POSSIBLE ASTEROIDAL ORIGIN OF SNC METEORITES;
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Shergottites, Nakhlites, and Chassignites are a small group of achondrite meteorites with unusual chemistries, cumulate textures, and anomalously young crystallization ages of 1.3-1.4 b.y. (see [1] for review). Based on evidence of recent volcanic activity on Mars and on various chemical arguments, it has recently been postulated that these meteorites originated on Mars [1-7]. It is physically very difficult to accelerate large masses of rock to the escape velocity of Mars, especially with the relatively minor to nonexistent shock damage observed in the SNC meteorites. We therefore investigate the possibility that they were crystallized from impact melts on a large asteroid or asteroids. We estimate the amount of kinetic energy to produce a crater of a given size from Gault's scaling law [8], and assume that either 50% or 25% of the kinetic energy is partitioned into heat. We distribute the heat in our model in a pattern suggested by the impact melt distribution in Brent Crater [9] and by the radioactivity distribution in Cactus nuclear explosion crater [10], both of which indicate the presence of a melt pocket buried deep in the breccia lens, in addition to a surficial melt layer.

We compute the time evolution of temperature for several locations around the crater. Assuming that the liquidus and solidus of the material are approximately 1200°C and 1000°C, respectively, the time the material spends between these two temperatures is the time available for the formation of the cumulate textures observed in SNC meteorites. In order to get cooling times (from 1200° to 1000°) of 12,500 yr, which we estimate would certainly be long enough for accumulation, our model requires a crater at least 30 km in diameter if 50% of the kinetic energy is converted to heat, and at least 57 km in diameter if 25% of kinetic energy is converted to heat.

The probability of collisions large enough to produce craters this large or larger is estimated from Wetherill's analysis of collisional probabilities in the asteroid belt [11]. His equation for the total probability of collisions for an asteroid of radius R is:

$$P_T = \int_{r1}^{r2} Cr^{-p} P_i (R + r)^2 dr.$$

P_i is the probability that any two objects whose orbits intersect will collide, r is the radius of the impactor, and $dN = Cr^{-p}dr$ is the assumed form of the size distribution of asteroids. The lower limit of integration, r_1, is the estimated size impactor required to produce the minimum size crater required (either 30 km or 57 km), and the upper limit of integration, r_2, is the minimum size impactor which will fragment the target asteroid. Values for P_i, C, p, and r_2 were taken from Wetherill's paper, and r_1 was calculated from Gault's scaling law [8], assuming densities of 3g/cm^3 and an impact velocity of 5 km/s. P_T was computed for each known asteroid large enough to sustain craters at least 30 km or 57 km in diameter and the results summed over all such asteroids. The results are shown in Table 1.

We conclude that it is plausible to assume that there are a number of asteroids large enough to have sustained impacts of sufficient size to produce rocks with cumulate textures and that there is a significant probability of occurrence of such impacts. Furthermore, it is physically much easier to partially fragment the asteroid at a later time by means of a second collision with a minimum of shock damage, and to perturb these fragments into Earth-crossing orbits.

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TABLE 1

Number of Collisions During Lifetime of Solar System as a Function of Different Constants in the Size-Density Distribution Function For Two Cases of Energy Partitioning

A. 50% of Impact Energy Converted to Heat

C	p	Number of collisions
2.81×10^5	3.01	129
6.90×10^5	3.28	29
1.02×10^6	3.40	13

B. 25% of Impact Energy Converted to Heat

C	p	Number of collisions
2.81×10^5	3.01	25
6.90×10^5	3.28	5
1.02×10^6	3.40	2