

Hot Idea

posted March 13, 2003



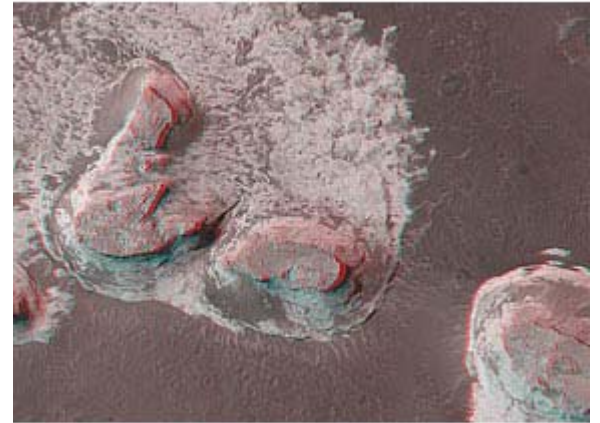
Flat-topped hills, Northern Terra Meridiani

Gray Iron Oxide in Meridiani, Mars

--- A deposit of gray hematite in Terra Meridiani may suggest that water once circulated through the rock layers in this region of Mars.

Written by [Linda M.V. Martel](#)

Hawai'i Institute of Geophysics and Planetology



(NASA/JPL/Malin Space Science Systems)

In our [continuing coverage](#) of the exploration of Mars and NASA's strategy of "follow the water," **PSRD** highlights recent research of the hematite deposit in Terra Meridiani. The iron oxide mineral called hematite (Fe_2O_3) forms on Earth in several ways, most involving water. For this reason, the announcement in 2000 of the discovery of crystalline gray hematite near the Martian equator was, in a word, a watershed for planetary geologists and astrobiologists interested in unraveling the history of water and climate on Mars. Detection of the hematite in Terra Meridiani is one of the key discoveries of the Thermal Emission Spectrometer (TES) instrument on the Mars Global Surveyor (MGS) mission. Using TES spectral data in combination with image and topographic data, Brian Hynek, Raymond Arvidson, and Roger Phillips (Earth and Planetary Sciences and McDonnell Center for the Space Sciences at Washington University in St. Louis) recently made detailed regional analyses of Terra Meridiani to better understand the origin and significance of the hematite in the Martian environment. Using Earth as a guide to hematite formation, researchers think the hematite could have formed on Mars by thermal oxidation of iron-rich volcanic eruptive products during eruption or it could have formed by chemical precipitation when iron-rich water circulated through the preexisting layers of volcanic material (ash). Hynek and his coauthors as well as other researchers studying data from Terra Meridiani prefer the chemical precipitation hypothesis because it is most consistent with their observations of the geology of the region.

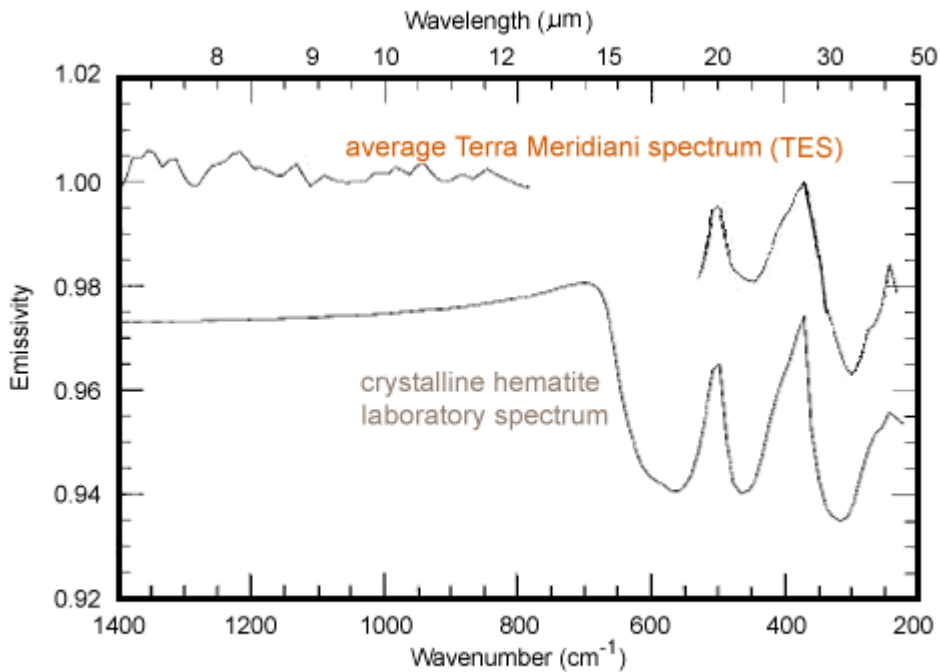
Reference:

Hynek, B. M., Arvidson, R. E., and Phillips, R. J. (2002) Geologic setting and origin of Terra Meridiani hematite deposit on Mars. *Journal of Geophysical Research*, v. 107, no. E10, 5088, doi: 1029/2002001891.

How hematite was found on Mars

Crystalline gray hematite (the coarse-grained form of the iron oxide we call rust when it's powdery and red) was found by scientists analyzing remote sensing data gathered by the Thermal Emission Spectrometer ([TES](#)) instrument during the early (1997-1998 aerobraking) phase of the MGS mission. The TES instrument measures the infrared energy emitted by surface materials and by CO_2 , water ice, dust, and water vapor in the atmosphere. Phil Christensen (Arizona State University) and a team of scientists studied over four million TES spectra. After removing the effects of the atmosphere, they were left with the distinctive spectral curves of the surface materials. These were compared with spectra measured in the laboratory for a wide variety of minerals. Shown below, the average spectrum for Terra Meridiani matched the laboratory spectrum for hematite. The depth and shape of the hematite fundamental bands reveal that this hematite is the crystalline and coarse-grained (greater than about 10 micrometers in diameter) gray variety of

the iron oxide.



(Figure based on Christensen et al., (2000) JGR, v.105(E4), Fig. 4, p. 9628.)

Christensen and the TES science team identified hematite in the TES data by the presence and shape of dips in the curve (called oxide fundamental vibrational absorption features) centered near 300, 450, and $>525\text{ cm}^{-1}$ and by the absence of dips (silicate absorptions) in the 1000 to 1400 cm^{-1} region. The gap in the TES spectrum is the location of an atmospheric absorption band, which gives no information about the surface. The two curves have been offset vertically for easier comparison.

Hematite in Terra Meridiani

The major hematite deposit was found in a relatively low, smooth area spanning latitudes approximately 1°N to 3°S and longitudes 8°W to 1°E in the region called Terra Meridiani (variously named Meridiani Planum or Sinus Meridiani.)

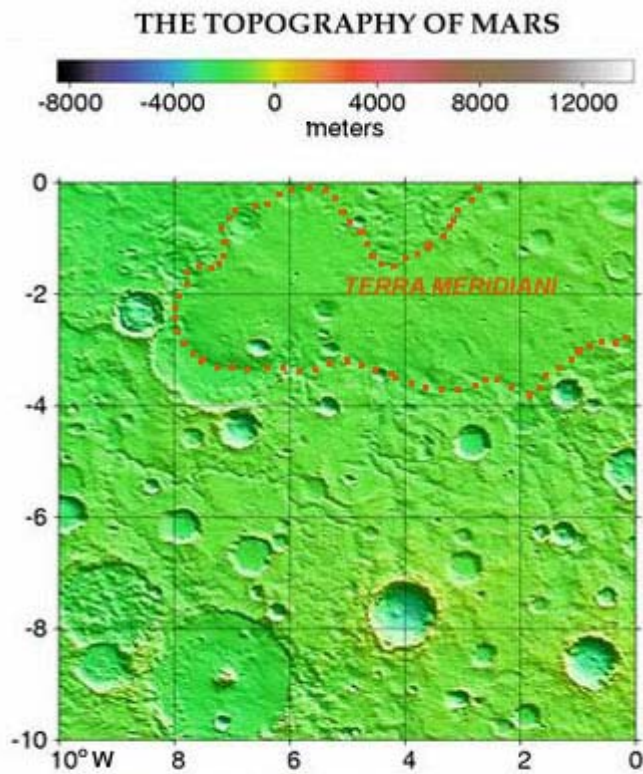
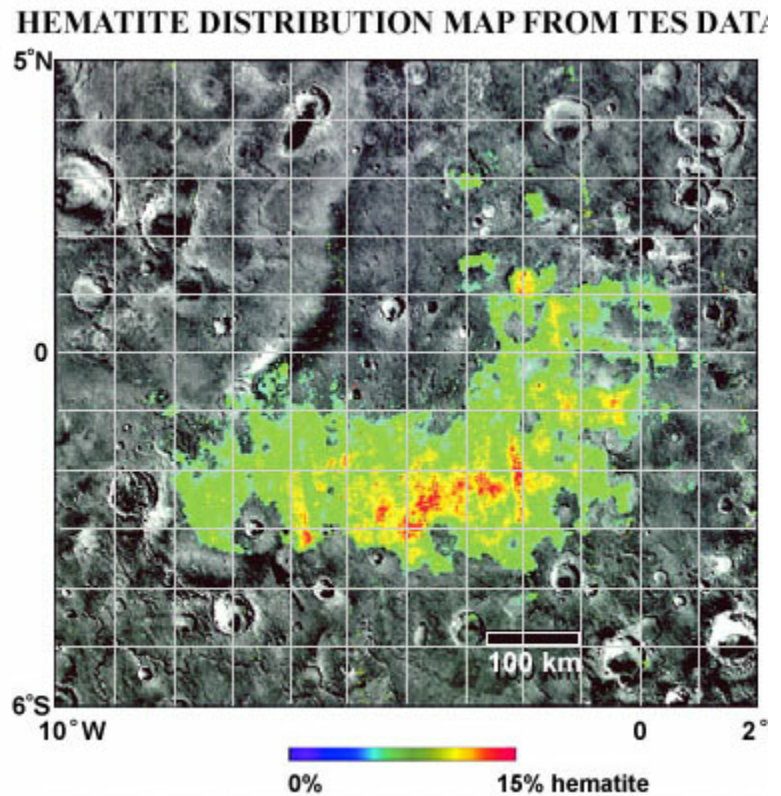


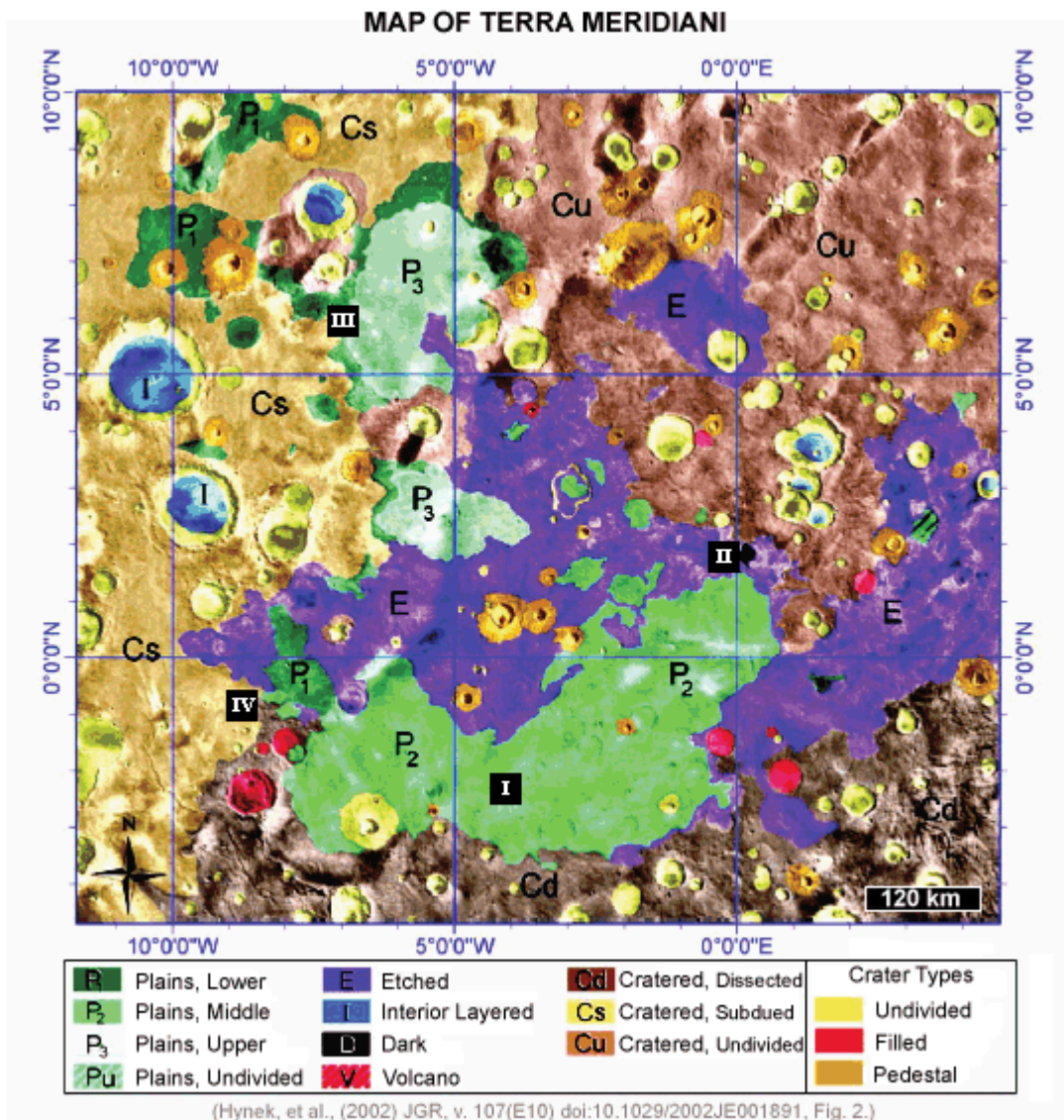
Image on the **left** is a topographic map (from the Mars Orbiter Laser Altimeter, MOLA) of the relatively smooth Terra Meridiani region and its neighboring cratered terrain to the south. Image on the **right** is a Viking photomosaic superimposed with TES-derived hematite abundance. Detectable hematite abundances range from approximately 5% to 15%. Corresponding latitude and longitude lines are shown in both images for easier comparison.



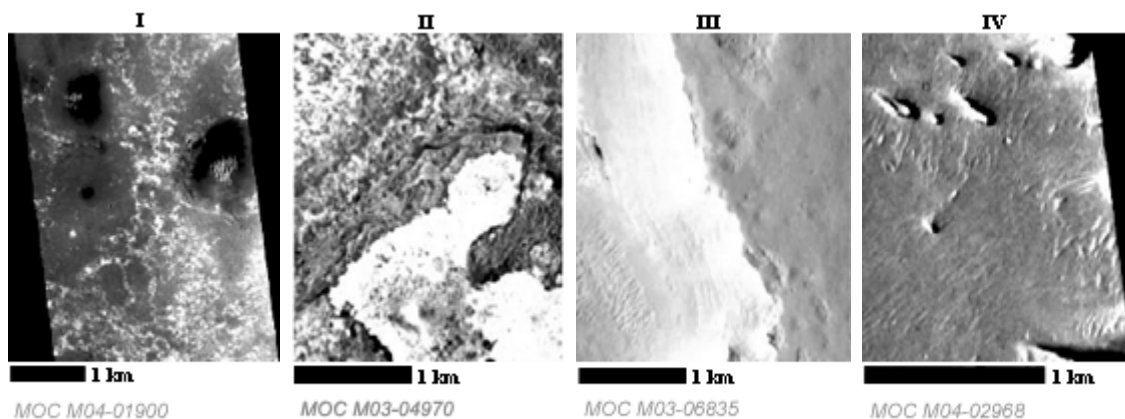
The Meridiani region has layered deposits covering ancient cratered terrain. The hematite occurs in one layer within a 600-meter-thick stack of layers composed of materials probably the size of coarse sand based on thermal conductivity studies and TES data. The layers are visible for hundreds of kilometers, which is remarkable on this planet where so much of the surface is obscured by dust. This layered terrain was probably even more extensive before it was eroded or buried. The thinness of the layers suggests they were deposited at regular intervals, but for how long nobody knows. What the layers are made of is an ongoing issue. Debates on the plausible origins of the layered materials generally center on whether they are sedimentary deposits or volcanic ash. Evidence is inconsistent for either origin because there is a lack of a topographic basin and large volcanoes in this region. Nevertheless, Hynek and co-authors favor a volcanic origin contending that if the ash came from volcanic air fall, then the source vents for the ash could simply be buried or distant, even several thousand kilometers away. A discussion of the hypotheses for the origin of the hematite deposit will follow the next section, which describes the geologic units mapped by Hynek and his colleagues.

Mapping the hematite

The key geologic units mapped by Hynek and colleagues in Terra Meridiani are plains, etched, and interior layered crater deposits (see map below). All these units are geologically distinct from and bury preexisting cratered terrain.



Typical surface features are shown in the MOC images below; their locations are indicated on the map of Terra Meridiani as black squares numbered I, II, III, and IV. Each image links to a web page at Malin Space Science Systems with options for downloading full-sized versions.



Plains units (P1, P2, P3) The units are all smooth, widespread, and somewhat eroded by wind. The upper most unit (P3) is a bright cliff-forming unit about 200 meters thick. The middle plains unit (P2) is dark basaltic plains, contains hematite, and is less than a few hundred meters thick. According to the TES data this unit has about 10 to 15% hematite. The lowermost unit is P1. It is about 200 meters thick. (See images I and III above.)

Etched unit (E) is characterized by many different deposits that appear to lie between and below the plains units. Extensive erosion has made it impossible to connect individual layers between outcrops of the etched unit. The material

forms ridges, mesas, pits, and troughs. (See image II above.)

Interior layered crater deposits (I) are mounds of thinly layered material found inside craters. They look like they may be isolated outcrops of the plains and etched units.

Cratered deposits are mapped as various units: dissected (Cd), subdued (Cs), undivided (Cu). All are rough but degraded meaning that crater rims are no longer sharp, but are rounded due to erosion. (See image IV above.)

Based on superposition of units and crater counts (more craters means the surface has been exposed longer to impacts), Hynek and colleagues report that the layered plains and etched unit have a probable age of [Late Noachian](#) to [Early Hesperian](#), that is about 3.7 to about 3.5 billion years old.

Was it chemical precipitation from iron-rich fluids?

What happened in Terra Meridiani to cause the formation of the coarse-grained gray hematite? What sequence of events led to stacks of thin, parallel-bedded deposits with only one hematite-rich layer? The events must not have been so common or else we'd expect to see more occurrences of gray hematite on Mars. As it stands now, at a detection limit of several percent, TES data show very limited exposures of gray hematite. Near-global mapping of TES data by Christensen and colleagues reveals deposits of gray hematite in only three places on Mars: Terra Meridiani, Aram Chaos (2°N, 21°W) and small scattered exposures in Valles Marineris.

In Terra Meridiani some layers appear loosely packed and easily eroded while other layers are more resistant to erosion and form cliffs and flat-topped hills. People continue to look at the data for evidence to explain the layering as volcanic, wind-blown, or water-laid deposits. The hematite might have formed at the same time as the layers (primary formation) or it may have formed long after the deposition of the layers (secondary formation). Hynek and coauthors considered the plausible origins of hematite that have been proposed and compared them to their own observations of Terra Meridiani. The table below shows a summary of their findings.

Consistency of proposed hypotheses with observations and regional mapping of Terra Meridiani hematite by Hynek, Arvidson, and Phillips			
Origin	Proposed hypothesis	Observations consistent with hypothesis	Observations inconsistent with hypothesis
Primary	precipitation from iron-rich, low-temperature waters, as in a lake or sea	smooth, layered, easily eroded deposits of constant thickness	no obvious closed basins or obvious sources for lake deposits; the age of the deposits may be too old to correspond with proposed "warm and wet" conditions on Mars that would be necessary to deposit 600 meters of lakebeds; only one layer of the 600 meter-thick stack is hematite-rich; lack of other minerals in TES data that would be expected in lake deposits (evaporites) or in banded iron formations (quartz, chert, carbonates)
Primary	precipitation from iron-rich, high-temperature waters, in hydrothermal systems	different erosional patterns within units; possible cemented joints; association with outflow channels	large areal extent ($>10^5$ km ²); lack of associated hydrothermal-alteration products in TES data; lack of evidence of tectonic processes or other obvious heat sources
Primary	thermal oxidation of volcanic deposits: iron-rich lava flows, ignimbrites, air fall Note: this hypothesis does not require liquid water to cause oxidation	materials have volcanic compositions (basaltic, andesitic); layers are widespread; there are possible flow features in some of the layers; layers are thin, flat, smooth, and drape the preexisting topography; some layers are susceptible to erosion	lack of nearby volcanoes; Martian lavas are generally far less susceptible to erosion than these deposits; layers have nearly constant thickness and conform to preexisting topography
Secondary	ground water - leaching	different erosional patterns within units; possible cemented joints; layers are widespread	red not gray hematite is more probable; sharp boundaries that correlate with local topography
Secondary	ground water - hydrothermal alteration along permeable layers	existence of one hematite layer in a 600 meter stack; different erosional patterns within units; possible joint systems; association with outflow channels	lack of associated hydrothermal alteration products in TES data; lack of evidence of tectonic processes or other obvious heat sources
Secondary	coatings of iron-rich rock by weathering from surface and/or atmospheric water	hematite coatings are common on Earth	red not gray hematite is more probable; lack of substantial atmospheric water on Mars

Of the primary formation options, Hynek and coauthors think it's plausible that the hematite could have formed as iron-rich deposits that were oxidized during eruptions from distant volcanoes. This kind of thermal oxidation of volcanic ash during eruption does not require water. In this scenario, however, a wider distribution of hematite-rich ash would be expected but is not seen in the TES data. Perhaps some hematite-rich ash layers are still buried or perhaps they have been eroded away.

Alternatively, the hematite may have formed by a later secondary mechanism in preexisting ash beds. In this case, Hynek and his colleagues favor precipitation of the hematite when iron-rich fluids circulated within the layered volcanic ash. This kind of secondary formation of the gray hematite, they say, is most consistent with their regional

geologic, topographic, and spectral observations.

Researchers are continuing to study a variety of remote sensing data of Terra Meridiani. Daytime infrared images from the Thermal Emission Imaging System (THEMIS) on the Mars Odyssey spacecraft allow new views of the layered terrain in better detail. Christensen and the THEMIS team see different temperatures for the different layers. They think this could indicate the layers have different physical properties (such as particle size, mineral composition, or density) perhaps due to changes in when or how fluids circulated through. Other researchers are still looking for evidence of surface water in the region (paleolake basins, for example) or trying to evaluate the potential of the hematite deposits to preserve microfossils. New studies and results will be reported at the annual [Lunar and Planetary Science Conference](#) in Houston, March 17-21, 2003.

Likely landing location



(Daniel Maas for Mission to Mars/Cornell Univ.)

Orbital MOLA topographic data and TES compositional data have given us testable hypotheses of how the hematite formed. We may soon be able to test these ideas right on the spot.

Terra Meridiani is a leading candidate for further exploration by one of the upcoming Mars Exploration Rovers (MER) because of its distinctive mineralogy and its relative safety as a landing site (in terms of low wind shear, low abundance of boulders, and low slope angles). After years of detailed evaluations of potential landing sites, debates and recommendations on scientific merit and safety issues, and a final peer review taking place this month we will finally hear the announcement of the two site selections in early April, 2003. Launch window for the first MER spacecraft opens May 30, 2003 for an early January 2004 landing. The second MER craft is scheduled for launch on June 24, 2003 followed by a late January landing. The data gathered by these robotic field geologists will help scientists here on Earth read the stories of the rocks, stories told in the language of texture, chemistry, and mineralogy about the role of water and whether or not the environment may have ever been suitable for life.

Additional Resources

[ASU Spectral Library](#) from Arizona State University Thermal Emission Spectroscopy Laboratory. Lists thermal infrared (2000 - 380 cm^{-1}) emission spectra of over 150 pure minerals, with an emphasis on common rock-forming minerals.

Christensen, P. R., Bandfield, J. L., Clark, R. N., Edgett, K. S., Hamilton, V. E., Hoefen, T., Kieffer, H. H., Kuzmin, R. O., Lane, M. D., Malin, M. C., Morris, R. V., Pearl, J. C., Pearson, R., Roush, T. L., Ruff, S. W., and Smith, M. D. (2000) Detection of crystalline hematite mineralization on Mars by the Thermal Emission Spectrometer: Evidence for near-surface water. *Journal of Geophysical Research*, v. 105 (E4), p. 9623-9642.

Christensen, P. R., Morris, R. V., Lane, M. D., Bandfield, J. L., and Malin, M. C. (2001) Global mapping of Martian hematite mineral deposits: Remnants of water-driven processes on early Mars. *Journal of Geophysical Research*, v. 106 (E10), p. 23,873-23,885.

Hynek, B. M., Arvidson, R. E., and Phillips, R. J. (2002) Geologic setting and origin of Terra Meridiani hematite deposit on Mars. *Journal of Geophysical Research*, v. 107, no. E10, 5088, doi: 1029/2002001891. ([pdf](#))

[Lunar and Planetary Science Conference](#) March, 2003 program with abstracts, including sessions on Mars (available as pdf files.)

[Mars Exploration Rovers \(MER\) - Athena instrument payload](#) from Cornell University.

[THEMIS image of Terra Meridiani](#) from the 2001 Mars Odyssey - Thermal Emission Imaging System from NASA/JPL/Arizona State University.

[Thermal Emission Spectrometer \(TES\)](#) on Mars Global Surveyor (MGS).



[[About PSRD](#) | [Archive](#) | [Search](#) | [Subscribe](#)]

[[Glossary](#) | [General Resources](#) | [Comments](#) | [Top of page](#)]

psrd@higp.hawaii.edu

main URL is <http://www.psrд.hawaii.edu/>