SPECTROPHOTOMETRIC MAPPING OF COPRATES QUADRANGLE, MARS
Paul E. Geissler and Robert B. Singer, Planetary Image Research Laboratory, Planetary Sciences Department, University of Arizona

Perhaps the best studied and yet least well understood region of Mars is the Valles Marineris, a 4000 kilometer long system of canyons running radially from the Tharsis uplift down towards the East. The Valles contain a notable diversity of terrain types revealing a complex history of tectonic rifting, infill and erosion, many details of which are still unclear. The great depth of the canyons, reaching 8 kilometers in places, offers a unique view of the stratigraphy and geologic history of the martian crust. Studies of the martian canyons to date have relied for the most part on the morphology, texture, and superposition relationships of geologic units as seen in high resolution monochrome images from the Mariner and Viking missions. Viking apoapsis multispectral images, although lower in resolution, offer a regional overview and the means by which to map surface units on the basis of their color and albedo properties. Broadband filters on the Viking VIS centered at 0.45, 0.53 and 0.59 μm yield limited spectral information allowing characterization and mapping of relative spectral variations, but not sufficient to permit detailed compositional interpretations. A complementary approach is to examine the variation in reflected radiance as a function of incidence and emission and phase angles, using multiple phase angle images. The extensive Viking data set, with its variable illumination and viewing geometry generated over numerous orbits, provides a unique opportunity to study the photometric properties of the martian surface and their spatial distribution in a geological context.

SPECTRAL PROPERTIES. As in other parts of Mars [1-5], the surface materials in Coprates Quadrangle broadly divide into 3 spectral units, while subresolution mixing results in areas with color properties intermediate among these three. (1) Bright Red materials have red to violet filter reflectance ratios (R/V) that reach up to 3, and have red filter radiance factors (rF) which approach 0.2 for images recorded at a phase angle (g) of 20°. They are distributed along the margins of the canyons, as wind streaks on the surrounding plains, and include both the canyon wall rock and most (but not all) of the younger interior layered deposits, which are often indistinguishable spectrally from the nearby canyon walls despite obvious differences in morphology. (2) Dark Red materials have R/V ratios near 2.5 and red filter r~ values typically 0.15 at g=20°. They are confined to the ridged plains of Lunae Planum. (3) Dark Grey materials are the darkest (red filter r~ < 0.1) and least (R/V < 2) of the materials exposed in the martian canyons. They occur as canyon floor cover (imparting the low overall albedo to the Valles Marineris), as splotches in craters and topographic lows, and as in-situ layers within the canyon wall rock and interior layered deposits. Many of the Dark Grey deposits are clearly mobile, displaying distinctive dune morphology in high resolution images.

The spectra of the Bright Red and Dark Red units display some important similarities. When the color data are transformed to hue, saturation and intensity (HSI) coordinates, the distinction between the Bright Red and Dark Red units disappears in the hue image. This appears to be true regardless of the phase angle at which the units are imaged, and confirms a similar relationship between these two units noted previously [5] in Oxia Palus, some 1500 kilometers to the North.

PHOTOMETRIC PROPERTIES. We are currently in the process of estimating the parameters of Hapke’s [6] bidirectional reflectance model for regions in Coprates Quadrangle using a selection of red filter images which span a range of phase angles from 20° to 120°. Of particular interest is the light scattering phase function of the surface particles, which describes the dependence of reflectance on phase angle (the angle between the source of illumination, the surface and the observ-
Laboratory measurements \cite{7,8,9} indicate that most natural materials (including the rock-forming silicates) scatter dominantly in the forward direction, away from the source. Back scattering materials invariably include internal scatterers such as grain boundaries, voids, inclusions, and fractures. Opaque minerals such as magnetite reflect specularly off the front surface, and can appear to be either forward- or back-scattering depending upon the particle roughness and observation geometry. Because materials having similar chemical compositions but which differ in their physical state can display markedly different scattering behavior, knowledge of the scattering phase function places constraints only on the physical makeup of the grains: forward scattering behavior is displayed by smooth, semitransparent particles which are free of internal defects, whereas back scattering indicates grain boundary defects as found in lithic fragments and grain aggregates.

Inversion of Viking Orbiter image data entails certain specific problems which may not be encountered in photometric analyses of other solar system objects. Anisotropic light scattering by aerosols in the martian atmosphere contributes to the photometric function measured by a spacecraft outside the atmosphere, and the opacity of the martian atmosphere varied significantly over the course of the Viking mission. Clouds, fog and dust plumes are often observed in Viking images of the martian canyons as well as changes in surface albedo patterns produced by aeolian transportation of dust and sand \cite{10,11,12}. The Valles Marineris region includes significant large scale topographic variations. Limitations of the coverage and quality of imaging data also affect the results and their interpretation. Lack of low phase angle images (<20°) of the area precluded determining parameters relating to the opposition effect; the surface (macroscopic) roughness could not be constrained by the available higher phase angle images. Errors in image calibration produced significant discrepancies in radiance estimates for the same surface measured under identical conditions.

Initial results obtained for the North-Central Valles indicate that the Dark Grey dune-forming materials display markedly different scattering behavior than the Bright Red and Dark Red materials of the surrounding plains. The particle scattering phase function of these dark sands is strongly forward-scattering, even allowing for the effects of atmospheric aerosols (estimated by comparing Hapke parameters calculated from predicted radiance factors for an ideal surface in a vacuum with those predicted for the same surface with a variety of model atmospheres using multiple scattering simulations). Observationally, this produces a contrast reversal phenomenon: in high phase angle images, these dark sand deposits appear brighter than the surrounding plains, i.e. the reflectance of the low albedo materials is greater than that of nearby surfaces with higher albedo. The single scattering albedo of the Dark Red unit is lower than that of adjacent Bright Red materials, but the scattering phase functions of these two units are similar (isotropic to slightly back-scattering).

**INTERPRETATION.** Evidently, the Bright Red and Dark Red units are similar in both composition and physical properties, supporting the idea \cite{4,5,13} that the Dark Red unit is simply an indurated or physically rougher form of the Bright Red material. The Dark Grey materials, on the other hand, appear to be physically and compositionally distinct. The very low reflectance of these materials at small phase angles seems to be a function more of their scattering phase function than an intrinsically low albedo. Smooth, semitransparent particles which are free of internal defects, such as mafic glass particles, best account for the observations.