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MARTIAN SURFACE MATERIALS

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Our knowledge of the physical properties of the surface materials on Mars is very limited. 1. No experiments aboard the Viking Landers were designed to measure physical properties. 2. Orbital and Earth-based remote sensing observations have measurement uncertainties, model dependent interpretations, and different sensitivity scales and depths; large areas are sampled so that the physical properties of a number of components are integrated. 3. Some materials have not been properly sampled or not sampled at all. 4. Relevant laboratory data are incomplete. 5. Natural materials have variable physical properties that may not be separable with the available data. Despite these shortcomings, a semiquantitative appreciation for the physical properties of the surface materials and their global variations can be gained from the lander and remote sensing observations.

Analyses of Lander data yield estimates of the mechanical properties of the soillike surface materials [1,2] and "best guess" estimates can be made for the remote sensing signatures of the soillike materials at the landing sites [2,3]. Two soillike materials (blocky and crusty to cloddy) at the landing sites appear to be strong and compatible with natural soils, but the third (drift) presents a problem because it appears to be weak and unlike most natural soils. Footpad 3 of Lander 1 penetrated blocky material a few centimeters upon landing at about 2.4 m/s but footpad 2 penetrated 16.5 cm into drift material. It is unclear whether drift material, a strong substrate of blocky material, or buried rocks arrested the penetration of footpad 2 [2]. The friction angle for drift material (18±2.4°), estimated from the limits of surface deformation in front the sampler for trenches in drift material [1,2], is compatible with lunar regolith simulants [4] that have bulk densities about 800-900 kg/m^3, but the estimated cohesions (1.6±1.2 kPa; range: 0-3.7) are typically much larger. It is possible that the friction angle has been underestimated [5] and the cohesions overestimated. Smaller cohesions would be consistent with the lumpy appearance of the materials in the tailings of trenches, natural slope failures, and the stabilities of trench walls in trenches of drift material [2]. The friction angles and cohesions of the lunar regolith simulants are direct functions of the bulk densities [4]. If drift material is like the lunar regolith simulant, a friction angle about 27°, a cohesion about 40 Pa, and a bulk density about 1100 kg/m^3 is possible. This bulk density is the same as that of disturbed drift material [6]. Friction angles and cohesions between the extremes are possible, but drift material remains relatively weak.

Drift material is fine grained [7] and powderlike [2]; it has a low bulk density. Thus, the thermal inertia should be low and range from 1 to 3 X 10^{-3} cgs units [8,9,10,2,3]. This range of thermal inertias is comparable to those reported from orbital observations for vast regions on Mars such as Tharsis [11,12]. Powders and very porous rocks with bulk densities that range from 800 to 1100 kg/m^3 should have relative dielectric constants that range from about 1.8 to 2.2 [13]. Normal reflectivities of quasi-specular radar echoes from the Tharsis region [14,15,16] suggest relative dielectric constants in this range. Color reflectances vary but they are like telescopic bright areas [17,18]. Thus, significant thicknesses of powderlike surface materials with physical properties similar to drift material are present on Mars and probably pervasive in the Tharsis region.

Crusty to cloddy material is fine grained [19], reasonably strong, and moderately dense (1400 kg/m^3) with estimated friction angles of 34.5±4.7° [1,2]. These friction angles are compatible with those of natural dry loess [20] and lunar regolith simulants [4] with moderate bulk densities. Cohesions (1.1±0.8 kPa; range: 0-3.2) are less than those of the loess, but larger than those of the lunar regolith simulants. Upon disruption, crusty to cloddy material breaks into thin crusts and prismatic clods, suggesting that the material is cemented. The effect of cementation on thermal inertias is not understood, but cementation should increase thermal inertias [21]. The thermal inertia has been estimated to be about 5.6 to 6.3 X 10^{-3} cgs units [2,3], using Orbiter thermal [22] and Lander data and theory [23]. These inertias are near the principal modal values for the bulk and fine component thermal inertias determined from Orbiter thermal data [11,12]. The relative dielectric constant of this material should be about 2.8 [3] and comparable to the 3.0 inferred from average normal reflectivities of quasi-specular radar echoes from Mars [14]. Although color reflectances vary, they resemble telescopic bright regions [17,18]. Thus, it appears likely that soillike materials similar to crusty to cloddy material are typical for Mars.

Blocky material is also strong, cemented, and possibly moderately dense. Upon disruption, it forms centimeter-size clods that are more coherent than those of crusty to cloddy material [2]. The friction angles (30.8±2.4°) are comparable to natural dry loess [20]. Cohesions (5.1±2.7 kPa; range: 2.2-10.6) are typically smaller than those of the loess (> 10 kPa) but larger than those of the lunar regolith simulants (40-100 Pa) for the same friction angles. The thermal inertia has been estimated to be about 8.2 to 9.3 X 10^{-3} cgs units [2,3]. The relative dielectric constant should be about 3.3 [3]. Color reflectances are similar to drift material [17]. Thus, it appears likely that soillike materials similar to blocky material are common on Mars.

Surface and near-surface rocks are probably abundant. About 19% of the surface at the Lander 2 site is covered by rocks (> 0.04 m) [3]. Assuming that entire rock populations have effective thermal inertias of 30 X 10^{-3} cgs units, 20±10% and 15±5% of the Lander 2 and 1 sites, respectively, are covered by rocks; the modal coverage is 6% and the range from 1 to 30% [24]. 12.6-cm depolarized echoes imply considerable variations in areal coverage by wavelength-size (0.08-0.76 m) rocks and similar roughness elements at and near the surface [13,14,25]; globally, the smallest area covered by rocks is about 3%, the greatest about 76%, and commonly about 4% [25]. Rocks on the surface were never sampled by the landers [2], but they should be like terrestrial rocks with friction angles about 60°, cohesions measuring in MPa, thermal inertias ranging from 30 to 60 X 10^{-3} cgs units (depending chiefly on their size), and relative dielectric constants ranging from about 8 to 9 [13]. Color reflectances of rock surfaces vary: some resemble telescopic dark regions and unoxidized basaltic andesite coated with about 30 μm of palagonite, others telescopic bright regions and palagonite, and still others local "soils" [17,18]. Rare rock fragments resemble mafic rocks [26].

The physical properties of martian surface materials vary with location. Successful interpretations of these properties will require the combined use of as much available information as possible such as lander, thermal inertia, radar, albedo-color, and, especially, high-resolution imaging data on Mars.

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