an ozone layer at an altitude of 30 kilometres (19 miles), another in the northern spring/summer at between 30 to 60 kilometres (19 to 37 miles), and a third above the south pole in winter at around 40 to 60 kilometres (25 to 37 miles).