MASS TRANSPORT BY AEOLIAN SALTATION ON EARTH, MARS AND VENUS: THE EFFECTS OF FULL SALTATION CLOUD DEVELOPMENT AND CHOKING.

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The purpose of this study is to be able to predict the characteristics of particle motion and the quantity transported by the wind under a variety of planetary environmental conditions. Aeolian transport of surficial material is an important part of the sedimentological cycle, and, on Earth, aeolian activity can strongly affect land utilization and habitability. Consequently, terrestrial aeolian processes have been extensively studied. Numerous expressions for the quantity of material moved in saltation as a function of wind conditions and particle type have been derived (see Greeley and Iversen, 1985, for review). However, these studies do not distinguish between the contribution of particle speed and particle concentration to the overall saltation flux. The wind speed range over which the saltation flux predictions are valid is sensitive to particle concentration, particularly in non-terrestrial cases. At wind speeds near saltation threshold, the predictions do not become accurate until the saltation is fully developed, i.e., when the particle concentration (and with it the particle flux from the surface) is high enough to fully mobilize surface material. At sufficiently high wind speeds, saltation is retarded when the particle concentration reaches a value at which mid-air collisions become common, interfering with the orderly transfer of momentum from wind to particles aloft to surface. This condition has been termed "choking" because too much material is moving in response to the wind stress to allow smooth flow (Williams and Greeley, 1985).

Two wind tunnels were used for this study: an open-circuit, terrestrial environment wind tunnel (ASUWT) and a closed-circuit tunnel capable of operating at venusian atmospheric density (for descriptions, see Greeley et al., 1985 (ASUWT) and Greeley et al., 1984 (VWT)). Particle concentration was determined by measuring particle speed and particle flux at the same height in the saltation cloud. Particle speed was measured using a particle velocimeter modified from a USDA design (Schmidt, 1977). Particle flux was measured using a stack of particle collectors (see Greeley et al., 1985). The mass concentration at the measurement height is the local mass flux, q, divided by the average particle speed, Vp. The particle concentration at that height is the mass concentration divided by the mass of an average particle.

The conditions necessary for full saltation development can be examined in the wind tunnel by measuring the total saltation flux, Q, and the particle speed near the surface. The upward particle flux from a unit surface area, Go, is Q divided by the average saltation pathlength, L. The horizontal momentum available for transfer to the surface is Go x Vp, per unit surface area. If gravitational differences are accounted for, surfaces composed of similar materials should require the same momentum availability for full saltation. Measurements taken at just above saltation threshold in the VWT for quartz particles of 250-300 μm diameter indicate that saltation becomes fully developed when the momentum available is ~3 gm cm/sec per unit surface area. Similar measurements in ASUWT under terrestrial conditions yield a value of ~2 gm/cm sec. If a value of ~1.5 gm/cm sec is considered, the lower value indicating the difficulty of obtaining measurements very near saltation threshold, then the corrosponding minimum saltation flux necessary for full saltation development on Mars is ~0.6 gm/cm sec (Williams and Greeley, 1986). Using the saltation flux equation in White (1979), the wind speed required for full saltation is ~10% above threshold. The presence of rocks on the martian surface further disperses the saltation cloud by increasing the rebound height of saltating particles. The saltation cloud, therefore, remains poorly developed, with less material in motion than predicted by application of equations derived for terrestrial conditions.

Choking of the saltation cloud due to high particle concentration does not occur on Mars, but can be significant on Earth and it certainly is on Venus. The onset of choking was determined in the ASUWT by observing the change in particle speed at a height of 2 cm as the wind speed increases. As the saltation cloud grows, the particle speed increases but the ratio of particle speed to freestream wind speed decreases, due to the velocimeter becoming relatively lower in the saltation cloud as the cloud thickens. The onset of choking is inferred to occur when the actual particle speed at 2 cm height decreases. This was observed in ASUWT for particles of walnut shell (density ~ 1.1 gm /cc) and quartz of 170-211 µm diameter; larger particles were not observed to display choking behavior. The walnut shell particles showed an actual drop in speed at 2 cm height when the freestream wind speed exceeded ~10.5 m/sec (2.0 x threshold); the quartz particles at wind speeds above ~12.5 m/sec (2.5 x threshold). The critical particle concentrations are ~20 particles/cc for walnut shell and ~10 particles/cc for quartz. The momentum available to the surface is about the same in each case; the difference in critical particle concentration is a reflection of the longer pathlength of the less massive walnut shell. Particle pathlengths on Venus are 1-2 orders of magnitude shorter than on Earth; the "compression" of the particles in saltation into the small volume near the surface causes choking to readily occur.

A summary of saltation behavior is as follows. On Earth, saltation fully develops at near-threshold wind speeds and rarely chokes. On Mars, saltation becomes fully developed only at favorable locations and at wind speeds well above threshold. The martian saltation cloud has an insufficient particle concentration to cause choking, particularly over a partially rocky surface. On Venus, full saltation occurs at wind speeds very near threshold, but saltation flux will increase less rapidly than expected at relatively modest wind speeds due to choking.

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