

WEATHERING ON VENUS: THE EFFECT OF OXIDATION ON THE VNIR SPECTRA OF OLIVINE

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Introduction: The crust of Venus is composed mostly of basaltic rock, which is in contact with its hot caustic atmosphere [1, 2]. Chemical reactions between Venus' basaltic crust and its atmosphere, 'weathering,' modify the surface's mineralogy and composition [3], which results in changes in their spectral characteristics and radar backscatter [4]. Without liquid water, weathering should be slow and mainly produce coatings on surfaces of grains and rocks [1, 3]. However, the chemical products and rates of basalt weathering on Venus and how these affect Visible-Near Infrared (VNIR) reflectance spectra are not well constrained. Here we present new VNIR reflectance data for olivine experimentally altered and oxidized in contact with the terrestrial atmosphere at 600° C and 900° C. These results constrain the rate at which olivine grains become coated with oxidation minerals, how the effects of surface coatings affect VNIR spectra, and how Venus may appear in the VNIR.

Methods: We obtained VNIR spectra on samples of olivine, which were oxidized in a previous study [5]: gem quality olivine crystals from San Carlos, AZ, and from China as purchased commercially (**Fig. 1**). The magnetic properties of the samples had been measured by vibrating sample magnetometer, and their mineralogy determined by Raman spectroscopy [5].

Olivine samples were oxidized in a box furnace under air at 600° C and 900° C and were incrementally removed after 0.2, 1, 5, 25, 125, and 625 hours [5]. For comparison, the surface of Venus is ~ 460° C. The fO_2 in the experiments was ~ QFM+10 [6] compared with fO_2 estimates of the atmosphere of Venus around the magnetite-hematite buffer (~QFM+5) [7, 8]. The experiments were done in under Earth atmosphere, rather than the CO₂-CO-SO₂-atmosphere [9]. Therefore, our results provide a zero-order constraint on the mineralogy and timescales of Venus weathering, and could be refined in experiments under more Venus-like conditions (e.g., [16]). Oxidation rates will depend on T (in addition to oxidation state); the temperature dependent part of the rate constants should be greater for 900° C than for Venus, but the temperature-dependent part at 600° C should be on the same order as for the surface of Venus. Finally, the effect of surface coatings on VNIR spectra is directly applicable as the oxidation mineralogy is expected to be similar to that on the surface of Venus (see below).

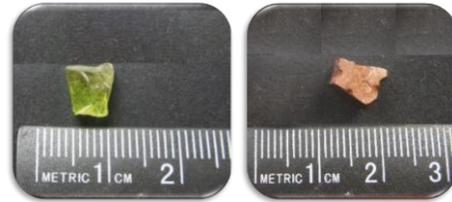


Fig.1. Olivine before and after 625 hours of oxidation at 900° C.

VNIR reflectance spectra of oxidized olivine and one unaltered olivine were measured from 350 to 2500 nm with a Spectral Evolution OreXpress VNIR Spectrometer with its Benchtop Reflectance Probe. Each crystal was measured unmounted for bulk spectral properties. All measurements were corrected using a white reflectance panel.

Results: All olivine crystals oxidized at 900° C have reddish-brown surface coatings, even those oxidized for only 12 minutes [5]. After 5 hours reaction, the olivine was completely coated with a reddish-brown layer, and no green olivine was visible. In the 600° C experiments, production and thickening of the reddish coating followed the same pattern as the 900° C experiments, but took longer to develop. Even after 1 month of reaction, green olivine was still visible through the coating.

The Raman spectra after oxidation showed that the samples remained primarily olivine, but abundances of magnetite and hematite increased with increasing time of alteration [5]. Raman spectra were consistent with minor proportions of enstatite and quartz may be present in the most oxidized samples. The magnetic properties of the samples changes with alteration duration, consistent with the changes in mineralogy. Every sample showed paramagnetic behavior before oxidation and ferromagnetic behavior after oxidation.

VNIR spectra here show features of the same minerals identified in the Raman spectra. Spectra of the unaltered olivine are consistent with pure olivine, with no minor minerals (**Fig. 2**). Oxidation at 900° C (**Fig. 2**) for only 12 minutes changed the VNIR spectra significantly (unlike Raman spectra, which were dominated by olivine features). The broad absorption around 1 μm, which is characteristic of Fe-bearing olivine, becomes weaker with increasing oxidation. This change is consistent with the formation of a surface coating. With increasing time of oxidation, the

spectra become almost flat, consistent with a coating of magnetite. After 1 month of oxidation, however, spectral features (i.e., the spectral shoulder near 700 nm and an absorption near 860 nm) characteristic of hematite appear. At this point, there spectrum shows no features characteristic of olivine (i.e., the broad 1 μm absorption), even though the sample is still dominantly olivine [5]. It appears that the visible and near-infrared wavelengths cannot penetrate the micron thick surface layers [5], which obscure signatures of the olivine, whereas the Raman measurements have greater penetration depth revealing the olivine underneath.

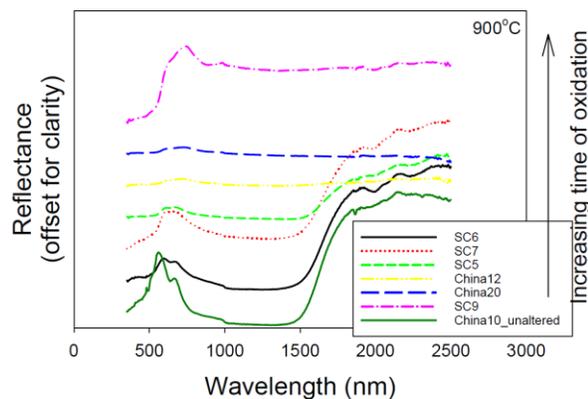


Fig. 2 VNIR reflectance for single crystals of olivine oxidized at 900° C, offset for clarity based on increasing time of oxidation.

The spectra for the 600° C experiments show a similar but less severe trend (**Fig. 3**). The olivine 1- μm absorption weakens, but never fully disappear. This is consistent with the visually observed cloudiness of the olivine and formation of magnetite/hematite coatings that do not fully enclose the olivine.

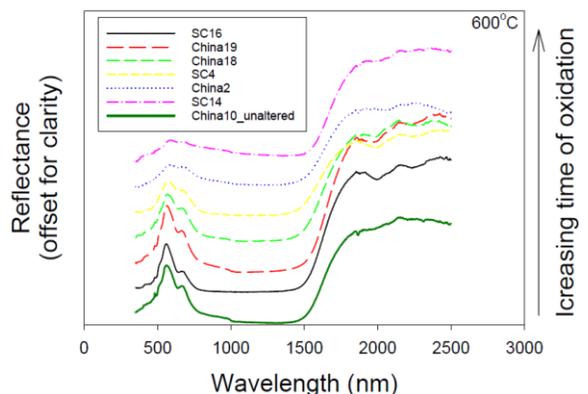


Fig. 3 VNIR reflectance for single crystals of olivine oxidized at 600° C, offset for clarity based on increasing time of oxidation.

Discussion and Implications for Venus: Venus' thick cloud deck largely obscures its surface from most visible to near-infrared wavelengths from orbit; however, the Visible Infrared Thermal Imaging Spectrometer (VIRTIS) on Venus Express could detect Venus' surface through three spectral 'windows', at 1.01, 1.10 and 1.18 μm [10]. Previous studies [11-14] have used these 'windows' to the surface to constrain physical properties of the crust, including its mineralogy and chemistry.

The results here highlight an important issue for detection of olivine (and other iron-bearing silicates) in the $\sim 1 \mu\text{m}$ region. **Fig 2.** shows that at 600° C, the reflectance signature of olivine around $\sim 1 \mu\text{m}$ is obscured after 1 month; instead the spectrum is flat and non-unique – consistent with the presence of oxidized iron oxide (presumably magnetite with some hematite). Such hematite surface coatings are consistent with Venus' surface coloration at the Venera 9 and 10 sites landing sites [15]. Therefore, the igneous iron-mineralogy, specifically olivine and possibly pyroxene, of the crust of Venus may be obscured from spectroscopic measurements by thin coatings of iron-oxide minerals. Future mission will likely need to see beneath these coatings to investigate the mineralogy, petrology, and geochemistry of the crust.

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