REWRITING THE BOOK O

DR SHOSHANA Z. WEIDER
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Mercury – the smallest and innermost planet – has long been one of the least understood components of our Solar System. Difficult to study from Earth because of its proximity to the Sun, Mercury had – until recently – been visited by only one spacecraft. In 1974–1975, NASA's Mariner 10 performed three 'flybys' of the planet, during which some rudimentary observations were made. Detection of Mercury's weak magnetic field suggested a partially molten core, and several species (including hydrogen, oxygen, and helium) were detected in the planet's 'exosphere'. However, the vagaries of Mariner 10's trajectory, coupled with the planet's tidally locked 3:2 spin-orbit resonance, meant that less than one half of Mercury's surface was seen from close range.

The Mariner 10 images revealed a grey surface, full of craters. Many planetary scientists wrote Mercury off as geologically similar to the Moon and not worthy of an extensive follow-up mission. But a committed and insightful group of scientists – led by Principal Investigator Professor Sean Solomon from the Lamont-Doherty Earth Observatory of Columbia University – were not so easily placated. They believed Mercury should not be so readily dismissed, and their dream of a new Mercury mission became a reality when the MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) mission concept was chosen as the 7th NASA Discovery-class mission in 1999.

To answer eight primary science questions about Mercury and its geologic history, MESSENGER was originally designed as a one-year orbital mission (the orbital mission eventually lasted for more than four years, ending with impact into the surface once all the spacecraft's fuel had been spent). The extreme heat of Mercury's location, as well as the neighbouring Sun's huge gravitational pull, however, presented major engineering challenges. For one solution, a protective 'sunshield' for the spacecraft was created from a novel heat-resistant ceramic. In addition, MESSENGER's journey to Mercury was specifically designed to reduce the velocity of the spacecraft before orbital insertion (and the amount of fuel required). Following its launch in 2004, MESSENGER followed a circuitous route – via flybys of Earth, Venus, and Mercury itself – before entering orbit around Mercury on 18th March 2011.

Less than two months earlier, I had moved across the Atlantic Ocean to start work as a MESSENGER Postdoctoral Fellow at the Carnegie Institution of Science's Department of Terrestrial Magnetism in Washington, DC. I joined the MESSENGER Science Team, working with Dr Larry Nittler, to analyse and interpret data from the spacecraft's X-Ray Spectrometer (XRS). By using the Sun as a natural (albeit fluctuating) source of X-ray radiation, we used the MESSENGER XRS to quantitatively measure the major-element composition of the planet's uppermost surface. This planetary X-ray fluorescence technique has been used – with mixed success – to characterise airless bodies in the inner Solar System for many decades.

Less than half of Mercury's surface was imaged with Mariner 10. The 1550-km-wide Caloris basin (radiating from centre left here) was seen in its entirety only once MESSENGER was in Mercury orbit. Credit: NASA/Jet Propulsion Laboratory.

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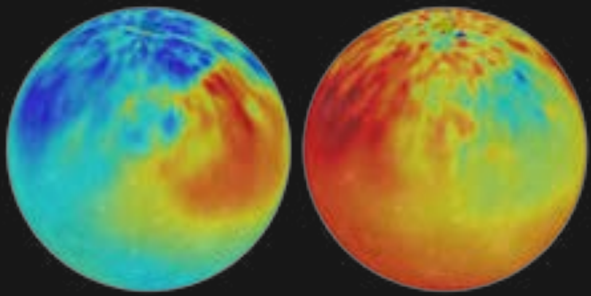

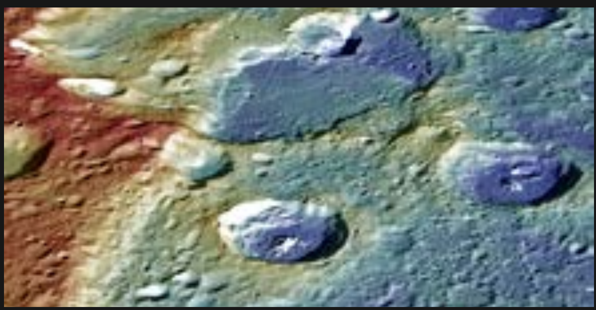

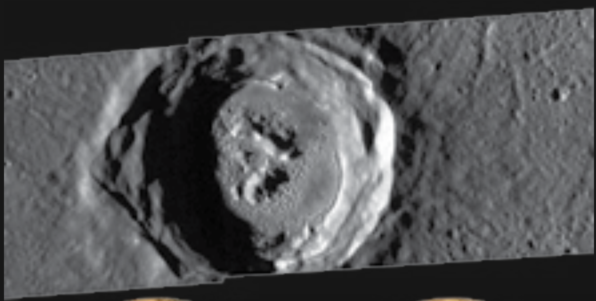

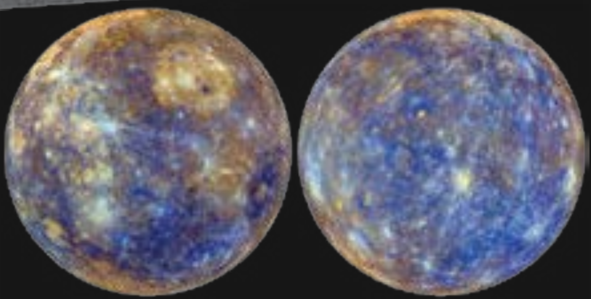

Images from top:

The magnesium (left) and aluminum (right) concentration of Mercury's surface (both relative to silicon), as determined from MESSENGER X-Ray Spectrometer data. Credit: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington.

Carnegie Rupes cuts through Duccio crater (133 km diameter). This lobate scarp (and others like it on Mercury) formed because of horizontal crustal shortening, in response to cooling and contraction of the planet's interior. Colours show topographic height, as measured by the Mercury Laser Altimeter on MESSENGER. Credit: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington.

Mercury's Kertész crater (31 km diameter) is extensively covered in hollows – shallow, irregular depressions that were discovered in MESSENGER images and that appear to be unique to Mercury. Credit: NASA/Johns Hopkins University Applied Physics Laboratory/ Carnegie Institution of Washington.

False colour maps of Mercury (created using images from MESSENGER's Mercury Dual Imaging System) that enhance the chemical, mineralogical, and physical differences between the rocks on the planet's surface. Credit: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington.

With MESSENGER, however, we used this approach to map the entire surface of a planet for the first time.

The XRS and other geochemical data we obtained from MESSENGER have helped to constrain theories for Mercury's early history. Scientists have long puzzled over the reason for Mercury's high density and disproportionately large core. Some believe that the outer (i.e., less dense) parts of proto-Mercury were obliterated during a huge impact event. Our results, however, revealed that Mercury's surface has a rich inventory of volatile elements. Most notably, the sulphur content of Mercury's crust is about 10 times that of typical terrestrial rocks. We expect volatiles to have been lost during the immense heating that would have accompanied a giant impact. Instead, we think, the peculiar major-element composition of Mercury seems to be indicative of the original material that accreted to form the planet. The jury is still out on what those precursors were, but experimental data suggest something akin to enstatite chondrite meteorites could be the answer.

In addition to the XRS, MESSENGER carried a payload of six other scientific instruments to study all aspects of the planet and its surrounding environment. Some of the most exciting findings from the mission include: detection of surface water ice in permanently shadowed areas near to the poles; a magnetic dipole that is offset from the equator; confirmation that Mercury's surface was predominantly formed by volcanism, with later modification from impact craters and global contraction; and long-term observations of Mercury's dynamic and ever-changing exosphere and magnetosphere. Despite the many answers we now possess, MESSENGER has also given rise to a whole new list of (slightly) better-informed questions about Mercury that will hopefully be addressed by the forthcoming European Space Agency/ Japan Aerospace Exploration Agency BepiColombo mission.

Moving to Washington and working on MESSENGER, as part of a hard-working and enthusiastic team, was an incredible and life-changing experience. The quantity and quality of scientific results that continue to stem from the mission is astounding. By studying Mercury for the first time in real detail, we are in a much better position to appreciate the full diversity of our Solar System. We have literally rewritten the book on Mercury. Put together by MESSENGER team members, *Mercury: The View After MESSENGER* will be published by Cambridge University Press in the coming months.

Read more about Mercury and MESSENGER: messenger.jhuapl.edu

Shoshana Weider is a freelance science writer and editor, with an MEarthSci from Oxford and a PhD in lunar geology from Birkbeck College: shoshanazweider.com