Three Years of Mars Exploration Rover Science

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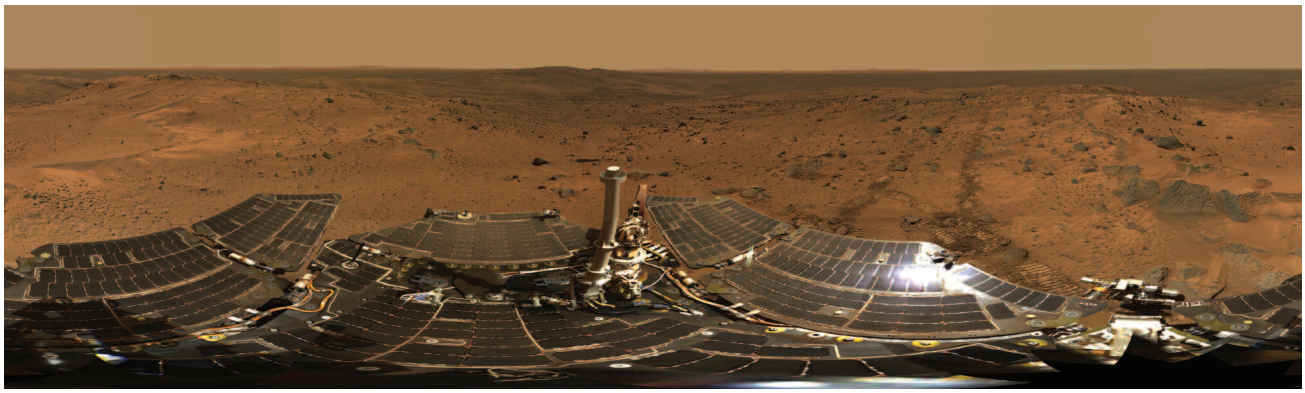


The panoramic camera on NASA's Mars Exploration Rover Spirit *took the hundreds of images combined into this 360-deg view, the "Husband Hill Summit" panorama. The images were acquired on* Spirit*'s sols 583 to 586 (Aug. 24 to 27, 2005), shortly after the rover reached the crest of "Husband Hill" inside Mars' Gusev Crater. This is the largest panorama yet acquired from either* Spirit *or* Opportunity*. The panoramic camera shot 653 separate images in 6 different filters, encompassing the rover's deck and the full 360 deg of surface rocks and soils visible to the camera from this position. This is the first time the camera has been used to image the entire rover deck and visible surface from the same position. Stitching together of all the images took significant effort because of the large changes in resolution and parallax across the scene.*

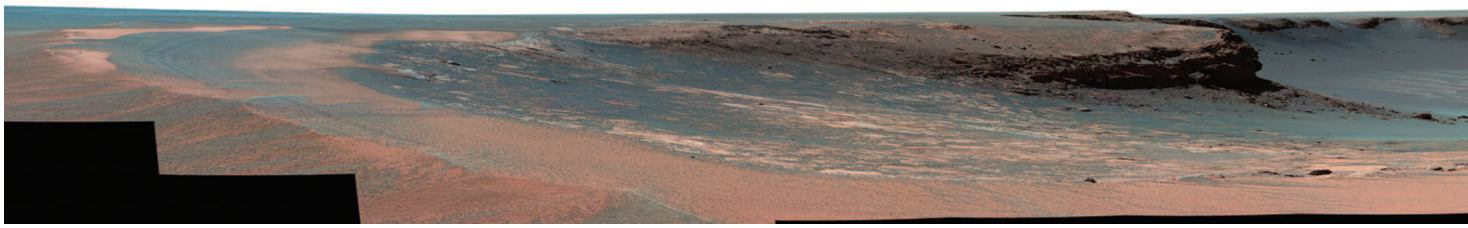
The image is an approximately true-color rendering using the 750-nm, 530-nm, and 480-nm filters for the surface, and the 600-nm and 480-nm filters for the rover deck. Image-to-image seams have been eliminated from the sky portion of the mosaic to better simulate the vista a person standing on Mars would see.

This panorama provided the team's first view of the "Inner Basin" region (center of the image), including the enigmatic "Home Plate" feature seen from orbital data. After investigating the summit area, Spirit *drove downhill to get to the Inner Basin region.* Spirit *arrived at the summit from the west, along the direction of the rover tracks seen in the middle right of the panorama. The peaks of "McCool Hill" and "Ramon Hill" can be seen on the horizon near the center of the panorama. The summit region itself is a broad, windswept plateau.* Spirit *spent more than a month exploring the summit region, measuring the chemistry and mineralogy of soils and rocky outcrops at the peak of Husband Hill for comparison with similar measurements obtained during the ascent.*

On January 4, 2004, the *Spirit* rover (MER-A) landed in Gusev Crater. Three weeks later, the *Opportunity* rover (MER-B) landed on Meridiani Planum. A prime mission objective is embodied in the NASA Mars Mantra "Follow the Water," and the rovers have greatly exceeded mission success criteria that included surface operations for at least 90 sols (Mars days) and traverses of at least 600 m. As of March 20, 2007, *Spirit* is conducting science activities on sol 1,141 and has 7,042 m on the odometer, while *Opportunity* is doing sol 1,121 activities with 10,286 m under its belt. Three Astromaterials Research and Exploration Science scientists – Doug Ming, Dick Morris, and Dave Mittlefehldt – are members of the MER Athena Science Team, working principally with the Mössbauer Spectrometer and Alpha Particle X-ray Spectrometer instruments.

Spirit in Gusev Crater

Gusev Crater was chosen as a landing site in part because of morphologic evidence that suggested the crater was partially filled by water-born sediments brought in via Ma'adim Valles from the south. Upon first look, *Spirit* saw a dusty plain littered with angular, dark rocks that proved to be volcanic, olivine-basalts little altered by aqueous fluids; water was not important in forming the plains rocks in Gusev Crater. But taking full advantage of the rover's capabilities, *Spirit* was commanded to strike out for the Columbia Hills roughly 3 km away. *Spirit* ascended one of the highest peaks, Husband Hill, and descended the other



side, into the region referred to as the Inner Basin. Along the way, *Spirit* encountered a wide range of rock types and some unusual soils.

Many of the rocks on Husband Hill are highly altered, as judged by the ratio of trivalent iron to total iron (Fe^{3+}/Fe_T) measured by the Mössbauer instrument. For the little-altered plains olivine-basalts, this ratio is about 0.12. In contrast, two distinct rock classes on Husband Hill have ratios of approximately 0.73 and are indications for the role of water in their formation. Although water was important in the history of these rocks, we are unsure how the rocks were formed. Based on the rock outcrop attitudes and textures, we infer that the rocks are clastic; that is, they are made up of rock and mineral fragments. They could represent volcanic rocks formed as air-fall deposits from an eruption, or ejecta deposited from some nearby impact event. In either case, they were highly altered at some point.

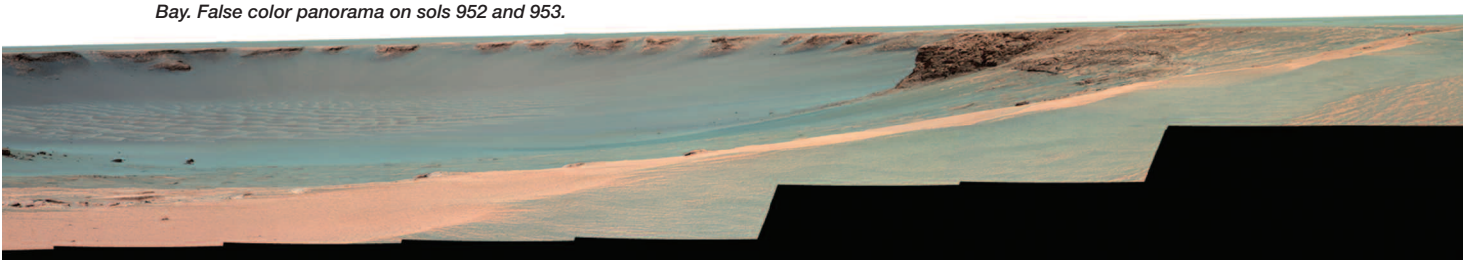
We also uncovered the light-toned soil Paso Robles that lay below the surface of normal dark soil. It contains very high sulfur content, which is a spectral signature for water bound in mineral structures. Mössbauer spectra show the iron mineralogy is dominated by ferric sulfate and has an Fe^{3+}/Fe_T of approximately 0.83. Similar light-toned, S-rich soils have been found in the Inner Basin, always found below normal-looking soil. At present, we have several hypotheses for how these soils were formed, and all of them point to aqueous fluids as an important ingredient.

Currently, we are examining a topographic feature informally named Home Plate. This feature is visible from orbital images as a bright ring roughly 80 m in diameter. Home Plate is composed of laminated rocks fining upward with microscopic and macroscopic textures that suggest an origin as air-fall volcanics. Compositionally, the rocks are unusual in being rich in some of the more volatile elements, namely chlorine, bromine, zinc, and germanium. Similar volcanic structures on Earth are often formed when magma erupts through water-saturated rock. A leading hypothesis for the origin of Home Plate is that magma ascended through rock saturated with brine – salt-rich water. The high volatile element contents of Home Plate rocks are, therefore, due to interaction with the salty water.

Opportunity on Meridiani Planum

Orbital spectroscopic study had shown that Meridiani Planum was rich in the ferric iron mineral hematite, Fe_2O_3, which forms in oxidizing aqueous environments. *Opportunity*'s first look showed a terrain composed of bright-colored, flattish, layered rock outcrops and dark drift sand, quite different from that at Gusev Crater. This terrain occupies the entire area *Opportunity* has traversed.

View of Victoria Crater, Meridiani Planum, from Duck Bay. False color panorama on sols 952 and 953.



The outcrops are composed of sedimentary rocks containing three main components: silicate sands, evaporite mineral sands, and hematite concretions. The first two components are reworked clastic materials, mineral and rock fragments from older rock units including weathered basalt and evaporites. Structures in the outcrops show that these sands were moved by wind, the same process that creates sand dunes and some types of sandstone on Earth. The upper part of the rock sequence was formed in wetter conditions; structures in the rocks suggest deposition in moving water. Meridiani rocks contain the mineral jarosite, a potassium-ferric iron-sulfate. Jarosite is stable only in oxidizing, acidic solutions. Thus, waters in which the upper sandstone units were deposited were highly caustic solutions. The hematite concretions, called "blueberries," were formed *in situ* in the rocks by deposition from oxidizing aqueous solutions that saturated the sandstones. These concretions are more resistant to weathering and erosion, and are liberated from the outcrops as they degrade. Because concretions are denser than silicate or evaporite minerals, and generally larger in size, they lag behind and are concentrated as martian winds that move the sands and dust across the surface. The hematite signature observed from orbit is a lag pavement of these concretions.

Observations by *Opportunity* along the rim of Victoria Crater, an 800-m-diameter crater, afford us a view of deeper strata than we have yet to see with the goal of gaining further insight into the ancient sedimentary environment in Meridiani Planum (see figure).

Summary

The key goals of the NASA Mars exploration program are to determine the role of water in early Mars history and the nature of aqueous environments that could have been hospitable to life, and the Mars exploration rovers have done admirable jobs of working toward those goals. They have shown that differing degrees of involvement of water are recorded, from just small amounts of alteration indicating low water/rock ratios to sedimentalogical evidence for flowing water on the surface. In all cases, however, the solutions were oxidizing and acidic. The data returned by the rovers provide important information for assessing the potential for life on Mars.