

The Color of the Surface of Venus

C. M. PIETERS, J. W. HEAD, W. PATTERSON, S. PRATT, J. GARVIN,
V. L. BARSUKOV, A. T. BASILEVSKY, I. L. KHODAKOVSKY,
A. S. SELIVANOV, A. S. PANFILOV, YU. M. GEKTIK, Y. M. NARAYEVA

Multispectral images of the basaltic surface of Venus obtained by Venera 13 were processed to remove the effects of orange-colored incident radiation resulting from interactions with the thick Venusian atmosphere. At visible wavelengths the surface of Venus appears dark and without significant color. High-temperature laboratory reflectance spectra of basaltic materials indicate that these results are consistent with mineral assemblages bearing either ferric or ferrous iron. A high reflectance in the near-infrared region observed at neighboring Venera 9 and 10 sites, however, suggests that the basaltic surface material contains ferric minerals and thus may be relatively oxidized.

THIS REPORT FOCUSES ON INFORMATION about the oxidation state of the Venusian surface that can be obtained from spectral reflectance measurements in the visible and near-infrared regions of the spectrum. Determination of the oxidation state of the surface of Venus, which is strongly dependent on the redox condition of the lower atmosphere, would help resolve broader questions concerning the current surface environment and buffer reactions that may occur between atmosphere and surface. In particular, an oxidized surface could act as the required sink for oxygen associated with the hypothesized early high abundance of water on Venus (1).

The redox conditions for the surface of Venus, however, are not well constrained. The data for the chemistry of the lower atmosphere provide different estimates for the near-surface partial pressures of O₂ and CO. Estimates have been made from extrapolation of the apparent nonequilibrium mixtures of O₂ and CO detected above the 30-km level by the Venera 13 and 14 gas chromatographs (2) and the Pioneer Venus mass spectrometer (3). On the basis of the kinetics of reactions with surface material, however, these nonequilibrium estimates are not expected to be stable in the near-surface environment (4). On the other hand, the "Kontrast" experiment on the Venera 13 and 14 landers provided evidence of a CO-bearing, reducing environment (5). It is currently unknown which of these conditions accurately describes the surface of Venus.

From the Venera x-ray spectrometer data (6) the surface at the Venera 13, Venera 14, and VEGA 2 sites is known to be basaltic in general composition. Oxide abundances were estimated to be as follows: FeO, 8.8 to

9.3%; SiO₂, 45.1 to 48.7%; MgO, 8.1 to 11.5%; Al₂O₃, 15.8 to 17.9%; CaO, 7.1 to 10.3%; TiO₂, 0.2 to 1.6%; and SO₃, 0.9 to 4.7%. The mineralogy of surface material should be influenced by the local redox conditions; conversely, the oxidation-reduction conditions of the surface environment can be determined indirectly if the surface mineralogy can be identified. The discussion below focuses on the distinction between the oxidized ferric and the relatively reduced ferrous compounds commonly found in basaltic material. Their spectral properties in the visible and near-infrared distinguish these compounds.

Ferric oxides have the following spectral characteristics (7, 8): (i) very low reflectance ($\leq 5\%$) from the ultraviolet into the visible; (ii) a relatively sharp absorption edge between 0.5 and 0.6 μm with a strong increase in reflectance toward longer wavelengths (for example, for hematite, $< 5\%$ reflectance at 0.5 μm , 30% at 0.75 μm , and up to 80% at 1.2 μm); and (iii) weaker absorption bands near 0.64 and 0.85 μm . The absorption edge characteristic of the ferric oxides is attributed to strong charge transfer transitions in the ultraviolet between overlapping orbitals of iron and oxygen as well as crystal-field electronic transition bands of ferric iron (8, 9). These features of ferric oxides account for their distinct red coloration and can be seen (Fig. 1A) in the spectrum for the ferric oxide hematite and spectra of altered or weathered basaltic material ("maroon" and "red" cinders). Identification of a ferric component in martian soils, for example, is based on such an absorption edge that is observed in remotely obtained spectra (10). Ferrous minerals, on the other hand, are either opaque throughout the visible (for example, magnetite and ilmenite) or exhibit

a more gradual increase in reflectance from the ultraviolet through the visible (for example, most iron-bearing silicates such as pyroxenes and olivines). These characteristics can be seen in the Fig. 1A spectra of unaltered basalt and "black" cinders.

The spectral properties of ferrous and ferric minerals have been studied by numerous investigators because iron-bearing compounds are among the most common minerals encountered in terrestrial, lunar, and meteoritic materials. Although the characteristics of the surface of Venus (which contains about 9% FeO) would be expected to be sensitive to the iron-bearing compounds present, inferences based on this assumption must be used with caution. Currently no evidence is available for or against unusual or perhaps unique compounds existing on the Venusian surface.

Two types of spectrophotometric data are available for the surface of Venus: (i) multispectral images obtained for three channels in the visible by the Venera 13 and 14 landers (11); and (ii) wide-angle photometer measurements for five channels through the visible to about 1.0 μm obtained by Venera 9 and 10 (12). Although both types are discussed here, initial analyses concentrated on the multispectral images because they contain spatial information that would allow the relations between different materials on the surface to be examined. This information is particularly important if metastable chemical weathering phases were to occur as rinds or varnishes on rock surfaces. It was suspected that if ferric oxides are present on the surface of Venus in material roughly similar to oxidized terrestrial basalts, the primary absorption edge of ferric oxides should be readily detectable in the Venera 13 and 14 multispectral images, and the surface rocks would appear distinctly red.

The Venera 13 and 14 landers each had two scanning cameras located on opposite sides of the spacecraft (11). In an imaging sequence the camera scanned from horizon to center (near vertical) to horizon. Each camera was capable of obtaining images in a blue (B), a green (G), and a red (R) channel;

C. M. Pieters, J. W. Head, S. Pratt, Department of Geological Sciences, Brown University, Providence, RI 02912.

W. Patterson, Department of Engineering, Brown University, Providence, RI 02912.

J. Garvin, Goddard Space Flight Center, National Aeronautics and Space Administration, Greenbelt, MD 20771.

V. L. Barsukov, A. T. Basilevsky, I. L. Khodakovskiy, Vernadsky Institute of Geochemistry and Analytical Chemistry, U.S.S.R. Academy of Sciences, Moscow, U.S.S.R.

A. S. Selivanov, A. S. Panfilov, Yu. M. Gektin, Y. M. Narayeva, State Center for the Study of Natural Resources, State Meteorological Committee, 123376 Moscow, U.S.S.R.