Statistical Evolution of Impact Ejecta from the Earth--Implications for Transfer to other Solar System Bodies

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The evidence that the Shergottite, Nakhlite, and Chassignite meteorites likely originated from Mars and the identification of a meteorite from the moon show that it is possible for material from one planet to reach another in the solar system. Melosh (1985) discussed the mechanism of spallation that allows large fragments to get off a parent body, some with very low shock levels. Additionally, he argued (Melosh 1988) that if Mars material reached earth, it seems reasonable that earth material might have reached Mars, perhaps carrying with it viable microorganisms and spores. Examining the exact orbital mechanics of transporting the material to the other planets from earth would require extensive numerical integrations of the orbits of the particles and the 6 or seven planets in question. Since the exact initial conditions are not known, hundreds of runs would be required to determine the outcome's sensitivity to various permutations. Such an analysis could at best provide only a statistical estimation of a particle's transport time and efficiency. A Monte Carlo simulation is clearly the reasonable alternative.

We developed an algorithm based on the theory of Öpik (1976), who models the general n-body problem as a series of independent two body interactions. This approach provides a statistical treatment of the orbital evolution of interplanetary material. Wetherill (1984) applied the theory to the SNC problem, showing that particles near Mars orbit can be transported to earth and that the majority of these arrive in less than 10 million years. Our algorithm was tested against the calculations of Wetherill (1984), using the same initial conditions which assume that Martian ejecta are isotropically distributed in a reference frame moving with the planet and an ejection velocity of 5.64 km/sec (corresponding to a 2.5 km/sec velocity after Mars escape) with very similar results. We have applied this model to study the fate of terrestrial ejecta. One typical simulation consisted of 1000 particles, and assumed a post-escape velocity of 2.5 km/sec distributed in random directions in a reference frame at rest with the earth. This resulted in 508 planetary impacts and 492 ejections from the solar system. The majority of the impacts (291) were onto Venus, 165 returned to earth, 20 dropped onto Mercury, 17 made it to Mars, 14 impacted Jupiter, and 1 terminated at Saturn. 54% of the ejected particles had their last encounter with Mercury (after already evolving to high eccentricities), 42% were ejected by Jupiter, and small fractions were ejected by each of the other planets. About 1.5% of the particles saw fiery doom in solar encounters. Other runs indicate the same general trend. The simulations show that particles are most likely to evolve inward toward the sun. This makes Mars is a particularly difficult target in connection with its small cross section and large orbital path. Figures 1, 2, and 3 show the time evolution of the earth ejecta that impacts earth, Venus, and Mars respectively. Due to the small number of Martian impacts, the statistical significance of figure 3 must be viewed with caution.

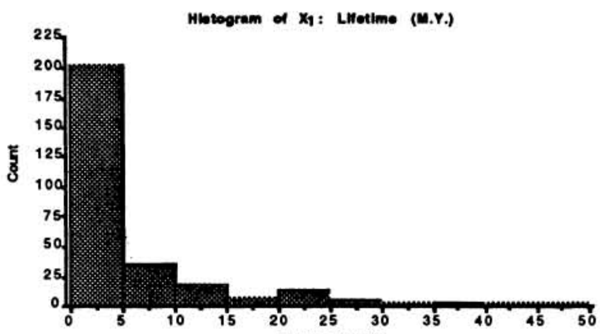

Figure 1: Time Evolution of particles impacting Venus

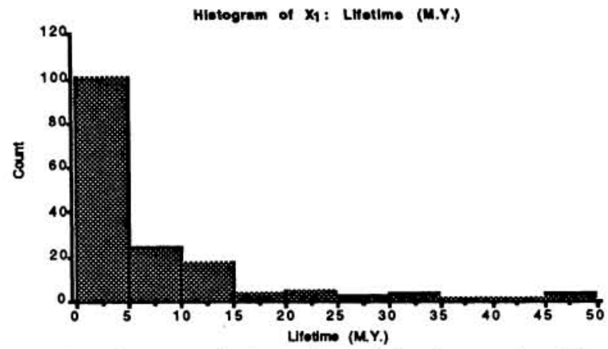

Figure 2: Time evolution of particles impacting Earth.

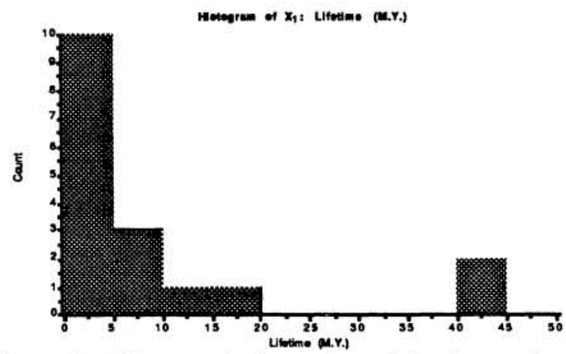

Figure 3. Time evolution of particles impacting Mars.

The simulations described above imply that while it is possible that earth ejecta does impact Mars the probability of it doing so is smaller than Mars ejecta impacting earth. First, the escape velocity of earth is much higher than Mars so the size and velocity of impactor must be larger to propel the material out of the earth's gravitational field. Melosh (1988) argues that it is likely that impacts making craters >100 km is diameter would loft near surface earth material to speeds greater than escape velocity. This is a much larger impact than is necessary to remove material from the moon or Mars and represents a smaller fraction of the impacts that have hit the planet since the development of life. Second, these simulations show that earth ejecta is only approximately 10% as likely to impact Mars than Mars material is to impact earth. More runs are needed to establish these statistics with a high degree of confidence, particularly the time evolution of earth ejecta arriving at Mars

These calculations also have an important bearing on the SNC meteorite controversy: It has often been noted that a far greater mass of putative Martian meteorites has fallen to the earth in historic times than lunar meteorites. A number of explanations of this apparent anomaly have been proposed, but one of the most plausible has supposed that the residence time of lunar ejecta in heliocentric orbit is much shorter than that of Martian ejecta. If this were the case, the current dearth of lunar meteorites could be merely statistical: there just hasn't been a large impact on the moon recently enough for us to continue to receive its ejecta. However, Fig. 2 demonstrates that the mean residence time of terrestrial ejecta in the earth zone is comparable to that of Martian ejecta (Wetherill 1984). Other computations using a model similar to that described above show that lunar ejecta have residence times similar to those of terrestrial ejecta, so that the apparent abundance of Martian meteorites compared to lunar meteorites cannot be due to a mere difference of residence times.

REFERENCES: Melosh, H. J. 1985. *Geology* **13**, pp 144-148; Melosh, H. J. 1988. *Nature* **332**, pp 687-688; Öpik, E. J. 1976. *Interplanetary Encounters*, Elsevier Scientific Pulbishing Company, Amsterdam; Wetherill, G. W. 1984. *Meteoritics* **19**, pp. 1-12