MUST THE VENUS SURFACE MATERIAL CONTAIN HEMATITE? John A. Wood, Smithsonian Astrophysical Observatory, 60 Garden Street, Cambridge MA 02138

Abstract of the abstract: The reflection spectrum of Venus surface material contains the strong signature of Fe\(^{3+}\). From this it has been concluded that the ferric mineral hematite is present in the surface material. This abstract argues that magnetite as the source of the Fe\(^{3+}\) signature cannot be ruled out.

Much uncertainty still attaches to the composition and degree of chemical equilibration of the near-surface atmosphere of Venus, and the equilibrium assemblage of minerals that would be formed at the surface by reaction of primary basaltic rock with the atmosphere [e.g., 1]. A key unknown parameter is the redox state (oxygen fugacity, f\(_{O_2}\)) of the atmosphere. This determines the identity of the stable Fe mineral on the surface of Venus (hematite at high values of f\(_{O_2}\), magnetite at intermediate values, an Fe sulfide at low values). If the Fe mineral that is present on the Venus surface were known, it would constrain f\(_{O_2}\) in the atmosphere.

Evidence of the actual surface mineralogy of Venus is contained in the spectrum of light reflected from the rocks and soil that Soviet spacecraft landed on in the 1970s and 1980s. Veneras 9 and 10 made photometric measurements that provide a crude spectrum in the visible and near-IR range of wavelengths (0.56--0.9 \(\mu\)m) [2]. Reflectivity of the surface material is seen to increase with wavelength, being \(~3\times\) greater at 0.9 \(\mu\)m than at 0.56 \(\mu\)m (Fig. 1). This pattern is characteristic of ferric iron. Pieters et al. [3] noted that no terrestrial or meteoritic basaltic material previously measured in the laboratory exhibits this type of spectrum, but they found that the spectra of hematite and of ferric-iron-bearing weathered basalt, when heated to Venus surface temperature, display similar spectra (see Fig. 1). Magnetite (at room temperature), on the other hand, has a relatively flat, featureless spectrum.

Thus the spectral evidence points to the presence of abundant Fe in the Ferric state on the surface of Venus. Since hematite has a strong spectral signature of Fe\(^{3+}\) and magnetite does not have (in spite of the fact that 2 of the 3 Fe atoms in the magnetite formula are Fe\(^{3+}\)), [3] conclude that hematite is the dominant Fe mineral on Venus. Students of thermodynamics have accepted this as a strong constraint on f\(_{O_2}\) in the Venus system [e.g., 4,5].

The present abstract argues that the constraint may not be as strong as it seems. All the minerals in a mixture of minerals to not contribute equally to the reflection spectrum of the ensemble. Minerals that are very transparent or very opaque have little effect on the spectrum of the mixture. [6] point out that the diffuse or body component of reflected light, which “has entered at least one grain and has been scattered back into space toward the observer...contributes most of the strength to any absorption features due to electronic transitions or charge transfers within the grains...The proportion of specular and body components of radiation depend on the optical-depth-to-grain-size ratio, i.e., how many scattering boundaries are traversed before the probability of absorption nears unity...The body component of reflected radiation has its maximum strength, and therefore deepest absorption bands, when the grain size is about one optical depth.” Magnetite is very opaque, and even finely ground particles may be larger than its optical depth, so little spectral information is contained in the small amount of radiation reflected (mostly specularly). Grain sizes have to be very small (<0.1 \(\mu\)m) for magnetite to display its absorption properties, but this is not completely unknown: Ramdohr [7] notes that “in extremely thin films a few hundred molecules thick, as, e.g., in inclusions occurring in some micas, [magnetite] is transparent brownish-grey...”
Most of the Fe in primary Venus basalts, as in basalts elsewhere, would be contained in augitic pyroxenes. However the Venus surface material is more or less weathered, and weathering would have the effect of removing Fe from the pyroxenes and converting it to an oxide. The oxide is probably not very far from the original sites of the Fe; i.e., the Fe oxide occurs as microscopic inclusions in decomposed relics of the original augite grains. None of the samples of planetary material we currently have access to has undergone this form of alteration (slow oxidation under dry conditions at a temperature in the annealing range), so the petrographic texture produced is probably outside the range of our experience. It may be that an array of magnetite plates or grains is produced with geometry and dimensions that permit the strong selective absorption of incident light by the Fe$^{3+}$ atoms in the magnetite, and that this, not the presence of hematite, is responsible for the slope of the reflection spectrum observed on Venus.

This is a highly speculative picture. My only purpose in drawing it is to argue against the view that there must be hematite on the surface of Venus because there is no other possible explanation for the reflection spectrum of Venus surface material.


![Figure 1](https://example.com/figure1.png)

Figure 1. A comparison of reflectance of the Venus surface measured by Venera landers [2] (shown with error bars) with laboratory measurements of several relevant materials by [3]. B, basalt; BC, black basaltic cinder; MC maroon cinder; RC, red cinder; H, hematite. Maroon and red cinder have been weathered and oxidized to different degrees in the terrestrial environment. Figure from [3].