IRIDIUM AND OSMIUM FLUENCES ACROSS THE K-PG BOUNDARY INDICATE A SMALL IMPACTOR. J. R. Moore[1], H. R. Hallock[2], J. W. Chipman[3], and M. Sharma[4], [1]Dartmouth College, Department of Earth Sciences, HB 6105 Fairchild Hall, Hanover, NH 03755, email: jason.r.moore@dartmouth.edu; [2]Dartmouth College, Department of Earth Sciences, HB 6105 Fairchild Hall, Hanover, NH 03755, email: hannah.hallock@gmail.com; [3]Dartmouth College, Department of Geography, HB 6017 Fairchild Hall, Hanover, NH 03755, email: jonathan.w.chipman@dartmouth.edu; [4]Dartmouth College, Department of Earth Sciences, HB 6105 Fairchild Hall, Hanover, NH 03755, email: mukul.sharma@dartmouth.edu;

Introduction: The impact of a large extraterrestrial body with the Earth ~66 million years ago [1] led to the global deposition of material significantly enriched in iridium, and many platinum group elements (PGEs) which has been detected at >50 locations to date. This material was then incorporated into the sedimentary record by a number of routes, either directly (e.g. associated with spherules that condensed out of the impact vapor cloud [2]), or indirectly (e.g. after dissolution into the oceans [3]). These separate pathways for the various elements that are enriched in the impactor provide the opportunity to draw together independent lines of evidence to investigate the nature of the impactor.

Increased iridium abundances at the K-Pg boundary first allowed Alvarez et al. [4] to hypothesize an impact at this point in geological time. They suggested that iridium peaks in measured profiles through K-Pg boundary sediments in Gubbio, Italy and Stevns Klint, Denmark, were congruent with the impact of an asteroid of between 6 and 14 km diameter (~3×10^{14} to 4×10^{15} kg). With the description of additional K-Pg boundary iridium profiles, it became possible to estimate average global iridium fluences associated with the impact, giving rise to the most recent estimate of 55 ng cm^{-2} [5], that correspond to an impactor diameter of ~7 km.

Methods: Here we reexamine the global iridium fluence record and compare those data to independent osmium fluence data calculated from perturbations of the osmium isotope composition of the oceans across the K-Pg boundary. New iridium fluence data were calculated for all available K-Pg boundary profiles. All profiles with insufficient resolution to calculate accurate fluences (too few or too widely spaced samples) were discarded. These newly calculated high-quality iridium fluences vary by over two orders of magnitude – from 8 ng cm^{-2} to 1087 ng cm^{-2} – but correspond to a global geometric mean of 53 ng cm^{-2} in agreement with previous estimates.

The osmium isotope ratio of oceans at the K-Pg boundary was lowered to 0.157 from a pre-impact background ratio of 0.42 [3] (Figure 1). Using a one-box model approach that assumes a single step decrease in the seawater $^{187}Os/^{188}Os$ ratio resulting from the addition of non radiogenic osmium from the impactor [3], an isotope ratio perturbation of this magnitude requires a global impact-related boundary osmium fluence of 30 ± 2 ng cm^{-2} yielding an Os/Ir fluence ratio of 0.6. Given that the impactor had a composition similar to carbonaceous chondrites with Os/Ir ratio of 1.1 [e.g., 7], either Os and/or Ir fluence estimates are inaccurate.

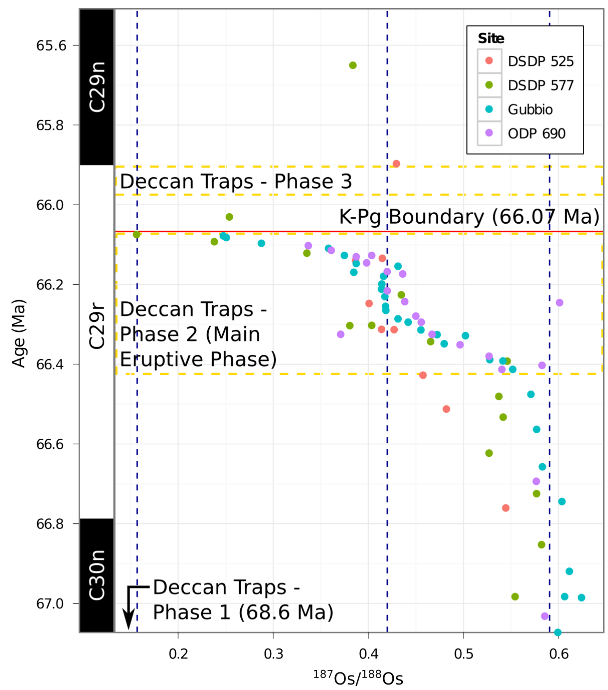

Figure 1 - Osmium isotope ratios across the K-Pg boundary from four sites. Gradual decrease in ratio from 0.6 to 0.42 corresponds to Phase 2 eruptions of the Deccan Traps. Rapid perturbation at ~66 Ma produced by the K-Pg impactor (modified from [6]).

Discussion: The observed incongruity between the two independent estimates of extraterrestrial input has been suggested to be due to non-quantitative dissolution of osmium in seawater [3]. Osmium should, however, be oxidised during the immediate aftermath of the impact to gaseous OsO_4 [8], which is relatively easy to dissolve in seawater [9], therefore such non-quantitative dissolution is unlikely. An alternative explanation for this disjunct is that the prior estimate of iridium fluence is too high. This is suggested by the markedly higher iridium fluences and markedly broader iridium peaks found in marine (particularly abyssal) localities in comparison to the less iridium rich, narrower profiles in terrestrial localities (Table 1). The broadened marine peaks, some spanning several meters of sediment, are indicative of the input of remobilized iridium [10]. Consequently, these data must be discarded when estimating global iridium fluences associated with the K-Pg impact. Data from terrestrial localities provides the least biased estimator of fluence, as these sediments frequently show no evidence of post-depositional remobilization [11,12].

Realm (# samples)	Ir fluence (ng cm^{-2})	Os/Ir	Mean peak thickness (cm)	Mean kurtosis
All (33)	52 ± 3	0.6	21 ± 2	0.68
Terrestrial (12)	28 ± 2	1.1	17 ± 2	1.31
Marine (21)	72 ± 4	0.4	23 ± 2	0.39
Neritic (1)	1087	0.02	31	1.62
Bathyal (17)	47 ±3	0.6	19 ± 2	0.24
Abyssal (3)	248 ± 2	0.1	43 ± 2	0.69

Table 1: Global iridium fluences, Os/Ir, and peak shapes

Calculated terrestrial iridium fluences from our new compilation range from 12 to 132 ng cm^{-2} with a geometric mean of 28 ± 2 ng cm^{-2}. Combined with the global osmium fluence estimate derived from marine osmium isotope mass balance, this gives an Os/Ir fluence ratio of 1.1 ± 0.1 – exactly that expected for a carbonaceous chondrite.

Conclusions: The excellent correspondence of these two independent datasets strongly suggests that current estimates of global iridium fluence are incorrect, and that significantly less extraterrestrial material was added to the Earth from the K-Pg impactor than is typically assumed. Assuming typical carbonaceous chondritic composition for the impactor, an iridium fluence of 28 ng cm^{-2} implies an input of 2.4×10^{14} kg of material, corresponding to an asteroid of ~5.7 km diameter.

The estimated fluence is sensitive to a) fraction of impactor that was not vaporized and b) the loss of impactor mass to space. As there is little evidence of impactor derived Os in samples of impact melt breccias and lithic clasts from Chixculub crater it is likely that bulk of the impactor was vaporized upon impact [13]. On the other hand the fluence is likely higher than estimated above as several studies have demonstrated that in such large impacts a portion of the impactor is completely lost to space in the impact vapor plume. Early estimates [14] suggested that for impacts in this mass range, such loss could exceed 70% at high velocities. More recent studies [15,16], however, place mass loss for the K-Pg impactor between 11% and 25%. Taking the higher of these estimates, our iridium and osmium fluence data suggest an impactor mass of ~3.2×10^{14} kg, and increasing the corresponding asteroid diameter to ~6.2 km. This latter estimate is very close to Alvarez's [4] original estimate based on iridium data from the Gubbio section in Italy.

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