ARE DARK RED SOILS AND BRIGHT DUST ON MARS RELATED THROUGH MINERALOGIC PHASE CHANGES? J. F. Mustard, Dept. Geol. Sci., Box 1846, Brown University, Providence, RI 02912.

Introduction: Low albedo regions on Mars consist of relatively fresh two-pyroxene basalts, analogous to the Shergotite meteorites [1], indicating that many regions of the planet have escaped oxidative weathering and alteration. Bright red regions and mobile dust are best modelled by various amounts of crystalline and nano-crystalline hematite in a poorly crystalline or dehydroxylated silicate (smectite?) host [2,3] and represent the thermodynamically stable final products of Martian weathering [4]. A fundamental unknown for Mars is the pathways by which crustal materials become the alteration products. Gas-solid reactions provide a direct mechanism to form bright materials from dark [5], but reaction rates under current Martian conditions are much too slow to be important The warmer-wetter climates postulated for past Martian epochs [6,7] permit the reactions to proceed at adequate rates, but the alteration products include ferric oxyhydroxides and hydroxylated silicates which are not observed in bright regions. A possible solution to these inconsistencies is presented in this paper that links bright and dark regions through dark red materials.

Dark Red ≠ Bright Red + Dark Grey: Thermal inertia, radar, and Viking color data have been cited as supporting evidence that dark red regions are simple mixtures of bright red and dark gray material, indurated to a variable extent by duricrust [8,9]. The principal defining characteristics are moderate to low albedo (0.15-.25), moderate inertia (3.5-7.7), a correlation between density (from radar) and thermal conductivity, and an apparent lack of mobility. However, comparative analysis of dark red units with dark gray and bright red regions using ISM data (spectra from 0.77 to 3.14 μm) indicates that dark red units cannot be adequately modeled as mixtures of dark gray and bright red materials [10,11]. Mixtures have a 2.1 μm pyroxene absorption band, not observed in spectra of dark red units, and cannot fit the absorption near 1.0 μm. The principal defining characteristics of dark red regions in the ISM data are the intermediate albedo, flat spectral slope, distinct shape and position of the 1.0 μm band, and lack of any pyroxene-related absorptions near 2.1 μm. The absorptions properties are consistent with several ferric oxyhydroxides such as ferrihydrite, jarosite, and goethite. However, the absorption bands in dark red regions are weak relative to laboratory spectra of pure crystalline minerals. Therefore is it probable that these ferric components are poorly crystalline and/or nanophase, similar to the ferric sulphates and oxyhyroxides formed in smectite clays thorough ion exchange reactions [12].

The assemblage of ferric oxyhydroxides, sulphates, and clay silicates is a reasonable model for duricrusted soils on Mars. Viking lander measurements of soil composition are readily accommodated by these mineral components [e.g. 13,14] while the higher concentration of sulfur in the duricrust measured at Viking Lander 1 suggests an increase in the abundance of a sulphate phase [15]. Burns and Fisher [16] determined that acid weathering of iron-rich basalts on Mars produces acidic solutions rich in Fe^{2+} and sulphate. Though these solutions are reducing beneath the surface, they can become oxidizing near the surface due to sublimation, interaction with the atmosphere, and UV radiation. The oxidized solutions rapidly precipitate nanophase ferric oxide, sulphate, and partially dehydroxylated clay silicates. Thus Martian groundwater reaching the surface may be expected to form near surface deposits of these components cementing the soils and creating duricrust. On the present day surface of Mars, however, this assemblage is thermodynamically unstable, and dehydroxylated clay silicates and hematite should form [5]. Nevertheless, they may exist metastably if the kinetics of dehydration reactions are sufficiently slow.

Type II Streaks: Type II dark streaks [17] in Oxia Palus (Fig. 1) provide supporting evidence for the mineralogic interpretations above, as well as insights into ongoing processes linking weathering and alteration. These streaks commonly occur in dark red plains, emanate from splotches in crater floors or depressions, and have bright red deposits on the upwind and downwind sides as well as distinctive narrow deposits along their margins [17]. These features have been the focus of many investigations and have been interpretated to indicate local stratigraphy involving dark red, bright red, and dark gray deposits [18,19], or as local deposition of bright material at the streak margins due to the effects of saltating dark sands and winnowing of bright dust [17] with

deposition enhanced downwind and along the streak margins by increased surface roughness over dark red regions [8].

An alternative hypothesis is proposed here, linking the compositional units described above through mineralogic phase changes by way of aeolian processes. The persistence of metastable compounds in dark red soils is facilitated by the cohesion fostered by cementation and duricrust. This kinetically inhibits the formation of thermodynamically favored compounds. The dark material of the crater floors and streaks, which are likely sand-sized [20], are transported by aeolian processes across the surface to form the streaks. The force of the sand grains transported across the surface [21] is sufficient to break up the loosely indurated duricrusted soils. This increases the surface to volume ratio in the soils, and lowers the kinetic barriers to predicted phase changes. The immature compounds of the dark red soils then mature to the typical assemblage of bright red regions. This process only affects a thin layer on the surface since there is no compelling evidence for significant scour or erosion in the streaks.

Summary: Dark red units on Mars cannot be adequately modeled as simple mixtures of bright red and dark red materials. The spectral properties of dark red plains are however consistent with immature ferric oxyhydroxides, sulphates, and clays predicted to form as a result of alteration of basaltic rock by water. The data presented here support the new hypothesis that the majority of the bright material associated with Type II dark streaks (e.g. Oxia Palus) is the result of maturation of immature compounds that exist metastably in the indurated, duricrusted soils of dark red regions. This maturation, which is inhibited by soil cohesion, is facilitated by the passage of dark sands across the surface that break up the duricrust. A consequence of this model is that the bright material along the boundaries of Type II dark streaks, and within the streaks represent regions of active maturation and mineral transformations. Alternative hypotheses that involve deposition, saltation, and winnowing fail to account for the tight associations of bright red, dark red, and dark gray materials within the streaks, but lack of bright deposits elsewhere on the dark red plains.

References: [1] Mustard, J.F., and J.M. Sunshine, (1995) *Science*, (*in press*). [2] Bell, J.F., *et al.*, (1990) *JGR 95*, 14,447. [3] Morris, R.V. *et al.*, (1989) *JGR 94*, 2,760. [4] Gooding, J.L., *et al.*, (1992) in *Mars* (H. H. Kieffer, *et al.* eds.) 626. [5] Gooding, J.L., (1978) *Icarus 33*, 483. [6] Pollack, J.B., *et al.*, (1987) *Icarus 71*, 203 (and references therein). [7] Squyres, S.W. and J.F. Kasting, (1994) *Science 265*, 744. [8] Arvidson, R.A., *et al.*, (1989) *JGR 94*, 1573. [9] Christensen, P.R. and H.J. Moore, (1992) in *Mars* (H. H. Kieffer, *et al.* eds.), 686. [10] Murchie, S.M. *et al*, (1993) *Icarus 105*, 454. [11] Mustard, J.F., (1994) *EOS Trans. AGU 75*, 407. [12] Bishop, J.L., *et al.*, (1993) *G&CA 57*, 4583. [13] Toulmin, P. (1977) *JGR 82*, 4625. [14] Clark, B.C.*et al.*, (1982) *JGR 87*, 10059. [15] Burns, R.G., (1987) *Proc. LPSC 17th, JGR 92*, E570. [16] Burns, R.G. and D.S. Fisher, (1993) *JGR 98*, 3365. [17] Thomas, P., *et al.*, (1981) *Icarus 45*, 124. [18] Soderblom, L.A., *et al.*, (1978) *Icarus 34*, 446. [19] Kieffer, H.H., *et al.*, (1981) *Proc. LPSC 12th*, 1395. [20] Edgett, K.S. and P.R. Christensen, (1991) *JGR 96*, 22765. [21] Greeley, R. and J.D. Iversen, (1985) *Wind as a Geologic Process*, Cambridge, 333 pp.

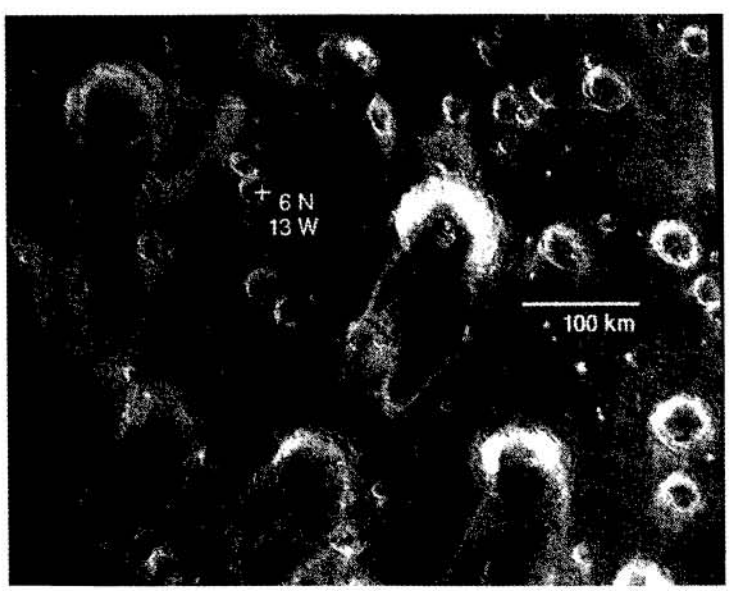

Figure 1. Type II dark streaks in Oxia Palus (Viking Orbiter frames 669a-49 and 669a-50). The medium-gray tones correspond to dark red plains, the dark tones to relatively unlatered dark sands, and the bright tones to mobile bright dust. Note that bright dust is found either in areas of aeolian traps (e.g. crater walls) or associated with dark sands transported across the dark red plains.