THE MARTIAN DUST CYCLE: A PROPOSED MODEL; *Ronald Greeley, Department of Geology and Center for Meteorite Studies, Arizona State University, Tempe, AZ 85287*

Martian dust storms have long been held in fascination. Yet, despite more than a decade of study, many of their characteristics and associated processes remain enigmatic, including the mechanisms for dust raising, mode(s) of settling, and the nature of dust deposits. However, observations of Mars dust, considerations of terrestrial analogs, theoretical models, and laboratory simulations permit the formulation of a ***Martian Dust Cycle Model*** (Fig. 1) which consists of three main processes; (a) suspension threshold, (b) transportation, and (c) deposition; two associated processes are also included: (d) dust removal and (e) the addition of "new" dust to the cycle. Although definitions vary, "dust" includes particles <4 to ~60 μm in diameter, which by terrestrial usage includes silt, loess, clay, and aerosolic dust particles.

Suspension threshold. Perhaps the least understood aspect of martian dust storms is the mechanism(s) for putting dust into suspension (1). Because of the low density atmosphere, extremely high winds are required to raise loose dust of the size inferred for martian dust. Although some dust may be raised by these high winds, most investigators invoke other threshold mechanisms. Dust devils may be one such mechanism; laboratory experiments show that vortical wind shear is very efficient in raising particles (2). With the discovery of dust devils on Mars (3) this possible mode of dust-raising is enhanced. Outgassing of volatiles (CO_2 or H_2O) from the regolith in response to changes in atmospheric temperature/pressure has also been suggested as a means of injecting dust into the atmosphere (4,5). Although slow outgassing does not cause dust injection, it can lead to surface fracturing and fissuring, which may be important in the "aggregate" mode of dust-raising discussed below.

Because sand-size grains are more easily moved than dust, it has been suggested that saltating sands could act as "triggers" to set dust into suspension (6,7). Laboratory experiments show this to occur, although in some circumstances, the saltating sands merely "indent" the surface without dislodging the dust (1). Sand "triggering" has been proposed for dust-raising in Australia in reference to "***parna***", which may be an analog to martian dust deposits. Parna is an aboriginal word meaning "sandy and dusty ground", used by Butler (8) for the extensive deposits that mantle parts of southeast Australia. The deposits consist of two components, dust (~2 μm) and large grains (~100 μm) termed as ***companion sand*** (9). Field studies show prevailing winds when the deposits were formed, possible source regions, and particle size distributions as a function of transport distance. Butler proposed that parna was transported in suspension as aggregates equal in size to the companion sands. Multiple layered deposits suggest climatic cycles in which clay was produced by chemical weathering during humid periods and redistributed by winds during more arid periods. Pre-existing sand dunes served as one source for the parna. Dust within the sand dunes was mobilized by triggering of the sand, which then became the "companion" component. Westerly winds then transported the aggregates in suspension more than 650 km where they settled as a uniform blanket over all terrain features--an aspect cited as evidence for transport via suspension. Once deposited, the pellets disaggregated, forming a matrix containing evenly-distributed sand grains. As discussed previously (10), parna may be an analog for the threshold, transportation, and deposition of some martian dust.

The third general mechanism of dust-raising involves ***aggregates*** (11) ("dust"-size grains collected into sand- and larger-size clumps). In addition to parna, four other sources of aggregates may occur on Mars: (a) deposits settled from the atmosphere as part of the dust cycle, (b) ancient lake bed deposits, similar to clay pellets derived from playas on Earth, (c) aggregates derived from frothy/crusty surfaces generated by fluctuations of saline ground water, and (d) crusty/cloddy weathering surfaces which may be disrupted, as by outgassing (discussed above). Aggregate strength is variable, depending on mode of bonding. Because the wind speeds on Mars required to set particles into motion are high, Sagan et al. (12) proposed that holocrystalline grains would be pulverized into fine grains by the "kamikaze" effect. If aggregates were involved, the destruction would be even more effective because of their low strength. Wind tunnel experiments with aggregates show that as they lift above the surface, they rupture into dust clouds (1). Thus on Mars, disaggregation may occur via "kamikaze dust explosions".

Transportation. The movement of dust in both local clouds and as global transport is documented through earthbased and spacecraft observations. Pollack et al. (13,14) and Haberle (15) have developed models to predict the patterns of transport and provide the key to this part of the dust cycle.

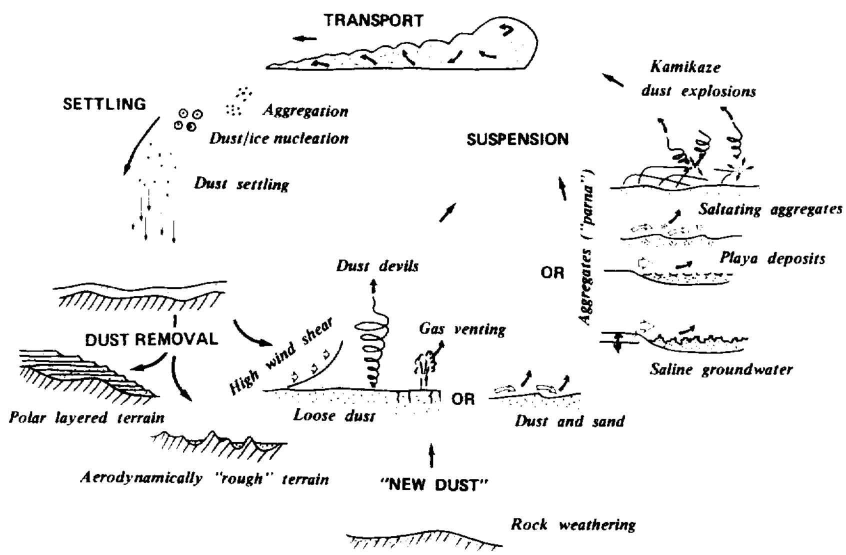

Fig. 1. Diagram of proposed Martian Dust Cycle.

Deposition. With a decrease in driving energy for dust clouds, in time particles settle from the atmosphere. However, because of possible "feedback" mechanisms (14), one of the problems in the dust cycle is how to shut-down dust storms. One mechanism involves the accretion of ice on dust grains (13). Aggregation of grains may also occur via electrostatic bonding, a mechanism demonstrated in laboratory experiments (11) and observed in volcanic dust clouds. Lee has shown (16), however, that the settling rate of larger grains (either ice/dust or dust/dust) is a function of the grain density and diameter, both of which change during accretion.

With settling and deposition, the cycle may be completed and the stage set for dust-raising to initiate the next cycle. However, in addition to the dust threshold, transport, and deposition components of the cycle, dust may be removed from the cycle, and "new" dust may be added.

Dust removal. On Earth, the largest "sinks" for dust removal are the oceans. Although these sinks are lacking on Mars, there are other areas where dust may be removed from the cycle. These include the polar regions (layered deposits) and surfaces that are aerodynamically rough such as impact ejecta fields, terrain that has been severely fractured by tectonic and other processes, and some lava flows. Once deposited on these surfaces, the dust would be difficult to remove until the roughness elements were effectively buried.

"New" dust. Dust may be added to the cycle by a variety of mechanisms on Mars, including chemical and physical weathering (clays are the normal end product of weathering on Earth), impact cratering, volcanism, and tectonism.

In summary, the proposed Martian Dust Cycle inter-relates many of the previously proposed aspects of martian dust, and introduces some new concepts, such as "kamikaze dust explosions".

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