Comment on "Determining Chondritic Impactor Size from the Marine Osmium Isotope Record"

Joanna V. Morgan, *et al.*

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Paquay *et al.* (Reports, 11 April 2008, p. 214) reported that osmium isotope ratios in marine sediments can be used to determine the size of a chondritic impactor. Their assumptions on the fate of an impacting projectile may need to be reassessed, however, because only a small, unpredictable fraction of the impactor ends up dissolved in seawater.

Paquay *et al.* (*1*) used the decrease in the ^{187}Os/^{188}Os ratio in marine sediments at the Cretaceous-Tertiary (K-T) boundary to constrain the diameter of the end Cretaceous impactor to 4.1 to 4.4 km. This diameter estimate assumes 100% vaporization and dissolution of the projectile in seawater [the lower dashed line in figure 4 in (*1*)]. Similarly, the authors used Ir fluence to calculate a projectile diameter of 6 km and concluded that numerical modelers, who use diameters of 14 to 19 km for the K-T projectile (*2*), overestimate the size of impactors. The calculations in Paquay *et al.* (*1*), however, assume that the entire projectile becomes incorporated in the distal K-T boundary sediments. This is almost certainly not the case, as a substantial fraction of the projectile may survive impact, remain close to the impact site, and/or escape Earth entirely.

In their original paper, Alvarez *et al.* (*3*) predicted that only a fraction of the projectile would be ejected worldwide, with most remaining close to the impact site. They used a ratio of 0.22 for the mass of the projectile that ended up in the distal K-T layer. This was based on the observation that a volume of 18 km^3 was erupted at Krakatoa in 1883 and only 4 km^3 reached the stratosphere. They calculated an impactor diameter of between 6.6 and 14 km from average Ir fluences of 8×10^{-9} g/cm^2 and 72×10^{-9} g/cm^2 in Italy and Denmark, respectively. Using the same calculations as in (*3*), the Ir fluence of 55×10^{-9} g/cm^2 used by Paquay *et al.* (*1*) would lead to a projectile diameter of ~12.5 km, not 6 km.

Simulations of impacts using laboratory experiments and numerical models indicate that the fate of the projectile is dependent on impact target properties, velocity, and angle, as well as projectile size (*4*, *5*). Impacts into deep water greatly increase the chance of survivability of the projectile (*4*), with up to 25% of the projectile failing to be vaporized on impact. For an impactor of the same size and velocity, more projectile material survives if the impact angle is oblique than if it is subvertical (*4*, *5*). Modeling also shows that, as impact velocity increases and impact angle decreases, an increasing fraction of the projectile leaves Earth at greater than escape velocity (*6*, *7*). In contrast, low velocity, subvertical impacts lead to an increasing fraction of the projectile remaining at, or close to, the impact site (*7*).

With the recent advances in computational power, we can now use three-dimensional numerical modeling codes to investigate the fate of a projectile in more detail. In particular, we can better estimate the proportion of the projectile that ends up at the impact site, within the proximal and distal ejecta, or escapes Earth. A recent suite of simulations of the K-T impact were performed (*7*) using a range of impact velocities, impact angles, and target properties, while keeping the diameter of the transient crater constant and equal to the measured value for the Chicxulub crater (*8*). These simulations indicate that subvertical impacts lead to too little projectile material (less than observed) ending up at distal K-T sites, whereas impact angles of 30° or less lead to too much projectile being deposited at distal sites. Simulations with impact angles between these extremes can roughly reproduce the observed Ir fluence, as well as the observed crater size (*7*). The same is likely to apply to Os fluence, even with anticipated differences in vaporization and condensation temperatures.

In the simulations that matched the observed data reasonably well (*7*), the impact velocity varied between 18 and 36 km/s, and impactor diameter between 10 and 14.4 km. The reason that these projectile diameters are smaller than those reported by Ivanov (*2*) is due to his use of low-velocity impacts (12 to 15 km/s). Projectile size is also not a particularly useful measure of an impacting body (mass is better), as assumptions have to be made about density and shape. Densities of meteorites that are measured on Earth (*9*) are typically higher than the densities of bodies with the same composition measured in space (*10*). Orbiting bodies are in tension, are often more porous, and show highly variable densities. If we know crater size but do not know impactor density, velocity, and impact angle, then the best we can do is provide a range of possible projectile sizes—using scaling laws or numerical models. A projectile size of between 4.1 and 6 km, however, cannot produce a crater as large as Chicxulub.

In summary, in terrestrial impacts, the fraction of projectile that ends up dissolved in Earth’s ocean is unpredictable without some knowledge of impactor density, velocity, and impact angle, as well as water depth at the impact site. Although Os isotopes can provide only a very rough estimate of projectile diameter, they do appear to be an exciting new tool for discovering past impact events.

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