

amounts, which is about the same as the red to green separation of the Venera cameras. Fourth, a regular but anomalous gradient in the green channel from lower to upper picture elements (pixels) was removed empirically.

This process produces the color image of Fig. 2 (lower panel), which should represent the color of the surface of Venus as if it were seen under "white light" illumination. This image is consistent with what is known independently about the properties of the scene. The red chip is red (a R/G ratio of  $1.8 \pm 0.3$ ), a diffuse shadow of about the right magnitude surrounds the lander, and the rocks and soil are very dark. The color of the surface in this image is distinctly gray. These data, including the red coloration of the "teeth" surrounding the base of the spacecraft, are also in agreement with the results of recent, more detailed analyses of the lander color cameras (14). A minor shift toward blue wavelengths is observed along the far horizons, consistent with an atmospheric scattering component. Although the horizon for a perfectly smooth spherical surface is about 3.5 km from the lander, the foreshortening of the camera perspective is extreme. The region of blue coloration in the images is calculated to begin about 20 to 60 m from the lander; this distance is probably suggestive of the scale at which local atmospheric scattering for visible light becomes comparable to the amount of light scattered from the surface.

The numerical data in Fig. 2 show that the rocks and soil at the Venera 13 landing site are essentially gray, or without strong color ( $0.90 \leq R/G \leq 1.10$ ), in the visible part of the spectrum. The magnitude of all color differences is small and could be accounted for either by physical properties of the material (for example, particle size or compaction), although minor compositional differences are not precluded, or by a residual artifact of camera calibrations. The precision of the data available does not allow for detailed comparisons between rocks and soil. Taken at face value, the distinct gray color and lack of an absorption edge in the visible would perhaps imply that Earth-like ferric oxides are not likely to be present in significant amounts. The Venusian surface, however, has its own unique environment and resulting characteristics. These observed spectral characteristics of the Venusian surface in the visible part of the spectrum are to be expected for either oxidized or reduced basaltic surfaces.

Shown in Fig. 1B is a composite spectrum for the surface of Venus derived from the wide-angle photometer data of Venera 9 and 10 (12). The half-power bandwidths (half-height bandpass) of the green and red

filters used for the Venera 13 and 14 imaging experiments are shown at the bottom of Fig. 1B. Error bars and data for Venera 9 and 10 photometers are from Ekonomov *et al.* (12). Half-power bandwidths of the filters used are shown as horizontal bars.

Although the color images of Fig. 2 and the spectral data of Fig. 1B refer to different areas, they can be considered to represent common bulk spectral properties. A basaltic composition is in accord with the data for all these sites (6), although the earlier geochemical data for Venera 9 and 10 are more limited than those for Venera 13 and 14. All four lander areas are in generally similar surface environments. Venera 9 landed on the flanks of the Beta Regio volcanic complex (at 2.2 km above the 6051-km reference surface), whereas Venera 10, 13, and 14 touched down in the adjacent upland rolling plains (at 1.3 km above the reference point) (15). These regions have been interpreted as volcanic plains in varying states of degradation (15, 16). Measurements of the physical and electrical properties at the surface of these sites (17) suggest that weathering and perhaps alteration involving the concentration or production of highly conductive phases may have taken place.

The color of the Venera 13 surface derived from the multispectral images is consistent with the spectroscopic data of Fig. 1B for Venera 9 and 10. Throughout the visible part of the spectrum the surface of Venus is very dark and not strongly colored. At wavelengths longer than 0.7  $\mu\text{m}$ , however, an increase in reflectance (by a factor of 2 to 3) is seen in the independent spectroscopic measurements for the Venera 9 and 10 sites, with the Venera 10 measurements exhibiting the sharpest increase. This distinguishing characteristic depends heavily on the albedo measurements made with the last filter near 0.9  $\mu\text{m}$ .

No terrestrial or meteoritic basaltic material previously measured in the laboratory exhibits this type of spectral character (7, 18, 19), although there are substantial variations in spectral characteristics from changes in temperature. Similarly, no lunar material, with the exception of the dark recrystallized pyroclastic glass of Apollo 17, exhibits the spectral properties observed at the Venera 9 and 10 sites. The unusual ilmenite-olivine-glass black beads (sample 74001) of the Apollo 17 titanium-rich pyroclastic soil from Shorty Crater are the only known basaltic assemblage that exhibits such a strong band near 0.65  $\mu\text{m}$ , which is associated with ilmenite (20). In a normal basaltic assemblage, ilmenite is opaque and spectrally flat; the 0.65- $\mu\text{m}$  band that is observed for the Apollo 17 black spheres is attributed to the unusual structure of the ilmenite,

which occurs as thin plates set in a non-opaque silicate matrix (20). For Venus, not only is the overall composition at the Venera 13 and 14 sites unlikely to produce major amounts of ilmenite (about 9% FeO and 1.5% TiO<sub>2</sub> for Venus compared with 22% FeO and 8% TiO<sub>2</sub> for sample 74001), but the unusual petrographic circumstances (fine-grained glassy spheres) required for normally opaque materials to become translucent are inconsistent with the surface morphology observed from the images.

At least three possible causes can, individually or combined, account for the unusual Venusian spectrum (dark and flat throughout the visible with an increase in reflectance at longer wavelengths). Listed in what is believed to be increasing likelihood, these include instrumental error, presence of unusual compounds, or the effects of the Venusian environment on the measured spectral properties of basaltic materials.

Instrument and environmental measurement errors for the spectra in Fig. 1B were considered by Ekonomov *et al.* (12). The combined error in the albedo measurements was estimated to be 25 to 30% and involved a variety of instrument calibrations and processing procedures (12). The error bars of Fig. 1B represent this value. Estimations of surface thermal emission at 0.9  $\mu\text{m}$  account for only about 5% of the flux at the surface. No additional instrument error is suspected.

Although ferric oxides are perhaps the most common type of mineral species in altered basalts with an absorption edge (that occurs in the visible), other less abundant minerals also display sharp absorption edges at different wavelengths. A variety of less common sulfur compounds, for example, exhibit absorption edges in the visible and near-infrared; stibnite (Sb<sub>2</sub>S<sub>3</sub>) has an edge near 0.7  $\mu\text{m}$  (21). Consideration of relatively rare species as the source of the absorption edge in the spectrum of the Venusian surface should not be ignored, but such minerals are considered less likely than minerals more common to known basalts of the solar system.

The spectral properties of many rock-forming minerals are affected by the ambient temperature and pressure of their environment. Pressure effects do not appear to be significant until about a few kilobars (22) and thus are not of importance for the surface of Venus. Temperature, on the other hand, is known to affect the spectral properties of some materials (23–25) and may play a considerable role in the determination of the spectral properties of Venusian surface material.

To understand the effects of temperature on the spectral properties of Venusian sur-