ARE COMETS RESPONSIBLE FOR THE PERIOD OF HEAVY BOMBARDMENT?;
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The cratering record in the inner Solar System and at Jupiter and Saturn indicates that at least five different crater populations occur at various locations in the Solar System (1,2). The heavily cratered regions of the terrestrial planets and outer planet satellites represents the period of heavy bombardment early in Solar System history. The crater population superposed on the lightly cratered plains of the Moon and Mars is very different from that in the heavily cratered regions of these bodies and almost surely represents the combined impact of comets and asteroids from the end of plains formation up to the present, i.e., during the last ≈ 4 B.Y. At present, the only objects that cross all planetary orbits are comets. Therefore, it has been proposed that comets were responsible for the period of heavy bombardment throughout the Solar System (3). The different crater populations on the heavily cratered surfaces of the inner planets, at Jupiter and at Saturn have led to the alternative interpretation that the period of heavy bombardment was due to different families of objects originating in those parts of the Solar System in which the different crater populations are found.

The Solar System cratering record in conjunction with an appropriate crater scaling law can be used to test whether comets have been the primary contributors to the period of heavy bombardment. The size/frequency distribution of the objects responsible for the crater populations can be recovered from the cratering record using the Holsapple-Schmidt (4) crater scaling law. Crater scaling parameters vary greatly for the various planets and satellites on which the different crater populations occur. It is conceivable that when these differences are taken into account the size/frequency distribution of the projectiles may be similar for two or more crater populations. Thus, one population of impacting objects may account for more than one crater population. For example, if the Callisto crater curve was shifted to the right (larger diameters) by two $\sqrt{2}$ diameter intervals, it would more closely match the inner Solar System highlands curve.

The orbital evolution for short-period comets over a period of 821 years has been derived by Carusi et al. (5). These orbital elements can be used to derive the impact velocity distribution for planet-crossing short-period comets. This results in 26 velocities for the Moon, 66 for Mars, 101 for Callisto, and 48 for the Saturnian satellites. A computer simulation was used to derive the projectile (comet nucleus) size distribution from the crater size distribution of the heavily cratered regions of the Moon, Callisto, and Rhea using the Holsapple-Schmidt crater scaling relation. In this computer simulation, impact velocities were randomly selected and applied to unbinned crater diameters. The projectile diameters were then binned into $\sqrt{2}$ diameter intervals. The curves show that the projectile size distributions closely mimic the crater curves. Furthermore, the Callisto curve has been shifted to the left (smaller diameters) relative to the Moon making the disparity between the projectile diameter distributions much greater than for the crater diameter distributions. The difference between the Rhea curve and those of Callisto and the Moon is more uncertain. The small dynamic range of Saturnian satellite crater diameters results in only two size

.ins which lie between the Callisto and lunar curves. This suggests a different size distribution than Callisto and the Moon, but the error bars are relatively large. In any event, the large disparity between the derived comet diameter size distributions for the Moon and Callisto strongly suggests that comets were not the major contributor to the period of heavy bombardment.

Another way of analyzing the problem is by using the crater scaling equation to solve for the impact velocity of a constant projectile diameter so that the downturn in the lunar highlands and Callisto curves coincide. In this case, a given size projectile must make a 100 km diameter crater on the Moon and a 50 km diameter crater on Callisto. The required impact velocities on the Moon are 30 times faster than on Callisto for a similar size projectile. This velocity difference is totally unrealistic for either short- or long-period comet orbits. For example, a 100 km diameter crater on the Moon requires a comet nucleus 10 km in diameter impacting at 45 km/sec. To produce a 50 km diameter crater on Callisto with the same sized nucleus requires the unrealistic impact velocity of 1.5 km/sec., or 1.6 times less than Callisto's escape velocity. The RMS impact velocity for short-period comets at the Moon and Callisto is 20 and 14 km/sec. respectively; for long-period comets it is 52 and 26 km/sec. respectively. Thus, the maximum difference between the RMS impact velocity at the Moon and Callisto (long-period comets at the Moon and short-period comets at Callisto) is only a factor of 3.7 compared to the factor of 30 required to account for the differences in cratering records of the two satellites.

The differences in the size distribution of projectiles derived from the cratering record and the totally unreqalistic comet impact velocities required to make the lunar and Callisto crater curves coincide, strongly indicates that comets were not the major cause of the period of heavy bombardment unless their size distribution in the inner Solar System was radically different from that at Jupiter. This is also unlikely because cometary nuclei would have to be on average about four times larger in the inner Solar System than at Callisto; just the opposite of what would be expected because comets rapidly lose mass in the inner Solar System compared to the outer Solar System.

REFERENCES

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