POSSIBLE PHYSICAL CAUSES OF REFLECTANCE CONTRASTS ON PHOBOS.

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Phobos and Deimos are generally considered to be rather bland spectrally, at least over the limited range of wavelengths spanned by pre-*Phobos 2* spacecraft imagery. Spatially, however, the martian satellites are anything but bland in appearance. Veverka and Thomas [1] noted the existence on Phobos of bright crater and groove rims, dark halo craters, dark diffuse extra-crater areas and dark markings on crater floors. To this list may be added bright and dark 'streamers', seen predominantly on the walls of craters, and bright crater rays. Unlike many of the features found in *Viking* imagery, the contrasts between bright rays and the surrounding regolith exhibit little dependence on phase angle; material associated with one crater (visible in frames 343A15 and 854A81) is 30% brighter than its surroundings at phase angles of 43° and 72°, suggesting that it has an intrinsically higher albedo and hence different composition.

This abstract seeks to clarify possibilities for relationships between observed reflectance contrasts that vary with phase angle and spatial heterogeneity in the *physical* characteristics of the regolith; the compositional variability of the surface layer will not be considered here, since spectral data best facilitate such studies (see [2]). Guided by a physically-based photometric model such as Hapke's equation [3,4], one may deduce three possible causes for reflectance contrasts, other than differences in regolith particle albedo: spatial variations in the width and/or magnitude of the opposition effect; a spatially-varying sub-pixel roughness; or local differences in angular scattering by single particles. Ideally, any physically-based explanation of reflectance contrasts should link one or more of these causes to specific physical phenomena, such as impact cratering, impact-related processes (e.g. outgassing) or mass wasting.

Low Phase Angles. Bright crater and groove rims are found on Phobos at low phase angles. It has commonly and erroneously been assumed [e.g. 5] that these features might result from a more brecciated, porous surface structure; in fact the opposite applies, as consideration of Hapke's shadow occultation model of the opposition effect [4] will illustrate. Figure 1 shows curves of reflectance versus phase angle for various values of h, the compaction parameter in Hapke's equation. The associated regolith porosities (in brackets) have been computed assuming a lunar-like particle size distribution [4,6]. Clearly, less porous material will have a broader opposition effect and will therefore appear brighter at low phase angles. Although porosity variations could be responsible for observed reflectance contrasts, they would perhaps have to be unrealistically large; a more plausible explanation in terms of Hapke's model would invoke small differences in the particle size distribution [6].

The marked tendency for bright rims to be conspicuous along local topographic highs suggests that movement of material downslope plays a rôle in their formation. This is consistent with the ideas above: downslope creep could leave an underlying, more compact layer of regolith exposed on crater and groove rims, particularly where there is a significant regional slope; alternatively, it could lead to sorting of the regolith, with a coarser size fraction remaining on the rims. The dark halo craters and diffuse patches of dark material observed in low phase angle *Viking* images may similarly be explained in terms of differences in opposition effect width. Here, however, downslope movement is unlikely to be responsible. One plausible scenario might be that these features have an above-average porosity resulting from the localised outgassing of volatiles, perhaps in response to impact-induced heating.

Other possibilities exist: firstly, variations in the *magnitude* of the opposition effect could also be responsible for the aforementioned reflectance contrasts, in which case downslope movement of material would create bright crater and groove rims by exposing optically-fresher material with a higher opposition surge amplitude. However, the magnitude of the opposition effect observed for planetary regoliths appears to be strongly coupled to particle single-scattering albedo [6,9]. Variations in opposition surge amplitude are therefore an unlikely cause of bright rims on Phobos; we would expect the corresponding contrasts in particle albedo to have a detectable signature in images obtained at higher phase angles, and this is not observed.

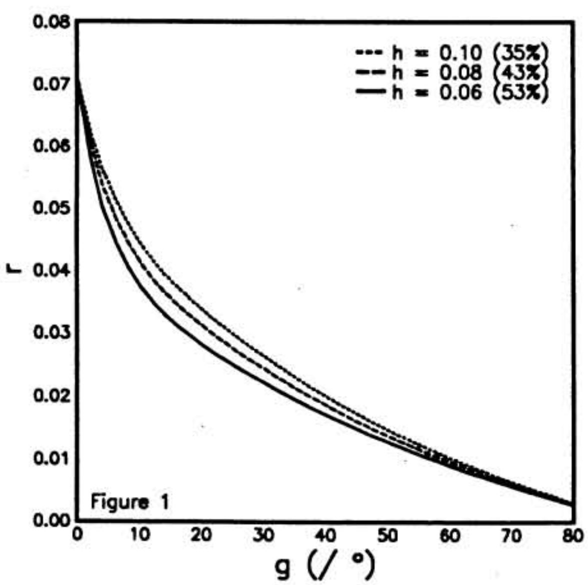
Alternatively, some phase angle-dependent mechanism other than shadow occultation, such as trough retroreflection by crystals [7] or interference between scattered rays [8], might be involved. According to one model for the former [7], the production of a lunar-like opposition peak by this means alone would require extremely small crystals. However, in equations describing the scattering characteristics of an average particle in a multicomponent regolith, endmember phase functions are weighted not only by number density and scattering efficiency but also by the scattering cross-section of endmember particles.

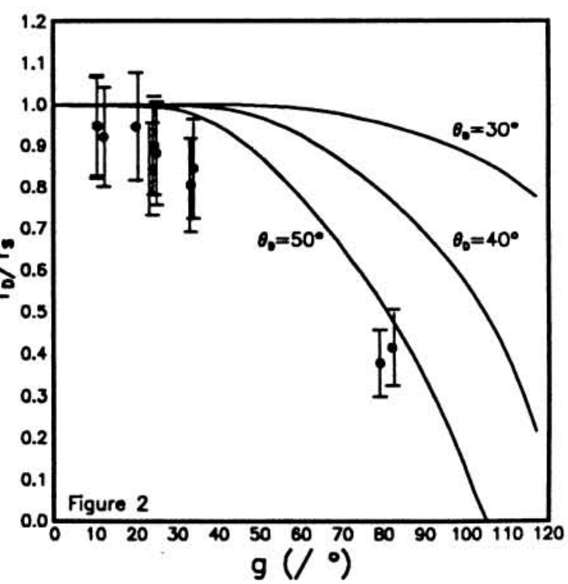
PHOBOS REFLECTANCE CONTRASTS: Efford, N.D.

Large particles will inevitably exert the greatest influence on $P(g)$, hence small crystals would have to be especially reflective and abundant relative to the other constituent particles in order to make a significant contribution to the opposition effect. A high albedo regolith component is also implied by explanations invoking an interference model of the opposition surge [8]. The absence of a detectable signature of such a component in higher phase angle images casts doubt on the validity of trough retroreflection or interference as an explanation for bright rims, despite the compelling arguments in favour of the latter provided by multispectral data [2].

High Phase Angles. Dark markings found to occur on the floor of many craters in high phase angle *Viking* images have been interpreted as signs of rough-textured devolatilised impact melt [10]. However, the alteration processes associated with an impact could conceivably change both the single-scattering albedo and the phase function of material occupying the crater floor. If this is the case, then one needn't suppose that the floor is any rougher than the crater's surroundings; instead, the dark material might be predominantly composed of particles that scatter less light in the sideways and forward directions than unaltered regolith. The roughness hypothesis is supported, however, by *Phobos 2* KRFM observations. These indicate that many crater floors have a high thermal inertia, suggestive of a more blocky surface [11].

In order to quantify the relative roughnesses of crater floor material and the surrounding regolith, reflectance measurements of material in and around a single crater have been made from several *Viking* images. Figure 2 plots the reflectance ratio for dark floor material and the surroundings as a function of phase angle, together with theoretical curves computed using Hapke's equation. A roughness of $\bar{\theta} = 25°$ was assumed for the surroundings, consistent with analyses of disk-resolved reflectance scans across Phobos, whilst the remaining parameters were fixed at values deduced by integral photometry [9]. If roughness is the sole cause of the reflectance contrast, then crater floors must be dramatically rougher than neighbouring areas. Furthermore, $\bar{\theta}$ is large enough, compared with surfaces elsewhere in the solar system, to favour accumulations of shock-lithified rubble over a melt pool of vesiculated material as a hypothesis for the nature of crater floor material.





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