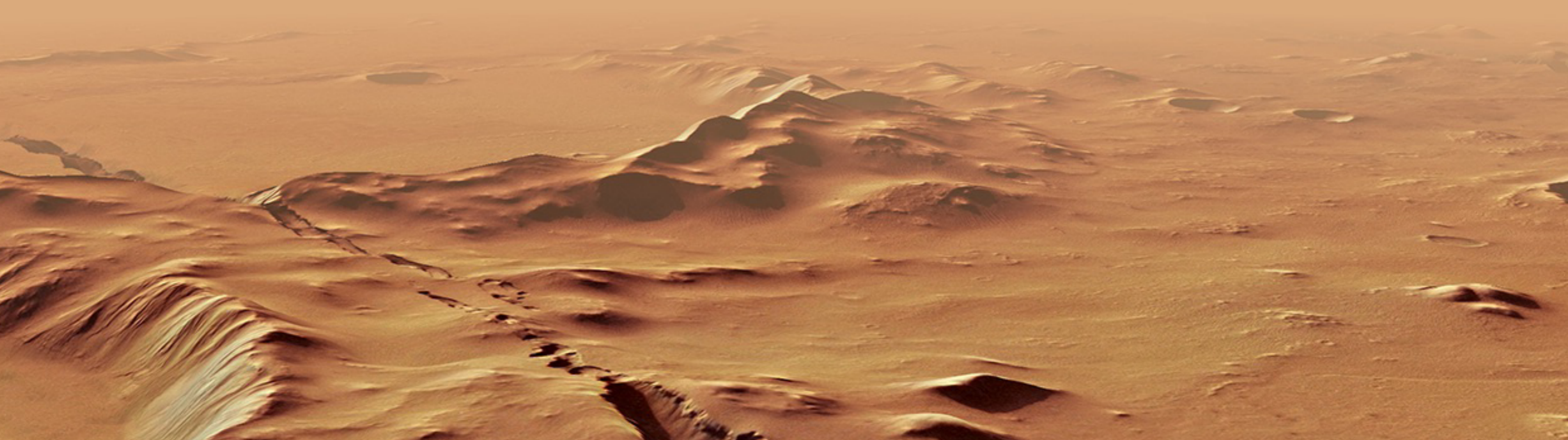
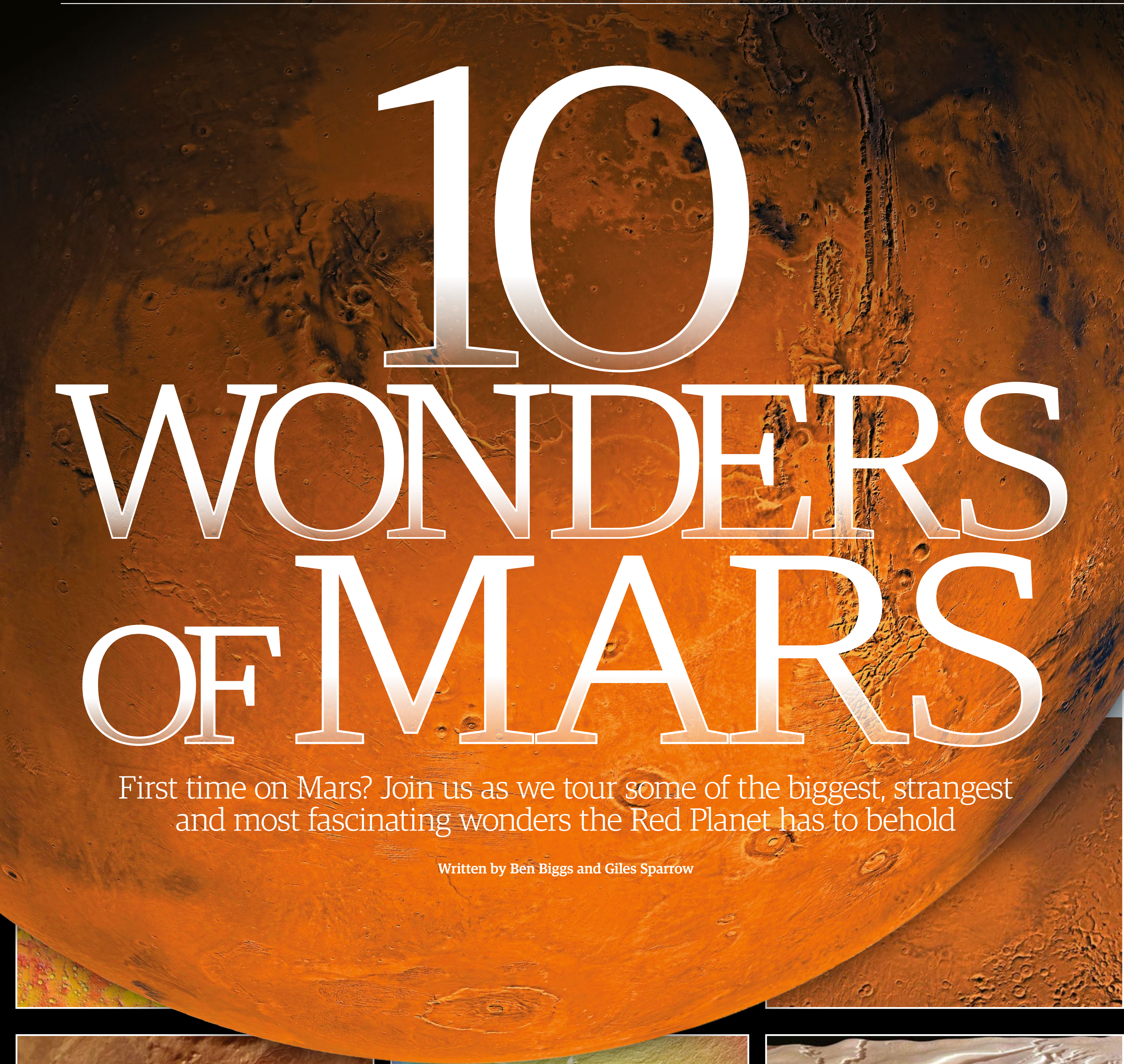
All About Space

10 WONDERS OF MARS

By Ben Biggs and Giles Sparrow

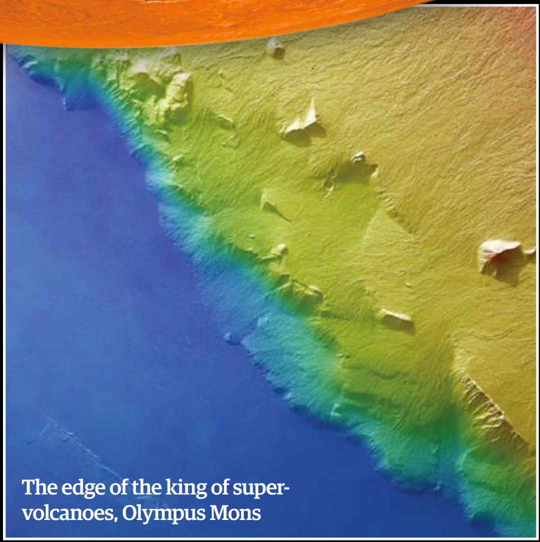




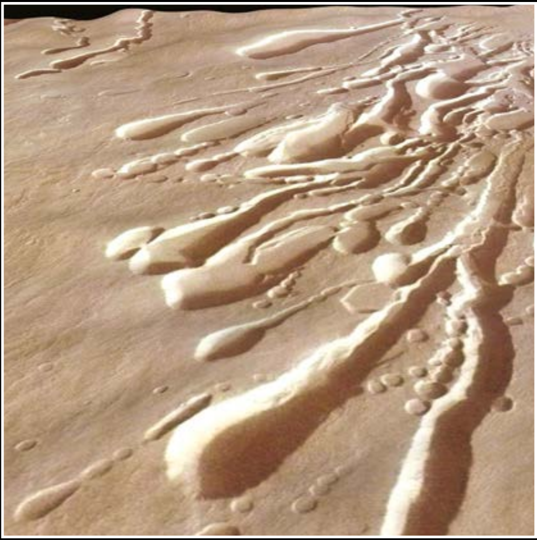
10 WONDERS OF MARS

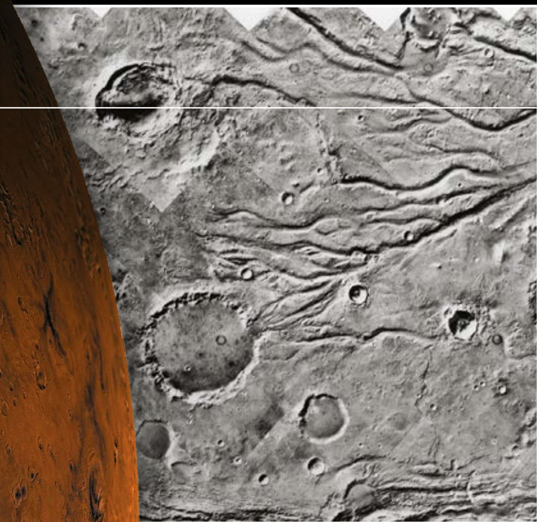
First time on Mars? Join us as we tour some of the biggest, strangest and most fascinating wonders the Red Planet has to behold

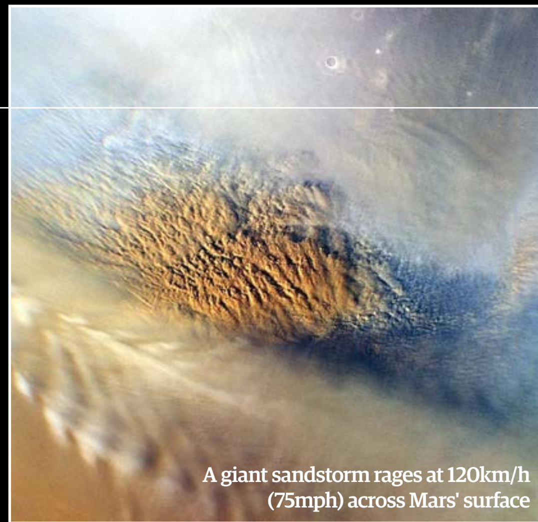
Written by Ben Biggs and Giles Sparrow



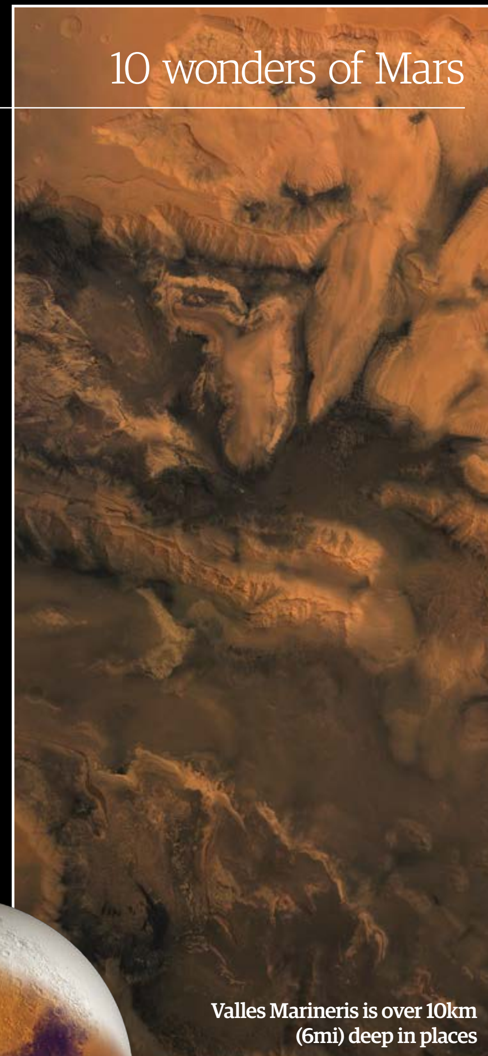
The edge of the king of super-volcanoes, Olympus Mons





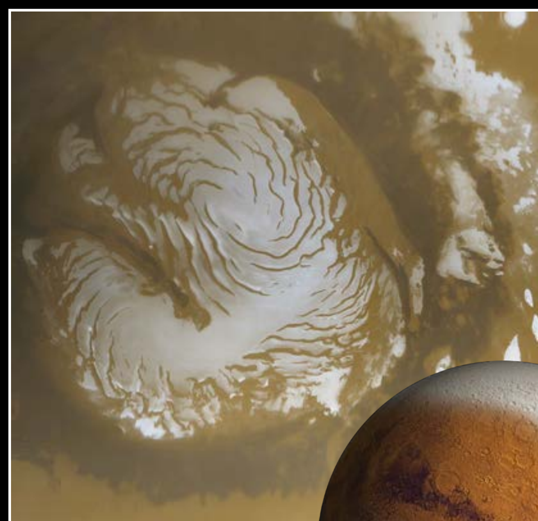


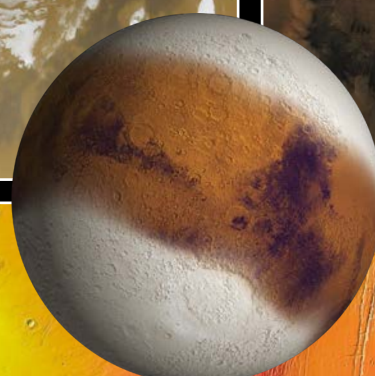
A giant sandstorm rages at 120km/h (75mph) across Mars' surface

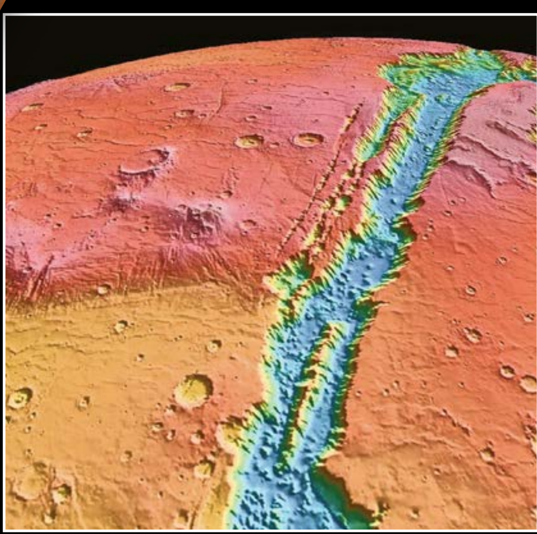


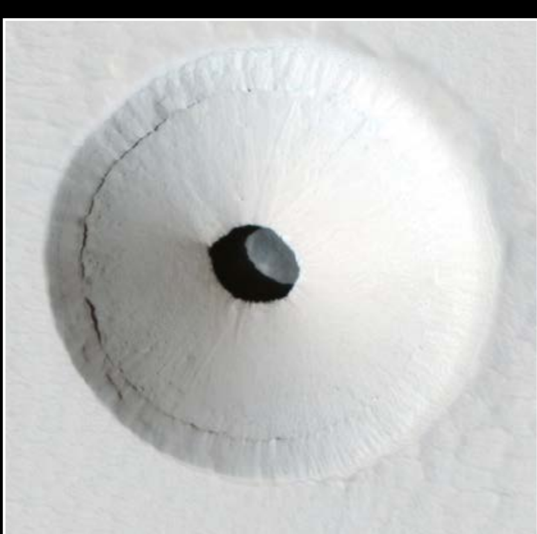
Valles Marineris is over 10km (6mi) deep in places

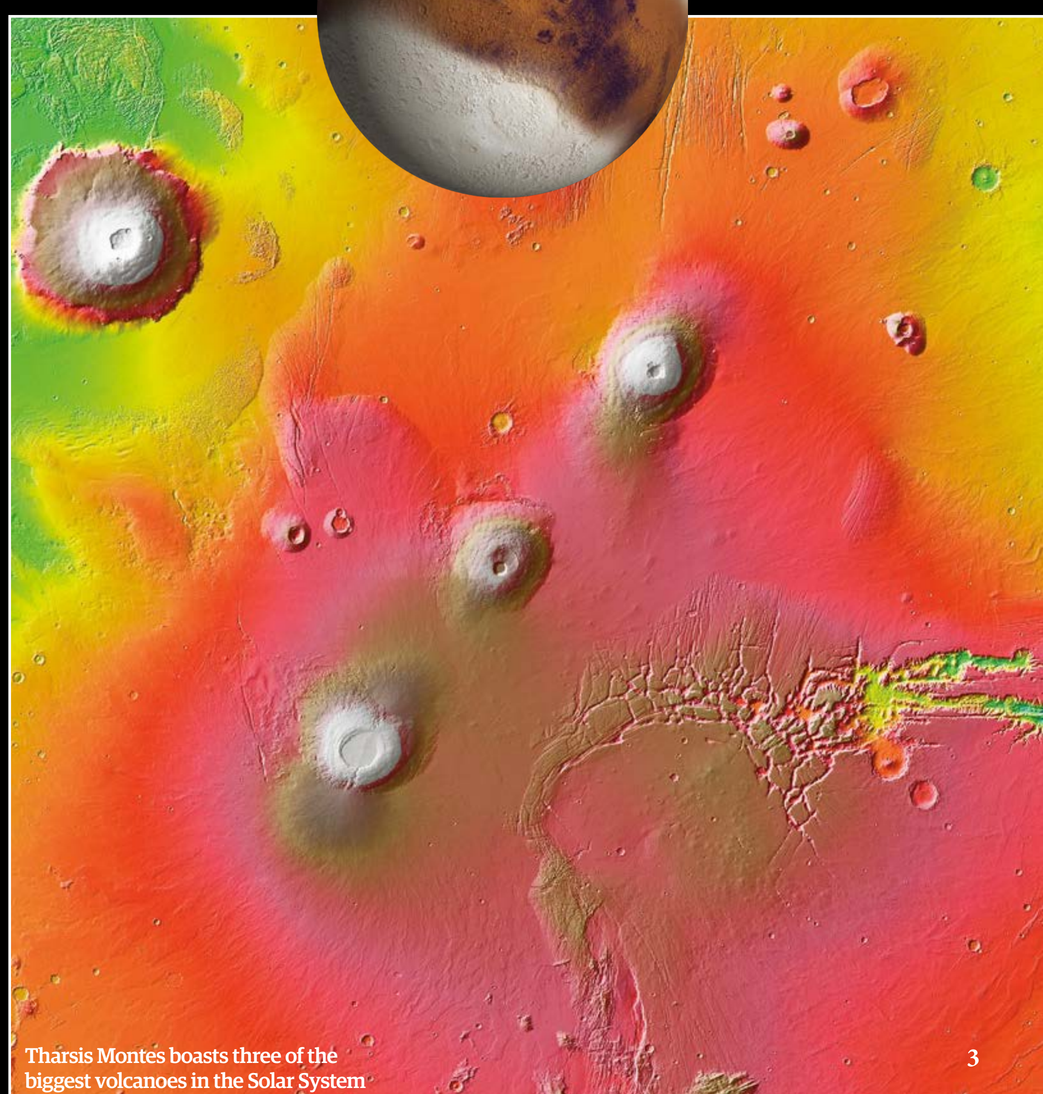
Ancient floods carved out the impressive Kasei Valles



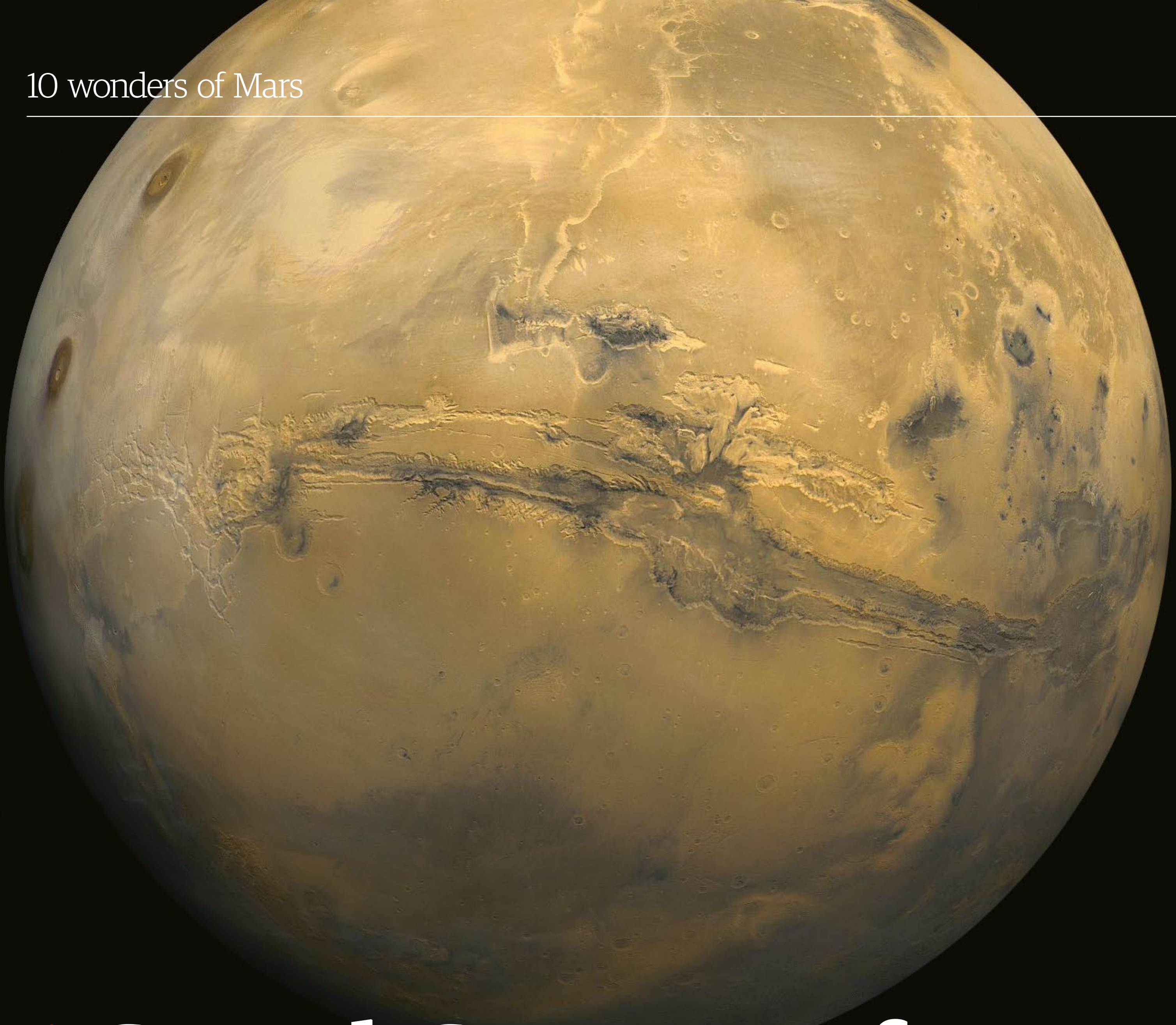








Tharsis Montes boasts three of the biggest volcanoes in the Solar System



1 Grand Canyon of Mars

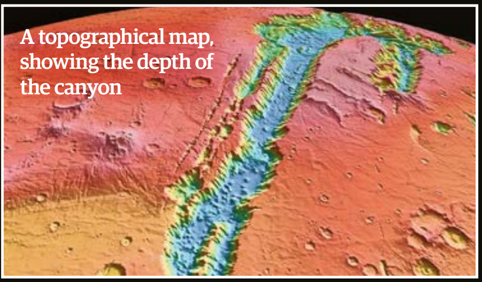
Welcome to Valles Marineris - the biggest canyon in the entire Solar System

It's difficult to recount exactly the impact the Grand Canyon has on you on your first visit. It's pretty overwhelming: at around 29 kilometres (18 miles) at its widest point and nearly two kilometres (1.2 miles) from the plateau to the Colorado River at its deepest, it's probably the biggest thing anyone could hope to witness in their lives. Yet the entire Grand Canyon would be no more than a mere gully in the biggest canyon in the Solar System.

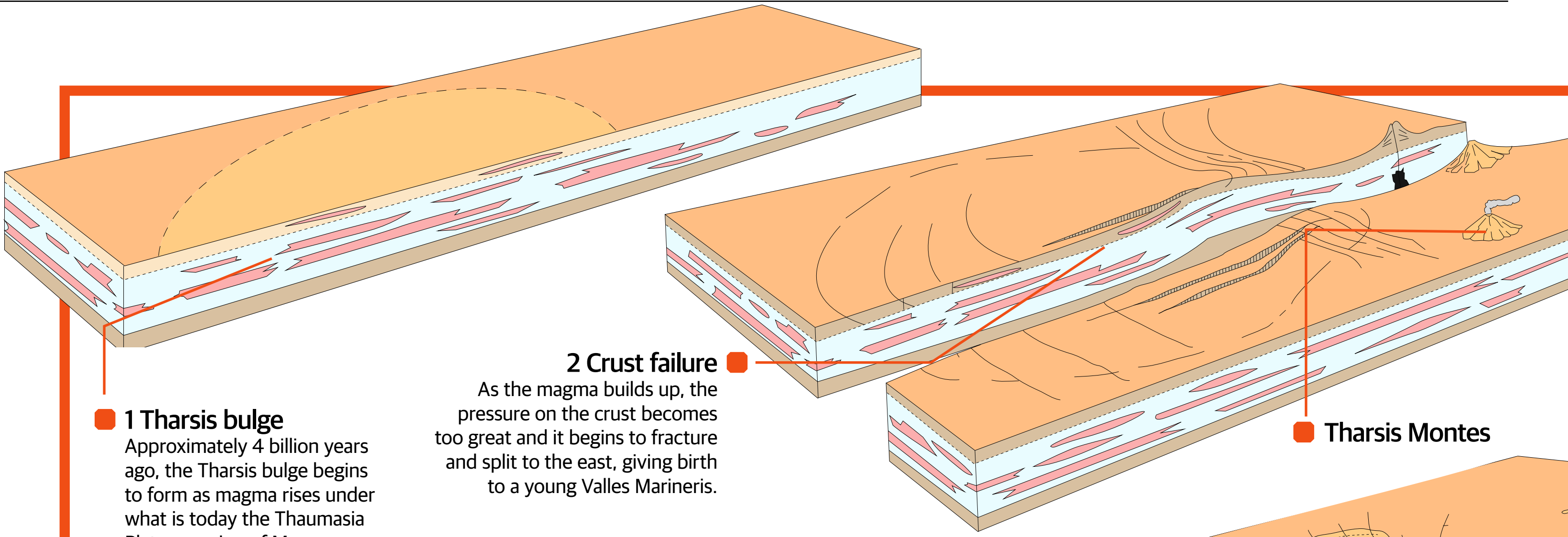
Valles Marineris is unbelievably enormous, spanning over 4,000 kilometres (2,500 miles) in length, with some parts of it 200 kilometres (125 miles) wide and over ten kilometres (six miles) deep. It would stretch across the entire United States if it was on Earth and its size is only exaggerated by the fact that Mars is around half the size of Earth - around 20 per cent of Mars' circumference is taken up by this massive gouge in its surface.

The canyon is, naturally, host to a plethora of interesting geological features that offer scientists clues as to its turbulent past. Located just south of Mars' equator, its western end begins with a series of steep, maze-like valleys given the sinister Latin title Noctis Labyrinthus, or 'the labyrinth of the night'. This region shows typical fault-line activity, with valley-forming depressions known as 'grabens'. Moving eastwards, Valles Marineris starts to grow in breadth and depth, with twin canyons called the Ius and Tithonium chasmata running parallel to each other, divided by a central ridge. This gives way to three more chasmata and the deepest part of the canyon at 11 kilometres (6.8 miles) from the plains above. These eventually lead to the eastern end: Coprates Chasma, defined by its layered deposits that could originate from landslides or water erosion, Eos and the Ganges chasmata and, finally, where the canyon terminates in the Chryse region, a mere kilometre (0.62 miles) above Valles Marineris' deepest point.

Although there's evidence of a number of processes at work here including water erosion, the scientific community generally agrees today that the volcanic region west of Valles Marineris played a major role in the formation of this huge rift, with water reshaping and deepening its course. It's thought that as the Tharsis Montes was pushed up by molten rock to form gigantic volcanoes, the crust split to form fault lines around 3.5 billion years ago, which inevitably widened to form Valles Marineris. Though they share many similarities, this is unlike the Grand Canyon, which was gradually carved out of the surrounding rock millions of years ago by the meandering of the Colorado River and its tributaries.

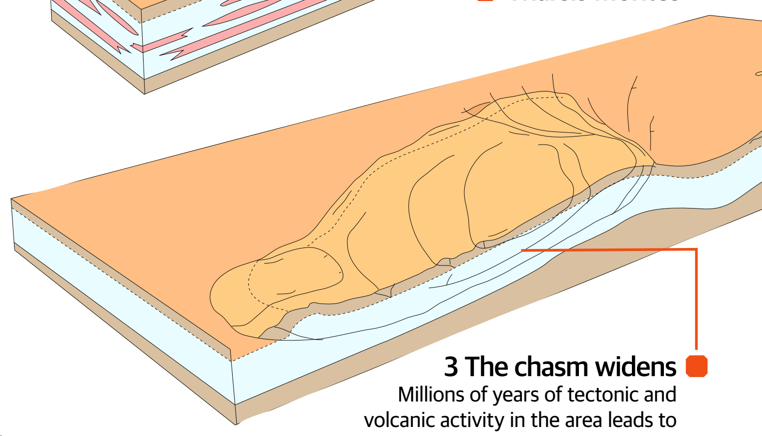


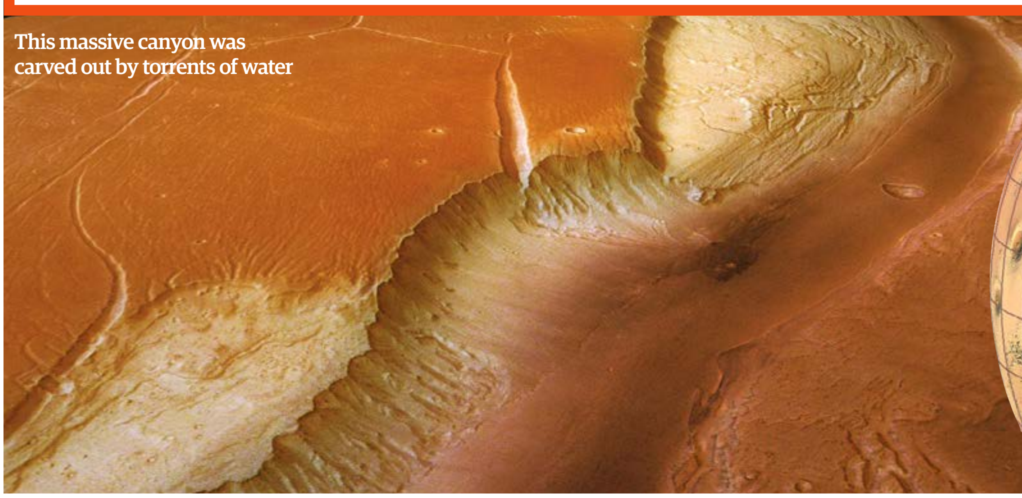
A topographical map, showing the depth of the canyon

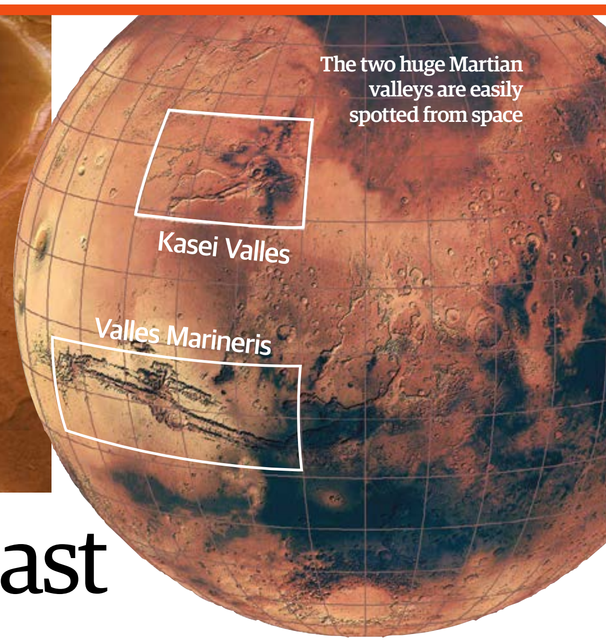


How Valles Marineris formed

It's thought that Valles Marineris is an example of a giant rift valley, similar to Africa's rift valley system. Its formation is primarily tectonic and consists of three main stages that begins with the Tharsis bulge, a region where Valles Marineris is today that began to uplift as magma rose, as early as 4 billion years ago. The pressure and extra weight of magma led to parts of the crust forming graben – valleys sunk along fault lines. The crust then began to float on the magma and, pushed to breaking point, splits along the length of Valles Marineris. Finally, tectonic activity, landslides, asteroid impacts and even meltwater could have widened and deepened the long chasm to form Valles Marineris as we see it today.




This massive canyon was carved out by torrents of water



The two huge Martian valleys are easily spotted from space

2 Chasm with a violent past

Meet Valles Marineris' little brother

If it weren't for its bigger sibling several hundred kilometres to the south, Kasei Valles would have taken the gong for being the biggest canyon system on Mars, if not the Solar System. As it stands, its 3,000-kilometre (1,900-mile) expanse, three-kilometre (1.8-mile) depth is still more than prominent enough to stand out from the surface to any passing orbiter. It even tops Valles Marineris in places, reaching over 300 kilometres (185 miles) at its widest.

Its size isn't what makes Kasei Valles a wonder of Mars alone though. All 1.5 million square kilometres (nearly 600,000 square miles) of the region were forged by some of the most violent events in Mars' history. Today, the most potent force Kasei Valles faces is the occasional, turbulent dust storm that, given the thin Martian atmosphere, is hardly about to carve another record-breaking canyon into it any time soon. It was a different story over 3 billion years ago, though: the same raging tectonics that were busy creating Valles Marineris were ripping the landscape apart further north, bringing groundwater to the surface which combined with ice melted by the volcanoes further west to create furious torrents of mud, forming and shaping the channels of Kasei Valles. The same violent floods failed to completely erode the outcrop of Sacra Mensa but further downstream, they made mincemeat of the southern rim of the 100-kilometre (62-mile) Sharonov crater.

> "The region was forged by some of the most violent events in Mars' history"

3 Super volcano

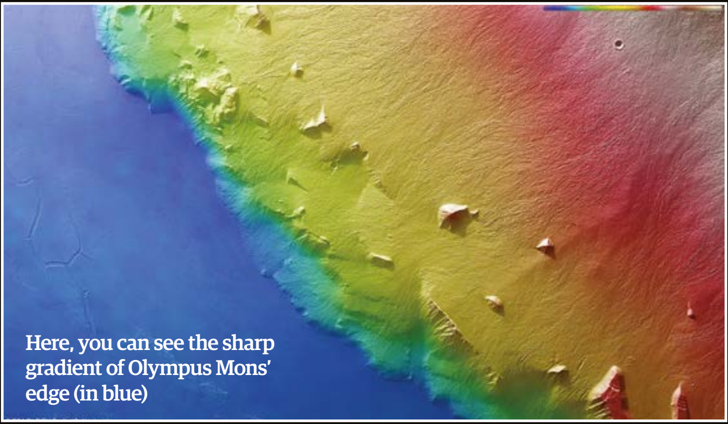
The tallest peak on Mars and in the Solar System

At some point in the distant future, when commercial space flights have reached the border of the asteroid belt and we can freely explore other planets, Olympus Mons will likely become the number one tourist destination in the Solar System, outside of any wonder on Earth. It holds some impressive titles, including the tallest known peak in the Solar System at 22 kilometres (14 miles) from base to tip and a diameter of around 624 kilometres (374 miles), nearly the same size as France and about the same size as the US state of Arizona. It has a caldera to match its enormous expanse: at around 80 kilometres (50 miles) in diameter, these six collapsed magma chambers form a single crater-like depression that's easily large enough to comfortably hold one of the biggest cities in the world by area, New York, with plenty of room to spare. And the volume of Olympus Mons is equally huge at around 100 times that of the Hawaiian volcano Mauna Loa, which is enough to contain the entire Hawaiian archipelago from Hawaii to Kauai, in fact.

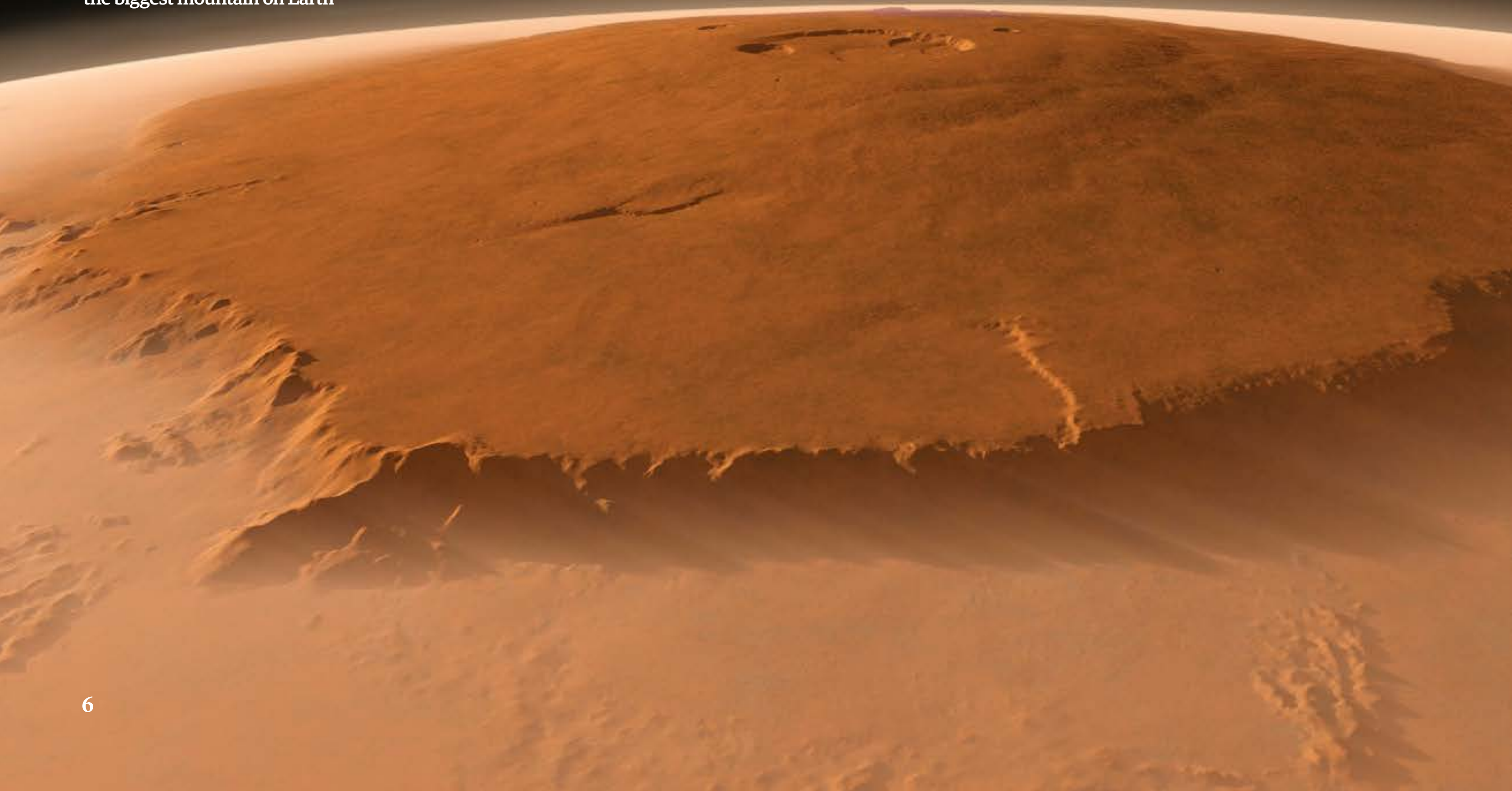
This is no mere mountain, however. Olympus Mons is a giant volcano, a shield volcano to be precise, the kind that spews lava slowly down its slopes rather than violently erupting magma, smoke and ash kilometres into the sky. As a shield volcano it has a low profile and its sides slope at an average incline of only five per cent. In fact, if you were standing at the top of Olympus Mons and didn't know it, you probably wouldn't be aware that you were at the summit of a very high mountain. If you walked to the far edge where the volcano begins to rise, you'd encounter an escarpment, or boundary cliff, an astonishing ten kilometres (six miles) high. That's higher than the largest volcano on Earth, Hawaii's own shield volcano Mauna Loa.

Olympus Mons' giant size is no fluke. Low Martian gravity has a part to play in the continuous build-up of cooling lava on its flanks. But tectonic activity on Mars is extremely limited compared to Earth, too: unlike the Hawaiian islands, for example, which have produced several smaller volcanoes as a result of plate movement over millions of years, Olympus Mons has been sitting in the same spot for a long time, allowing the volcano to continuously erupt and grow to its current size.


Olympus Mons' 80km (50mi) wide caldera is actually a combination of six magma chambers that collapsed over multiple eruptions


Here, you can see the sharp gradient of Olympus Mons' edge (in blue)

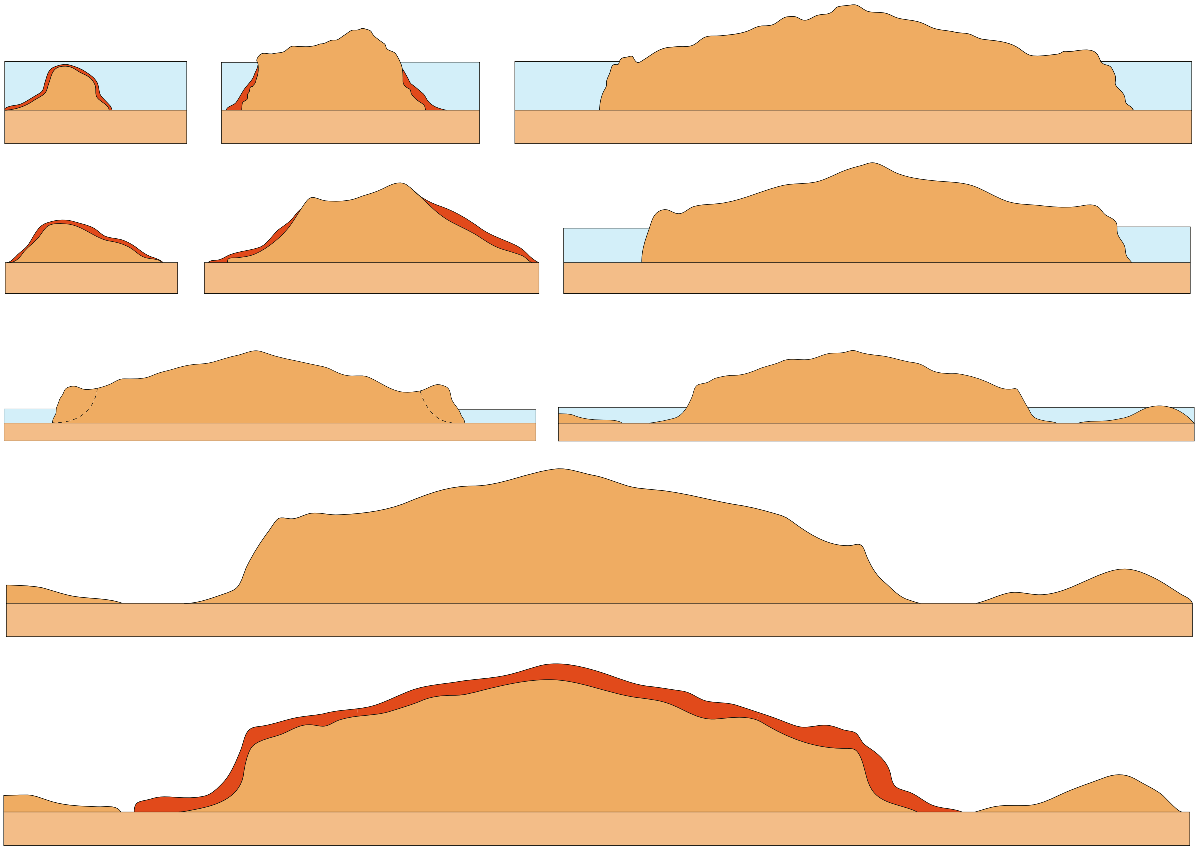
Olympus Mons towers far above the biggest mountain on Earth



How Olympus Mons was created

The theories on how the biggest volcano in the Solar System formed

KEY
Lava
Water
Fracture



Subaqua birth
One theory is that lava flowed underwater, piling up until it reached the surface and then spread out sideways after.

Subaerial birth
In the subaerial theory, the lava piled up and flowed in the air, with water rising later to change the dynamics of the lava flow.

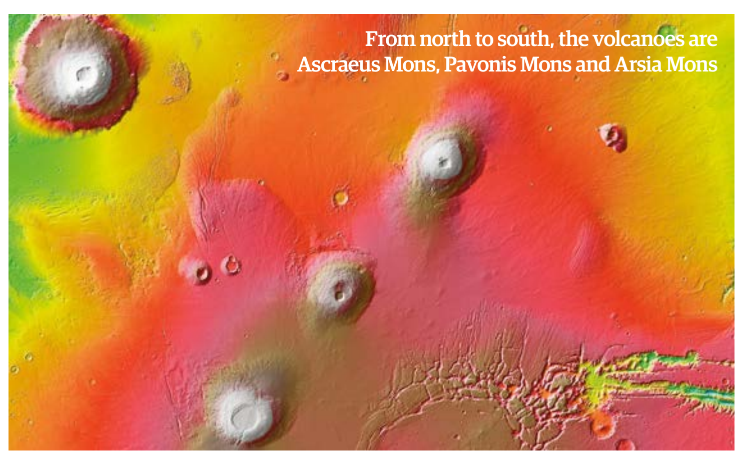
Landslides
Regardless of whether Olympus Mons was partially underwater or not, instability resulted in multiple landslides, reducing its size.

Water drains
As the water drained from the northern lowlands, further landslides shaped Olympus Mons, giving it its distinctive lopsided aureole.

New lava
When the water surrounding Olympus Mons disappeared, fresh lava flow smoothed its previously scarred surface.

4 Volcanic hot spot

Tharsis Montes is responsible for Mars' most famous features



From north to south, the volcanoes are Ascraeus Mons, Pavonis Mons and Arsia Mons

Mariner 9 was the first spacecraft to orbit another planet when it arrived at Mars in November 1971, with the Red Planet engulfed by one of its characteristic dust storms at the time. As the orbiter began to return unprecedented close-ups of the surface of Mars to Earth, NASA could make out three faint but distinctive spots. This was the Tharsis Montes region of Mars and the spots were actually the peaks of three enormous volcanoes, evenly spaced in a northeast-southwest orientation. To the northwest, what had been known as 'Nix Olympica' since the 19th century and was suspected to be a mountain, was discovered to be a massive volcano, and it was subsequently renamed as Olympus Mons after Mariner 9 observed it.

Tharsis Montes is the biggest volcanic region on Mars: it's some 4,000 kilometres (2,500 miles) wide and is home to 12 huge volcanoes up to 100 times bigger than their equivalent on Earth.

The Tharsis Montes region is responsible for many of Mars' more interesting wonders. Around 4 billion years ago, rising magma caused what is now a plateau to rise, forming the Tharsis bulge, a geological feature the size of North America. This led to the formation of Valles Marineris, the Tharsis Montes volcanoes and Alba Mons, a huge volcano with a diameter of roughly 1,500 kilometres (930 miles) but with an extremely low relief that makes it unique on Mars. Olympus Mons is often (understandably) attributed to the area, although it's actually not part of the plateau.

5 Martian two-face

The planet-shattering reason behind Mars' strange north-south divide

Sometimes it's hard to see the woods for all the trees, as is the case with the strange, near-hemispheric dichotomy of Mars' southern highlands and northern lowlands. The difference between the two hemispheres has been observed for decades now, with investigation by orbiting probes in the late Seventies highlighting the radical contrast between the topography of each region: the south is rugged, volcanic and pock-marked with craters and features the tallest peaks in the Solar System, while the north is a huge plain of unparalleled smoothness, with an altitude typically several kilometres below the lower regions of the south. Up until recently no one really knew why this was, although it was known that this feature was very ancient, almost as old as the planet itself.

A few theories had been postulated as to why the two halves were so different: one was that convection in the mantle caused upwelling in the south and downwelling in the north. The other, originally proposed in 1984, was that the hemispheric dichotomy was the result of a single enormous impact. It was the simplest solution to the mystery that meant the entire northern region, an area 8,500 kilometres (5,300 miles) wide and 10,600 kilometres (6,600 miles) long, was a colossal impact basin. However, that theory quickly got shot down because the borders of the northern hemisphere didn't fit the expected round shape of an impact crater.

However, since the Eighties, several confirmed craters have been discovered with strangely elliptical borders, such as the Moon's South Pole-Aitken basin. The case for the massive impact theory wasn't helped by the fact that the Tharsis bulge and its enormous volcanoes formed after this huge crater was created, obscuring the shape of the rim on one side. So it was only after two decades of surface and gravitational field observations by various spacecraft that the unambiguously elliptical impact basin of the northern hemisphere was revealed.

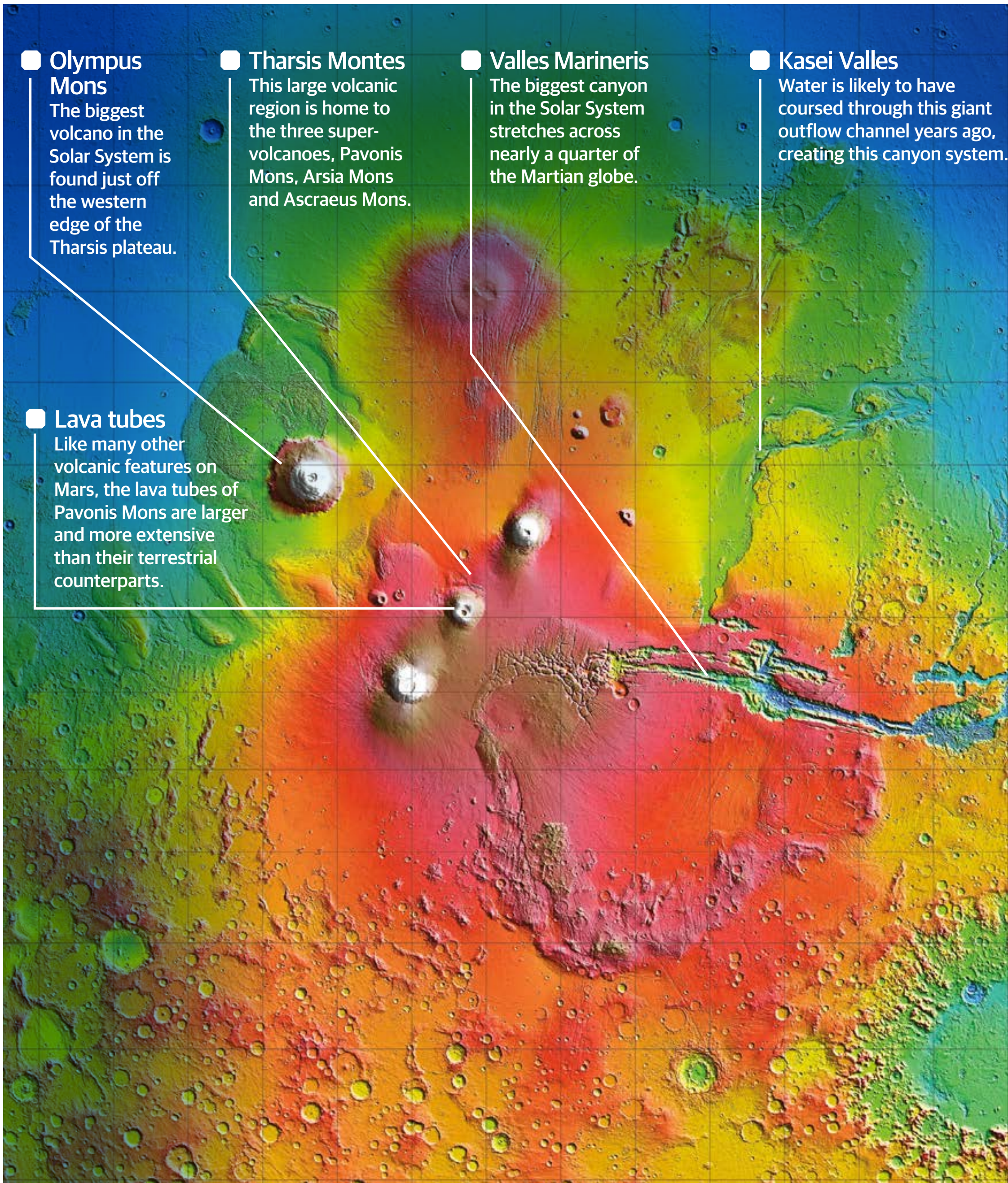
Today, although the giant impact theory hasn't been proved beyond doubt, the evidence weighs heavily in its favour. The Borealis Basin, if it is the result of an ancient impact, will be the largest known crater in the Solar System: covering an area of around 90 million square kilometres (35

Mapping the surface of Mars

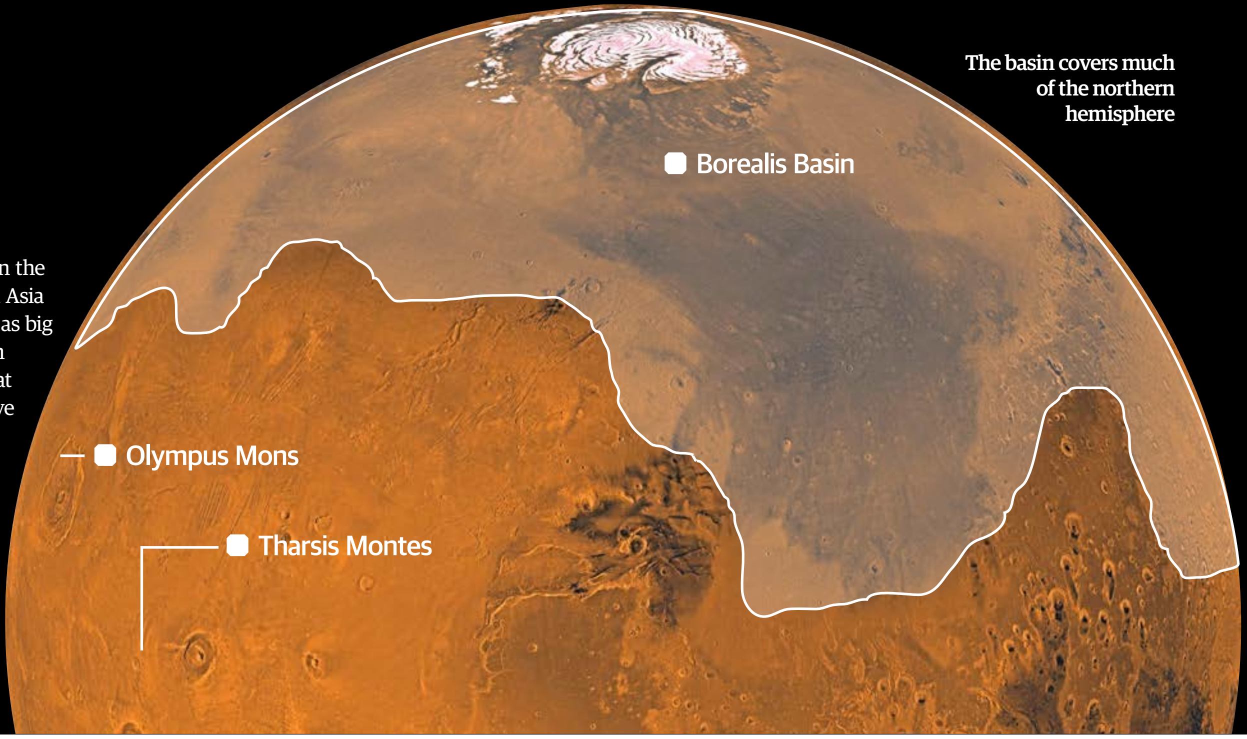
The Mars Global Surveyor was sent to orbit Mars with the expressed goal of doing the job of a terrestrial surveyor, but on an enormous scale. Among its major missions (which included surveying the Martian atmosphere and interior), it was tasked with mapping the entire Martian surface and geology with the aim of providing the foundations of future NASA missions for years to come.

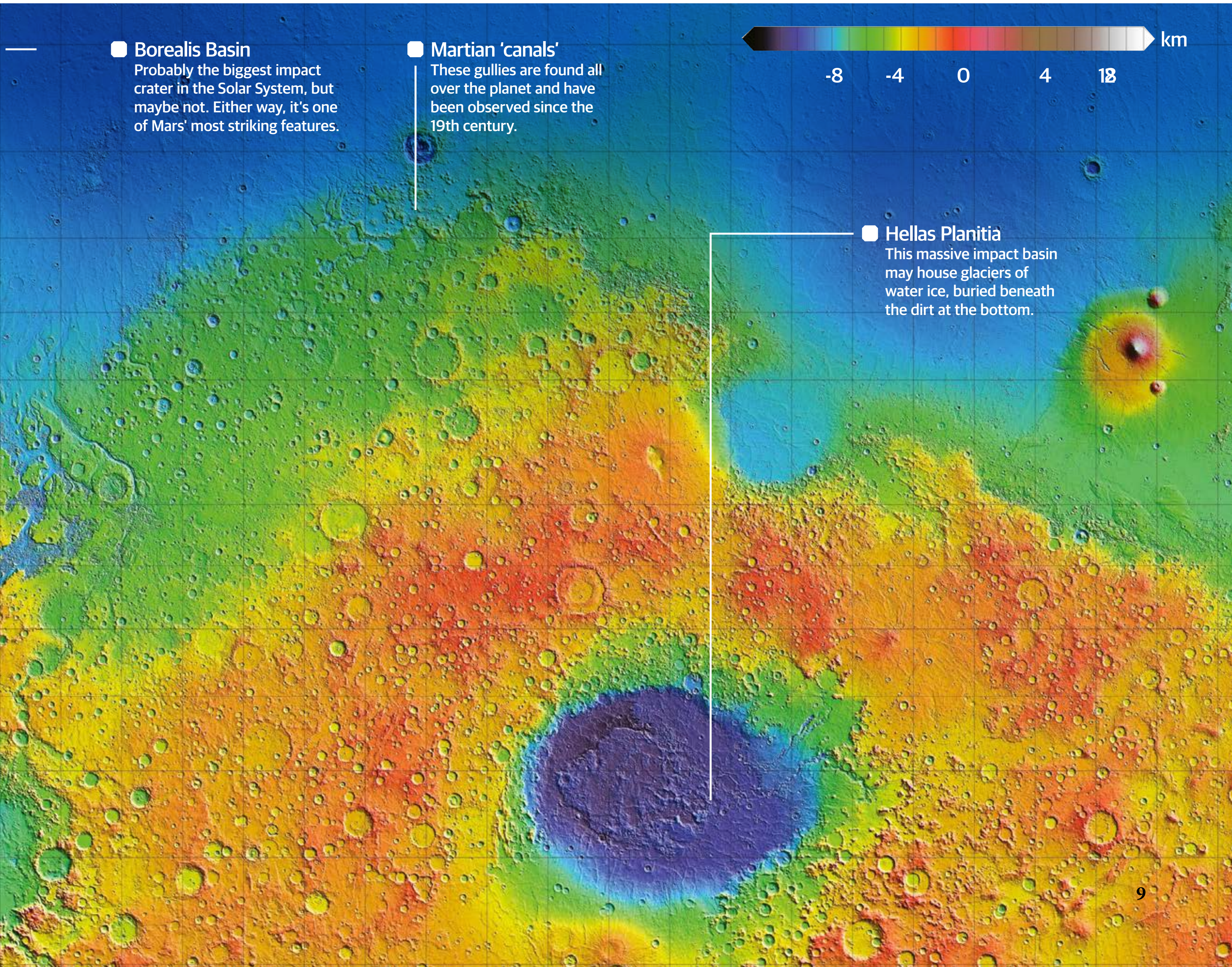
Using the Mars Orbiter Laser Altimeter (MOLA) this mission was phenomenally successful, creating a flat, high-resolution map from over 640 million elevation measurements assembled into a global grid with an accuracy that ranged from 13 metres (42 feet) to within two metres (six feet). The map is so accurate and complete that it gives us a better knowledge of Martian topography than some continental areas of Earth.

The findings of this survey include the discovery of Mars' full topographic range, which is about one and a half times that of Earth and goes from the deepest trough in the Hellas Impact Crater to 30 kilometres (19 miles) higher at the tallest point of Olympus Mons. The Mars Global Surveyor also gave us a much clearer idea of the dynamics of water on the surface of the Red Planet, with the huge difference in elevation between the northern and southern hemispheres meaning that the lowlands of the north would have drained around three-quarters of the surface of Mars, at an earlier period in Martian history when water could have flowed freely on the surface.



million square miles), it's larger than the continents of Europe, Australia and Asia combined. That's nearly four times as big as the next biggest known crater on Mars, Hellas Planitia. The object that created the Borealis Basin must have been terrifyingly massive, around 2,000 kilometres (1,200 miles) in diameter, striking at an angle of 45 degrees to create the elliptical basin. These objects and collisions were relatively common 4 billion years ago, shaping the geography and the orbits of the planets to mould the Solar System as we know it today.





6 Giant dust storms

The enormous clouds of fine red dust that can sometimes grow to engulf the entire planet

The surface of Mars is covered in dust far finer than the sands of any desert on Earth – indeed it's the iron oxide (rust) content of this dust and the underlying rock that gives the planet its distinctive ruddy colour. From month to month, the gentle Martian winds blow clouds of dust across the landscape, stripping the surface sands away to reveal underlying rock in some places, and accumulating in other places to form spectacular dunes.

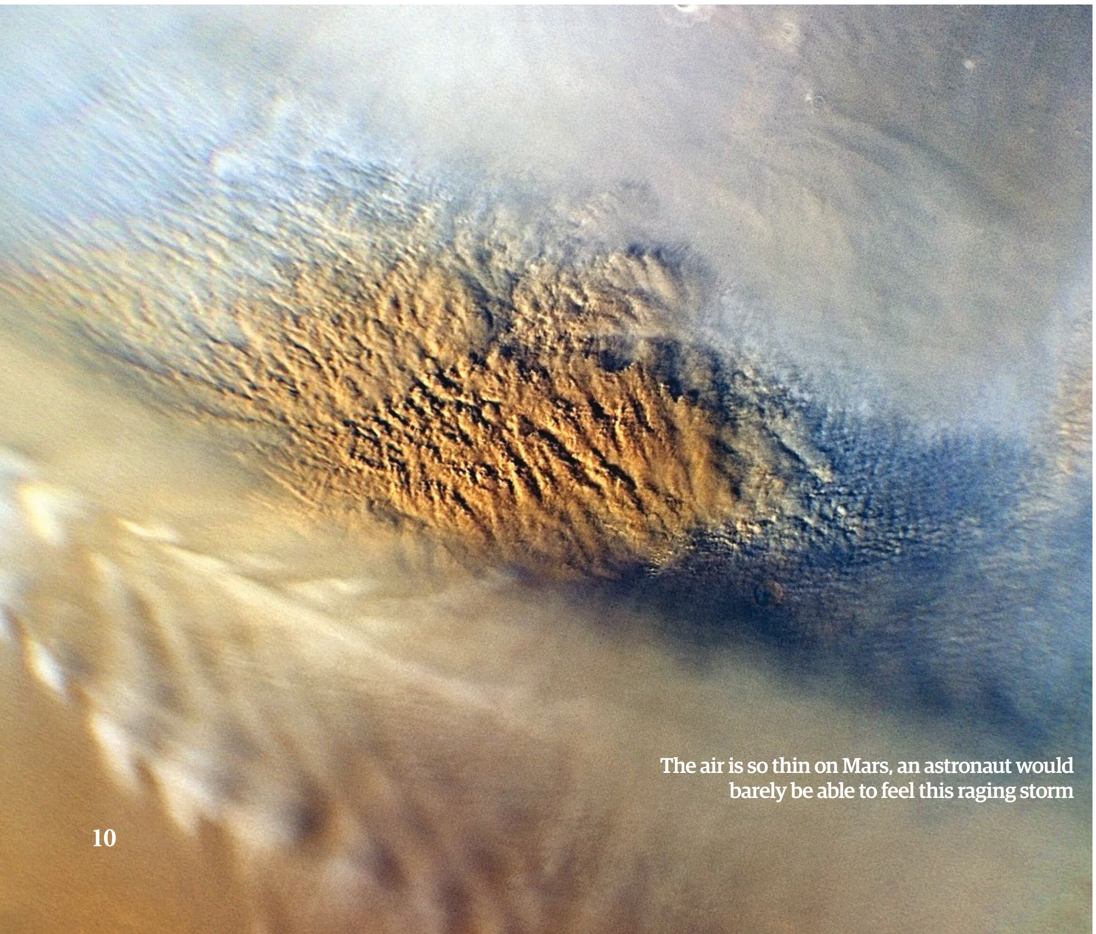
Normally, these billowing dust storms flare up and die away in a couple of days, but occasionally they can grow in size to the scale of entire continents before subsiding. And every couple of years, around the time of Mars' closest approach to the Sun, they can run out of control to wrap the entire planet in an orange murk that persists for several months.

These enormous storms are only possible because of the size of Martian sand – the Red Planet's thin atmosphere (exerting just one per cent of the Earth's atmospheric pressure) means that even the strongest winds of around 120 kilometres per hour or 75 miles per hour (equivalent to hurricane force on Earth), would barely be able to shift Earth-sized sand grains. But atmospheric dust grains on Mars, worn down by billions of years of steady erosion, are comparable in size to the particles in cigarette smoke, so that even the gentle winds of the planet's thin atmosphere can lift them from the ground. Wind speeds in a typical storm are around 100 kilometres per hour (62 miles per hour), but an astronaut on the surface would barely feel that as a light breeze.

Once lofted into the air, dust particles may linger for months. The reasons for this persistence are still uncertain, but it's possible that weak electromagnetic fields help to repel them from each other and prevent them settling back on the ground. This means that once the dust particles are stirred up, they can move at speeds many times faster than those in dust storms on Earth, and travel much further. As they absorb sunlight and prevent it from reaching the surface, atmospheric temperatures may rise dramatically by up to 30 degrees Celsius (86 degrees Fahrenheit).

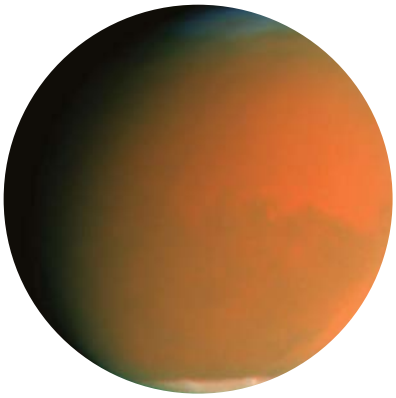
Awesome though they may appear, the main threat from storms to either current Mars rovers and landers, or future astronauts, comes from the dust they carry within them. As it settles back out of the atmosphere it may coat equipment and solar panels with particles that get into delicate mechanisms and cut down the efficiency of solar panels. Fortunately, NASA engineers have discovered that encounters with the occasional 'dust devils' that spiral across the Martian surface can also help remove dust and restore power.

"Dust storms can wrap the entire planet in an orange murk for several months"



The air is so thin on Mars, an astronaut would barely be able to feel this raging storm

In June 2001, the Hubble Space Telescope captured this crystal-clear image of Mars, highlighting clouds around its north and south poles



Three months later, as Mars approached perihelion, a planet-wide dust storm blocked Hubble's view of everything but the bright polar caps

Storm cycles

Major dust storms are typically most common around Martian perihelion (the planet's closest approach to the Sun). Because the orbit of Mars, unlike that of the Earth, is distinctly elliptical, it receives up to 40 per cent more sunlight around this time, which helps to create strong temperature differences across the planet that in turn generate high winds. Unfortunately for earthbound astronomers, perihelion is also the best time to view Mars, so the Red Planet is frequently engulfed in clouds around the time when it is at its largest and brightest in Earth's skies. Even space probes are not immune to the problem – in fact Mariner 9, the first space mission to enter orbit around Mars, arrived during a major dust storm in November 1971 and had to wait for about a month until the atmosphere cleared and it was able to send back the first detailed photographs of the Martian surface.

7 Subterranean lava tubes

A hidden world of caves that could shelter Martian microbes

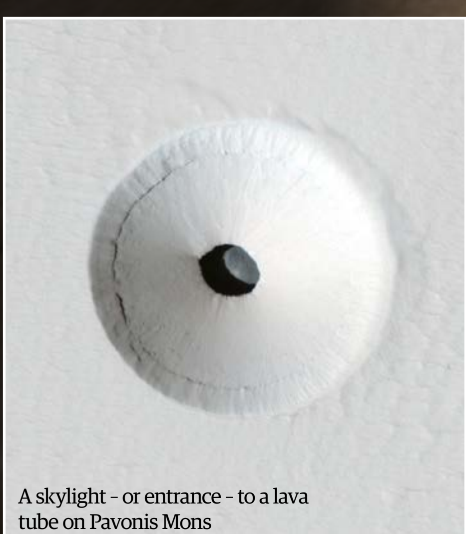
Rising to about 12 kilometres (7.5 miles) above the surrounding dusty plains, Pavonis Mons is roughly three kilometres (1.9 miles) higher than Everest. However, it has another feature that qualifies as a Martian wonder in its own right.

Running down the volcano's southwest flank are a number of parallel, tadpole-shaped features that look at first like empty riverbeds. Tens of kilometres long, their heads point roughly towards the volcano's summit, while their tails peter out or merge to form broader depressions.

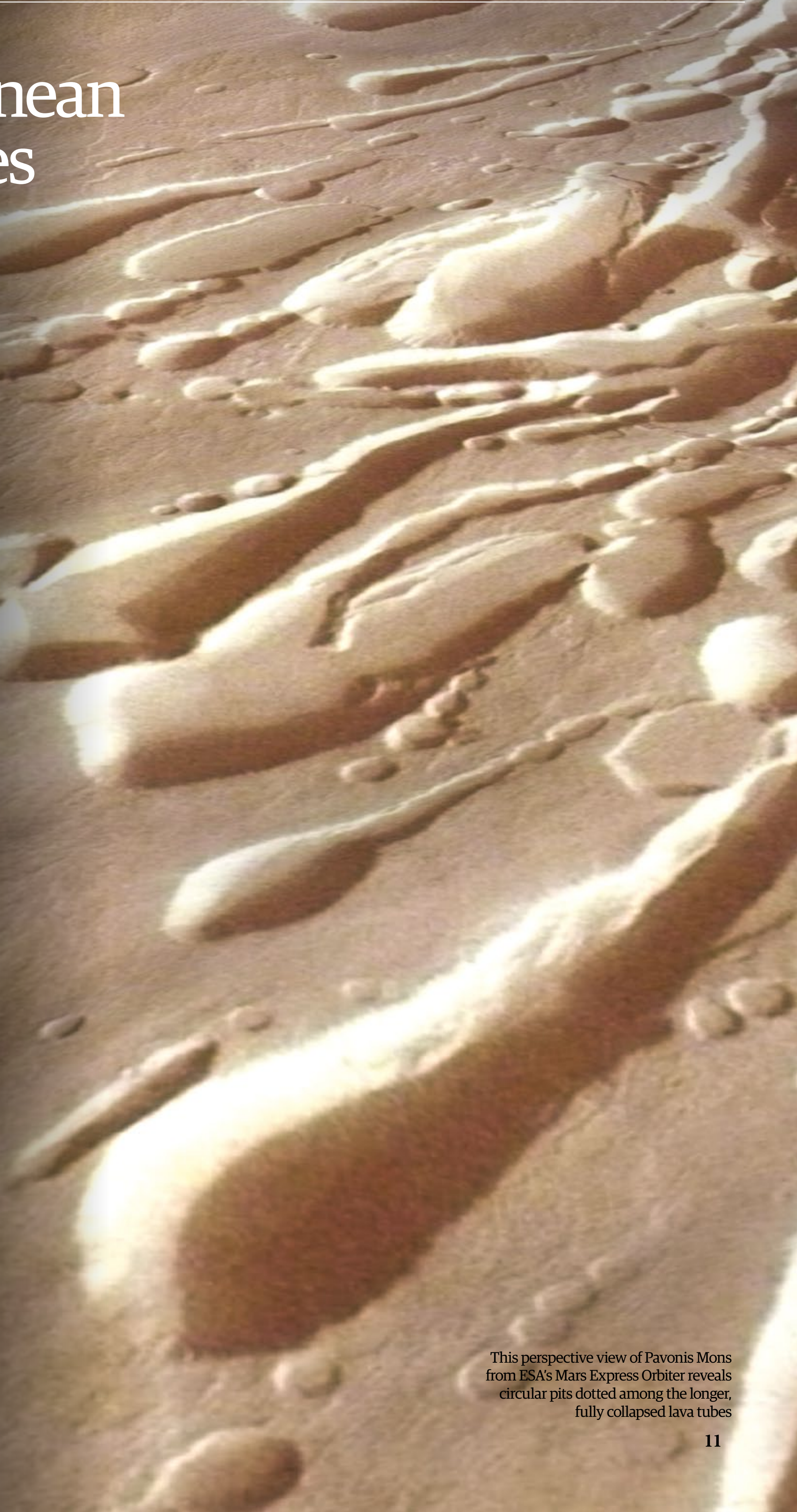
But these valleys are not the work of water erosion. Known as 'lava tubes', they form when the surface of a lava flow starts to cool and solidify, but molten rock continues to run below the surface. When the eruption finally comes to an end, the underground river of lava may drain away completely, leaving behind a cavernous subterranean passage.

Normally, lava tubes are all but invisible from the surface, but over time, the weight of overlying rock may cause their ceilings to cave in, creating steep-sided valleys like the ones seen on Pavonis Mons. In other places, the surface may just subside to form a string of circular depressions known as a pit chain. When the middle of the depression then collapses inward, the result is a 'skylight' opening into the lava tube.

When the first astronauts reach Mars, they may head straight for these curious portals. Lava tubes offer natural protection from the harsh surface environment, and are an obvious place to set up a long-term base. And for the same reasons, they are also one of the most promising places to look for simple Martian life.



A skylight – or entrance – to a lava tube on Pavonis Mons



This perspective view of Pavonis Mons from ESA's Mars Express Orbiter reveals circular pits dotted among the longer, fully collapsed lava tubes

8 Frozen carbon dioxide poles

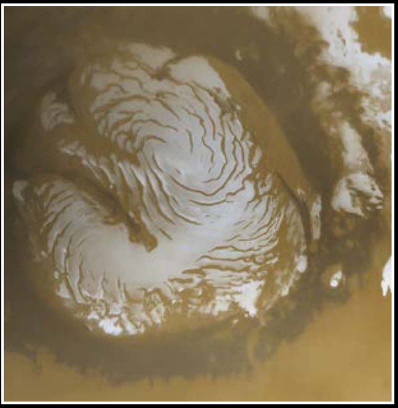
Mars has two permanent ice caps, but they're not like Earth's poles…

The temperature at the Martian equator is probably not as bitter as you might think, pushing the mercury as high as 20 degrees Celsius (68 degrees Fahrenheit) during the summer, with a soil temperature that has been recorded close to a positively beachy 30 degrees Celsius (86 degrees Fahrenheit). It's a different story at the poles, however: with a desperately thin atmospheric pressure of just 600 pascals to insulate them – a fraction of Earth's 101,000 pascals – little heat is retained at either end of the Red Planet. Here, temperatures have been known to drop to as low as a bitterly cold -153 degrees Celsius (-243 degrees Fahrenheit) in the complete darkness of a Martian polar winter.

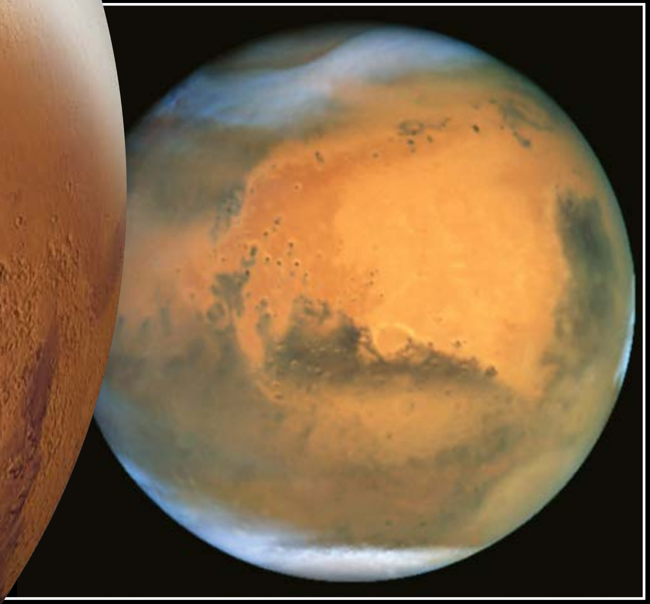
The Martian caps are pretty puny compared to those on Earth. The biggest of the two, the northern ice cap, has an estimated volume of 1.6 million cubic metres (56 million cubic feet), while the Antarctic ice sheet, the biggest on Earth, has a volume of 26.5 million cubic metres (935 million cubic feet). However, the extreme cold at the Martian poles results in over a quarter of Mars' atmosphere freezing into enormous slabs – and because over 95 per cent of Martian air is carbon dioxide, winter brings a deposition of up to two metres (6.5 feet) of dry ice. When summer comes around, rising temperatures cause the frozen carbon dioxide to sublimate (turn immediately from solid to gas) and return to the atmosphere. The changes in the amount of carbon dioxide in the atmosphere, along with the increasing and receding poles during summer and winter, is so great that the gravitational field of Mars changes with the seasons as a result.

Mars also experiences ice ages across a time scale of hundreds of thousands of years, caused by marginal changes in its orbit and axial tilt. Like Earth it's currently in an interglacial period, but from around 2.1 million to 400,000 years ago, a time when sabre-toothed cats, woolly mammoths and other Pleistocene megafauna roamed Earth, Mars was plunged into an ice age of its own. The increased tilt on its axis heated the poles, evaporating ice into the atmosphere only for it to settle and spread from the 60 degree latitude mark to around 30 degrees north of the Martian equator in both hemispheres.

Mars during its ice age over 400,000 years ago. The ice caps reached the equivalent latitudes of Mexico in the north and Australia in the south



The Martian north pole (right-hand image) can get even colder than the south (left) in a Martian winter, and reaches temperatures as low as -153°C (-243°F)



The Martian polar caps are shown in this Hubble image of the Red Planet taken in 2001. A huge dust storm can also be seen at the northern cap

This massive impact basin can easily be seen from Earth

9 Deep impact

The huge Martian crater that's visible from Earth

Hellas Planitia is a huge crater that was formed in the early days of the Solar System, an era of heavy meteorite bombardment around 4 billion years ago when enormous objects flew around and collided with others on a regular basis. With its bright, reflective floor it's a spectacular site, even when viewed from Earth.

It has a diameter of 2,250 kilometres (1,400 miles) and over nine kilometres (5.6 miles) separate the rim of the crater from its floor. The rims are nearly two kilometres (1.2 miles) high, which puts the floor of the basin seven kilometres (4.3 miles) below what on Mars would correspond with sea-level on Earth. At this depth, the atmospheric pressure at the bottom is nearly double that at the top. Under certain conditions, that's enough for liquid water to form. There's evidence to suggest that the gullies around the basin rim were formed by glacial movement as well as explosive boiling of the water into steam.

Hellas Planitia would be the biggest crater on Mars, if it wasn't for the suspected (but still unconfirmed) Borealis Basin in Mars' northern hemisphere.

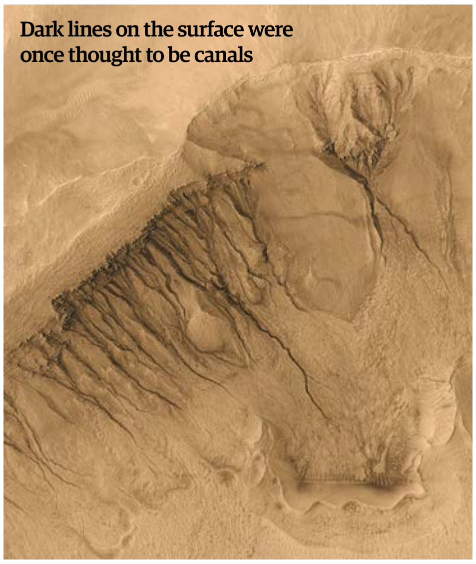
10 Martian 'canals'

The features that went on to inspire a century of science fiction

In 1877, astronomer Giovanni Schiaparelli observed numerous gullies criss-crossing the surface of Mars, which he described in his native Italian tongue as 'canali'. For better or for worse, the literal translation of 'canals' was made into English and from there, early 20th century academics (including a certain Percival Lowell), flushed with the prominence of a new scientific age, promptly assumed that evidence of an intelligent civilisation was inferred.

Fortunately, others were more scientific in their observations, pointing out that the 'canals' were caused by an optical illusion in poor-quality telescopes that joined visible features by lines. Spectroscopic analysis showed that atmospheric pressure on Mars was indeed too low for liquid water and that the Red Planet was considerably colder than originally anticipated. Finally, powerful telescopes of the day showed no such lines on Mars, which led to this rather tenuous theory quickly being debunked, although the notion of a Martian civilisation lived on in science fiction for decades.

Today, albedo features – the craters and basins like Hellas Planitia that contrast the russet background, as well as dust streaks leading across mountains and dust storms – can be considered the remains of what were once thought to be the great Martian canal system.



Dark lines on the surface were once thought to be canals

Are we Martians?

The theory of panspermia, that an asteroid bearing the 'seeds' of life impacted the Earth aeons ago, isn't a new one. But following a major scientific conference in Italy recently, the idea that life on Earth may have originated from Mars, is picking up some serious traction. We don't know exactly how the building blocks of life came about, the RNA, DNA and amino acids that were brought together to form the prebiotic 'soup', but we're pretty sure that RNA was there first. On Earth, the minerals necessary for creating the RNA template would likely have dissolved in the oceans, but that wouldn't have been the case in the relatively arid environment of ancient Mars. The theory, outlined by Professor Steven Benner of the Westheimer Institute for Science and Technology, is that these minerals oxidised on Mars, eventually forming RNA. This was then transported to Earth and deposited via one or possibly many meteorites (Martian meteorite strikes are still very common today), conceiving the first life on Earth.