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REPLY

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Rubincam (1986) states that accretion of meteoritic dust, e.g., the Brownlee particles, by the earth is too small to account for the dust mantles invoked by Frank et al. (1986) to suppress the vaporization of H_2O from the surfaces of the small comets. For this reason Frank et al. (1986) did not identify the major constituent of these cometary mantles as the Brownlee particles. However the topic of the possible nature of these cometary mantles deserves further attention.

An upper limit for the vaporization rate of H_2O for these small comets can be estimated from upper limits for the density of pick-up hydrogen ions in the solar wind at 1 A.U. The reader is cautioned that most unknown quantities in the following discussions are necessarily order-of-magnitude estimates. The density of the small comets at the earth's orbital position and outside of its gravitational field is $\sim 3 \times 10^{-26}$ /cm^3. Due to the rapid increase of H_2O vapor pressure in the small comets with decreasing heliocentric radial distance it is presumed to be likely that the comet density is considerably lesser than the above value at the orbit of Venus. If an average density of $\sim 3 \times 10^{-27}$ comets /cm^3 is assumed for the region between the earth and Venus orbits, then the production rate of water vapor, H_2O molecules/cm^3-sec, is about $3 \times 10^{-27} \times A \times R$, where A is the surface area of a 12-meter diameter comet and R is the average vaporization rate in units of H_2O molecules/cm^2-sec. If the hydrogen from H_2O is completely converted to $2H^+$ by charge exchange and photoionization, then the corresponding H^+ density at 1 A.U. is $6 \times 10^{-27} \times A \times R \times L/V$, where L is the radial distance between the earth and Venus orbits, $\sim$ 0.3 A.U., and V is the solar wind speed, $\sim$ 400 km/sec. Thus an approximate relationship between the pick-up H^+ density at 1 A.U., $n(H^+)$, and the cometary vaporization rate is $n(H^+) \simeq 3 \times 10^{-15}$ R. For pure water snow and comet P/Encke $R \simeq 3 \times 10^{17}$ and 10^{16} H_2O molecules/cm^2-sec, respectively, at 1 A.U. (Delsemme, 1982). The corresponding pick-up ion densities $n(H^+)$ are $\sim 10^3$ and 30 cm^{-3}, respectively, or factors of ten or more above solar wind ion densities. Thus suppression of the vaporization rate with a mantle or another mechanism is required.

An upper limit for the pick-up ion densities may be gained from solar wind ion measurements. For an interplanetary magnetic field orientation at large angles to the radially outward solar wind ion flow, the H^+ ions are expected to be observed at an energy/unit charge of approximately 4 times that of the solar wind protons, or alternatively identified as He^+, with an electrostatic analyzer. Bame (1972) presents measurements of the solar wind ion spectra that display a small intensity at the anticipated energy for pick-up H^+ ions. He notes that the appearance of this ion distribution is sporadic and that the ions are probably not of solar or interstellar wind origins. We suggest here that these ions may be the H^+ pick-up ions from the small comets. From such solar wind ion measurements an upper limit for $n(H^+)$ at 1 A.U. is $\sim 10^{-3}$ to 10^{-4} cm^{-3} if no thermalization of these pick-up ions is assumed. The corresponding range of H_2O vaporization rates is $R \simeq 3 \times 10^{10}$ to 3×10^{11}/cm^2-sec.

Fanale and Salvail (1984) consider the Knudsen flow of water vapor through a solid porous medium and apply their findings to extinct comets. The vapor pressure of the water ice is exceeded by the weight of the porous mantle in the stable configuration. For mantle thicknesses of a few centimeters vaporization rates are as low as $R = 3 \times 10^9$ to 3×10^{10} H_2O molecules/cm^2-sec. Thus a porous mantle with thickness $\lesssim$ 1 cm appears to be adequate for limiting the vaporization rates of the small comets. Because the comet mass, and hence surface gravity, is small then the tensile strength of the mantle or water snow may replace the mantle weight as the mechanism for vapor containment.

If the mantles of the small comets are 1 cm in thickness and with density 0.1 gm/cm^3, then the accretion rate of mantle material in the earth's atmosphere is $\sim 5 \times 10^{12}$ gm/year. The corresponding upper limit for the influx of Brownlee meteoritic material, with particle diameters $\gtrsim$ micrometer, is $\sim 10^{11}$ gm/year from measurements above the earth's atmosphere, on the lunar surface and from deep-sea sediments (cf. Brownlee, 1978). This latter influx corresponds to a mantle thickness of $\sim 2 \times 10^{-2}$ cm. Even for this upper limit for Brownlee particle accretion the corresponding mantle thickness for the small comets appears inadequate. However, it should be noted that the mantles of the small comets should be injected deeply into the atmosphere thereby requiring a particle determination at altitudes $\lesssim$ 50 km and thus below satellite altitudes. Substantially larger accretion rates of possibly extraterrestrial dust as taken at balloon and rocket altitudes are reported in the literature (see summary by Brownlee, 1978).

An undetermined, but small fraction of the small comets may be disrupted at higher altitudes above the earth than the several thousands of kilometers estimated by Frank et al. (1986). The fragmentation of their mantles may be responsible for the impulsive swarms of micrometeoroids at altitudes $\lesssim 10$ R_E as reported by Fechtig et al. (1979). Estimates of the dust masses of the parent bodies of these swarms are in the range of 10 to 10^6 gm.

The composition of the mantles of these small comets is not necessarily limited to cosmic particles of the Brownlee type and composition. For example, it can be expected that methane is also

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a constituent to be found within these small comets. These small comets are thought by us to be ancient, perhaps dating back to the nebular period of the solar system. Solar wind ion bombardment or ultraviolet exposure of methane is likely to dissociate this molecule and release the hydrogen (cf. Cheng and Lanzerotti, 1978). A mantle comprising carbon dust or perhaps a carbon polymer may be thusly formed on these small comets in the outer solar system over geological time. For such mantles, the required thickness may be considerably less than the 0.1 gm/cm^2 that is used in the archetypical calculation above. Bradley and Brownlee (1986) report the presence of small carbon grains in extraplanetary material that is thought to be of cometary origins. The comet mantles may be an amalgam of mineral grains and carbonaceous material. During passage of the small comets through the thermosphere some fraction of the carbon may react with atomic oxygen in the thermosphere to form CO and CO_2.

Several of our considerations of the nature of the dust mantles prior to publication of the paper by Frank et al. (1986) are outlined above. Rubincam's (1986) argument is one of these considerations. Our conclusion remains that current observational knowledge of cosmic dust does not exclude the existence of the small comets and their mantles.

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