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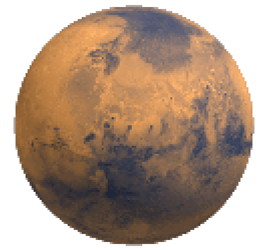
The Tricky Business of Identifying Rocks on Mars



--- A new analysis of thermal emission spectra suggests a new interpretation for the composition of the Martian surface.

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The Mars Global Surveyor mission carries a remote-sensing gizmo called the Thermal Emission Spectrometer (TES). TES detects heat waves flowing from the surface of the Red Planet. The TES team, led by Phil Christensen (Arizona State University), identified two large regions on Mars that have distinctive spectral properties. Using mathematical mixing calculations based on the thermal emission spectra of numerous materials, the TES team reported in papers led by Josh Bandfield and Victoria Hamilton that the two regions had mineral abundances similar to basalt (Surface Type 1) and andesite (Surface Type 2), two common volcanic rock types on Earth. Andesite has more silicon than does basalt, giving rise to a distinctive mineralogy.

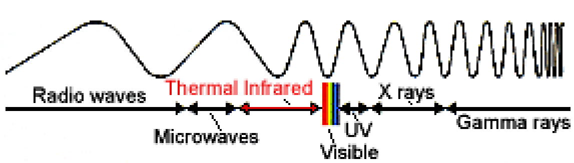
Scientists had mixed reactions to the possibility of andesite on Mars, greeting the news with fascination, consternation, or skepticism. One question raised is how uniquely the spectra of Surface Type 2 matches andesite. Michael Wyatt and Harry Y. McSween (University of Tennessee) have taken another look at the TES spectra by using a larger collection of aqueous alteration (weathering) products in the spectral mixing calculations. They show that weathered basalt also matches the spectral properties of Surface Type 2. Wyatt and McSween also note that Type 2 regions are generally confined to a large, low region that is the site of a purported Martian ocean that sloshed around billions of years ago. They suggest that basalts like those in Surface Type 1 were altered in the ancient Martian sea. Independent data are needed to test the andesite vs. altered-basalt hypotheses. For now, we may have to be satisfied with at least two working hypotheses and a lively debate.

References:

Wyatt, M. and McSween Jr., H. Y. (2002) Spectral evidence for weathered basalt as an alternative to andesite in the northern lowlands of Mars. *Nature,* vol.417, p. 263-266.

Bandfield, J. L., Hamilton, V. E., and Christensen, P.R. (2000) A global view of martian surface compositions from MGS-TES. *Science,* vol. 287, p. 1626-1630.

Hamilton, V. E., Wyatt, M. B., McSween Jr., H. Y., and Christensen, P. R. (2001) Analysis of terrestrial and martian volcanic compositions using thermal emission spectroscopy: II. Application to martian surface spectra from the Mars Global Surveyor Thermal Emission Spectrometer, *J. Geophys. Res.,* vol. 106, p. 14,733-14,746.



Thermal Eyes

There is a wealth of information in the heat waves emitted from the surface of a planet. TES measures the intensity of the heat radiated in the wavelength range from 6 to 50 micrometers, well beyond what we humans can see. The intensity at different wavelengths (called spectra) allow experts like Phil Christensen and his team to deduce some physical properties of the surface, such as the abundance of boulders versus dust.

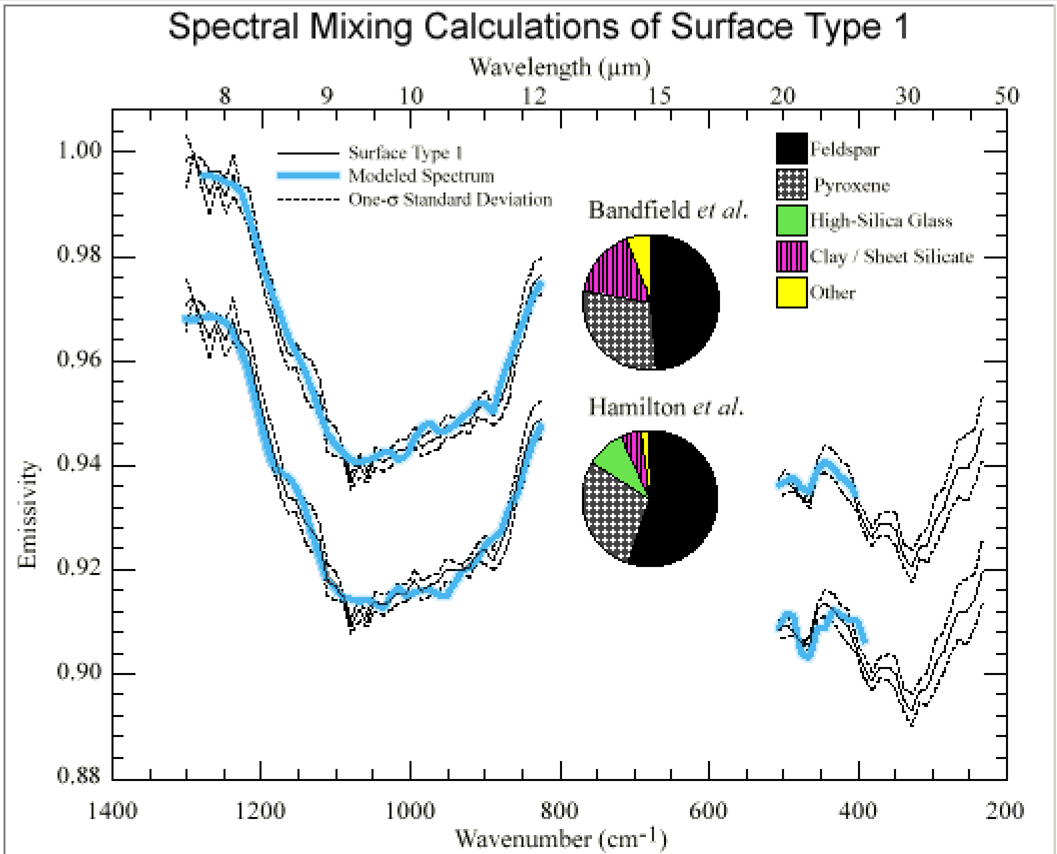
Thermal spectra also allow us to infer what minerals are present on the surface and in what proportions. This is possible because most minerals have unique spectra--a spectral fingerprint. The trouble is that a planet's surface has more than one mineral, so all the fingerprints are on top of one another. The TES team had to separate each fingerprint, a technique called spectral deconvolution. This unmixing requires correcting for the effects of the gases and dust in the Martian atmosphere, calibrating the response of the instrument at each wavelength, and making other corrections. The whole effort has been done as well as the best forensic laboratories do in identifying the culprits of crimes from smudgy fingerprints at a crime scene.

The thermal spectra of numerous minerals have been measured in the laboratory. Christensen and his colleagues have assembled all the measurements into a spectral library--a database of spectral fingerprints like that maintained by the FBI for human fingerprints. This allows them to mathematically combine the spectra of several minerals into a theoretical composite spectrum for comparison with the Martian surface. If there is a good match between calculated and theoretical spectra it suggests that the minerals used in the calculation are present in the proportions that produced the good match. The trouble is that there is not necessarily a unique combination of minerals that match the measured Martian spectra. It depends on which minerals go into the theoretical mix, the chemical compositions of the minerals, and how distinctive each mineral's spectrum is. It's a tricky business.

Distinctive Surface Types

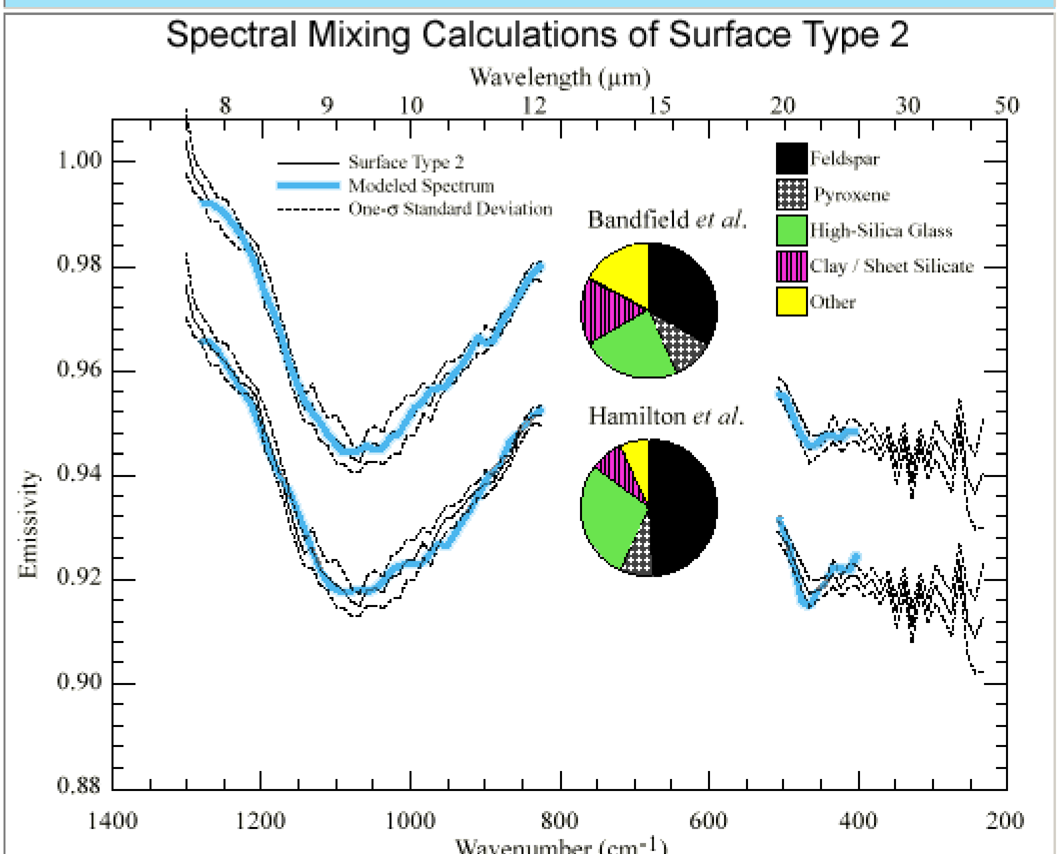
Much of the surface of Mars is covered with reddish dust. The dust gives Mars its dramatic red color, but obscures the materials beneath it. Fortunately, there seem to be areas relatively free of dust. Josh Bandfield and other TES team members interpreted the spectra from these areas as falling into two categories. One (Surface Type 1) is similar to spectra from basalt. This was not too surprising as basalt is the most common rock type on Earth and occurs on Venus, the Moon, and even some asteroids.

The other category (Surface Type 2) was a surprise. Banfield and coworkers (reaffirmed by Hamilton and others) interpreted the spectra of Surface Type 2 as indicating a volcanic rock called andesite. This interpretation is supported by analyses of rocks by an instrument on the Mars Pathfinder rover. Andesite contains more SiO_2 than does basalt (52-63 wt% in andesite vs. < 52 wt% in basalt). On Earth, andesite forms in two ways. Most andesite forms where oceanic crust descends at converging margins of tectonic plates. Water released from the wet oceanic crust rises to promote melting in the wedge of mantle above it. This happens in the Andes Mountains, from which andesite gets its name. There is no evidence, such as the presence of arc-shaped mountain ranges, that large plates dove beneath other plates on Mars.



(from Wyatt and McSween, Jr., 2002)

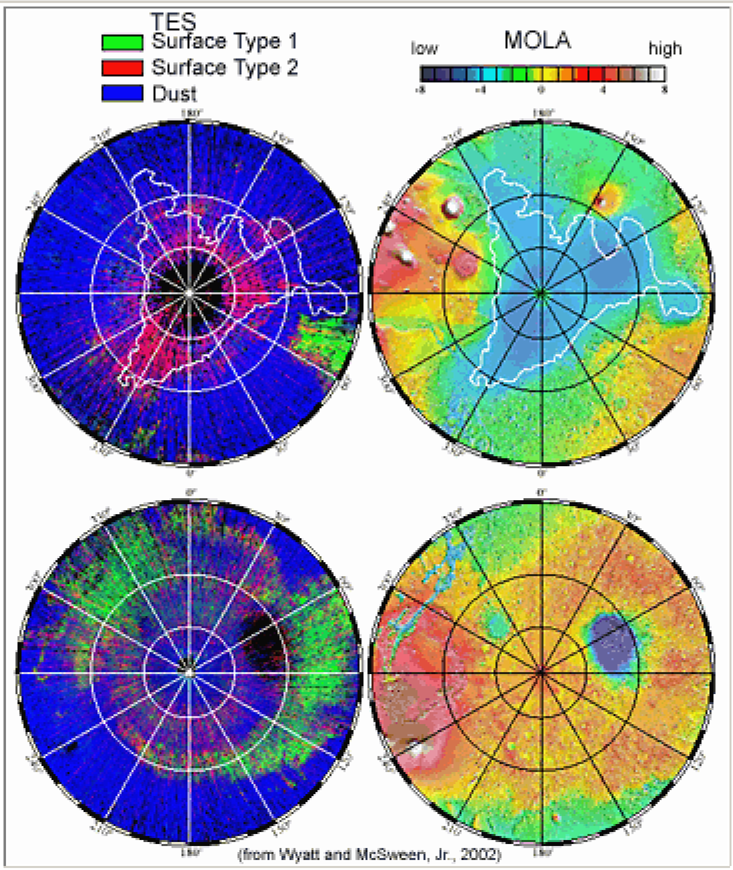
Spectral mixing calculations of Surface Type 1 (above) and Surface Type 2 (below) indicate that they have different mineral abundances. Detailed analysis and conversion of the mineralogy to chemical composition suggests that Type 1 is basalt and Type 2 is andesite.



(from Wyatt and McSween, Jr., 2002)

The other way of making andesite is by removing crystals as they form in basalt magma, a process called fractional crystallization. Removal of minerals that contain less SiO_2 than does the magma causes SiO_2 to increase, eventually reaching the andesite range. (Some geologist call such magma icelandite rather than andesite, to distinguish the two ways it can form. For simplicity, I'll stick with andesite.) McSween and members of the Mars Pathfinder team have argued that this process could not produce the large volume of andesite observed (if it is really andesite). They point out that the amount of SiO_2 observed in andesite is not reached until 90% of the original basalt magma has crystallized. In other words, there ought to be much more basalt than andesite.

It is possible to produce andesite when only about half of a basalt has crystallized if the basalt magma contains dissolved water. Michelle Minitti and Mac Rutherford (Brown University) showed that fractional crystallization of a magma with the composition of shergottites (a type of Martian meteorite) will reach 58 wt% SiO_2 after only 60% crystallization. Nevertheless, Wyatt and McSween still think that there ought to be lots of basalt associated with the andesite--about equal amounts of each. This is consistent with Banfield's observations: If Surface Type 2 is andesite, maps of the distribution of basalt and andesite suggest that equal amounts of basalt and andesite exist on Mars (you can estimate the abundances of Surface Types 1 and 2 in the maps below). On the other hand, if andesite formed by fractional crystallization, it ought to be associated more intimately with the basalt, rather than concentrated in different places. This drove Wyatt and McSween to look at other ways to interpret the TES data. They tested the idea that Surface Type 2 is not andesite at all. They suggest it could be basalt altered by interaction with water. One clue to this possibility is that the andesite-like surface is confined mostly to a region suspected to have been the site of an ancient Martian sea [See **PSRD** article: Outflow Channels May Make a Case for a Bygone Ocean on Mars].

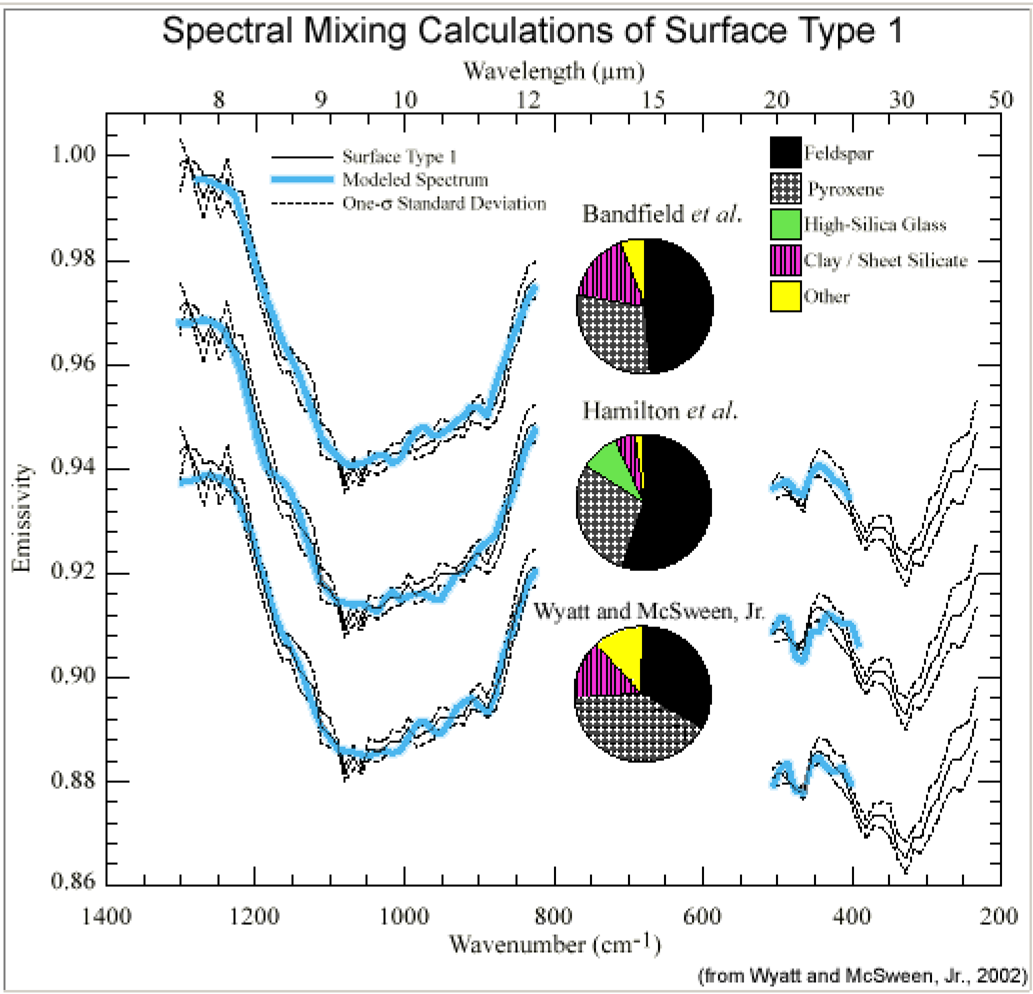


The basalt and andesite identified by Josh Bandfield and the TES team occur in different places on Mars (shown on the lefthand maps of the northern and southern hemispheres.) The surface interpreted as andesite (red, Surface Type 2) is concentrated in the northern hemisphere in a large, low region previously interpreted as an ancient ocean on Mars, as seen in the topographic map on the right. The white line outlines the location of the purported shoreline. Click on the image for a larger version.

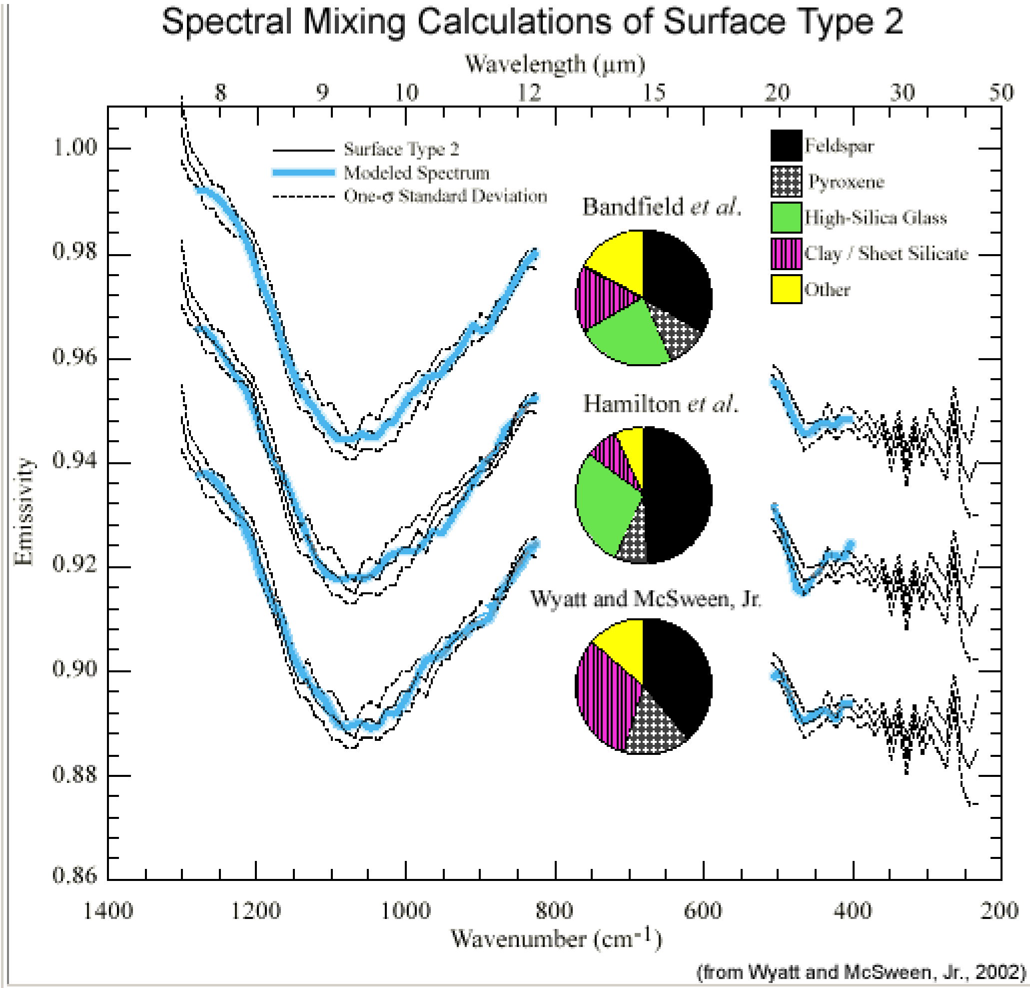
Back to the Spectral Library for Some Weathering Products

To test this hypothesis, Wyatt and McSween used a different set of minerals from the Arizona State spectral library. If the Type 2 area lies at the bottom of a former ocean, they reasoned, maybe all that water chemically altered basalt. Water certainly affects the mineralogy of rocks on Earth, forming an assortment of water-bearing (hydrous) minerals. Which minerals form depends on numerous factors, including the temperature, the acidity, and the amount of oxygen and other elements dissolved in the water. Nevertheless, the basic idea of altered basalt can be tested by a greater number of hydrous minerals in their mixing calculation compared to the set used by Bandfield and Hamilton. Most important, Wyatt's calculations differed from Bandfield's and Hamilton's by not including a component of glass rich in SiO_2. Such glass is a logical component of andesitic rock, but is not abundant in basalt.

The new calculations produce good matches to the observed spectra. For Surface Type 1, Wyatt's calculation agrees with Banfield's and Hamilton's. It looks like relatively unweathered basalt: lots of pyroxene and plagioclase and not much weathering products (clay minerals, sulfates, carbonates). For Surface Type 2, however, the modeled mineral abundances are quite different. Bandfield and Hamilton concluded that there were high abundances of plagioclase feldspar and high-silica glass, and low abundances of pyroxene and weathering products. In contrast, Wyatt finds high abundances of hydrous minerals and other weathering products. He finds no high-silica glass, of course, because he did not use it in the calculation. Quantitative assessments of the quality of the match between measured and calculated spectra indicate that all matches are very good--another example of how tricky it is to determine mineralogy from thermal emission data.



Mike Wyatt's calculation suggests that it is possible that Surface Type 2 (below) is weathered basalt rather than andesite. His calculated spectrum contains more clay minerals than do the spectra calculated by Bandfield and Hamilton.



Wyatt's calculation differs from the others in that he substituted hydrous minerals for high-silica glass. It turns out that the clays used in Wyatt's calculation have very different spectral properties between 18 and 20 microns. Unfortunately, the Martian atmosphere (mostly carbon dioxide) is opaque in this wavelength range, so a definitive test cannot be made. Some independent measurements will be needed, perhaps made by instruments directly on the surface.

Fresh and Weathered Natural Basalt

Like silverware, rocks tarnish. They rust. They rot. Take a good look at any natural rock surface on Earth. Look at its color. Then smash off some of the surface with a rock hammer. The fresh surface will look different, usually shinier and a different shade of color than the weathered surface.

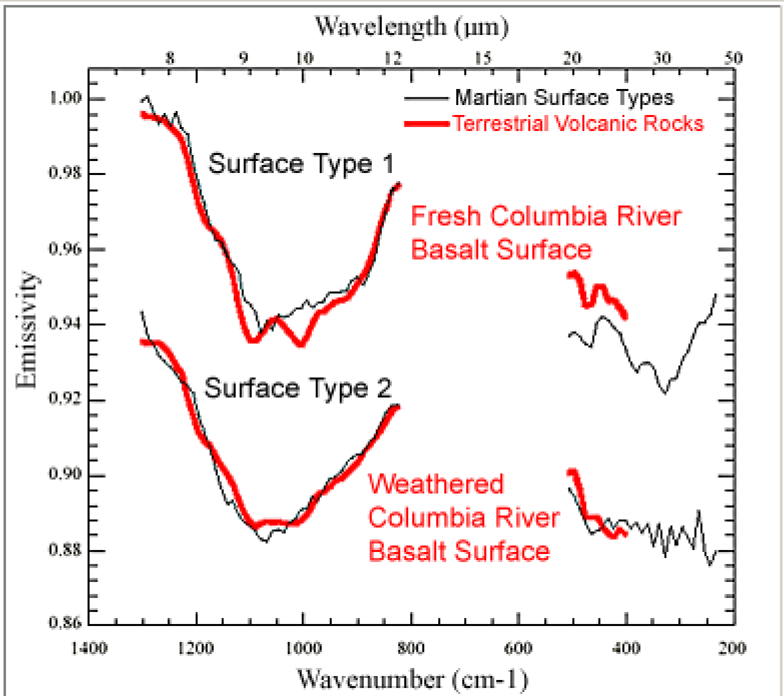
Wyatt and McSween decided to test their idea by obtaining spectra of weathered and fresh basalt from the Columbia River plateau in Washington and Oregon, USA. These are extensive flows of basalt and are fairly typical of terrestrial basalts. Fresh surfaces of Columbia River basalts are somewhat browner than weathered surfaces, which are darker in color.

Wanopum Basalts, Columbia River Basalt Group

This road-side photograph by Thor Thordarson shows lobes of pahoehoe lava from the Columbia River basalts. Unweathered (grey-brown) pahoehoe lobes overlie strongly weathered, darker basalt pahoehoe lobes.

(Photo courtesy of Thorvaldur Thordarson, Univ. of Hawai'i.)

Wyatt measured the thermal spectra of fresh and weathered basalt and compared the results to Surface Types 1 and 2. He found that the fresh basalt is somewhat similar to Surface Type 1, the one interpreted by everyone to be basalt. On the other hand, the weathered surface of the basalt was not a bad match for Surface Type 2, the one interpreted previously by Bandfield and Hamilton to be andesite. One problem with using the Columbia River basalts as terrestrial analogs is that they were not weathered under the same conditions as Wyatt and McSween hypothesize for Surface Type 2 on Mars. The Columbia River basalts were weathered by rain and the atmosphere. They were not sitting at the bottom of a Martian ocean.



(from Wyatt and McSween, Jr., 2002)

Fresh and weathered terrestrial basalt spectra match Surface Type 1 and 2, respectively. This is consistent with Wyatt and McSween's suggestion that Surface Type 2 is weathered basalt, not andesite.

Wyatt also did spectral deconvolution calculations on the Columbia River basalt spectra. He found that the fresh basalt contains mostly pyroxene and plagioclase, which matches detailed study of the Columbia River basalts. In contrast, the weathered basalt should contain lots of clay minerals (about 30%), which it does. Using a smaller number of clay minerals and adding glass, as Bandfield and Hamilton did, produces a calculated mineralogy that it should contain lots of glass (25%), which it does not. Nevertheless, the Bandfield technique still yields a good fit to the data. The difference, Wyatt and McSween suggest, may be that the silica glass mimics noncrystalline weathering products that could be present in the weathered rock surfaces, rather than volcanic glass.

So what is Surface Type 2?

Surface Type 2 might be andesite. It might be basalt. It might be something else nobody has considered. Finding out what it is will probably require other types of data for Mars. It is an important issue because it makes a huge difference in how we picture the igneous history of Mars and even the nature of processes operating inside the plumbing systems of Martian volcanoes. The Gamma Ray Spectrometer (GRS) carried onboard the Mars Odyssey spacecraft, currently in orbit around Mars, may help settle the argument. The GRS can measure Si quite readily, so should be able to determine if Surface Types 1 and 2 differ in Si, as they would if they were composed of basalt and andesite, respectively. If the Si concentrations are similar, it would favor the hypothesis that Surface Type 2 is made of weathered basalt. We should know this answer in a year or two as the GRS onboard Odyssey methodically determines the composition of the Martian surface.

Additional Resources

ASU Thermal Emission Spectral Library.

Bandfield, J. L., Hamilton, V. E., and Christensen, P.R. (2000) A global view of martian surface compositions from MGS-TES. *Science,* vol. 287, p. 1626-1630.

Hamilton, V. E., Wyatt, M. B., McSween Jr., H. Y., and Christensen, P. R. (2001) Analysis of terrestrial and martian volcanic compositions using thermal emission spectroscopy: II. Application to martian surface spectra from the Mars Global Surveyor Thermal Emission Spectrometer, *J. Geophys. Res.,* vol. 106, p. 14,733-14,746.

Mars Odyssey homepage.

Mars Odyssey Gamma Ray Spectrometer homepage.

Minitti, M.E. and Rutherford, M.J. (2000) Genesis of the Mars Pathfinder "sulfur-free" rock from SNC parental liquids. *Geochim. Cosmo. Acta,* vol. 64, p. 2535-2547.

Wyatt, M. and McSween Jr., H. Y. (2002) Spectral evidence for weathered basalt as an alternative to andesite in the northern lowlands of Mars. *Nature,* vol.417, p. 263-266.

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