OSMIUM ISOTOPE CONSTRAINTS ON THE PROPORTION OF BOLIDE COMPONENT IN CHICXULUB IMPACT BRECCIAS

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Abstract:

The Alvarez team made a rough estimate of the proportion of meteoritic material that would be distributed in the target rocks when they introduced the K/T impact theory in 1980, [17]. They predicted that though the bolide would have been destroyed on impact, as much as 60% of the impactor would have polluted the atmosphere. The remaining 40% of the bolide would be distributed among the target rocks. Impact craters consist of several types of impactites. These rocks will reflect not only the characteristics of the target rocks, now impact breccias, but also reflect the chemistry of the impactor. The amount and distribution of meteoritic material transferred to the target rocks at Chicxulub is still poorly constrained. In this study, Re-Os isotopic analyses of impact melt breccias from Yaxocopil - 1 borehole were used to determine the distribution and proportion of the bolide component in the samples. The meteorite was assumed to have a $^{187}Os/^{188}Os$ ratio of 0.127, which reflects the average value of carbonaceous chondrites. The target rocks are assumed to have a value of ~ 1, the value of seawater at 65 Ma. One of the objectives of this study was to determine how much of the bolide mixed with the target rocks. This was determined by mixing calculations and assumptions regarding the character of the meteorite and the target rocks. Mixing calculations on the proportions of bolide-derived Os mixed with the impact rocks suggest little meteoritic material, only 0.1%, is required to reduce the $^{187}Os/^{188}Os$ ratio to a nearly chondritic ratio and significantly change the Os concentration in the composition of the target rocks. None of the samples analyzed exceed 0.1%. This suggests that while the meteorite did not add a significant amount of material to the impactites, the bolide did contribute a considerable proportion of Os to the target rocks. Another objective was to determine where in the stratigraphy the meteoritic component was most highly concentrated in the Chicxulub structure. No correlation between Os isotopic composition and stratigraphy (or type of impact melt breccia) was discovered. It is concluded that most of the samples were variably contaminated with the impactor, $^{187}Os/^{188}Os$ ratios ranging from 0.195 to 2.31, but none have purely chondritic osmium.

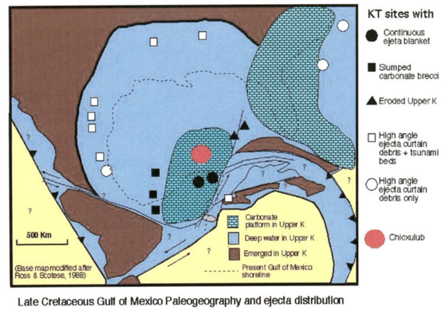


Figure 1: Paleogeography of the Late Cretaceous, [16].

Samples:

Three types of impact breccias have been studied. The first type is a green altered impact meltrock found in the lower portion of the impact sequence. The texture of the rock is microcrystalline and is composed of pyroxene, plagioclase, and alkali feldspars. Its composition is consistent with continental margin rocks. It is generally massive with some flow structures. The rock was brecciated and altered after solidification and contains small amounts of both shocked and unshocked clasts of the impact lithologies. These lithologies include lithic quartzite, and isolated feldspar crystals. The compositions of these rocks are similar to those seen in meltrocks sampled by the Yucatan-6 borehole [8, 9]. Our study includes samples YAX-1 861.4, YAX-1 863.51, YAX-1 876.46, which represent both the top and lower portion of the of the green impact meltrock. The middle sample in the sequence has the least amount of (mineralogical) alteration [10].

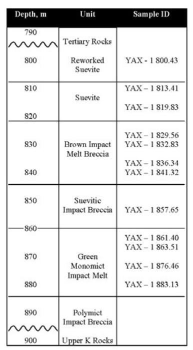


Figure 2: Stratigraphic diagram of Yaxocopoil - 1 borehole. Many types of impactites were extracted from the borehole. The Chicxulub crater is one of the only large craters on Earth with all of the different types of impactites. The samples analyzed in this study from the Yaxocopoil - 1 borehole included suevite, green monomictic impact melt breccias, and several xenoliths. Impact rocks from within the crater are buried under a kilometer of Tertiary deposits.

The second type of melt breccia under study is a brown altered impact meltrock. It also has a microcrystalline texture and both shocked and unshocked clasts of the target material. Even though this rock type has been altered, remnant schlieren, metaquartzite, and micritic calcite have been identified. Sample YAX-1 841.32 is representative of this type of rock. It was recovered from a polymictic breccia in the middle of the impact sequence.

Three samples of xenoliths have also been included in the analysis. They also were obtained from the YAX-1 borehole. The first is the sample YAX-1 821.76. It is a mafic clast containing very fine-grained diorite or basaltic andesite. It contains a minor amount of alteration (~ 5%) of the chlorite after mafic sites. The second is a granitoid clast labeled YAX-1 828.28. It is a coarse-grained holocrystalline porphyritic granite. The last xenolith is also a granitoid clast of medium- to coarse-grained holocrystalline equigranular granodiorite. It is significantly altered with carbonate veins, K-feldspar matrix flooding and shreddy biotite after black biotite.

Additional samples have been obtained via the Universidad Nacional Autonoma de Mexico (UNAM). These samples contain some of the highest recorded iridium concentrations as analyzed by UNAM. It is suspected that they include clasts of the impactor as well as large clasts of feldspars

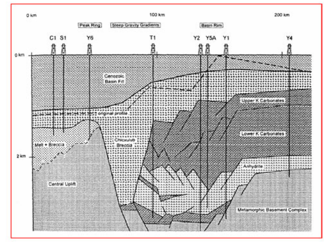


Figure 3: Schematic diagram of Chicxulub impact structure.

The samples come from the borehole marked Y1. The UNAM samples also come from Y1. They are green monomictic impact melt breccias.

Analytical Methods

Samples were spiked for isotope dilution analysis and digested in Carius tubes in reverse *aqua regia* at 230°C. Subsequent separation/ purification was accomplished via solvent extraction (Os) and anion exchange chromatography (Re). Osmium analysis was accomplished via negative thermal ionization mass spectrometry using the University of Maryland Bobcat I mass spectrometer. Rhenium was analyzed using the University of Maryland *Nu Plasma* multi-collector ICP-MS. Analysis was done using a triple electron multiplier arrangement for simultaneous measurement of masses 185, 187, and 190 (for ^{187}Os correction). Blanks for Re and Os averaged 13 pg, and 1.0 pg, respectively. The $^{187}Os/^{188}Os$ of the blank averaged 0.17. All ratio measurements were better than ± 0.5%. Most samples have quite low concentrations. Analytical uncertainties are variable, with the greatest uncertainty resulting from high blank/sample ratios. Our initial two measurements were of sample aliquants of approximately 0.1 g (YAX-1 861.4; YAX-1 876.46). Due to low concentrations of Re and Os, uncertainties in Os concentrations and isotopic composition are approximately ± 10%. Rhenium quantities were at blank levels and are not reported. More material was digested for subsequent samples and blank/sample ratios decreased accordingly. Uncertainties for these samples are approximately ± 1 for isotopic composition and ± 1-6% and ± 5-30% for Os and Re concentrations, respectively.

The $^{187}Re/^{188}Os$ ratios for all samples are relatively low, so corrections for 65 Ma of ^{187}Os ingrowth are minor.

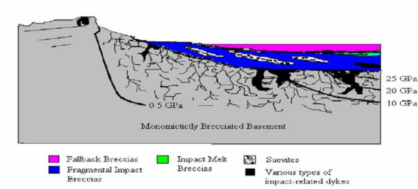
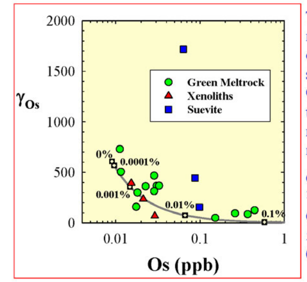


Figure 4: Schematic diagram of a simple crater, after [5]. Shows the different types of impactites and their occurrences.

Figure 5: Meteoritic Component and Mixing Curve



This figures shows that not much meteoritic contamination is needed to significantly change the Os concentration and IC of the target rocks. The end-members used in the mixing model are:

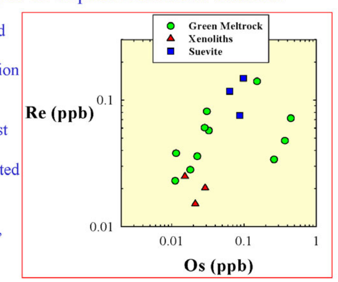
Crust: 0.009 ppb Os, $^{187}Os/^{188}Os = 0.9$;
Carbonaceous Chondrite: 573 ppb Os, $^{187}Os/^{188}Os = 0.127$

Results

The results suggest that the impact breccias from the depths sampled include only minor Os from the bolide. No samples examined exhibit a pure meteoritic signature. This is consistent with both the low abundances of Os in the rocks, the suprachondritic Re/Os ratios, and the suprachondritic initial $^{187}Os/^{188}Os$ ratios.

The proportion of the impactor is estimated at ~ 0.1%. The model used assumed a $^{187}Os/^{188}Os$ ratio of 0.9 for the target rocks, similar to the isotopic composition of modern seawater [11], the bolide component could constitute as much as 40% of the Os in the meltrocks (less than 0.1% of the total mass of the rock). More likely the isotopic compositions of the target rocks were substantially lower and the percentage of bolide Os is likely <10%. Atom for atom the meteorite contributed more Os, ~ 10%, than the target rocks contained pre-impact. However, as the bolide disintegrated only about 0.1% of the impactites were originally meteoritic material. The lower initial ratio of the suevites and higher Os concentration may suggest either a higher percentage of the bolide component, or a substantially different mix of target lithologies. Effects of subsequent alteration cannot yet be estimated, but the similarity in isotopic systematics between the closely spaced YAX-1 861.4 and 863.51 samples (combined they define a 65 Ma isochron) suggests minimal open-system behavior.

Figure 6: Meteoritic component in the different types of impact meltrocks studied.



Suevitic meltrocks had the most significant meteoritic contamination followed by the xenoliths. The green meltrocks had the most variability. These concentrations suggested that while all of the samples contained a meteoritic component, they were variably contaminated.

The UNAM samples did come from the YAX-1 borehole. They are also green monomictic impact melt breccias. These samples which are purported to have meteoritic clasts within them mostly have a substantially lower Os isotopic ratio than all of the other types of samples. The ratio is still suprachondritic.

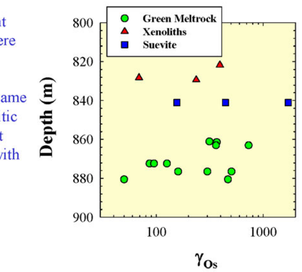
Table 1: Rhenium-Osmium Data for Chicxulub Impact Melt Breccias

Sample	Weight (g)	Re (ppb)	Os (ppb)	$^{187}Os/^{188}Os$	$^{187}Re/^{188}Os$	$^{187}Os/^{188}Os_I$	γ_{Os}
YAX-1 821.76 (70,3) xen	0.36	0.025	0.0153	0.6340	8.34	0.625	394
YAX-1 828.28 (58,4) xen	0.58	0.020	0.0291	0.2169	3.40	0.213	69
YAX-1 829.36 (54,3) xen	0.54	0.015	0.0212	0.4298	3.56	0.426	237
YAX-1 841.32 (65, 4)	0.40	0.149	0.0984	0.3316	7.47	0.324	156
YAX-1 841.32 (65, 5)	0.42	0.117	0.0635	2.312	11.4	2.30	1717
YAX-1 841.32 (65, 4)	0.31	0.075	0.0873	0.6940	4.45	0.689	445
YAX-1 861.4 (55, 6+3)	0.73	0.081	0.0307	0.6063	13.6	0.592	367
YAX-1 861.4 (55, 3)	0.51	0.057	0.0326	0.6022	8.93	0.592	368
YAX-1 861.4 (55,4)	0.11	nd	0.0285	0.5246	nd	nd	314*
YAX-1 863.51 (67, 5)	0.72	0.036	0.0226	0.5932	8.11	0.584	362
YAX-1 863.51 (67, 3)	0.53	0.023	0.0112	1.062	10.7	1.05	730
YAX- 1 872.4 UNAM 1	0.80	0.072	0.4445	0.2868	0.795	0.286	126
YAX-1 872.4 UNAM 1	0.65	0.048	0.3681	0.2369	0.634	0.236	86.6
YAX-1 872.4 UNAM 1"	0.72	0.034	0.2606	0.2479	0.637	0.247	95
YAX-1 876.46 (64,3)	0.12	nd	0.0175	0.3289	nd	nd	160*
YAX-1 876.46 (64, 4)	0.54	0.028	0.0181	0.5156	7.80	0.507	301
YAX-1 876.46 (64,6)	0.60	0.038	0.0115	0.7847	17.1	0.766	505
YAX-1 880.5 UNAM 2	0.86	0.060	0.0285	0.7305	11.0	0.719	468
YAX-1 880.5 UNAM 2"	0.77	0.141	0.1516	0.1948	4.51	0.190	50

* From the first set of data, contained an error due to the small amount of sample and the blank to spike ratio.

Figure 7: Depth vs. Meteoritic Component

Each of the different types of samples were retrieved from the borehole at approximately the same depths. The meteoritic component does not vary substantially with depth.



Conclusions

- Most rocks were variably contaminated with the impactor.
- None of the samples are purely chondritic.
- Little meteoritic material, 0.1%, is required to significantly change the Os concentration and isotopic composition in the target rocks.
- The bolide only contributed ~ 0.1% of its bulk composition to the impactites.

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Acknowledgements: This work was partially supported by NASA grant NAG510425 (to RJW). We also wish to acknowledge the International Continental Drilling Program, Universidad Nacional Autonoma de Mexico, and Chicxulub Scientific Drilling Project team.