ASTEROID AND COMET IMPACTS ON CONTINENTAL AND OCEANIC SITES: COMPUTER SIMULATIONS OF CRATERING AND INFERRED Fe/Ir RATIOS IN EJECTA VAPOR COMPARED WITH Fe/Ir RATIOS MEASURED AT THE K/T BOUNDARY FROM THE SHATSKY RISE (PACIFIC OCEAN); D.J. Roddy, U.S. Geological Survey, Flagstaff, Ariz., R.A. Schmitt, The Radiation Center and Departments of Chemistry and Geosciences, and College of Oceanography, Oregon State University, Corvallis, Oregon, and S.H. Schuster, California Research and Technology, Chatsworth, Calif.

Detailed studies of the K/T boundary show complexity on a global scale in both geochemical and shock metamorphic anomalies, presumably due to multiple impacts events as well as to other natural processes (1,2,3). Understanding the contributions from impact events versus those from other sources is critical in defining the consequences of major energetic events, such as large-body impacts and/or regional volcanism, and their global biologic effects. For example, substantial levels of Ir, noble metals, and the presence of shocked silicates identified in the K/T boundary are attributed to a large impact event(s) that vaporized both impactor and part of the target rocks and ejected vapor, melt, and fine particles into the air. Part of this material, especially the vapor, was then distributed globally in the atmosphere and deposited in a world-wide fallout layer, i.e., the K/T boundary strata (4,5). Unfortunately, direct comparisons between absolute values of fallout, such as condensed Fe and Ir, versus those values predicted from cratering models are complicated due to limited understanding of ejection mechanics, initial distributions with range and time, and different local geologic processes. A better method is to compare ratios of critical materials measured in the field at the K/T boundary with the same critical materials involved in the vapor ejection phase, quantities that can be calculated using both detailed geologic modeling and advanced cratering computer codes.

We have made a set of preliminary comparisons of Fe/Ir ratios using the results from computer simulations of large asteroid impacts into oceanic and continental sites. Our calculations permit direct comparisons of Fe/Ir ratios of ejected vapor with Fe/Ir ratios recently measured in K/T boundary strata on the Shatsky Rise (central Pacific Ocean at K/T time), a section composed of nearly pure carbonate rocks (6). Our computer simulations describe the passage of a 10-km-diameter asteroid through the Earth's atmosphere at 20 km/sec and the subsequent cratering and ejecta dynamics in both oceanic and continental sites as shown in Figure 1 (7). Transient crater diameters are about 100km. Total ejecta masses are listed in Table 1. The amount of target rock vaporized in the continental impact was calculated to be about 0.5% and all of the asteroid was vaporized; essentially all of the vapor was ejected by 120 seconds at high velocities to above the troposphere. We estimate about 0.1% of target rock was vaporized in the oceanic impact. In our calculations, we assumed the average Fe was 19% in a C1 chondritic-type asteroid, 4% (North American Shale Composite) in the continental impact site, and 9% in the oceanic impact site. We assumed the average Ir was 0.48ppm in a C1 chondrite-type asteroid and that the target rock had 0.0002ppm. Consequently, the Fe/Ir ratio of vapor (target rock & asteroid) at the continental impact site is,

$$Fe/Ir = \frac{(0.9x10^{18}gm)\,(4\%) + (1.3x10^{18}gm)\,(19\%)}{(0.9x10^{18}gm)\,(0.0002ppm) + (1.3x10^{18})\,(0.48ppm)} = 450{,}000$$

The Fe/Ir ratio of vapor (target rock & asteroid) in the oceanic impact is,

$$Fe/Ir = \frac{(0.0423x10^{18}gm)\,(9\%) + (1.3x10^{18}gm)\,(19\%)}{(0.0423x10^{18}gm)\,(0.0002ppm) + (1.3x10^{18})\,(0.48ppm)} = 400{,}000$$

Considering the uncertainties in the estimates, the Fe/Ir ratios derived in these calculations are remarkably similar to the weighted means and dispersions of the Fe/Ir ratios measured in the K/T cores from the Shatsky Rise, i.e., 370,000 ±30,000 for pure $CaCO_3$ samples (8).

Within the reliability of the Fe and Ir estimates for the asteroid, we conclude that these calculations can be used to predict reasonable global Fe/Ir ratios and that they tend to support the validity of the crater/ejecta computer modeling. Moreover, comparison between Fe/Ir ratios in the chondritic classes suggest that the LL's and enstatite I compositions may be ruled out as potential asteroid candidates for the K/T event. However, current experimental error and uncertainties in the chemistry of the impactor do limit our capability to distinguish unequivocally between continental and oceanic impact sites.

There are no comet Fe/Ir data to make reliable estimates but calculations based on general assumptions for comets (9) suggest similar results to our calculations for asteroids. Based on other considerations we currently favor multiple comet impacts in continental sites for the K/T boundary event. One reason is that the best age candidate, the Manson structure (65 Ma old), is not large enough to produce the amount of material in the global fallout layer or to produce the necessary Fe/Ir ratios. This suggests that more than one impact occurred, possibly in the Yuccatan region (10). We concur with Hut et. al. (11) that fragmentation into more than one impacting body seems more reasonable with lower-strength comets than asteroids.

In addition, based on the arguments by Alvarez et al. (4,5), Jin and Schmitt (8) calculated that the total Fe, expected in the ejecta (available for global dispersal) from a 100 km diameter crater created by a 10-km-asteroid impact, would consist of asteroidal Fe plus 10-30 times more Fe from terrestrial ejecta, with total Ir derived essentially from the impactor. Because the expected Fe/Ir ratio would have been 10-30 times that of Cl chondrites, one of us (RAS) ruled out a direct asteroid or comet impact and proposed cometary fragmentation in the earth's atmosphere (12). In our opinion now, the calculations by Roddy et al. (7), the work in this paper, and Schmitt et al. (6) negate the special conditions of destruction of large "clean" and "dirty" comets in the earth's atmosphere.

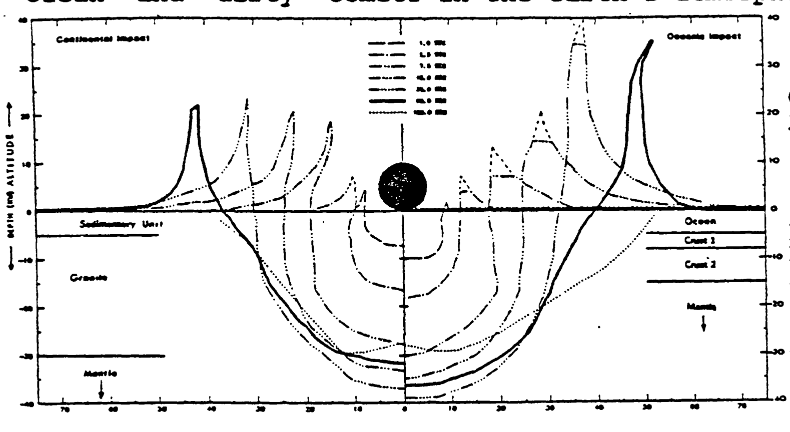

Fig. 1. Profiles showing sequence of formation of the transient craters, uplifting rims, and rebounding floors after asteroid impact at continental and oceanic sites.

TABLE 1. Total Mass (t) and Percentages of Asteroid and Target Ejected at the End of 60 Seconds After Impact at Oceanic and Continental Sites.

OCEANIC CRATER					
Asteroid	Water	Crust 1	Crust 2	Mantle	Total
0.00684×10^{14}	0.464×10^{14}	0.224×10^{14}	0.199×10^{14}	0	0.894×10^{14}
0.8%	51.9%	25.1%	22.2%	0%	100%

CONTINENTAL CRATER				
Asteroid	Sedimentary rock	Granitic rock	Mantle	Total
0.00905×10^{14}	1.65×10^{14}	0.264×10^{14}	0	1.92×10^{14}
0.5%	85.8%	13.7%	0%	100%

Note: Pre-impact mass of the asteroid was 1.3×10^{12} t. By 60 s, all of the asteroid vaporized, and ~52% of the asteroid vapor at the oceanic site and ~70% at the continental site had been ejected. Most of the remainder of the asteroid vapor continued to be ejected to the end of the calculation at 120 s.

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