DURICRUSTS ON MARS: EVIDENCE FROM THERMAL, RADIO AND RADAR DATA.

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Introduction. Duricrusts are present on the Mars surface, as evidenced by their appearance at the Viking landing sites (1, 2) and by interpretation of thermal infrared remote sensing data (3, 4). The discussion here centers on evidence for the ubiquitous presence of a duricrust on the Mars surface, and its relationship to global surface properties. The duricrust seen at the lander sites is characterized by a cohesion greater than that expected for loose particulate fine material (1, 2), a salt concentration greater than that of neighboring unbonded material (5, 6), and an inferred presence either at or very near the surface everywhere at the Viking landing sites (1, 2). The global existence and distribution of this duricrust will be an important factor in understanding the nature and evolution of the near-surface layer.

Thermal data pertaining to duricrust. Thermal infrared data can be interpreted in terms of the effective particle size of the surface (7). For the landing sites, the derived thermal inertia for the fines (after removing the effects of the observed rocks) is greater than that expected on the basis of the particle sizes observed (3, 8); this difference has been attributed to the presence of a duricrust-type material, with bonding together of individual grains increasing the thermal conductivity, and hence the thermal inertia, of the fines (3). Christensen (4) analyzed the observed diurnal temperature variations and concluded that the fraction of the surface covered by rock was relatively constant over the surface, and that the thermal inertia of the fines predominantly determined the bulk inertia of the surface; he suggested that it was the degree of formation of a duricrust like that seen at the landing sites which resulted in the observed distinction between the high and low thermal inertia regions. The initial correlation between rock abundance and inertia (4) was not present when all of the global data was analyzed (9), indicating that the model is self-consistent and does not require unrelated properties to vary together in order to reproduce the data.

Comparison with other remote-sensing data sets. The relatively low rock abundances found by Christensen (4, 10) contrasted with the larger abundances obtained by Jakosky and Muhleman (11) based on the observed correlation of thermal inertia and radar cross-section. In this latter model, both properties were shown to increase upon increasing the amount of rock mixed in with a fine component of low inertia. The discrepancy between the models was tentatively attributed to the choice of rock size in the diurnal thermal model (4). Alternatively, we suggest here that the presence of a global ubiquitous duricrust of varying degree of formation can account for both data sets. To produce the correlation of radar cross-section and thermal inertia requires that an increased thermal conductivity be associated with an increased bulk density; this obtains with a duricrust because the increased grain thermal contacts are produced by a deposition of salts or other mobile species by water, simultaneously filling the pores near the surface and increasing the density. That the radar correlation holds at $\lambda 70$ cm (11) and is somewhat degraded at $\lambda 12.5$ cm (11, 9) indicates that scattering by surface and subsurface rocks plays a minor role in the correlations. These results are consistent with Earth-based $\lambda 2.8$ cm radio observations of Mars (11, 12) and require no spatial variation of rock abundance. They are consistent with the $\lambda 3.5$ mm measurements reported by Epstein et al. (13) if the high-inertia regions have a higher microwave emissivity at $\lambda 3.5$ mm than at $\lambda 2.8$ cm; that is, the density

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is greater and the duricrust is better formed some several centimeters below the surface than right at the surface.

Using a different approach, Ditteon (14) reached similar conclusions regarding duricrusts. He analyzed a variety of the possible non-uniform, non-homogeneous surface configurations (e.g., temperature-dependant surface properties, exposed surface rocks, time-of-day dependant albedo, surface slopes, airborne dust, subsurface layering) to determine which could produce afternoon temperatures observed to be as much as 25K cooler than predicted by a simple model; he concluded that only a layered surface could produce the effect, and he attributed the layering to the presence of a duricrust. There are, however, several problems with this work: He ignored in his final model effects other than layering which are known to occur and which, when added up, can have an equally-large thermal effect(8); layering alone did not reproduce the observed cooling, but only managed to explain about half of the effect; and layering also did not reproduce the time-of-day behavior of the observed effect, but still left significant deviations from the model. Thus, while Ditteon suggests the presence of an underlying duricrust, his results must be viewed with caution in terms of ruling out other mechanisms and extrapolating to global properties.

Formation of duricrust. On Earth, duricrusts often result from a rising and falling water table (e.g., 15), although they may also form from salts deposited by small amounts of adsorbed water (16, 17). Their variable nature on Mars, correlated with the thermal inertia, must be consistent with the depositional formation (18, 4) and current expansion (19) of the low-inertia regions and with the paucity of subsurface water (20). The duricrust may form from the movement of water in and out of the regolith on the 10^5-year timescale (see 21), with the movement tending to concentrate salts near the surface as that is where the water would be most mobile and variable. This mechanism is consistent with a steady deposition of dust onto and consequent growth of the low-inertia regions over this same period, with insufficient time having elapsed for a duricrust to form. By this model, dust accumulates preferentially in low-inertia regions during periods when water does not exchange with the regolith, with little concomitant duricrust formation. When water moves through the regolith, crusts form over the entire surface; these crusts are subsequently eroded and the loose material is redeposited to form new regions of low inertia. The location of the low-inertia regions is controlled by surface and atmospheric properties (19), and these may vary from cycle to cycle. The timescale for this process would be $>10^5$ years, and is consistent with global deposition and erosion rates (22, 23).

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