How strong is the evidence that a meteorite caused the mass extinction of the dinosaurs?

INTRODUCTION

66 million years ago, 75% of all fossilizable species on Earth were wiped out by a catastrophe known as the Cretaceous-Paleogene extinction event (Pope et al, 1998). Introduced by Walter Alvarez 1980, the revolutionary concept that a meteorite triggered this disaster, has proceeded to spark controversy and excitement amongst many, and the result: more than 2000 published papers surrounding the conjecture over next 10 years. Ultimately, the proposition was endorsed by a panel of 41 experts in March 2010, who specified the Chicxulub impact as solely causing the extinction (Yarris, 2010). Despite this, recent theories, predominantly relating to volcanic eruptions, are beginning to challenge the asteroid prospect, and yet again, we remain as perplexed about the concept as we did 40 years ago.

Regardless, how do we suppose that a meteorite provoked the extinction? Predictions concerning the explanation have faced modification over time, but currently, the widely accepted proposition states that the 10-15km-wide asteroid collided with carbonate rock, containing countless combustible hydrocarbons and sulfur. Much of this sulfur was then vaporised, and a series of chemical reactions proceeded to produce sulfuric acid aerosols. Models indicate that this global aerosol cloud would take at least 10 years to dissipate, blocking out over 50% of sunlight during this time (Pope et al, 1997), and accounting for the extinction of plants and phytoplankton, and subsequently herbivores and their predators, if the freezing temperatures resulting from cooling aerosols hadn't already. Acid rain produced as aerosols fell terminated organisms demonstrating calcium carbonate shells, and the impact itself would induce a mega tsunami. This differs to previous disproved ideas declaring that a lack of photosynthesis, produced by a massive dust cloud triggered the extinction. It is important to recognise that the devastation described is largely theoretical - other postulations suggest that the entry of ejecta into the atmosphere would include a brief, intense pulse of infrared radiation, producing a flash heating effect, thus instigating extinction in this way. Consistent with all the summarized theories above, is that an asteroid itself did not kill off the dinosaurs, it induced changes in the climate, that, as a result, led to mass termination. Therefore, we must recognise that such meteorite *indirectly* triggered the extinction.

METEORITE EVIDENCE

Alvarez's discoveries

When examining evidence for the bolide-impact theory, a fitting place to begin is the source of the premise itself – the initial documentation from which the entire meteorite theory is derived (aside from a few previous suggestions). The concept itself can be attributed to geologist Walter Alvarez and the convincing evidence he discovered in 1980. Whilst examining patterns in layers of rocks in Gubbio, Italy, Alvarez and his team spotted an unusual layer of brown clay between limestone; and, stating it to be 65 million years old, he identified this to be the boundary between the Cretaceous and Tertiary time periods (the KT boundary). The immediate observations were interesting: below the clay layer was an abundance of microscopic marine fossils; however above it, far fewer fossils were discovered. This discovery itself denotes a catastrophist explanation, illustrating a sudden loss in marine life consistent with that of an extreme event, such as one the bolide-impact would have provoked.

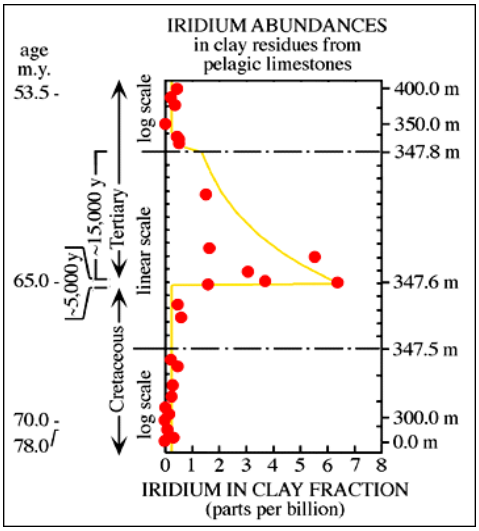

Figure 1: the iridium spike at the KT boundary (Hoopermuseum.earthsci.carleton.ca, n.d.)

This enigmatic discovery inspired the experts to carry out further experiments which would come to be even more paramount in supporting the hypothesis. Through observing iridium quantities, in an attempt to find the rate of formation of the clay layer, Alvarez saw iridium concentrations of more than 100 times what is normally found. Iridium occurs naturally in normal seafloor sediments in microscopic quantities, but the rare element was found only to be present in the clay layer, and therefore must have been deposited in a large, single 'iridium spike,' (formed by the global scattering of a debris cloud) (Stow, 2012), as spotted in Italy. Essentially, the same high ratio of iridium can be found in an asteroid. After further tests in similar clay layers in Denmark, Alvarez produced results of iridium quantities consistent with that of results from Italy - decidedly, it was not an anomaly. Presently recorded in nearly 60 locations worldwide, evidence in support of this hypothesis continues to advance.

The Chicxulub crater

Located in the Yucatan Peninsula, buried beneath ~1000m of marl and limestone layers, lies what we assume to be an impact crater- the Chicxulub crater - 180km in diameter and 20km in depth. Core analysis has shown that the origin of the melt rock dates back ~65 million years -the same time the KT boundary was formed (Carroll, 2016). The uncovering of such crater began in Haiti, following the discovery of an unusually thick sequence of impact ejecta approximately 0.5m thick. Subsequent laboratory analysis revealed deposits comprised of mainly impact melt spherules, capped with a layer of iridium-rich, and shocked quartz-bearing sediment (Lpi.usra.edu, 2019). Upon impact, a small proportion of impact melt created, is ejected and separated into molten droplets that quench to glass in the atmosphere before landing. Exceedingly high shock pressures can generate planar deformation through the naturally abundant mineral quartz, thereby producing 'shocked quartz'. (Ibid) Indeed the presence of impact melt and shocked quartz, (products of a cratering event), provides notable evidence for the meteorite theory, as until recently, it was thought that only an asteroid impact event could produce such atypical features.

An IODP-ICDP Chicxulub drilling project carried out in 2016, provides further substantial evidence that a meteorite terminated the dinosaurs. The Chicxulub crater is the best-preserved peak-ring impact basin on Earth (Geosociety.org, 2017), therefore when core was recovered from depths 505.7-1334.7m below sea level, ground-breaking analysis of the shock metamorphosis of Earth's crust was obtained.

Interestingly, found amongst the sample was pink granite, a rock usually found deep within the crust but not, however, in sea-floor deposits. From this, we can infer that impact was sizeable enough to shock and melt rocks found deep in the crust, forcing them up into the atmosphere, before they inevitably fell back down, forming peak rings. Moreover, the samples of granite found were both lighter in weight and weaker than normal, a result of the extreme impact conditions (St. Fleur, 2016).

Gypsum, a sulphate-bearing rock present in the shallow seabed of the region, was unusually deficient amongst the samples. From its absence, scientists deduced that the gypsum had likely been vaporised

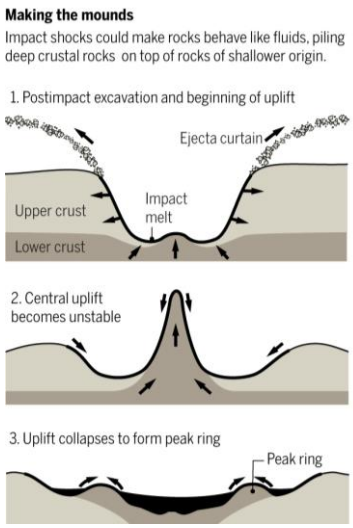

Figure 2: the formation of peak rings. Hand E. (2016).

to enter the atmosphere, an event subsequently followed by a mega tsunami triggered on impact, which laid a bed of sand ~100m in depth, above the peak ring (Hand E. 2016). Evaluation of this evidence indicates that a 120-mile peak ring, upheaval of deep-seated rock, vaporization of gypsum and a tsunami are all the distinguished result of an asteroid event. As we have this reliable and updated evidence of the effects of the asteroid, we can acknowledge the meteorite extinction theory with greater confidence.

Fossil evidence

Many a mystery has been uncovered through the proxy that is fossil evidence, and the enigma of dinosaurs is no exception. Previous suppositions expressed that impact was distant enough from the poles, meaning that dinosaurs located there, (already accustomed to months of low food supply and darkness), were better equipped to deal with the environmental consequences. Hence; they didn't die out as rapidly. However, a study of 6,000 marine fossils taken from Seymour Island (dating back to 65-69 million years ago) revealed a reduction of ~70% of species living in the Antarctic 66 million years ago (Cosmosmagazine.com, 2016). James Witts of the university of Leeds led the investigation, discerning that whilst rare fossils disappeared sooner and common fossils later, most importantly, a fossil-free gap appeared directly below the KT layer. The rapid and intense decline shown in these fossils indicate a sudden event (an extinction as such), rather than a slower reduction brought about by natural shifts in the environment, or severe volcanic eruptions. The significant size of the study makes it one of the most accurate extinction-related fossil records, highlighting the strength of the theory in relation. Moreover, analysis of the fossils rendered the majority unscathed – alluding to two possibilities: either the predators themselves were extinct, or low oxygen conditions instigated microbe blooms in an ocean where the food web was altered by the extinction (Lee, H. 2016).

FLAWS WITH THEORY

Arguably one of the most prominent flaws surrounding the meteorite premise can be seen through recent fossil evidence, in particular samples taken by Gerta Keller. The palaeontologist obtained samples in a three-year analysis of a rock section in El Kef, Tunisia, and her results are seen as some of the most accurate relating to the extinction. Keller specialises in studying foraminifera, the fossils of which are abundant and well-preserved. Palaeontologists are able to trace extinction patterns with considerable accuracy, and thus rely on them as a proxy for patterns amongst other organisms. Contradictory to James Witt's fossil analysis, some foraminifera populations did not experience a sharp decline, but rather a gradual one that began 300,000 years before the proposed asteroid event. Keller observed that populations had steadily decreased, until very rapidly around 1/3 of them vanished. The palaeontologist summarises that an instantaneous event could not produce a population pattern like this. Perplexingly, evidence based on 5 different proxies from the Yaxcopoil-1 core in 2001, (~60km from centre of the Chicxulub crater), indicates that the impact actually predated the KT boundary by ~300,000 years (Pope et al, 1998). Moreover, samples gathered by Keller in El Peñón, Mexico, displayed proof of forum populations present following the impact. In essence, these recent studies are massively damaging to the catastrophist model and asteroid conjecture, as it simply does not make sense for species to decline pre-bolide-impact.

Volcanic activity

In the early 90s, the meteorite theory was all but accepted by almost every scientist, but despite facing backlash, Keller has led the pathway in claiming that the mass extinction was not triggered by an asteroid at all – instead believing it was a series of volcanic eruptions. Volcanism supporters believe these eruptions to have taken place between 67.5 and 64.5 million years ago in the Deccan Traps, India, one of the largest volcano provinces in the world. Included in Keller's paper on Deccan volcanism in 2008, was unprecedented evidence that lava flows, capable of devastating the Indian Subcontinent, just predated the extinction. It is theorised that ash, mercury and gases including sulfur, methane and

carbon dioxide were released into the atmosphere, wreaking havoc worldwide. Keller predicts that the ash and mercury poisoned many creatures, sulfur induced a cooling effect on the climate and drenched Earth in acid rain, and carbon dioxide and methane acidified the oceans, rendering them uninhabitable to plankton and other organisms. Keller has since found evidence to support her predictions, for example mercury levels shot up following the largest eruptions (Bosker, 2018). The patterns of fossil evidence mentioned in the previous paragraph align with the Deccan eruption sequence. A bewildering aspect of the meteorite- volcanism debate, is the fact that the consequences of any one theory are not synonymous with such event, therefore supporting one using such meagre evidence does not bolster the argument to a sufficient extent.

Increasingly detrimental to the meteorite model, are recent discoveries, displaying evidence that iridium deposits are no longer solely attributed to meteorites as previously thought. The deposits are now known to be a common product of volcanic eruptions. The Deccan plume, distinguished by 500,000 square km of basalt flows (Volcano.oregonstate.edu), could well be held responsible for the iridium spikes originally thought to be the product of a meteorite. If we consider this possibility, it appears evidence for the volcanism proposition is surprisingly strong. Similarly, shocked quartz grains have been found in the volcanic pipes of Southern Africa, therefore, provided the feeder vents for the Deccan Traps extend sufficiently deep into the mantle (Stow, 2012), we can assume that shocked quartz may also have been blown from the eruption.

The time from within which extinction took place is certainly a dominant issue associated with the meteorite theory. Alvarez's 1980 works stated that the main extinction occurred within 1-10 years, however Hsu has indicated that the effects may have lasted over 1000 years (Benton, M. 1990). Scientists in general can't seem to decide on the rate of the event, evidence surrounding the time frame is very unclear, especially considering fossil evidence is so inconclusive. On another theme, it is fair to say that when the meteorite theory was proposed, the prospect seemed like a perfectly elegant solution to the prehistoric puzzle. Perhaps the clarity of the 'intellectually fashionable' solution (Ibid) led us to acknowledge the idea in the first instance, when the theory itself does not actually hold sufficient weight.

A paramount reason as to why providing concrete evidence, and hence proving the real cause of the termination has been so challenging, is due to gaps in the fossil record - typical of most sections across the KT boundary that now lie on land. A 'fossil hiatus' can be caused by any number of things, such as a lack of deposition or subsequent erosion. (Stow, 2012) At any rate, what appears as an abrupt extinction event could just as easily been a transitional change – we simply do not have the adequate fossil samples to know this yet, and in terms of samples we do have, our elusive and inaccurate dating limits us.

Conclusion

Ultimately, sufficient evidence enables us to conclude that a bolide-impact event occurred 65 million years ago. Similarly, we must also appreciate that volcanic activity caused disruptions around that time too –it would be foolish to state otherwise considering the strength of the proof. Although documentation just a few years ago pointed firmly towards the former as the trigger for extinction, recent evidence, (whether it be issues with the notion itself, or proof that volcanism was just as likely), has definitely revealed cracks in the hypothesis, that quite frankly, we do not yet have the resources to resolve. Moreover, the subject becomes even more perplexing when we discover that evidence begins to contradict itself at times. I would argue that two theories are not necessarily as mutually incompatible as their proponents may have us believe - perhaps it was a combination of these events, and the

subsequent impact on the climate that resulted in mass extinction? Frustratingly, one of the major inaccuracies that we are particularly uninformed about, is the time frame in which the extinction occurred, yet ironically, this seems to be information that we require the most to reach a logical conclusion. The limitations of our fossil records, in addition to proxies for environmental change, and our blatant lack of knowledge surrounding the capabilities of the two theories (Lee H. 2016), continue to leave our questions unanswered. Taking all corroboration into account, it appears that the evidence that a meteorite caused the mass extinction of dinosaurs, is in fact, rather tenuous.

2494 words (inc. title) Holly MacDonald

Bibliography

1. Alvarez, L. and Alvarez, W. (1980). [online] Courses.seas.harvard.edu. Available at: https://courses.seas.harvard.edu/climate/eli/Courses/EPS281r/Sources/KT-boundary/3-Alvarez-Alvarez-etal-1980.pdf [Accessed 6 Mar. 2019].
2. Benton, M. (1990). *Intro*. [online] Palaeo.gly.bris.ac.uk. Available at: http://palaeo.gly.bris.ac.uk/essays/dino90.html [Accessed 28 Feb. 2019].
3. Bosker, B. (2018). *The Nastiest Feud in Science*. [online] The Atlantic. Available at: https://www.theatlantic.com/magazine/archive/2018/09/dinosaur-extinction-debate/565769/ [Accessed 2 Mar. 2019].
4. Carroll, S. (2016). *The Day the Mesozoic Died*. [online] Nautilus. Available at: http://nautil.us/issue/32/space/the-day-the-mesozoic-died [Accessed 6 Mar. 2019].
5. Lpi.usra.edu. (n.d.). *Chicxulub Impact Event*. [online] Available at: https://www.lpi.usra.edu/science/kring/Chicxulub/discovery/ [Accessed 1 Mar. 2019].
6. En.wikiversity.org. (2019). *Controversies in Science/What killed the dinosaurs - Wikiversity*. [online] Available at: https://en.wikiversity.org/wiki/Controversies_in_Science/What_killed_the_dinosaurs [Accessed 6 Mar. 2019].
7. Cowen, R. (1999). *The KT extinction*. [online] Ucmp.berkeley.edu. Available at: https://ucmp.berkeley.edu/education/events/cowen1b.html [Accessed 6 Mar. 2019].
8. En.wikipedia.org. (2019). *Cretaceous–Paleogene extinction event*. [online] Available at: https://en.wikipedia.org/wiki/Cretaceous–Paleogene_extinction_event#2016_Chicxulub_crater_drilling_project [Accessed 6 Mar. 2019].
9. Volcano.oregonstate.edu. (n.d.). *Deccan Traps | Volcano World | Oregon State University*. [online] Available at: http://volcano.oregonstate.edu/deccan-traps [Accessed 1 Mar. 2019].
10. Geosociety.org. (2017). *GSA Today - Chicxulub and the Exploration of Large Peak-Ring Impact Craters through Scientific Drilling*. [online] Available at: http://www.geosociety.org/gsatoday/science/G352A/article.htm [Accessed 1 Mar. 2019].
11. Hoopermuseum.earthsci.carleton.ca. (n.d.). *Impact Theory*. [online] Available at: http://hoopermuseum.earthsci.carleton.ca/saleem/meteor.htm [Accessed 2 Mar. 2019].
12. Hyperphysics.phy-astr.gsu.edu. (n.d.). *Iridium-Rich Layer*. [online] Available at: http://hyperphysics.phy-astr.gsu.edu/hbase/Geophys/iridium.html [Accessed 1 Mar. 2019].
13. Lee, H. (2016). *New study finds evidence for a 'fast' dinosaur extinction | Howard Lee*. [online] the Guardian. Available at: https://www.theguardian.com/environment/climate-consensus-97-per-cent/2016/jun/15/new-study-finds-evidence-for-a-fast-dinosaur-extinction#img-2 [Accessed 6 Mar. 2019].
14. Cosmosmagazine.com. (2016). *New evidence supports asteroid theory of dinosaur extinction | Cosmos*. [online] Available at: https://cosmosmagazine.com/palaeontology/new-evidence-supports-asteroid-theory-of-dinosaur-extinction [Accessed 2 Mar. 2019].

15. Pope, K., D'Hont, S. and Marshall, C. (1998). *Meteorite impact and the mass extinction of species at the Cretaceous/Tertiary boundary*. [online] pnas.org. Available at: https://www.pnas.org/content/95/19/11028 [Accessed 4 Mar. 2019].
16. Pope, K., Ocampo, A. and Ivanov, B. (1997). *Energy, volatile production, and climatic effects of the Chicxulub Cretaceous/Tertiary impact*. [online] Available at: https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/97JE01743 [Accessed 4 Mar. 2019].
17. Rogers, P. (1979). *Researchers Uncover First Evidence That Dinosaur Extinction Caused ByAsteroid Impact*. [online] Www2.lbl.gov. Available at: https://www2.lbl.gov/Science-Articles/Archive/dinosaur-extinction.html [Accessed 2 Mar. 2019].
18. St. Fleur, N. (2016). *Drilling Into the Chicxulub Crater, Ground Zero of the Dinosaur Extinction*. [online] Nytimes.com. Available at: https://www.nytimes.com/2016/11/18/science/chicxulub-crater-dinosaur-extinction.html [Accessed 1 Mar. 2019].
19. Stow, D. (2012). *Vanished ocean*. Oxford (GB): Oxford University Press.
20. Hand E. (2016). *Updated: Drilling of dinosaur-killing impact crater explains buried circular hills*. [online] Available at: https://www.sciencemag.org/news/2016/11/updated-drilling-dinosaur-killing-impact-crater-explains-buried-circular-hills [Accessed 4 Mar. 2019].
21. ScienceDaily. (2007). *Volcanic Eruptions, Not Meteor, May Have Killed The Dinosaurs*. [online] Available at: https://www.sciencedaily.com/releases/2007/10/071029134743.htm [Accessed 5 Mar. 2019].
22. Yarris, L. (2010). *Alvarez Theory on Dinosaur Die-Out Upheld: Experts Find Asteroid Guilty of Killing the Dinosaurs | Berkeley Lab*. [online] News Center. Available at: https://newscenter.lbl.gov/2010/03/09/alvarez-theory-on-dinosaur/ [Accessed 3 Mar. 2019].