



Unusual flow patterns in Phlegra Montes

02 December 2011

Phlegra Montes is a mountainous massif on Mars that extends for several hundreds of kilometres from the northeastern part of the Elysium volcanic region (between 30 and 50 degrees north) to deep into the northern lowlands. The mountain range consists of numerous rolling hills and ridges, the origin of which can be traced back to tectonic activity caused by stresses in the Martian crust. These images of the southern Phlegra Montes were acquired with the High Resolution Stereo Camera (HRSC) on board ESA's Mars Express spacecraft; the camera is operated by the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt; DLR). One large valley in which long flow patterns are clearly visible is particularly striking.

The valley is almost 50 kilometres long and about 15 kilometres wide. The flow patterns are clearly revealed in box 1 in the black-and-white aerial view and in two of the perspective views. Geologists refer to such flow patterns as 'lineated valley fill'. On closer inspection, it can be seen that almost all of the hills are surrounded by a clearly plastic material (box 2), forming 'lobate debris aprons' at the downstream end. In general, the material appears to be moving downslope from the chains of hills.

Several craters filled with material can also be seen, where very similar flow patterns are visible. These are linear and trace out circular crater rims in places; they are known as 'concentric crater fill' (box 3). Radar measurements indicate that large quantities of water ice are buried beneath surface of this region.

The flow patterns, which are aligned in parallel, bear a strong similarity to the surfaces of 'rock glaciers' on Earth. Such bodies of ice are interspersed with boulders and rocky debris, and primarily occur on Earth in regions of permafrost on high mountain ranges or at polar latitudes.

Did glaciers create the linear infill in valleys and craters?

It is known from terrestrial rock glaciers that the ice itself is not visible at all on the surface; the scree covering protects it from melting for long periods. On Mars, it is conceivable that rock glaciers slowly moving across the surface of the planet created the structures occurring here. This presumption is not based solely on the evidence of images acquired from orbit.

The southwestern branch of Phlegra Montes was imaged on 1 June 2011 from an altitude of almost four hundred kilometres during orbit 9465. The image resolution is about 16 metres per pixel. The images show a section at 33 degrees north and 162 degrees east.

The colour images were created using data from the nadir channel, the field of view of which is directed vertically down onto the Martian surface, and the colour channels. The perspective views were computed using data from the HRSC stereo channels. The anaglyph image, which conveys a three-dimensional impression of the landscape when viewed with red/blue or red/green glasses, was derived from the nadir channel and one stereo channel. The black-and-white image is based on data from the nadir channel, which has the highest resolution of all the channels. The false-colour view is based on a digital terrain model of the region, from which the topography of the landscape can be derived. The images were produced by the Department of Planetary Sciences and Remote Sensing in the Institute for Geological Sciences of the Freie Universität Berlin.

The High Resolution Stereo Camera (HRSC) experiment on the European Space Agency's Mars Express mission is led by the Principal Investigator (PI) Prof. Dr Gerhard Neukum, who was also responsible for the technical design of the camera. The science team for the

experiment consists of 40 co-investigators from 33 institutions and 10 nations. The camera was developed at DLR under the leadership of the PI and it was built in cooperation with industrial partners EADS Astrium, Lewicki Microelectronic GmbH and Jena Optronik GmbH. The instrument is operated by the DLR Institute of Planetary Research, through ESA/ESOC. The systematic processing of the HRSC image data is carried out at DLR. The scenes shown here were processed by the PI-group at the Institute for Geological Sciences of the Freie Universität Berlin.

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The Phlegra Montes region

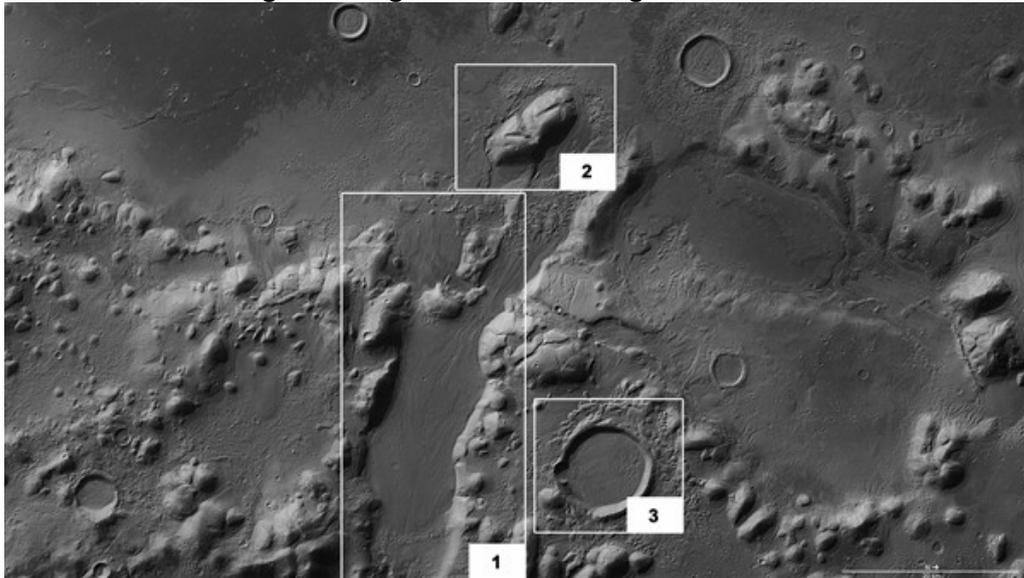


This colour image was created using data from the nadir channel, the field of view of which is directed vertically down onto the Martian surface, and the High Resolution Stereo Camera (HRSC) colour channels; north is to the right in the image. Copyright note: As a joint undertaking by DLR, ESA and FU Berlin, the Mars Express HRSC images are published under a Creative Commons licence since December 2014: ESA/DLR/FU Berlin, CC BY-SA 3.0 IGO. This licence will also apply to all HRSC images released to date. Even though the ochre-coloured shadows associated with Mars dominate the landscape, the image data from the four HRSC colour channels can be processed to enable the material and textural differences on the surface of Mars to be accentuated to a degree. This can be seen, for example, in the low plains to the west of the region (upper left in the image), in the valley surrounded by hills in the right half of the image and in the neighbouring valleys. These colour differences may be related to variations in the geological composition of the surface of Mars, or they might be caused by

differing material properties such as disparate particle sizes or dissimilar degrees of compaction.

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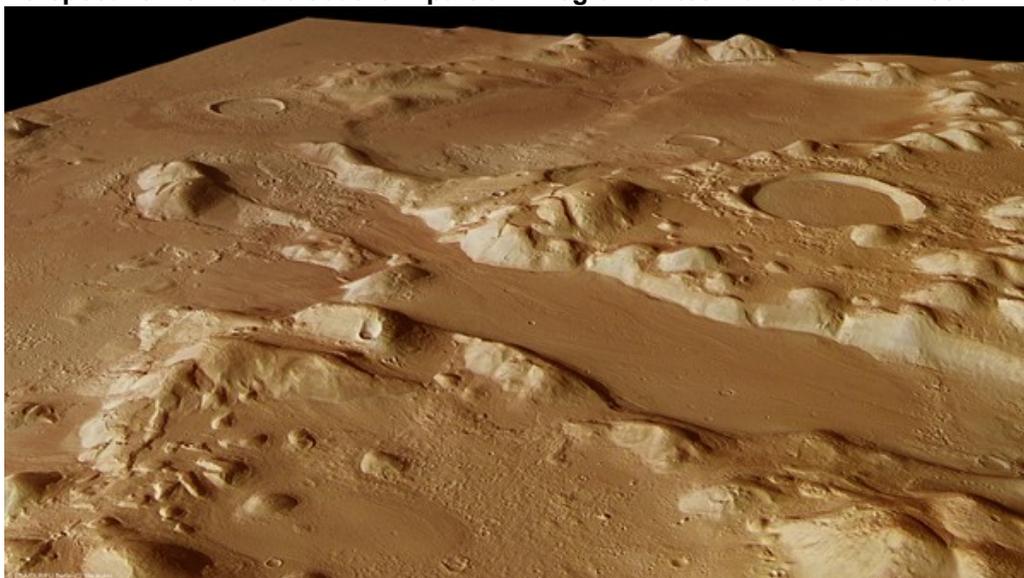
Black-and-white image of Phlegra Montes showing selected areas



The nadir channel, the field of view of which is directed vertically down onto the Martian surface, provides the highest image resolution in the High Resolution Stereo Camera (HRSC) camera system. During orbit 9465, the ESA Mars Express spacecraft was about 400 kilometres above the surface, resulting in an image resolution of 16 metres per pixel. To improve the depiction, the resolution in the images shown here has been slightly reduced; north is to the right. In the framed areas, conspicuous phenomena characteristic of the region are visible: elongated, parallel flow patterns in valley-shaped depressions (box 1), hills around which plastic material has flowed (box 2), and partially filled impact craters in which the flow structures are aligned parallel to the crater rim (box 3). Copyright note: As a joint undertaking by DLR, ESA and FU Berlin, the Mars Express HRSC images are published under a Creative Commons licence since December 2014: ESA/DLR/FU Berlin, CC BY-SA 3.0 IGO. This licence will also apply to all HRSC images released to date.

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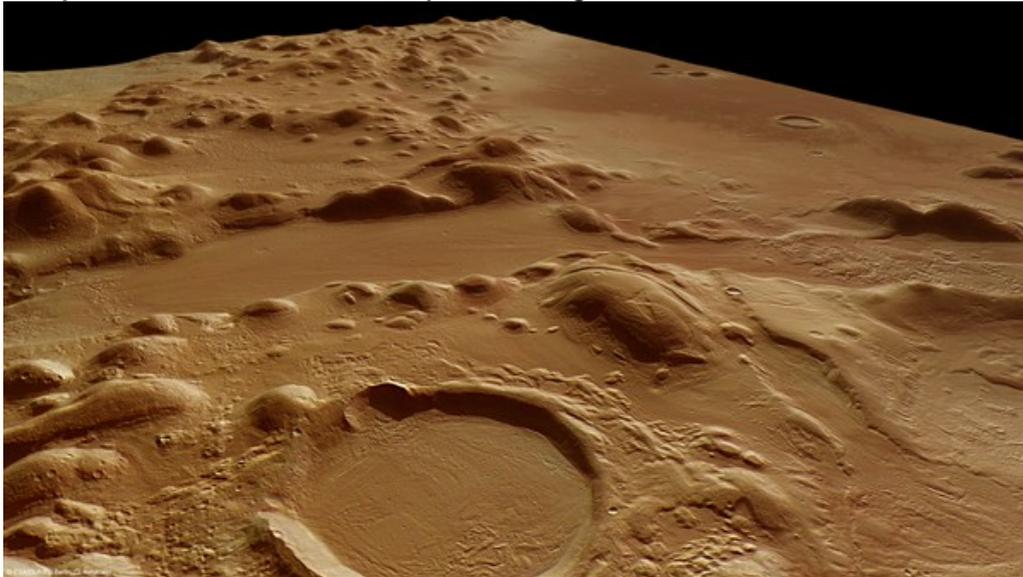
Perspective view of the southern part of Phlegra Montes from the southwest



Realistic perspective views of the Martian surface can be generated from data acquired by the stereo and colour channels of the High Resolution Stereo Camera (HRSC) on ESA's Mars Express spacecraft, which are oriented at an angle with respect to the planet's surface. A valley-shaped depression can be seen in the centre of the image, which has been partly filled with material that has presumably been transported there from the hills in the higher Phlegra Montes. Flow patterns can be seen on the surface of the valley floor, indicating that this material had viscoplastic flow properties. The flow patterns, which are aligned in parallel, bear a strong similarity to the surfaces of 'rock glaciers' on Earth. Such bodies of ice are interspersed with boulders and rocky debris and occur on Earth primarily in regions of permafrost on high mountain ranges or at polar latitudes. Copyright note: As a joint undertaking by DLR, ESA and FU Berlin, the Mars Express HRSC images are published under a Creative Commons licence since December 2014: ESA/DLR/FU Berlin, CC BY-SA 3.0 IGO. This licence will also apply to all HRSC images released to date.

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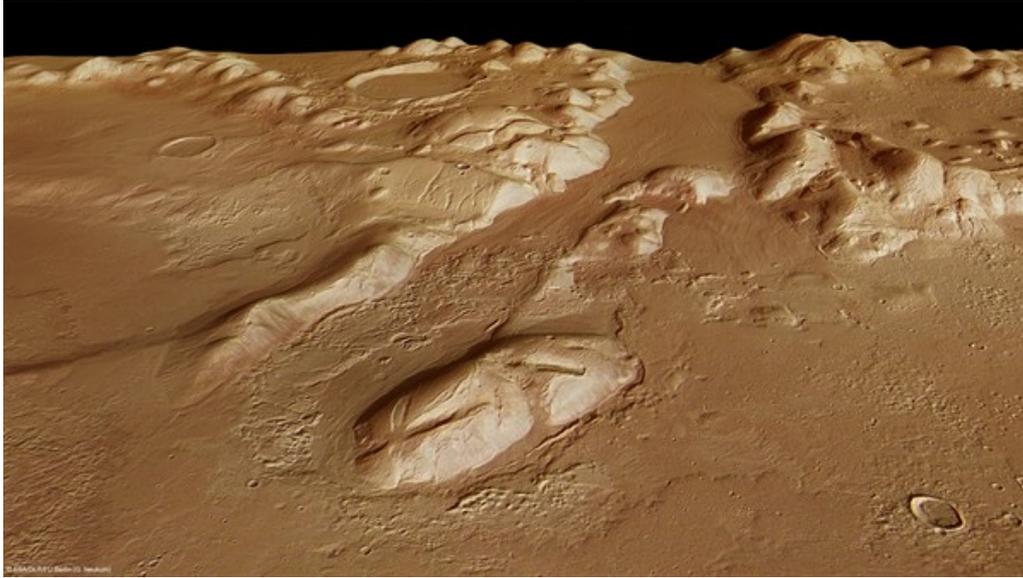
Perspective view of the southern part of Phlegra Montes from the northeast



Realistic perspective views of the Martian surface can be generated from data acquired by the stereo and colour channels of the High Resolution Stereo Camera (HRSC) on ESA's Mars Express spacecraft, which are oriented at an angle with respect to the planet's surface. Copyright note: As a joint undertaking by DLR, ESA and FU Berlin, the Mars Express HRSC images are published under a Creative Commons licence since December 2014: ESA/DLR/FU Berlin, CC BY-SA 3.0 IGO. This licence will also apply to all HRSC images released to date. This image shows an impact crater in the foreground, which has been filled with material with plastic properties – presumably via the gap in the crater rim on the left hand side. This can be seen in the flow patterns that have formed in the interior of the crater, in part parallel to the crater rim. These can also be seen on the surface of the area surrounding the crater. Flow patterns can also be seen in the valley-shaped depression in the centre of the image. These might have arisen from 'rock glaciers' – bodies of ice interspersed with boulders and rocky debris that also occur on Earth, primarily in regions of permafrost on high mountain ranges or at polar latitudes.

Credit: ESA/DLR/FU Berlin, CC BY-SA 3.0 IGO.

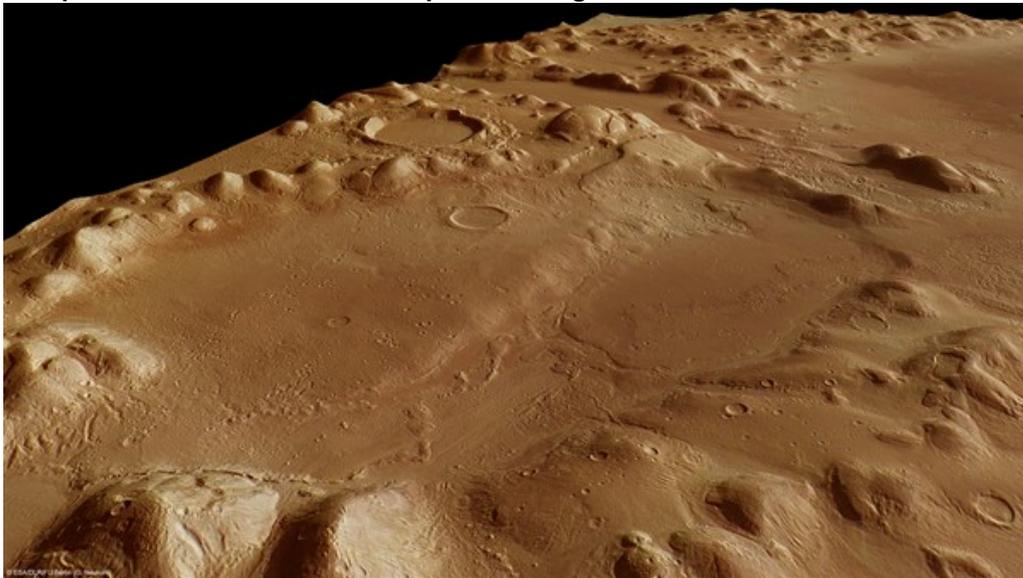
Perspective view of the southern part of Phlegra Montes from the west



Realistic perspective views of the Martian surface can be generated from data acquired by the stereo and colour channels of the High Resolution Stereo Camera (HRSC) on ESA's Mars Express spacecraft, which are oriented at an angle with respect to the planet's surface. A valley-shaped depression in Phlegra Montes has been level filled; on the surface of infill, parallel-running flow patterns can be seen. In the foreground, an elongated hill is visible, partially surrounded by similar flow patterns. It is conceivable that rock glaciers – bodies of ice interspersed with boulders and rocky debris – slowly moving across the surface of the planet created these patterns. Copyright note: As a joint undertaking by DLR, ESA and FU Berlin, the Mars Express HRSC images are published under a Creative Commons licence since December 2014: ESA/DLR/FU Berlin, CC BY-SA 3.0 IGO. This licence will also apply to all HRSC images released to date.

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Perspective view of the southern part of Phlegra Montes from the northwest

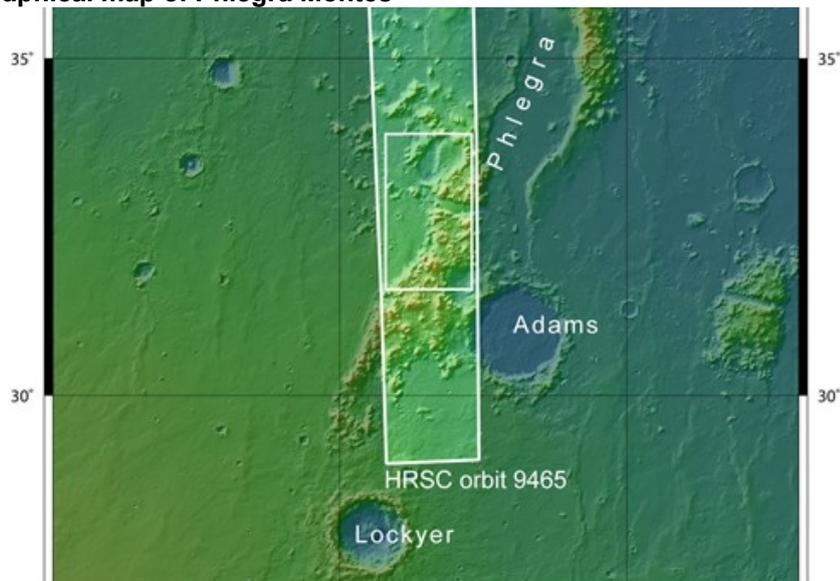


Realistic perspective views of the Martian surface can be generated from data acquired by the stereo and colour channels of the High Resolution Stereo Camera (HRSC) on ESA's Mars Express spacecraft, which are oriented at an angle with respect to the planet's surface. Copyright note: As a joint undertaking by DLR, ESA and FU Berlin, the Mars Express HRSC images are published under a Creative Commons licence since December 2014: ESA/DLR/FU Berlin, CC BY-SA 3.0 IGO. This licence will also apply to all HRSC images released to date. In the centre of the image, a depression can be seen between the chains of hills in Phlegra Montes, into which material with plastic properties has flowed – presumably from higher altitude regions – partially filling it. In general, the material appears to have moved downslope from the

chains of hills; 'lobate debris aprons' have formed at the downstream end. The mountains in the foreground are about 2000 metres high.

Credit: ESA/DLR/FU Berlin, CC BY-SA 3.0 IGO.

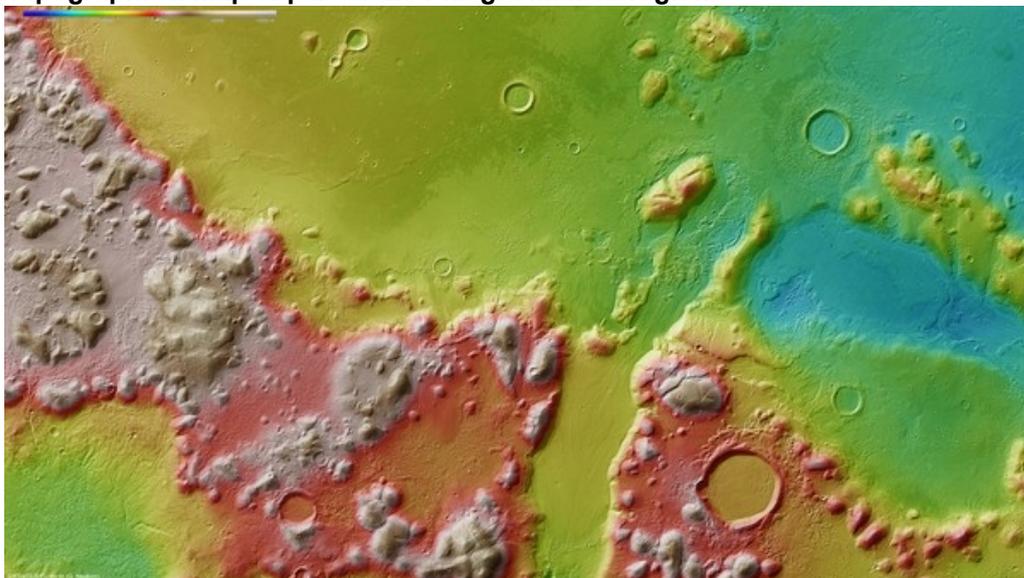
Topographical map of Phlegra Montes



Phlegra Montes is a mountainous massif that stretches for several hundreds of kilometres to the northeast of the Elysium volcanic region. It forms the boundary between Utopia Planitia to the west and Arcadia Planitia to the east. ESA's Mars Express spacecraft flew over the region on 1 June 2011 at an altitude of around 400 kilometres during orbit 9465, and the HRSC instrument on ESA's Mars Express spacecraft imaged a long strip. The images in this article are located in the framed area, covering a region around 73 kilometres wide and 140 kilometres long – some ten thousand square kilometres or roughly the size of the Tyrol.

Credit: NASA/JPL (MOLA) / FU Berlin.

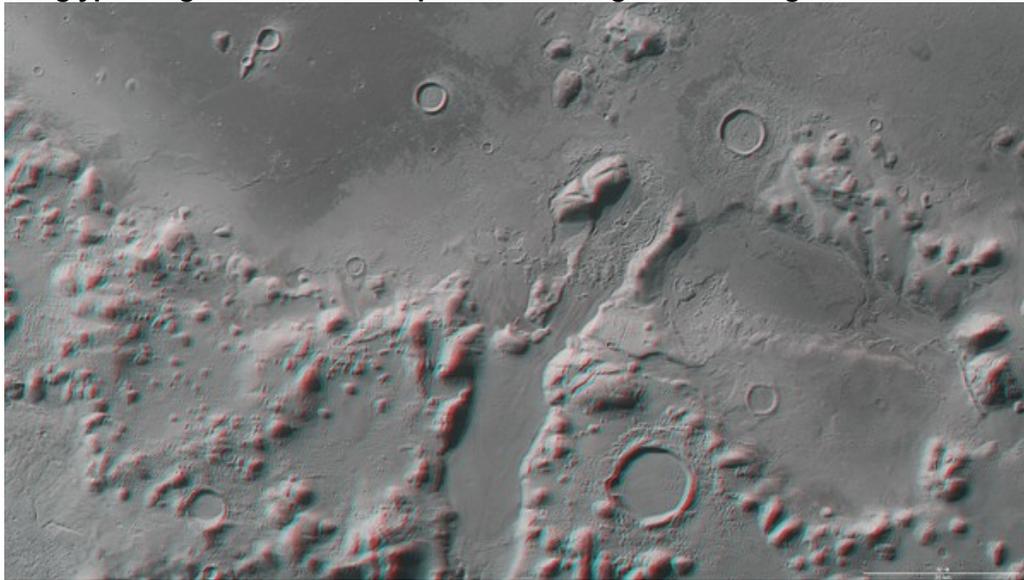
Topographical map of part of the Phlegra Montes region



Digital terrain models can be generated using data acquired by several of the nine channels of the High Resolution Stereo Camera (HRSC) on ESA's Mars Express spacecraft, which image the planetary surface from different angles. The use of false colours enables the topography to be pictorially represented – the elevation scale is at the top left of the image; north is to the right. In the absence of 'sea level', the elevation data is referenced to an areoid – a modelled equipotential surface on which everything experiences the same gravitational attraction towards the centre of the planet. The Phlegra Montes mountain chain running diagonally through the image is elevated some 2000 to 3000 metres above the surrounding Elysium and Arcadia Planitiae. In general, material forming the distinct flow patterns in the valley at the centre of the image – but which is also found in other depressed areas – appears to have moved from the hills towards the lower-lying regions. Copyright note: As a joint undertaking by DLR, ESA and FU Berlin, the Mars Express HRSC images are published under a Creative Commons licence since December 2014: ESA/DLR/FU Berlin, CC BY-SA 3.0 IGO. This licence will also apply to all HRSC images released to date.

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Anaglyph image of the southern part of the Phlegra Montes region



Anaglyph images can be created using data from the nadir channel of the High Resolution Stereo Camera (HRSC) camera system, the field of view of which is directed vertically down onto the Martian surface, and one of the four stereo channels, which are directed obliquely towards the surface. By using red/blue (cyan) or red/green glasses, a three-dimensional impression of the landscape is obtained; north is to the right in the image. The numerous rounded, one- to two-thousand-metre high hills and the ridges of Phlegra Montes are striking. Similarly the rims of a number of fresh – and therefore younger – impact craters are clearly elevated above their environs. More subtle, but still easy to recognise, are small differences in altitude that have been caused by the flow of material. Flow patterns with thin, mostly parallel-running rilles can be seen, as can numerous 10-metre-high flow fronts, the lobate tongues of which hint at large-scale material transportation. Several impact craters have been partially filled by this process as well. The flow patterns bear a strong similarity to the surfaces of 'rock glaciers' on Earth. Copyright note: As a joint undertaking by DLR, ESA and FU Berlin, the Mars Express HRSC images are published under a Creative Commons licence since December 2014: ESA/DLR/FU Berlin, CC BY-SA 3.0 IGO. This licence will also apply to all HRSC images released to date.

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Black-and-white image of the Phlegra Montes region



The nadir channel, the field of view of which is directed vertically down onto the Martian surface, enabled the High Resolution Stereo Camera (HRSC) camera system to acquire image data with a resolution of 16 metres per pixel as Mars Express flew over the Phlegra Montes region during orbit 9465. This enables small-scale geological structures to be identified. To improve the depiction, the resolution in the images shown here has been slightly reduced; north is to the right. The flow patterns in the depressions in this mountainous region, originating from mass transportation of plastically deforming material, are particularly striking. Large volumes of rocky material appear to have moved along the topographical slope, flowing around obstructions such as hills and filling low-lying areas. Such mass transportations are probably the result of 'rock glaciers'—bodies of ice interspersed with boulders and rocky debris that also occur on Earth, primarily in regions of permafrost on high mountain ranges or at polar latitudes. It is conceivable that rock glaciers slowly moving across the surface of the planet created these flow patterns. Copyright note: As a joint undertaking by DLR, ESA and FU Berlin, the Mars Express HRSC images are published under a Creative Commons licence since December 2014: ESA/DLR/FU Berlin, CC BY-SA 3.0 IGO. This licence will also apply to all HRSC images released to date.

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