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Mineralogy of the Martian Surface:
Crustal Composition to Surface Processes

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Accomplishments: Over the course of this award we have: 1) Completed and published the results of a study of the effects of hyperfine particles on reflectance spectra of olivine and quartz, which included the development of scattering codes. Research has also progressed in the analysis of the effects of fine particle sizes on clay spectra. 2) Completed the analysis of the mineralogy of dark regions, showed the insitu compositions are highly correlated to the SNC meteorites, and determined that the martian mantle was depleted in aluminum prior to 2-3 GA ago; Studies of the mineralogic heterogeneity of surficial materials on Mars have also been conducted; 3) Performed initial work on the study of the physical and chemical processes likely to form and modify duricrust. This includes assessments of erosion rates, solubility and transport of iron in soil environments, and models of pedogenic crust formation. The main results are summarized below:

Crustal Composition:

The results of this research were reported in Mustard et al. (1997) and are summarized here. Twenty-six spectra were analyzed that satisfy the criteria for weakly altered properties and also provide acceptable solutions from the MGM. MGM absorption band parameters (center, strength, width) provide the basic information for a determination of mineralogy and for the assessments of diversity among the regions. For pyroxene mixtures, the ratio of the strength of the low-calcium (LCP) to the high-calcium (HCP) pyroxene bands has been shown to be a quantitative measure of the relative abundance of these minerals. The specific spectra that have been investigated fall naturally into three major areas: Syrtis Major (minimum ratio), Ophir Planum, and Valles Marineris (maximum ratio).

These results show that the volcanics in Syrtis Major are enriched in HCP relative to the materials on the floor of Valles Mariners, while the plateau plains of Ophir Planum are intermediate between these. The relationship between the LCP:HCP ratios was used to calculate the change in relative pyroxene abundance of these areas. The change in band strength ratios correspond to an approximate decrease in HCP/(LCP+HCP) relative to Syrtis Major of 10% in Ophir Planum and 20% in Valles Marineris. It is evident from this, and previous analyses (Mustard and Sunshine, 1995) that two-pyroxene basalts with a high proportion of HCP are common on Mars. These compositions are comparable to the basaltic SNC meteorites that are thought to have crystallized from magmas with major element composition analogous to terrestrial basaltic komatiites. These analyses provide convincing evidence that well crystalline, high iron, low aluminum basaltic lithologies analogous to the basaltic SNC predominate in exposed, weakly altered terrains for a wide range of inferred surface ages.

Hyperfine Particles:

During the previous award, we completed an investigation of the effects of extremely fine particles (<25μm) on reflectance and emittance spectra from the visible to mid-infrared (Mustard and Hays, 1997). Narrow 5 μm size fractions from 0-25 μm were obtained of the minerals olivine and quartz. Spectra of all separates were measured with

RELAB (0.3-25 μm), and the olivine separates were also measured in J. Salisbury's directional hemispherical instrument (6-15 μm), and P. Christensen's emittance spectrometer (7-15 μm). Spectra from all three systems exhibit important, fundamental effects, primarily due to particle size, which have not been previously reported. When the wavelength of light approaches the dominant particle size of a given separate, the reflectance undergoes a steep decline. This basic observation can be understood through application of Mie theory for particles sizes • wavelength of light and can be linked to n, the real part of the index of refraction. When the particle size is less than $(2\lambda)/(\pi(n-1))$ the spectra should exhibit a decline in reflectance. This accounts for the observation that the wavelength of maximum reflectance for the transparency feature is shifted systematically to shorter wavelengths with decreasing particle size. Observed systematic changes in the spectral contrast of the restrahlen bands can also be explained by these results. These results were then taken farther and a Mie-Hapke hybrid scattering model for olivine and quartz particulate surfaces was developed.

Although the study by Mustard and Hays (1997) provided insight into the effects of hyperfine particles on reflectance spectra, these observations were focused on silicate minerals for which optical constants were available. New studies (Cooper and Mustard, 1997) have been conducted on materials and samples more relevant to the surface of Mars. These include hyperfine separates of smectite clays and palagonite. These results confirm some of the findings of Mustard and Hays (1997), but also present new problems and conundrums. It is expected that the clay-size fraction of all materials is in the •2 μm size range, and that so-called larger separates (e.g. 25-45 μm) are simply agglomerations of smaller particles. Yet, the sequence of spectra acquired for 5 μm dry-sieved separates of the •25 μm particle size show decreasing band strength with particle size in the visible-near infrared, and more complex behavior in the mid-infrared (Cooper and Mustard, 1997). Thus agglomerations of particles apparently behave as functionally larger particles. We also observed important changes in the strength and character of adsorbed water bands.

Duricrust Studies:

In the interval between the Mariner and Viking missions to Mars, several Type-II dark streaks in the Oxia Palus regions exhibited changes in position and length which were thought to be caused by movement of the dark sands across the surface. Recent observations by MOC of representative streaks indicate that indeed there are dark dune forms that can be tracked from the interiors of the craters to the surrounding plains. The differences in areal coverage of the streaks that changed between Viking and Mariner were used to determine area affected and spectral mixture modeling was used to calculate the abundance of lithic fragments that had been transported into the regions. Using equations for the time averaged rate of eolian abrasion and estimates of the susceptibility to abrasion, the average amount of erosion for the areas affected was on the order of 10 cm/yr (Cooper and Mustard, 1998; 1999).

This amount of material is more than sufficient to explain the associations of bright material along the streak edges. The 10 cm/yr of erosion in the areas affected translates to •0.3 mm/yr of dust if spread out over the entire Oxia Palus region. This assumes that the transformation of the dark red duricrust to bright red dust is 100% efficient. An important implication of this work is that the dust produced by this disaggregation process would be a complex assemblage of phases, consistent with the results of the magnetic dust properties experiment on Pathfinder.

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