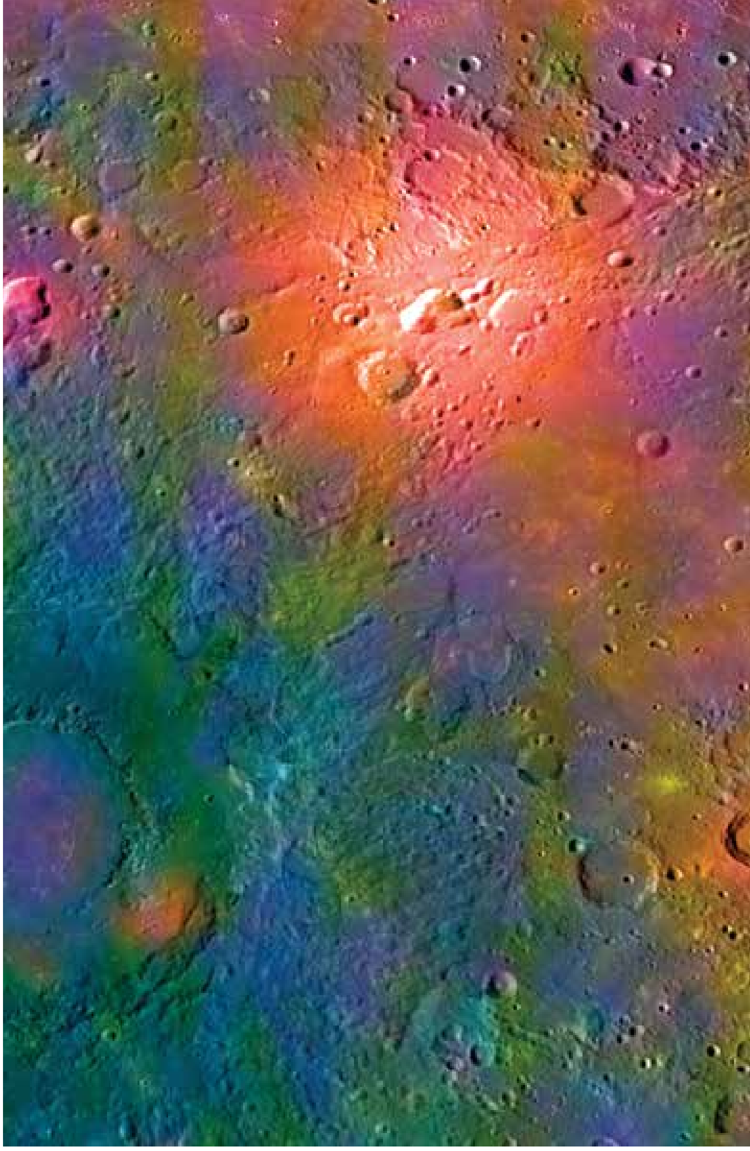
MERCURY'S volcanic secret

Before NASA's latest mission to Mercury arrived at the innermost planet, scientists had erroneously though that it had been inactive since the birth of the Solar System. **Jasmin Fox–Skelly** finds out how we are learning instead that Mercury has lived a far more interesting life.

Mercury seems to have been a more volcanic world than we believed, which is teaching us about the circumstances in which it was born. Image: NASA/JHUAPL/Carnegie Institution of Washington.



When volcanoes erupt on Earth, molten hot magma containing volatiles such as water, sulphur dioxide and carbon dioxide spew out of the mouth of the volcano and onto the surface. On the other hand, it had long been thought that Mercury, being so close to the Sun, must lack the compounds necessary for volcanic eruptions as they should have boiled off when the planet formed 4.5 billion years ago. However, NASA's MESSENGER probe is showing that volcanoes exploded on Mercury for a substantial portion of the planet's history, which throws into question what we think we know about how Mercury formed.

MESSENGER first spotted volcanic ash deposits – the telltale signature of volcanic explosions – in 2008 during one of its fly-by visits of Mercury prior to entering orbit in 2011. What was not clear from the initial images was the timeframe over which the explosions occurred. Did Mercury's volatiles – that is, materials that have a relatively low boiling point – burn up in a barrage of explosions early in the planet's history? Or has Mercury held on to its volatiles over a much longer period?

Researchers from Brown University in Rhode Island, USA, have been analysing detailed images taken when MESSENGER entered orbit around Mercury. What they have seen has convinced them that not only did Mercury have volatiles, but it also held onto them for much longer than had previously been imagined. The findings suggest that volcanoes could have erupted on Mercury as recently as one billion years ago.

Led by Tim Goudge, a graduate student in the Department of Geological Sciences at Brown University, the team of researchers looked at 51 volcanic ash deposit sites distributed across Mercury, as well as their associated vents. These vents measure up to 25 kilometres in length and appear to have been the source of tremendous volumes of very hot lava that rushed out over the surface of Mercury and eroded the substrate, carving valleys and creating teardrop-shaped ridges in the underlying terrain. Goudge's team found that some of the vents and deposits were more eroded by meteoric impacts than others, suggesting that they cannot all have formed at the same time.

Luckily many of the vents and ash deposits were found inside impact craters, which can be dated by scientists. This is possible because the rims and walls of craters become eroded and degraded over time and the extent of their degradation can be used to infer their approximate age. The vent sites must be younger than the crater they are found in, because otherwise they would have been destroyed by the impact that caused the crater.

"The youngest craters that we have identified volcanic vents in are between 3.25 billion to one billion years old, which means that volcanic activity had to have occurred more recently than 3.25 billion years ago, but it is very difficult to pin down exactly how recently volcanic activity occurred," says Goudge.

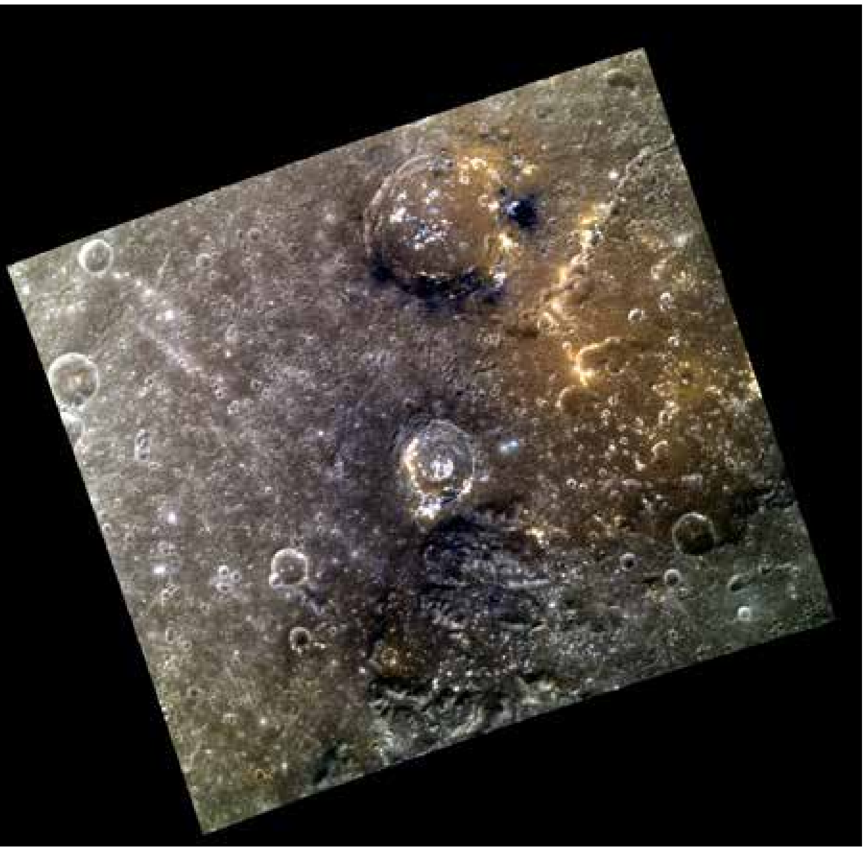
Volcanic vents close to Rachmaninoff Basin on Mercury. The bright area in this false-colour infrared image is a pyroclastic deposit. Image: NASA/JHUAPL/Carnegie Institution of Washington.

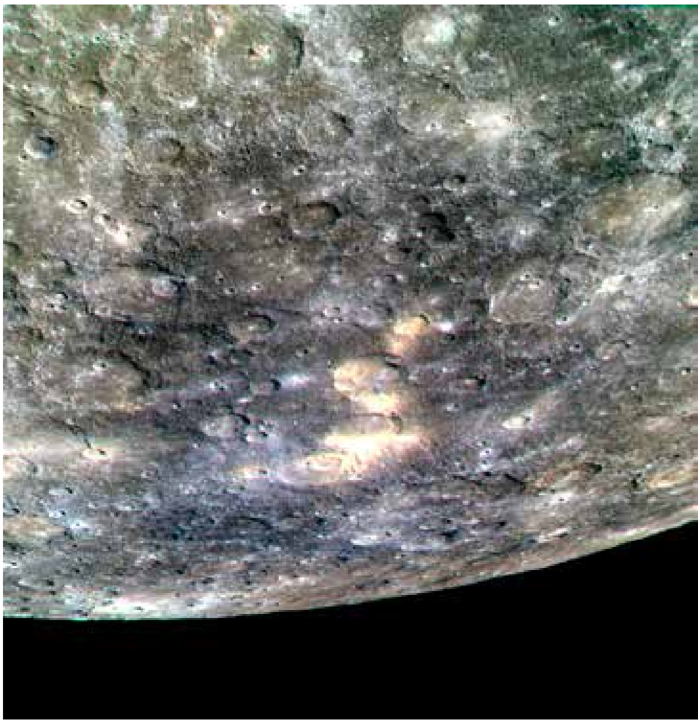
Searching for vents

Clearly, these relatively young ages rule out the possibility that Mercury's volcanism ceased shortly after the planet formed. For Sean Solomon, the Principal Investigator of the MESSENGER mission, this discovery is crucial to better understanding diminutive Mercury.

"These results, along with the earlier findings from MESSENGER's fly-bys of Mercury are important for several reasons," he says. "They indicate that temperatures inside Mercury were sufficiently hot for the silicate mantle to be partially molten for a long fraction of the planet's history. They also demonstrate that the formation of impact craters was a vital process without which there may have been no geologically recent volcanism on Mercury. After Mercury was formed it was subjected to substantial compressive forces as it contracted. Those forces would normally have prevented magma from rising up to the surface, but the impacts that caused the craters that host pyroclastic deposits [i.e. fragments of volcanic rock that are explosively erupted by a volcano] must have fractured the underlying crust sufficiently to relieve these horizontal compressive stresses, allowing the magma to flow upwards."

David Rothery, Professor of Planetary Geosciences at The Open University, has also analysed MESSENGER data to look for signs of volcanic activity on Mercury. In a





The yellow areas indicate pyroclastic deposits within the crater Hesiod on Mercury, in an area of the planet that contains the highest number of volcanic vents. Image: NASA/JHUAPL/Carnegie Institution of Washington.

Situated on the eastern edge of Mercury's enormous Caloris Basin are craters sporting reddish deposits that have a spectrum that appears volcanic in origin. Image: NASA/JHUAPL/Carnegie Institution of Washington.

paper published this year in the 1 January edition of *Earth and Planetary Society Letters*, he describes a vent complex consisting of at least nine overlapping volcanic vents, each of which are up to eight kilometres in diameter, situated about 100 kilometres inside the south-western rim of Mercury's giant Caloris Basin. The vent formation, described as a 'kidney-shaped depression,' is surrounded by pyroclastic deposits, providing clear evidence of volcanic activity.

"Volcanism appears to have gone on for quite some time on Mercury," says Rothery. "Some of the vents that we observed have a really crisp shape, whilst others are really muted and a lot have been softened or buried by pyroclastic material. This suggests that the vents are of different ages.

"We have vents on the floors of craters that belong to the youngest class of craters we have on Mercury. Most of the volcanism is more ancient but there has certainly been some that has carried on into the relatively recent past. We think that we have volcanoes extending into the past billion years of the planet's history."

Mercury's formation

The idea that volcanic explosions shook Mercury for most of its existence clashes with many established theories about its formation. Like the rest of the planets in our Solar System, Mercury formed when a nebula consisting of dust and gas collapsed, forming the Sun and surrounding it with cosmic materials that eventually coalesced to become the planets. Mercury, the smallest and innermost planet in our Solar System, has a thick, rocky surface rich in heavy elements and iron. It has an extremely high density, with an enormous two-thirds of its mass made up by its metal core.

Different theories have been proposed to explain why Mercury has such a large metal core but only a thin outer crust. One theory argues that the Sun might have vaporised part of Mercury's rocky exterior early in the planet's life; however, this would have caused volatile elements to have largely boiled off, rendering explosive volcanism impossible. Another theory suggests that dense, metal-rich planetary building blocks may have been drawn close to the Sun where Mercury formed, but MESSENGER data seems to indicate that Mercury's composition contains less oxygen than would be expected if this were the case. One idea mooted was that a large object colliding with the planet early in its history could have destroyed most of its crust, but because this would likely have removed any volatiles necessary for volcanic explosions, this theory must also be thrown out.

"Originally, many thought that since Mercury formed so close to the Sun, most of the volatiles would not have survived the planet formation process," says Goudge. "Additionally, one of the hypotheses to explain Mercury's large core was that it was hit by a large impactor, which again people thought might have 'blown off' much of the remaining volatiles in Mercury's interior. Our observations do not support either of these hypotheses, as our observations suggest that Mercury held on to volatiles in its interior for longer than previously thought."

Reconciling Mercury's volcanism with its large core and thin outer crust has become a significant dilemma for planetary scientists like David Rothery. "MESSENGER data has shown that Mercury has high levels of both potassium and sulphur," he says. "You wouldn't have expected sulphur, which is a volatile, to be that abundant in Mercury's crust, so all these lines of evidence suggesting that Mercury's rocky exterior is rich in volatiles just do not fit with the idea of how Mercury might have been left with this big core surrounded by only a thin rocky layer."

Moving Mercury

Perhaps we are going about this all wrong, trying to model the birth and formation of Mercury based on where it is now when instead we should entertain the possibility that Mercury formed further out from the Sun and migrated inwards. This theory is not as crazy as it sounds: many of the planets wandered all over the place during the early years of our Solar System. Jupiter, for example, probably formed further out in the outer Solar System than it is today.

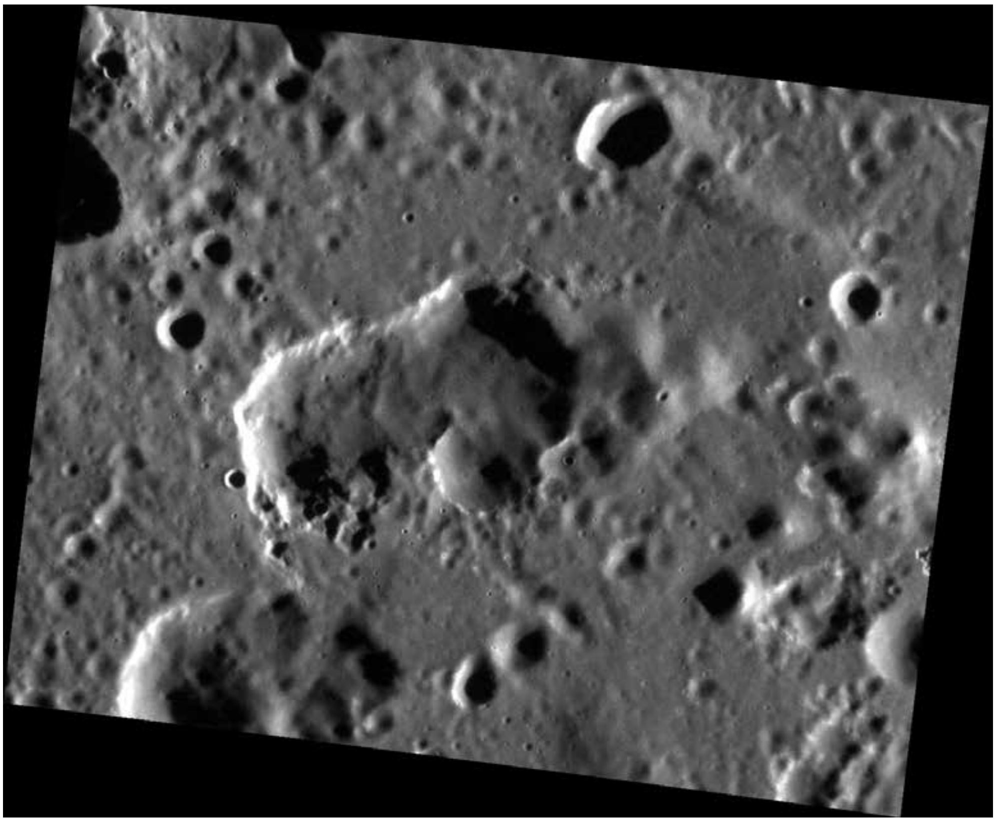
As Jupiter orbited the Sun after its birth, it created spiral waves within the dense cloud of gas and dust in the protoplanetary disc that was still coalescing to form the other planets. The outer spiral waves had a greater effect than the inner waves, causing Jupiter to be pushed in towards the Sun. The planet may have migrated so far towards the Sun that it would lie in the orbit that Mars now occupies. So could Mercury have undergone a similar process?

"Nobody really knows, but these findings have blown wide open the earlier ideas that it was a giant impact that blew off the rocky outer layer," says Rothery. "Maybe Mercury formed further out from the Sun than we now see it and migrated inwards, which would explain its high abundance of volatiles, but it would still not explain why it has this big core relative to its rocky crusted mantle. Also, how would Mercury get past Earth and Venus without causing all kinds of chaos and trouble? Every solution we come up with gives us a different set of problems to try and get round. So it is a mystery."

Rothery is part of the team working on the European Space Agency's BepiColombo mission, which is scheduled to launch in 2016 and reach Mercury in 2024. The mission is equipped with sensors more advanced than MESSENGER's that will be able to tell us more about Mercury's volcanic history and hopefully answer some of these questions.

Until then Mercury's secrets will probably remain hidden. "There is much more for us to learn," says Goudge, "Including what the history of volatiles in Mercury's interior is and also getting better age constraints for the formation of these volcanic features. Hopefully with more data and more people working on the problem we will be able to start to address these questions and more!"

Jasmin Fox-Skelly is a freelance science writer. Her website is www.jasminfox-sciencewriter.com.



A possible kidney-shaped depression containing multiple volcanic vents on the south-eastern edge of the Caloris Basin that David Rothery has been investigating. Image: NASA/JHUAPL/Carnegie Institution of Washington.

A cross section of Mercury that shows how the metal-rich core makes up a significant amount of mass within the planet. The outer core is possibly molten, which provided magma for the volcanoes. Image: Nicolle Rager Fuller/NSF.