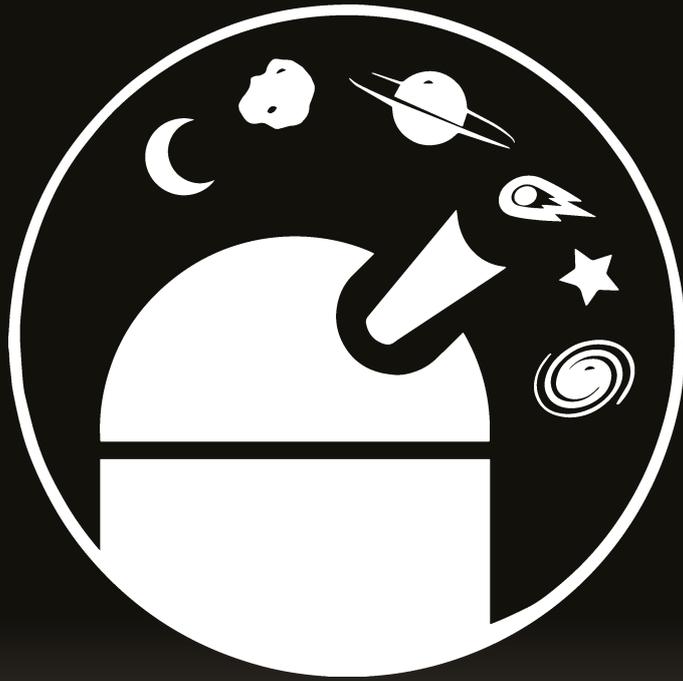


All About Space



14 YEARS OF
DISCOVERIES



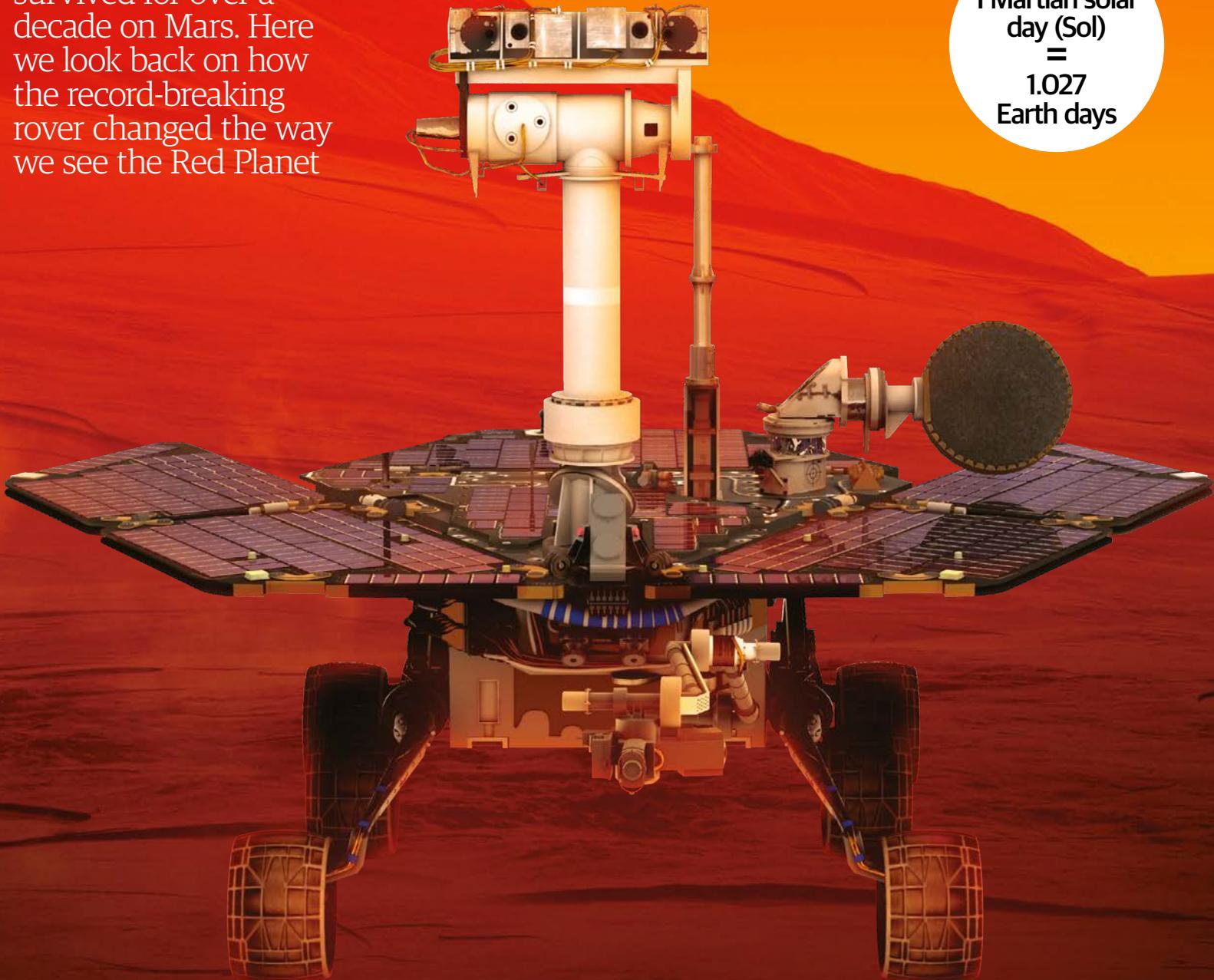
14 years of discoveries

14 YEARS OF DISCOVERIES

MARS

Designed to last 90 days, Opportunity survived for over a decade on Mars. Here we look back on how the record-breaking rover changed the way we see the Red Planet

1 Martian solar day (Sol)
= 1.027 Earth days



Opportunity's objectives

-  Search for signs of past liquid water ✓
-  Determine distribution and composition of Martian rocks ✓
-  Discover the geological processes which formed the Martian terrain ✓
-  Validate measurements made by probes orbiting Mars ✓
-  Search for iron containing minerals that may have been formed in water ✓
-  Determine the texture of rocks and soils and what created them ✓
-  Assess whether Mars' climate was ever fit for life ✓

39 Sols



Signs of past water

This is a microscopic image of part of a rock called 'Last Chance'. The view here is around five centimetres (two inches) across and was taken on Opportunity's 39th Martian day. The texture of the rock has led scientists to believe that water was once present in the area in which it was found - the Meridiani Planum area of Mars, which is close to its equator.

91 Sols

Opportunity from orbit

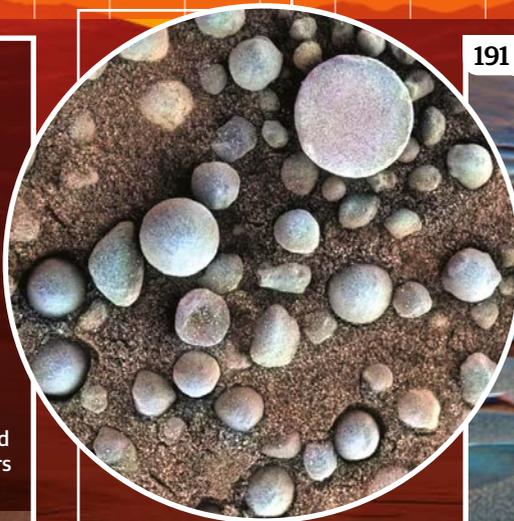
Opportunity's journey across Mars has been closely watched and calibrated by the satellites in orbit around the Red Planet. This image from NASA's Mars Global Surveyor shows some of the tracks of the rover, the craters it was visiting, its back shell and parachute, along with the location of its discarded heat shield. It was taken on 26 April 2004 on Sol 91 from a distance of around 400 kilometres (249 miles).



0 Sols

Made of World Trade Center metal

Part of Opportunity is made from aluminium debris salvaged from the World Trade Center, which collapsed on 11 September 2001. It was turned into a credit-card-sized sheet of metal, to which a United States flag emblem was added. That metal protects the cables that form part of Opportunity's drilling mechanism. The same is true of the Spirit rover. The team who built the part worked just six blocks away from the towers in downtown Manhattan.



84 Sols

Martian blueberries

Microscopic analysis of the Martian surface revealed tiny spheres resembling blueberries. Each of the balls you can see here is a few millimetres across. This image was taken near Fram crater in April 2004 on Opportunity's 84th Sol on Mars and shows how the mineral hematite can come together to form small structures. It has been suggested they were deposited here by liquid water long ago in Mars' warmer past.

191 Sols



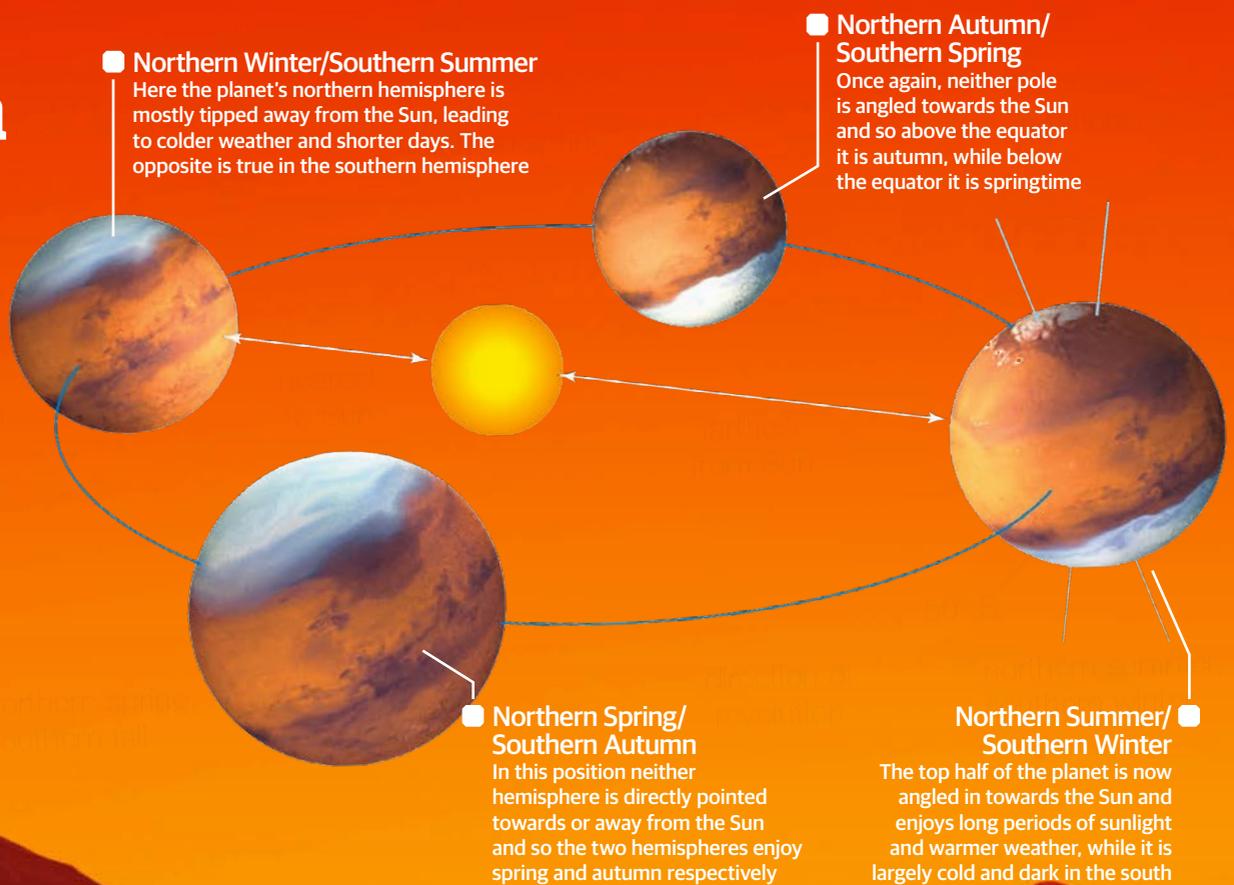
Sand dunes

As Opportunity entered Endurance crater it found dunes on the crater floor. Each of the ridges of sand are less than one metre (3.3 foot) high and are likely caused by the winds that whip across the dry Martian surface. Before approaching the dunes to take the photograph, the rover drivers had to assess the likelihood of Opportunity becoming marooned in the dunes. The image is in false colour and was taken by the PanCam instruments on board the rover.

257 Sols

Frost on the Red Planet

Being further from the Sun than the Earth, temperatures on Mars regularly plummet below freezing. On October 13 2004, 11 minutes after sunrise, NASA scientists noticed that frost had formed on one of the calibration targets for the PanCams. So even near the equator - the location of Opportunity's landing site - temperatures drop enough for frost to form. No such frost observations were seen on Spirit, Opportunity's twin rover, which was situated on a different part of the planet.



200

300

400

324 Sols

Glancing at its impact site

In this image you can see the area where the rover's heat shield impacted the Martian surface. It was taken on Sol 324, so nearly a year after Opportunity touched down on Mars. The main heat shield is on the left-hand side and is sitting inverted. The circular crater created by the heat shield is 2.8 metres (9.2 foot) wide, but no more than ten centimetres (four inches) deep.



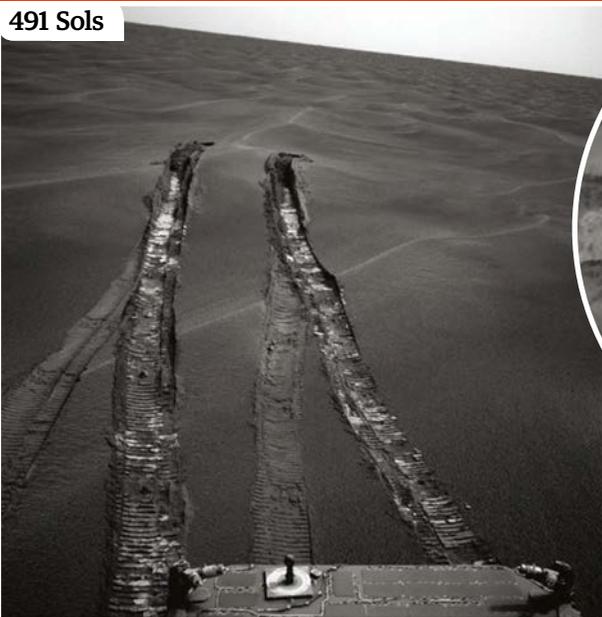
339 Sols

Meteorite find

In January 2005, Opportunity was examining the impact site of its own heat shield when it came across a meteorite on the surface of Mars. It was subsequently named Heat Shield Rock. About the size of a basketball, it was the first meteorite to be discovered on another planet (two others had previously been found on the Moon). Its iron structure meant that the abrasion tool could not be used to scratch it, as it would have been damaged.



491 Sols



Stuck in Purgatory

During April 2005, Opportunity's wheels became embedded more than ten centimetres (four inches) down into some soft, sandy material. It took five weeks of planning, testing and expert driving in order to extricate the stricken rover. Due to its hellish effect on Opportunity, this region was dubbed Purgatory Dune. It could nearly have been the rover's final resting place. Luckily, it was able to escape and has continued to operate for more than a decade after its little mishap.



727 Sols

Signs of water at Roosevelt

Opportunity's microscope shows a close-up view of a structure known as Roosevelt, found near the edge of Erebus crater. Scientists have hypothesised that the fractures were caused by liquid water moving through the structure. The image is a mosaic of several smaller images all taken on Sol 727. The feature is younger than the surrounding rocks, meaning that liquid water may have been present in the area after the other sedimentary rocks had formed.

1162 Sols

Opportunity learns to drive itself

This view of Opportunity's tyre tracks was taken after it drove a curved path that was more self-determined than before. Engineers were testing out a piece of software called Field D-star, which helps Opportunity decide for itself how to get to a given destination while avoiding obstacles along the way. It was taken on Sol 1162 and Victoria crater can be seen in the background. For scale, the rocks in the centre foreground are seven to ten centimetres (2.8 to 3.9 inches) tall.



500

750

1000

1250

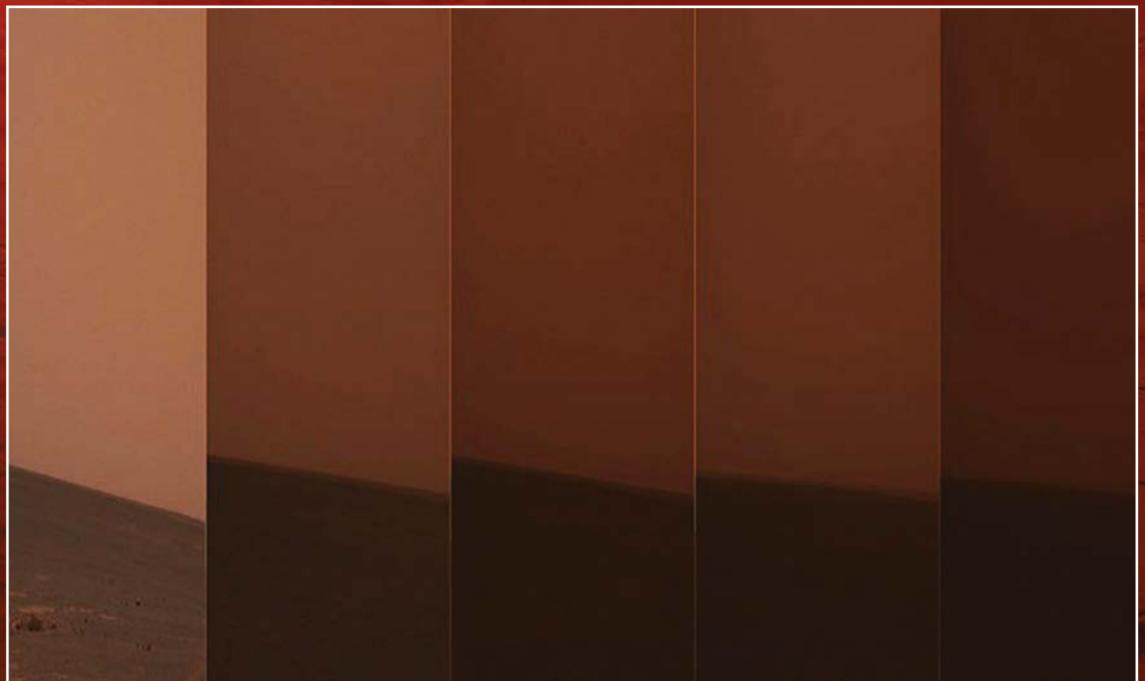
1500

1236 Sols

Opportunity weathers its first dust storm

In July 2007 both Opportunity and its twin rover Spirit came under severe threat from vicious dust storms whipping across the Martian surface. The rover gets its power from its array of solar panels, but the huge volume of dust brought by the storms blocked out 99 per cent of the available sunlight. Opportunity was effectively put into hibernation for a few days and the amount of contact with the rover was scaled back. Fortunately, the storms moved away and the rover survived intact.

As the dust storm gathered, the amount of daylight available to the Opportunity rover dropped dramatically. These images, taken by the rover's PanCam, shows how the sky darkened over several weeks





2117 Sols

Inspecting Marquette Island Rock

From November 2009 to mid-January 2010, Opportunity inspected this basketball-sized rock as NASA experts believed it might have originated deep in the Martian crust and been thrown to its present location by an impact event. The day before, the rover's abrasion tool had scratched a five-centimetre (two-inch) wide hole in the rock to help scientists learn more about its composition. It is named after an island in northern Michigan, US.

2476 Sols

Textures of Santa Maria crater

This image from Sol 2476 shows just how different areas of the same crater can appear. In the background of Santa Maria crater the material appears smooth, while it is a lot more jagged in the foreground. The crater is about 90 metres (295 feet) in diameter and the rover was perched close to the rim of the crater on its southeastern edge when this photograph was taken using the navigation cameras (hence why it is black and white).



2000

2500

0-3968 Sols

Opportunity's marathon

Opportunity's sheer tenacity means it has lasted a lot longer than mission controllers had originally envisaged. In 2015, after more than 11 years exploring Mars, the rover clocked up a total distance of 42.1 kilometres (26.2 miles) - the equivalent of running a marathon. On its journey from Eagle crater to Endeavour crater, it found signs of past water on Mars as well as clues as to the potential habitability of the Red Planet, including its salinity.

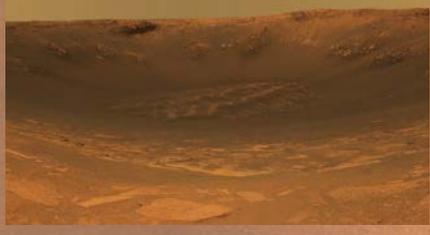
1 Eagle crater

Opportunity landed in this 22m (77ft) wide crater, just south of the equator, where it found signs of acidic water in the area's past.



2 Endurance crater

Opportunity spent May to December 2004 exploring this crater and found that liquid water was likely once present there.



3 Victoria crater

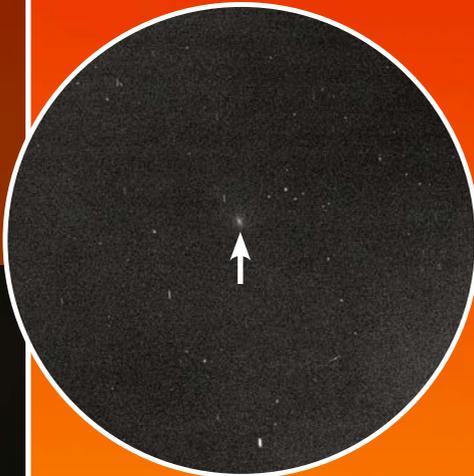
After 21 months on Mars, Opportunity reached this 730m (2,395ft) wide crater and it explored the crater's exterior and interior.



3078 Sols

Transit of Phobos

On Sol 3078, Opportunity caught Mars' largest moon Phobos transiting the Sun. Technically it is an annular eclipse - the moon doesn't block out all the Sun's light. As the moon has an incredibly rapid orbit around Mars - just 7.6 hours - transits of Phobos only last around 30 seconds. However, they happen very frequently as the moon orbits close to the Martian equator.



3809 Sols

Snaps of a close comet encounter

Back in October 2014, mission scientists pointed Opportunity's cameras towards the sky and captured this image of the Comet Siding Spring. It was taken about two and half hours before the comet reached its closest point to the Red Planet. However, at that time, the Sun would have risen and made taking the photograph impossible. Some nearby stars, as well as effects of cosmic rays, can be seen alongside the icy denizen from the outer Solar System.

Opportunity loses its memory

Over the years Opportunity has experienced several issues with its computer flash memory - a system which can store data even when the rover is turned off. In March 2015 mission engineers installed a software update, which they hoped would fix the issue. However, the problem recurred. The rover was only designed for a 90-day mission, and more than a decade of Mars exploration continues to take its toll on Opportunity's memory. Mission controllers must reformat the rover's memory banks whenever a glitch occurs.



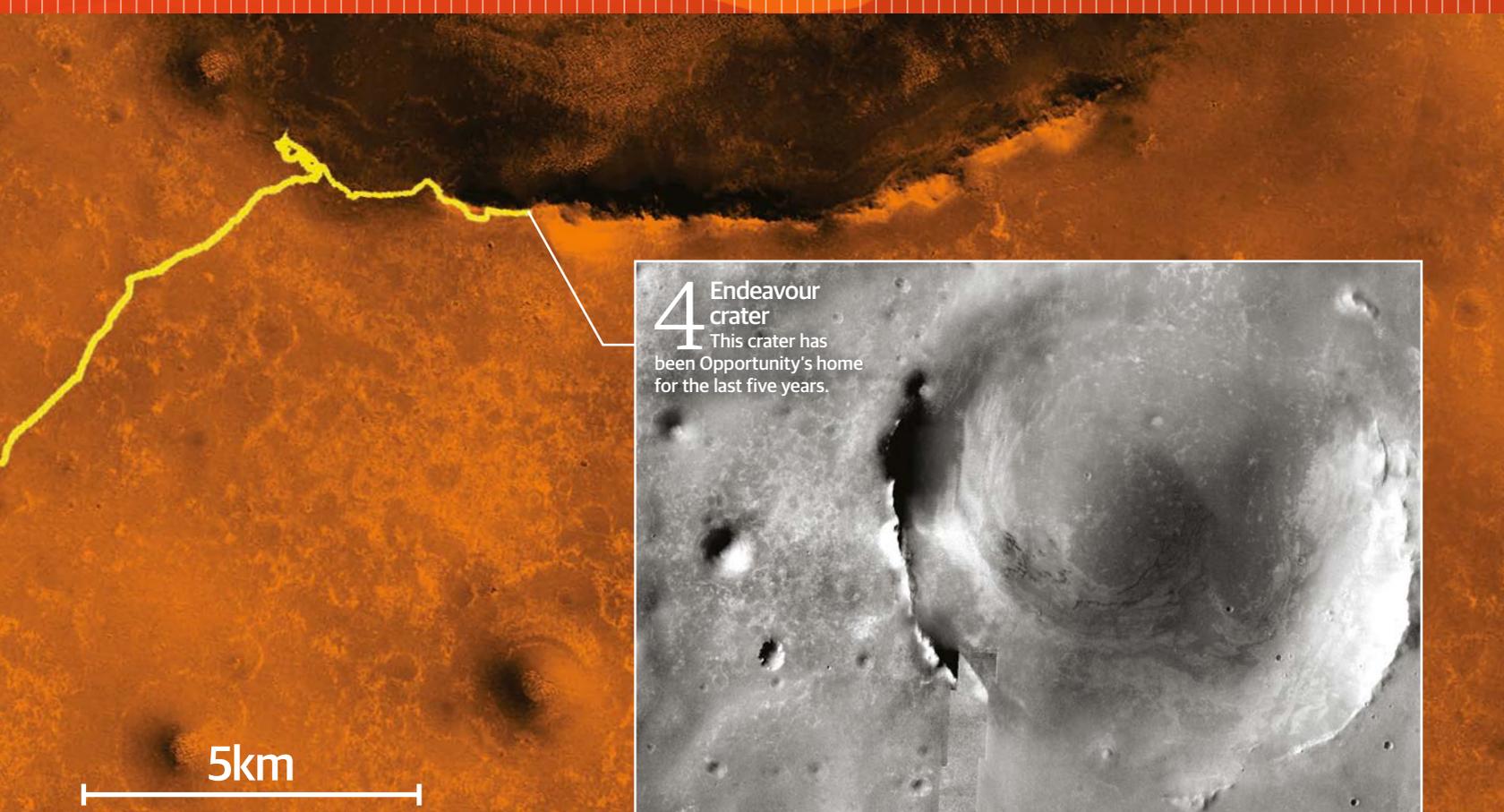
Opportunity's memory: 128MB RAM
Modern computer memory: 16GB RAM



Opportunity's camera pixels: 1 megapixel
An iPhone 7's camera pixels: 12 megapixels

3000

3500



4 Endeavour crater

This crater has been Opportunity's home for the last five years.



5km



3974 Sols

Spirit of St Louis

This panoramic image from Opportunity shows the elongated crater known as "Spirit of St Louis." Towards the centre is a spire of rock stretching upwards towards the Martian sky. The crater is 34 metres (112 foot) long and about 24 metres (79 foot) wide. The spire of rock is thought to be between two and three metres (6.6 and 9.8 foot) tall, meaning it sits slightly higher than the rim of the crater. The image was taken in late March 2015, around the time Opportunity was celebrating its 4,000th Martian day.

4332 Sols

Dust devil spot

After climbing up Knudsen Ridge in the Marathon Valley, Opportunity looked back in the direction from which it came and spotted this dust devil spinning across the Martian surface. It was taken by the NavCams on Sol 4332 on the 31 March 2016. It was a pretty rare sight for Opportunity who hasn't seen as many dust devils as its counterpart Spirit. These events are caused by a rising and rotating column of air, which whips up the dust.

5111 Sols

Last contact

On 10 June 2018, the final signal from Opportunity was received before it was engulfed by a planet-encircling dust storm. Unable to charge its solar panels properly, the rover entered hibernation two days later. Despite many efforts, NASA were unable to re-establish contact.

5353 Sols

Mission ends

After sending over 1,000 signals to Opportunity in the hope of getting a response after the dust storm cleared, NASA declared the mission officially complete on 13 February 2019.

4000

4500

5000

5500

Opportunity by numbers

32°

The steepest slope tackled by Opportunity during its visit to the Marathon Valley

217,594

The number of raw images captured by the rover's suite of cameras during its 14 years of surface activity

6

Number of wheels on the rover, which allow it to trundle across the Martian surface



45.16km

The total distance travelled by the rover during its mission between 2004 and 2018

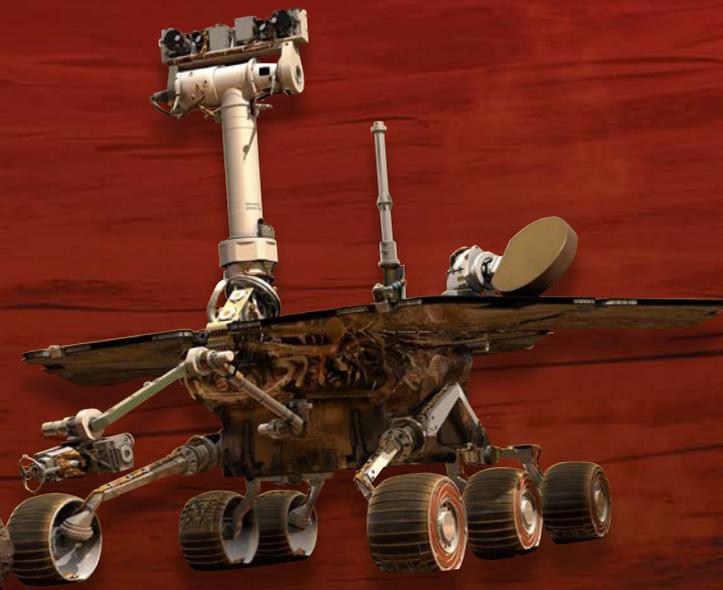
185kg

The mass of the rover - a little over the combined mass of two average humans



0.18km/h

The rover's maximum speed. That's about four-times faster than a snail's pace



The anatomy of Opportunity

The equipment that helped Opportunity (and us) see the Red Planet

NavCam

A pair of black and white cameras mounted on the mast of the rover helped scientists to see the rover's surroundings and plan out its route across Mars

PanCam

A pair of colour cameras enabled Opportunity to take panoramic images of the Martian surface. The resolution of the cameras was designed to mimic the human eye

PanCam calibration target

A sundial with different coloured corners and engraved with the message: "Two worlds one Sun." Engineers calibrated the PanCams by adjusting the image until the colours look as they should

High-gain antenna

This antenna could beam information in a particular direction, such as towards the Earth or at one of the flotilla of satellites in orbit around Mars

Low-gain antenna

This antenna could send and receive signals from all directions. Radio waves were sent to and from the rover by the orbiting satellites

Front HazCam

One of four black and white cameras, these HazCams could see for three to four metres (9.8 to 13.1 foot) around the rover and were used to look for obstacles

Solar arrays

These solar panels generated up to 140W of power for up to four hours per Martian day. The rover needed 100W to drive. Two rechargeable batteries provided backup power

In-situ instruments

Four scientific instruments were mounted on this front robotic arm, including a microscope for close-up views of rocks and an abrasion tool for scratching surfaces

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