extrusive lava resurfacing on Earth [1], the martian total is nonetheless equivalent to the release of ≥ 500 g/cm^2 averaged over the planet for every 0.1% (wt/wt) of volatile species released from magma. Quantitatively, this is sufficient to make up as much as 5% of the fine-grained regolith weathering product to a mean depth of 100 m. This reservoir of fine-grained material can be readily mobilized globally by episodic dust storms. With the relative absence of soil-consolidation factors, such as reworking by liquid water, tectonically driven metamorphism, and burial processes that are ubiquitous on Earth, survival of some material over significant portions of geologic time on Mars may have been possible. As fines are repeatedly transported over the surface, they have experienced weathering regimes from various geologic settings and epochs. Mixed fines could represent a planetwide sampling of the physical and chemical products from various surface, near-surface, and impactor materials.

Excess acidity in the fines can occur due to the preponderance of acidic volcanic emissions. Some minerals will be more susceptible to weathering than others, but reaction rates vary enormously as a function of temperature [11] and H_2O availability. Initial weathering rinds will typically form barriers to further conversion of source material. Resistant units such as rocks and bedrock outcrops would be subjected to a balance between surficial chemical weathering and physical removal by eolian abrasion. Because of saltation heights and wind-shadowing effects, three-dimensional geochemical gradients of weathering may be found on exposed surfaces on boulders such as those observed at the Viking 1 lander site.

Although carbonates and nitrates are widely expected in the martian regolith, current evidence is lacking or weak. Reworked fines may have been chemically scrubbed of any weathering product of either class of compounds since it has been demonstrated experimentally that volcanic SO_2 gas can undergo rapid heterogeneous-phase displacement reactions with susceptible solid substrates, even under simulated dry and cold martian conditions [12], to release CO_2 and NO_x back to the atmosphere.

On the other hand, magmas release additional volatiles that would not be recyclable because of their lower vapor pressures and/or chemical stability. A variety of data relevant to volatility would imply that weathering products may be highly enriched in elements such as Na, Cu, Zn, As, Se, Br, Rb, Cd, In, Sn, Sb, Hg, Tl, Pb, and Bi compared to rock compositions [13]. Many of the compounds formed by these elements may be soluble in H_2O, as data indicate for the S- and Cl-bearing compounds in martian fines, and hence be subject to transport processes that create duricrust and soil peds. The occurrences and distributions of these elements could provide key evidence of weathering history and magmatic degassing.

Where alteration products have been exposed to bulk liquid water, chemical sediment deposits with evaporite sequences should be found on Mars. Quasistable liquid brine pools might also have resulted. However, if the dominant soluble anion on Mars is SO_4^{2-}, then most strong freezing-point depressant salts would not be available for contemporaneous brine. Even if formed, subzero brines would have restricted mobility, because of high viscosity and reduced chemical activity of H_2O molecules compared to pure water.

Although it is widely believed that the missing H_2O is buried in the regolith as physical deposits of permafrost ice, it cannot be ruled out that significant portions, perhaps most, of this inventory has been incorporated into secondary minerals. A pervasive drawdown of atmospheric volatiles would result from chemical reaction with abraded and comminuted surface materials and may be central to probing the climatological evolution of Mars.

References: [1] Greeley and Schneid (1991) *Science, 254,* 996–998. [2] Owen T. (1992) in *Mars* (H. Kieffer et al. eds.), 818–834, Univ. of Arizona. [3] Biemann et al. (1978) *Icarus, 34,* 645–665. [4] Clark et al. (1982) *JGR, 87,* 11059–10067. [5] Clark B. (1987) *Icarus, 71,* 250–256. [6] Clark B. (1993) *GCA,* in press. [7] Banin et al. (1993) *JGR,* in press. [8] Clark B. and van Hart D. (1981) *Icarus, 45,* 370–378. [9] Baird A. K. and Clark B. C. (1981) *Icarus, 45,* 113–123. [10] Banin et al. (1992) in *Mars* (H. Kieffer et al. eds.), 594–625, Univ. of Arizona. [11] Burns R. (1993) *GCA,* in press. [12] Clark et al. (1979) *J. Molec. Evol., 14,* 91–102. [13] Clark and Baird (1979) *GRL, 6,* 811–814.

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THERMAL AND HYDRAULIC CONSIDERATIONS REGARDING THE FATE OF WATER DISCHARGED BY THE OUTFLOW CHANNELS TO THE MARTIAN NORTHERN PLAINS. S. M. Clifford, Lunar and Planetary Institute, Houston TX 77058, USA.

The identification of possible shorelines in the martian northern plains suggests that the water discharged by the circum-Chryse outflow channels may have led to the formation of transient seas, or possibly even an ocean, covering as much as one-third of the planet. Speculations regarding the possible fate of this water have included local ponding and reinfiltration into the crust; freezing, sublimation, and eventual cold-trapping at higher latitudes; or the *in situ* survival of this now frozen water to the present day—perhaps aided by burial beneath a protective cover of eolian sediment or lavas. Although neither cold-trapping at higher latitudes nor the subsequent freezing and burial of flood waters can be ruled out, thermal and hydraulic considerations effectively eliminate the possibility that any significant reassimilation of this water by local infiltration has occurred given climatic conditions resembling those of today.

The arguments against the local infiltration of flood water into the northern plains are two-fold. First, given the climatic and geothermal conditions that are thought to have prevailed on Mars during the Late Hesperian (the period of peak outflow channel activity in the northern plains), the thickness of the cryosphere in Chryse Planitia is likely to have exceeded 1 km. As discussed by Clifford [1], a necessary precondition for the widespread occurrence of groundwater is that the thermodynamic sink represented by the cryosphere must already be saturated with ice. For this reason, the ice-saturated cryosphere acts as an impermeable barrier that effectively precludes the local resupply of subpermafrost groundwater by the infiltration of water discharged to the surface by catastrophic floods. Note that the problem of local infiltration is not significantly improved even if the cryosphere were initially dry, for as water attempts to infiltrate the cold, dry crust, it will quickly freeze, creating a seal that prevents any further infiltration from the ponded water above.

The second argument against the local infiltration of flood water into the northern plains is based on hydraulic considerations. As discussed by Carr [2] and Clifford [1], repeated impacts have likely brecciated the martian crust down to a depth of roughly 10 km. Given a value of permeability no greater than that inferred for the top 10 km of the Earth's crust (~10^{-2} darcies [1,3]), a timescale of

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as much as a billion years or more for the martian groundwater system to achieve hydrostatic equilibrium, and the ~2–4 km elevation difference between the outflow channel source regions and the northern plains, the water confined beneath the frozen crust of the northern plains should have been under a significant hydraulic head. Thus, the existence of a hydraulic pathway between the ponded flood waters above the northern plains and the confined aquifer lying beneath it would not have led to the infiltration of flood water back into the crust, but rather the additional expulsion of groundwater onto the surface.

A more detailed discussion of the fate of flood waters discharged by the martian outflow channels is currently in preparation.

References: [1] Clifford S. M. (1993) *JGR, 98,* 10973–11016. [2] Carr M. H. (1979) *JGR, 84,* 2995–3007. [3] Brace W. F. (1980) *Int. J. Rock Mech. Min. Sci. Geochem. Abstr., 17,* 241–251.

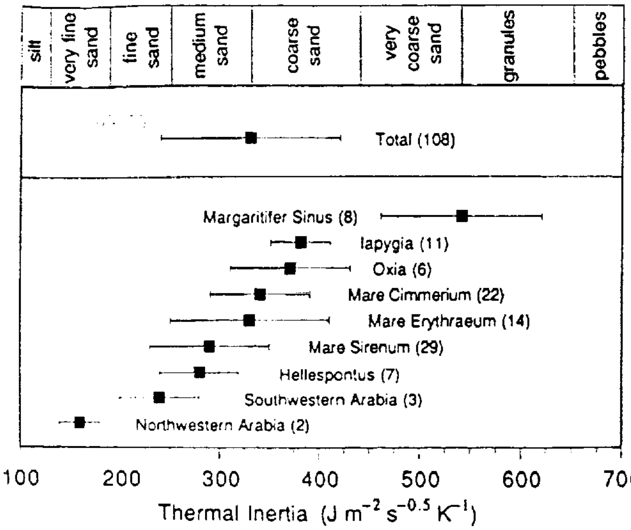

Fig. 1. Mean and standard deviation of thermal inertias for dark intracrater features in different regions. Numbers in parentheses indicate total craters examined. To convert thermal inertia to units of 10^{-3} cal cm^{-2} s$^{-0.5}$ K^{-1}, divide by 41.84.

REGIONAL SEDIMENTOLOGICAL VARIATIONS AMONG DARK CRATER FLOOR FEATURES: TOWARD A MODEL FOR MODERN EOLIAN SAND DISTRIBUTION ON MARS.

K. S. Edgett and P. R. Christensen, Department of Geology, Arizona State University, Tempe AZ 85287-1404, USA.

It has been known since 1972 that many martian craters (≤ 25 km diameter) have dark features on their floors, and that when seen at higher image resolution, some of the dark units are dune fields [1–3]. Interpretations of thermal inertia derived from Viking Infrared Thermal Mapper (IRTM) data have been used to suggest that many dark intracrater features, including those where dunes are not observed in images, contain some amount of sand or particles in the range 0.1–10 mm [4,5]. However, it has never been known if all these dark features consist of dunes.

We assembled a set of 108 carefully constrained Viking IRTM observations for dark crater-floor units. The data and selection criteria are described in detail elsewhere [6–9]. Studied in conjunction with Mariner 9 and Viking orbiter images of each crater, these data indicate that the dark crater-floor units in some regions have different thermal properties than those in other regions [7–9]. Figure 1 shows thermal inertia means and standard deviations for dark intracrater units in nine different regions. Thermal inertias were computed using the Viking thermal model of H. H. Kieffer and corrected for atmospheric CO_2 effects using the relationship for a dust-free atmosphere shown by Haberle and Jakosky [10]. The thermal inertias and interpreted particle sizes in Fig. 1 are regarded as upper limits, with lower limits (due to suspended dust in the atmosphere) perhaps 50–200 J m^{-2} s$^{-0.5}$ K^{-1} less than shown [10,11]. However, because the atmosphere had a nearly uniform dust opacity from L_s 344°–125° over the regions examined [12], the relative differences between regions in Fig. 1 are genuine [9].

The thermophysical differences illustrated in Fig. 1 [also see 7–9] are probably related to regional variations in the amount of surface covered by sand and perhaps dunes. In two of these regions, Hellespontus and Oxia, the thermal differences are consistent with an observed difference in the morphology of dunes comprising the dark features. In Hellespontus there are large transverse dunes while in Oxia there are fields of small barchans [2,9,13]. The regional differences are independent of the exact thermal inertia and particle size inferred for each, but sand (0.06–2 mm) is probably the dominant particle size [5,9,14].

In an unvegetated environment, the form and scale of eolian sand deposits are functions of sand availability, grain size distribution, wind energy and directional variability, the presence of topographic obstacles (e.g., crater walls), and climatic variations that might affect any of these factors [15]. In terms of sand-deposit morphology, grain size is probably not a significant control except among zibars [16]. Barchan and transverse dunes are typical of unidirectional wind regimes; their differences are largely considered a function of "sand supply": the amount of loose sand available for eolian transport in a region [17]. Barchans form in areas of low sand supply, though transverse dunes do not form exclusively in places of high sand supply [18]. Transverse dunes on Mars can be large deposits like those in Hellespontus or they can be small and difficult to identify without high-resolution images (an example occurs in Pettit Crater [19]).

To first order, the areal coverage of eolian sand (dunes, drifts, sheets) may be the main factor causing the observed regional differences in the thermal properties of low-albedo intracrater units [8,9]. The percentage of dune cover [8] may be similar among craters within a given region, but different between regions. The amount of sand transported and deposited is likely related to two main factors: sand supply and wind regime.

Sand sources that are regional in extent might include pyroclastic deposits laid down over a vast area, or perhaps fluvial and lacustrine strata. Detection of such sources will require high-resolution imaging or investigation on the planet's surface to find deposits or outcrops of volcaniclastic or fluviolacustrine sandstones from which dark sand might have eroded. Location of sand sources will also require remote multispectral observations to determine the mineralogy of the sediment and to trace wind-worked sand back to source areas.

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53 91 NBS ONLY

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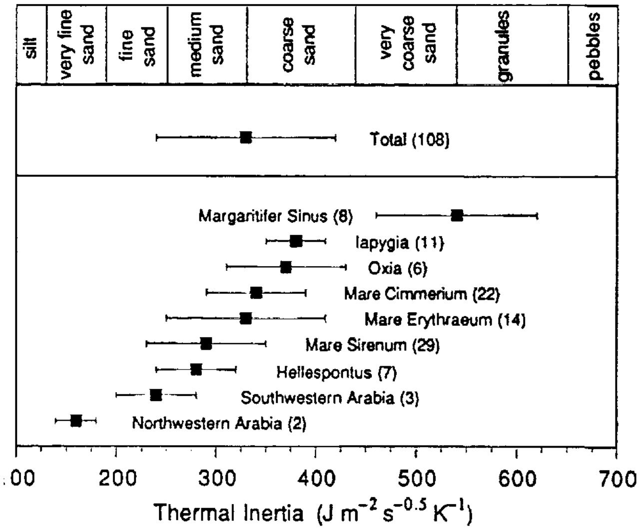

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