Implications for the Origin of the Objects Responsible for the Period of Late Heavy Bombardment from the Terrestrial Planet Cratering Record; R.G. Strom, Department of Planetary Sciences, University of Arizona, Tucson, Arizona 85721

In the inner Solar System, the heavily cratered terrain on the Moon, Mercury, and Mars all have similar size/frequency distributions representing the period of late heavy bombardment. On Mercury and Mars, there is a paucity of craters less than about 40 km diameter relative to the Moon. This paucity of craters is probably the result of crater obliteration by intercrater plains formation on Mercury and both intercrater plains and atmospheric erosion and deposition on Mars.

A comparison of the cratering curves for the Moon, Mercury, and Mars shows that they are laterally displaced with respect to each other at diameters between about 40 km and 150 km, where the curves are probably unaffected by erosion and deposition and where the statistics are relatively good. They are displaced in such a manner that higher impact velocities are required at planets with smaller heliocentric distances, i.e., larger craters at Mercury and smaller craters on Mars compared to a given size crater on the Moon. This is consistent with a single family of objects in heliocentric orbits. The Martian curve is laterally displaced to smaller diameters by about one $\sqrt{2}$ diameter bin compared to the lunar curve, while the Mercurian curve appears to be displaced to larger diameters by about a half a $\sqrt{2}$ diameter bin compared to the Moon.

In order to determine the orbital elements of the objects responsible for the period of late heavy bombardment, Monte Carlo computer simulations were devised to attempt to reproduce the observed displacements of the crater curves from impact velocities appropriate for objects with various semimajor axes and eccentricities. In these simulations, a projectile size/frequency distribution was recovered from the lunar highlands cratering curve using a modified Holsapple-Schmidt crater scaling law and randomly selected impact velocities derived from objects with semimajor axes from 0.5 to 2.5 AU and eccentricities from 0.5 to 0.9. This projectile population was then used in another Monte Carlo simulation to generate crater size/frequency distributions on the Moon, Mercury, and Mars using randomly selected impact velocities derived from objects with various orbital elements.

To date, four general cases have been tested: 1) objects with short period-like comet orbits with semimajor axes between 3.5 to 5.5 AU and eccentricities from 0.5 to 0.95, 2) objects confined to the inner Solar System in orbits confined to the zones within the orbits of Mercury, Earth, and Mars, i.e., narrow ranges of semimajor axes and small eccentricities, 3) objects confined to the inner Solar System with semimajor axes grouped between 0.5-1.5 AU, 1.5-2.5 AU, 2.5-3.5 AU and 0.5 to 2.5 AU, and eccentricities between 0.5 and .9, and 4) a special case for objects with semimajor objects close to that of Earth and large eccentricities from 0.7 to 0.9.

Because of the $\sqrt{2}$ crater binning, the random selections of impact angles, impact velocities, and projectile densities, only orbital elements that result in large velocity differences (about a factor of 1.4-1.5) between the Moon, Mercury, and Mars produce the observed lateral crater curve displacements. Preliminary results indicate that cases 1 and 2 produce crater curves with no lateral displacements although there are moderate differences in the RMS impact velocities. Only case 3 for semimajor axes between 0.5 and 1.5 AU and case 4 produce crater curves that show lateral displacements similar to those observed. These preliminary results indicate that the objects responsible for the period of late heavy bombardment at the terrestrial planets were confined to the inner Solar System.

Other cases have yet to be tested, but at present the simulation which best matches the lateral displacements of the crater curves is case 4 in which the semimajor axes are close to that of Earth's and the eccentricities are large (> 0.7). If this should prove to be true after other simulations have been conducted, then it suggests that the origin of the objects responsible for late heavy bombardment in the inner Solar System is related in some way to the Earth-Moon system. One possible explanation may be the collisional event of the Earth with a planet-sized object that has been proposed to account for the origin of the Moon. A mechanical analysis of such a collision (Melosh and Sonett, 1987; Melosh, personal communication) indicates that as much as 1.5 lunar masses could be ejected in the form of vapor at velocities as high as 30 km/sec. Solid objects entrained in this vapor cloud may reach velocities of about 10-15 km/sec (Vickery, 1986), and could possibly attain orbits with large eccentricities, and semimajor axes similar to Earth's. This material may have been responsible for the period of late heavy bombardment if the time scale for sweep-up by the terrestrial planets was comparable to the time scale for late heavy bombardment ($\sim 7 \times 10^8$ yrs.). Until additional simulations and dynamical studies of material ejected from Earth by an Earth/planet-size collision are completed, this scenario should be considered highly speculative.

References

1. Melosh, H.J., and C.P. Sonett, 1986. When Worlds Collide: Jetted Vapor Plumes and the Moon's Origin, in *Origin of the Moon* (Ed. Hartmann, Phillips, and Taylor), Pub. Lunar and Planetary Institute, Houston, Texas, pp. 621-642.

2. Vickery, A., 1986. Effect of an Impact-Generated Gas Cloud on the Acceleration of Solid Ejecta, *J.G.R.*, **91**, pp. 14,139-14,160.