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Leveraging Rock Type, Mineralogy, and Oxidation State from Six-Window Emissivity Spectra at 440C

M. Darby Dyar (1,2), J. Helbert (3), A. Maturilli (3), T. Widemann (4), E. Marcq (5), D. Wendler (3), I. Walter (6), M. D'Amore (3), G. Allemano (3), N. Müller (3,7), S. Smrekar (7). (1) Planetary Science Institute, Tucson, AZ, USA, (2) Dept. of Astronomy, Mount Holyoke College, South Hadley, MA USA (mdyar@mtholyoke.edu). (3) Inst. for Planetary Research, DLR, Berlin, Germany, (4) Observatoire de Paris, France, (5) LATMOS, Université Paris-Saclay, France, (6) Institute for Optical Sensor Systems, DLR, Berlin, Germany, (7) Jet Propulsion Laboratory, Pasadena CA, USA.

Abstract

The Venus Express mission has shown that orbital observations through transparent windows in the CO_2 atmosphere of Venus near 1 µm can produce viable data of the surface below. The resultant six windows coincidentally lie in a spectral region where visible-near infrared (VNIR) features of both Fe^{2+} and Fe^{3+} occur. Here, we report on laboratory data acquired from a range of well-characterized Venus-candidate rocks and minerals. We discuss how emissivity differences may be interpreted to derive information about rock type, mineralogy, and oxidation state.

1. Introduction

Building on the success of the VIRTIS instrument on ESA's Venus Express (VEX) mission, the Venus Emissivity Mapper (VEM) was developed to study the surface of Venus through six different windows at 0.85, 0.90, 0.99, 1.02, 1.10, and 1.18 µm [1]. In a manner analogous to the eight-filter imaging on the Pancam instrument of the Mars Exploration rovers [2], the six windows occur conveniently in a diagnostic spectral region that overlaps most Fe^{3+} and Fe^{2+} features. Thus they have the potential to provide great insights into Venus surface geology.

2. Samples studied

Samples were selected from collections at Mount Holyoke College and the Planetary Spectroscopy Laboratory at DLR. They include an ultramafic mantle xenolith, basalt, basaltic andesite, andesite, dacite, rhyolite, granite, granodiorite, trachybasalt, trachyphonolite, and syenite. Several minerals were selected based on their possible presence on Venus: pyrite, pyrrhotite, sodalite, apatite, turquoise, prehnite, calcite, forsterite (olivine), diopside (pyroxene), magnetite, hematite, labradorite and bytownite feldspar. Rock samples were prepared as 5 cm diameter, 1 cm thick round disk by cutting a square chip and then rounding the corners by hand on a grinding wheel. Mineral samples were prepared either as disks or as granular particles with specific grain size ranges, commonly ca. 45-125 µm.

Compositions were determined by x-ray fluorescence (XRF) by Bureau Veritas Mineral Laboratories or by electron microprobe at Brown University. Fe^{3+}/Fe^{2+} ratios were measured using Mössbauer spectroscopy in the Mineral Spectroscopy Laboratory at Mount

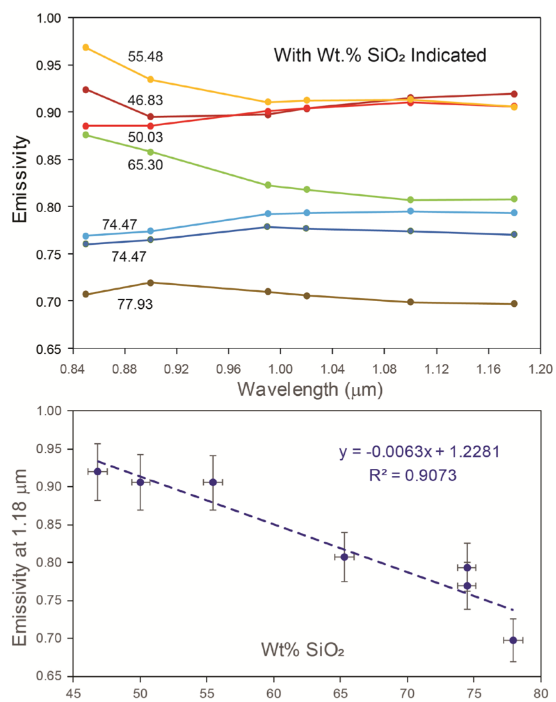

Figure 1: High temperature emissivity spectra of several different bulk rock types. Modelling of current best estimate errors suggests error bars of 0.7, 0.7, 0.4, 0.3, 0.7 and 1.2% on the six windows, in increasing λ.

Holyoke College. Mössbauer data were especially useful in accurately identifying the iron oxide phases, which can be confused in hand sample. Visible near-infrared (VNIR) data for this project were collected in the Planetary Spectroscopy Laboratory (PSL) at the German Aerospace Center DLR in Berlin [3].

3. Results

A key capability needed for understanding Venus is distinguishing between basalt plains and other various igneous rock types (e.g., basaltic andesite, andesite, dacite), and high SiO_2 rock types such as rhyolites and granites that form in the presence of water [4]. Although igneous rock classification is based on SiO_2 content, Si and Fe+Mg are known to be inversely correlated. Thus the Venus spectral windows, which lie close the region where Fe^{3+} and Fe^{2+} features occur in many common rock-forming silicates, can be used to determine rock type and SiO_2 contents.

Figure 1 shows emissivity spectra collected from rock slabs of three basalts (red to orange), a granodiorite (green), granite (blue) and rhyolite (brown). It is apparent that low SiO_2, Fe-rich rock types have much higher emissivity at all wavelengths studied. The intensity of emissivity is related to composition, as seen in the bottom of Figure 1 where emissivity at 1.18 μm is plotted vs. SiO_2 contents. Intensities at other longer wavelengths (0.99, 1.02, and 1.10 μm) also show an inverse correlation with SiO_2. This relationship between intensity and emissivity likely arises from the pervasive Fe^{2+} features at or above 1 μm as well as those from other transition metals. Thus emissivity spectra in this region can be used to distinguish among the critical rock types proposed to be present on Venus: basalt vs. granite.

Potential interactions between surface rocks and the Venus atmosphere may also be documented by these spectra. Weathering between the corrosive atmosphere and surface rocks should cause oxidation of basalt and associated minerals such as olivine [5,6] and pyroxene. Fe^{3+} and Fe^{2+} bands generally lie on opposite sides of the 1 μm region, with Fe^{3+} in the near-UV. Thus the lower-wavelength VEM bands should be most affected by Fe^{3+} contents, as seen in our data as a difference in slope between 0.85 and 0.90 μm. Iron-rich samples with higher Fe^{3+} contents all have negative slopes in that region, while more reduced, Fe^{2+}-rich rhyolites have positive slopes. Further analysis of our experimental data and completion of measurements of all our rock samples are needed to fully understand these trends.

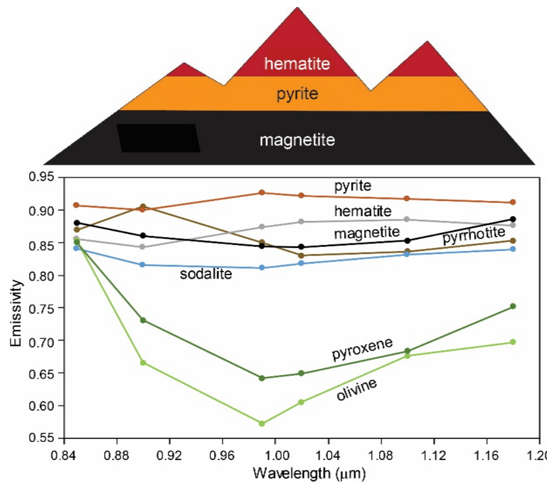

Figure 2: High temperature emissivity spectra of several minerals studied to date. Errors as in Figure 1. Changes in mineralogy that have been hypothesized to occur with elevation (top) should be identifiable with VEM data. For example, note the positive slope of magnetite between 1.1 and 1.18 μm, vs. the negative slopes of pyrite and hematite. Pattern recognition and unmixing algorithms, similar to those used on the Pancam instrument, should facilitate mineral identifications on the basis of these spectra.

Surface-atmosphere chemical reactions also result in changes to surface mineralogy. Several of the possible minerals that might be responsible for the differences in emissivity and radar backscatter are included in our sample suite. Initial results (Figure 2) suggest that mineral spectra are full of information. Again, the lowest Fe minerals have the lowest emissivities. Sulfides have very different signatures that the silicates. Overall, these minerals have distinctive spectral signatures that should be sufficient to distinguish them on Venus.

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