CRATER PRODUCTION ON VENUS AND EARTH BY ASTEROID AND COMET IMPACT

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Observations of the impact-crater record on the surface of Venus obtained by means of the Venera 15 and 16 spacecraft (Ivanov et al., 1986; Basilevsky et al., in press) have stimulated renewed interest in the cratering rate on Venus (e.g., Schaber et al., in press). Accordingly, we have carried out new calculations of the collision probabilities of asteroids and comets with Venus based on the orbits of the known Venus-crossing asteroids and comets. For comparison, we recalculated asteroid and comet collision probabilities and cratering rates on the Earth and Moon and normalized the estimated cratering rates on Venus to those of the Earth.

Of 71 Earth-crossing asteroids discovered through October 1986 (one more than reported by Shoemaker and Shoemaker, this volume), 48 currently pass perihelion inside Earth's orbit and 24 pass perihelion inside the orbit of Venus. For these objects, approximate collision probabilities with Earth and Venus can be calculated by means of Opik's (1951) equations. Because we use the mean orbital elements of the Earth and Venus in these equations, collision probabilities with the Earth can also be calculated for three additional asteroids that pass perihelion inside the mean aphelion of Earth's orbit.

We are primarily concerned here with calculating the relative collision and cratering rates on Venus and Earth; use of the Opik collision probabilities is expected to yield a satisfactory preliminary estimate of the relative cratering rates from asteroid impact on the two planets. Although Opik's equations lead to significant errors for the collision probabilities of individual asteroids (Shoemaker et al., 1979), the average probability of collision with Earth calculated from Opik's equations for 22 asteroids is only 13% greater than the average obtained by much more rigorous methods. We have neglected the contribution to the total impact rate on Earth of Earth-crossing Amors and the contribution to the impact rate on Venus of an analogous set of asteroids that have part-time overlap with the orbit of Venus. Collision probabilities for these objects can only be obtained by methods based on secular perturbation theory; these much more difficult calculations have been deferred for future study. The part-time overlapping objects contribute only about 25% of the total impact rate; for purposes of this preliminary investigation, we have assumed that the proportion of their contribution to the total impact rate is the same on Earth and Venus.

Cratering rates (number of craters per unit area per unit time) have been derived from collision probabilities by methods described by Shoemaker and Wolfe (1982). Uncertainties about the total population of impactors and their physical properties do not affect our results, as we report only relative cratering efficiencies and relative cratering rates (Table 1). We have assumed that the distribution of physical properties is the same for Venus- and Earth-crossing impactors.

The new mean collision probability with Earth calculated from 48 Apollo and Aten asteroids is 80% higher than the mean collision probability found by Shoemaker et al. (1979) for 22 Apollos and Atens. This increase is due chiefly to the discovery of several asteroids having unusually high collision probabilities with Earth. Half of the total probability of collision with Earth is contributed by 12% of the asteroids in the observed sample of Earth crossers. Because the distribution of collision probabilities is strongly skewed, it is critically important to continue surveys for planet-crossing asteroids in order to obtain reliable estimates of both absolute and relative cratering rates on the terrestrial planets.

The relative asteroid cratering rate shown in Table 1 for Venus (∿0.9 times the cratering rate on Earth) is strictly applicable only to craters large enough for the shielding effect of the Venusian atmosphere to be considered negligible. A correction should be applied to account for an undiscovered class of Venus-crossing asteroids whose orbits are entirely inside the orbit of the Earth. These asteroids are expected to have been captured by repeated encounters with Venus, just as Aten asteroids have been captured in small orbits by combined encounters with Earth and Venus. In the case of Earth, Atens account for 27% of the total estimated asteroid impact-cratering rate. A similar but probably somewhat smaller contribution to the cratering rate on Venus can be expected from the undiscovered class of Venus-crossing asteroids. We tentatively estimate the total asteroid impact-cratering rate on Venus at 1.0 to 1.1 times the rate on Earth.

The relative rates of crater production by comet impact were evaluated from the orbits of long period comets listed by Marsden (1986). Calculations were made for all Earth- and Venus-crossing comets having periods greater than 20 years. The crater production on Earth and on Venus by impact of comets having shorter periods is sufficiently small to be neglected. Orbits are available from Marsden's catalog for a total of 400 long period Earth-crossing comets; 255 of these comets are also Venus crossers. The relative comet impact-cratering rate on Venus, calculated by the methods described by Shoemaker and Wolfe (1982), is 1.14 times the rate on Earth (Table 1). Again, this rate applies only to craters large enough that the shielding effect of the Venusian atmosphere can be considered negligible. Probably few, if any, craters smaller than about 100 km in diameter have been formed by comet impact on Venus (cf. Melosh, 1981; Ivanov et al., 1986; Basilevsky et al., in press).

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Table 1. Crater production on Earth, Venus, and the Moon by impact of asteroids and long period comets

	N	P	A km^2	V km/sec	D	R
Asteroid Impact Craters						
Earth	1.00	0.635×10^{-8}	0.509×10^{9}	17.5	1.00	1.00
Venus	0.48	0.788×10^{-8}	0.460×10^{9}	21.1	1.14	0.88
Moon	1.00	0.241×10^{-9}	0.380×10^{8}	16.1	0.82* 1.07+	0.77* 1.37+
Comet Impact Craters						
Earth	1.000	0.308×10^{-8}	0.509×10^{9}	57.7	1.00	1.00
Venus	0.638	0.414×10^{-8}	0.460×10^{9}	64.3	1.09	1.14
Moon	1.000	0.214×10^{-9}	0.380×10^{8}	57.6	0.98* 1.27+	0.89* 1.58+

N = Number of impactors overlapping orbit of planet normalized to number overlapping orbit of Earth.
P = Mean probability of collision per year per asteroid or mean probability of collision per perihelion passage per comet.
A = Surface area of planet or the Moon.
V = Root mean square impact velocity weighted according to probability of collision (atmospheric retardation neglected).
D = Weighted mean diameter of crater produced by impactor of a given mass normalized to diameter of crater produced on Earth. D is applicable only at diameters greater than the threshold below which the planetary atmospheres shield the surfaces from crater production.
R = Crater-production rate per unit surface area normalized to crater production rate on Earth. R is applicable only at diameters greater than the threshold below which the planetary atmospheres shield the surfaces from crater production.
* Values of D and R calculated for lunar craters smaller than threshold diameter for crater collapse (generally less than 20 km).
\+ Values of D and R calculated for lunar craters larger than threshold diameter for crater collapse (generally greater than 20 km).