Dinosaur Demise from a Collision: A Theory in the Making

By Kurt Zeppetello

Introduction

An asteroid impact as a cause of the extinctions 65 million years ago (**Mya**) is now well accepted among the scientific community. My paper is about how the evidence was built that moved it from ideas to hypothesis to theory.

The impact hypothesis was first proposed after the discovery of a worldwide iridium anomaly at the Cretaceous-Tertiary boundary by team of scientist from Berkeley headed by the Noble Prize wining physicist, Luis Alvarez (Alvarez et al., 1980). Iridium is an element that is found in relatively high concentrations in meteorites but rare in Earth's crust. According to their original hypothesis, the high concentrations at the Cretaceous-Tertiary bo undary (**KTB**) are a result from a very large meteorite (a.k.a. asteroid) or a comet striking Earth and exploding, as the dust from this explosion settled, an iridium-rich layer formed around the planet. Since then, their hypothesis has gained so much support, it is no longer disputed (Figure 1).

Figure 1: Image represents an asteroid colliding with Earth at the end of the Cretaceous (http://nai.arc.nasa.gov/).

Of course this was not always the case. I was born in the 1960s and was fascinated about all aspects of science. Like most young people, learning that gigantic lizards once roamed the planet was of particular interest. Being so large and fearsome I could not help wonder what happened to these beasts. I kept my fascination through high school and studied geology and chemistry in college.

As I delved further into my training I asked our professors why the dinosaurs didn't survive after being so successful for 180 million years. The Paleontology professor described them as on their way out before the end of the Cretaceous. He described various theories as why they went extinct, such as the increase of angiosperms somehow being toxic to them and changes in Earth's climate. He also mentioned that perhaps a catastrophic event may have, in part, led to their demise.

Extinction of Dinosaurs

Controversies between gradualism, extinction occurring over many thousands or even millions of years, vs. catastrophism, rapid planetary scale events, dominated paleontology during 19th and 20th century. Since finding a dinosaur fossil is so rare, researchers were not sure how long it took for there eventual extinction. Were they thriving until the point they went extinct or did it take millions of years? Darwin's theory of natural selection seemed to fit in really well with gradualism. Scientists understood that organisms change over time favoring traits that help them survive. If organisms do not adapt fast enough to changing conditions, they may go extinct. Catastrophism is supported by the fact that many different species besides dinosaurs went extinct at the end of the Cretaceous.

Early explanations for dinosaur extinction include dramatic falls in sea or gentle cooling of the earth (Fastovsky and Weishampel 1996, p. 401). Both occurred and reflect a more gradual extinction mechanism favored by paleontologists as well as most other scientists prior to the 1980s (Alvarez 1997, p. 57).

One of the first extraterrestrial hypotheses for the extinctions came from Dale Russell, a paleontologist who believed the dinosaur extinction was sudden, and Wallace Tucker, a physicist who believed climate could be affected by a supernova (Alvarez 1997, p. 58). Their hypothesis, from 1971, was that radiation doses as a result of the interaction of high-energy cosmic rays and gamma rays with the atmosphere would account for the mass extinction (Russell and Tucker 1971). Another hypothesis that got a lot steam for a while was that huge volcanic eruptions from the Deccan Traps of India were responsible. This hypothesis was first put forth by Peter Vogt in 1972 and revived in the mid 1980s by Charles Officer and Charles Drake (Frankel 1999, p. 38). Of the various scenarios only the Deccan Traps had any supportive evidence since iridium can be released during volcanic eruptions; however, because other data which will be discussed in the next section does not support the hypothesis, it too is no longer accepted even among volcanologists.

Indirect Evidence for an Impact

Platinum Group Elements

A group of scientists from the University of California first suggested that a meteor or comet was the cause for the extinctions at the end of the Cretaceous (Alvarez et al., 1980). Their evidence was the discovery of a worldwide iridium anomaly at the

Cretaceous-Tertiary boundary (Figure 2). Iridium (Ir), a platinum group element (PGE) that is abundant in meteorites and in the earth's mantle but rare in the crust, was found in above normal concentrations in Cretaceous-Tertiary boundary (KTB) samples from Italy, Denmark, and New Zealand. More than 95 Ir anomalies have been reported since then (Alvarez and Asaro, 1990). Other platinum group elements (Pt, Pd, Os, Ru, and Rh) and siderophiles (PGE, Fe, Co, Ni, and Au), 'iron loving', have also reported with above normal concentrations in the KTB (Kyte et al. 1985; Orth et al. 1982; Ganapathy 1980). Iridium is generally chosen to represent the PGE's, because its limit for detection is lower.

Figure 2: The KTB exposed in the Raton Basin at the Starkville outcrop in Colorado. The light gray unit in the middle of the photograph (marked with the rock hammer) marks the boundary (courtesy of the U.S. Geological Survey).

Isotopes

Other evidence for an extraterrestrial event at the KTB is found in isotopes, such as Osmium (Os). For example, the 187Os/ 186Os ratio of old crustal rock is noticeably larger when compared to meteorites. However, the 187Os/ 186Os ratios are reported in the KTB layers are similar to those found in meteorites (Luck and Turekian 1983). Also, Uranium (U) and thorium (Th) isotope anomalies have also been reported in KTB sites. For example, meteorites have higher $^{234}U/ ^{232}Th$ ratios than crustal rocks. The $^{234}U/ ^{232}Th$ ratio is higher in the boundary clay than in the shale and mudstone above and below it (Holloway and Farmer 1990).

Tektites

Tektites are small, rounded, black to yellow bodies of glass produced when ejecta from an impact melts due to the high velocity through the atmosphere and then solidifies before it hits the ground. Very small tektites, microtektites, have been recovered in KTB sediments with compositions similar to oceanic basalt. These microtektite-like spheroids are believed to have been produced by the impact of a large asteroid colliding with the ocean floor (Montanari et al., 1983). Some of the target rocks, basaltic in composition, were ejected with enough velocity for melting to occur. Microtektite-like spheroids have been identified in most of the outcrops which have the Ir anomaly (Smit and Romein 1984).

Shocked Quartz and other Stishovite

Mineralogical evidence also supports an impact by an extraterrestrial body 65 Mya. Shocked mineral grains, mainly quartz, are identified by the presence of intersecting lamellae (lineations) caused by the energy released from an impact in the form of shock waves. Shocked minerals have been found in KTB samples worldwide with the highest concentration in North America (Bohor and Izett 1986). Other mineralogical evidence comes from stishovite, a mineral found at most impact sites such as Meteor Crater in Arizona (McHone et al. 1989). Stishovite, a dense quartz polymorph, forms at high pressures such as produced by an impact and has been found in Raton, New Mexico (McHone et al. 1989) and Brownie Butte, Montana (Bohor et al. 1984).

Global wildfires

In addition to the direct impact related evidence, later occurring events which resulted from the collision have also been reported. Carbon (C), in the form of soot (elemental C) and charcoal have shown enrichment patterns in 11 KTB sites worldwide (Wolbach et al. 1990) and is attributed to global wildfires ignited by the impact of giant meteorite. The initial energy of the impact would have leveled nearby forests but the shockwave would have heated up the atmosphere as well (Wolbach et al. 1990).

Tsunamis

If the impact occurred in or near an ocean, giant ocean waves or tsunamis would be expected. Thick layers of disturbed sediment were detected in KTB outcrops in Texas (Smit and Romein 1985) and at the Beloc Formation in Haiti (Maurrasse 1991). These layers not only suggest giant tsunamis were in fact produced by an impact but also the location is somewhere in the vicinity of the Caribbean (Maurrasse 1991).

Amino Acids

The importance of α -aminoisobutyric acid and isovaline is their rarity in terrestrial sediments but high concentration in certain types of meteorites known as carbonaceous chondrites (Cronin and Moore 1971; Pizzarello et al. 1991). Carbonaceous chondrites are believed to be most primitive (oldest) stony objects in our solar system. Most of the asteroids in the asteroid belt between Mars and Jupiter are thought to be carbonaceous chondrites. Amino acids also play an important role in defining what took place 65 Mya. Two amino acids, α-aminoisobutyric acid and isovaline, have been identified in KTB sediments from outcrops in Stevns Klint, Denmark (Zhao and Bada 1989). In addition, I detected α-aminoisobutyric acid in KTB sediments at Raton Basin, Colorado as part of my Masters Thesis (Zeppetello 1992). The presence of these amino acids indicates not only that an object impacted the earth 65 Mya but suggests the impacting body was most likely a carbonaceous chondrite (Zhao and Bada 1989; Zeppetello 1992).

Direct Evidence for an Impact

The biggest piece of missing evidence for a collision at the end of the Cretaceous was lack of any crater. The Alvarez team estimated the object to be 10 km in diameter, thus leaving a crater of 150-200 km in diameter. Although it would seem an impact crater, or astrobleme, of this magnitude would be easily detected, none was found. As any geologist knows, after 65 million years it could be eroded, buried, or subducted. However, the tsunami deposits and a 50-centimeter-thick ejecta layer which is approximately 25 times as thick as any known K-T site and suggests an impact site in the proximity of the Gulf of Mexico or Caribbean Basin (Hildebrand and Boynton 1990).

In their respective books, *T. rex and the Crater of Doom* (Alvarez 1997) and T*he End of the Dinosaurs* (Frankel 1999), Walter Alvarez and Charles Frankel explain there was circular feature in the Yucatán near the coastal town of Progreso that had been known about since the early 1950s from geophysical surveys. These surveys and subsequent exploration was completed by PEMEX, the Mexican Oil Company, which was focused on finding oil. Their surveys were not promising for finding oil but did show the buried structure to be 180 km in diameter. They attributed this to be a volcanic caldera after drill holes struck the volcanic bedrock known as andesite. The volcanoes in eastern Mexico are commonly composed of andesite. During the late 1970s, PEMEX scientists Antonio Camargo and Glen Penfield conducted a new survey of the circular feature in the northern Yucatán. Since the results their study showed no similarities to a volcano, they hypothesized that it may be an impact crater. Although scientists who work for oil companies publish much less than their academic counterparts, as most of the data are confidential, Penfield and Camargo gave a talk and published in the abstracts of the Society for Exploration Geophysics yearly conference in 1981. In his book, Alvarez laments how ironic it was that the previous year they published the evidence for a giant impact and it took ten years put the two together. While the Alvarez team spent countless hours scanning the globe searching for the crater, the location was sitting in the files of PEMEX. Eventually, through his extensive research, Alan Hildebrand, at the time a graduate student from the University of Arizona, brought Yucatán crater, known as the Chicxulub crater after the fishing harbor near ground zero, to the attention of the KTB researchers (Hildebrand et al. 1991). Finally, Camargo presented their full study at the Snowbird Conference in Houston in 1994 and deal was done, the last major piece of the puzzle was solved.

What Caused the Extinction of the Dinosaurs and Other Organisms?

While an asteroid impact at the end of the cretaceous is now accepted, it is not yet fully known how it caused the all of the extinctions. The Alvarez team (Alvarez 1980) suggested that impact produced a giant cloud of dust in the atmosphere which blocked off the Sun's rays for months and thereby stopped photosynthesis. This would have led to the collapse of the food chain on land and sea. Frankel (1999) provides a good overview of the effects of the impact, a summary of which follows:

Impact/Regional Effects

The 10-kilometer diameter asteroid assumed to be traveling at 20 kilometers/second based on most other Earth-crossing asteroids would yeild more than 10,000 times the explosive energy of the world's entire nuclear arsenal. Shock waves would spread through the atmosphere producing winds initially at 20 km/s but diminishing as the ring of air grew further away from the blast. After ten minutes, the velocities would be 1,000 kilometers/hour at approximately 500 kilometers away. Tsunamis would also be produced; however, they would be limited in height to only 100 meters as that was the depth of water where the impact took place. If it occurred in a deep ocean basin, the Tsunamis could have been a kilometer or more. Dinosaurs and other organisms would have been destroyed up to 1000 km away and some of the coastal life on the interior coastal North America would have drowned.

Global Effects

The impact would also have produced magnitude 10 earthquakes, activating faults and landslides in the vicinity of the crater. Shock waves may have been felt worldwide. The initial blast produced a crater with a depth of 30 km but within in minutes the steep walls collapsed to form the 180 km wide crater. The asteroid along with approximately 200,000 km^3 of bedrock, was blown into the sky. Some of this solid, molten, and vaporized material quickly settled back down close to the impact whereas other material spread around the globe in the atmosphere. The heat released from initial blast and from reentering ejecta heated the stratosphere up enough to trigger global wildfires.

In addition, since meteorites have high concentrations of toxic heavy metals such as nickel, chromium, and cobalt, it would be expected that the fragments of the impacting body would release these element to the environment. Further, the temperature of the atmosphere was raised high enough to cause nitrogen to react with oxygen and produce harmful nitrogen oxides, thus forming nitric acid rain. If that wasn't enough, the limestone bedrock ($CaCO_3$) where the impact occurred was interbedded with layers of anhydrite ($CaSO_4$). As the layers were vaporized, huge amounts of carbon dioxide (CO_2) and sulfur dioxide (SO_2) were released.

Following some the events occurring soon after the impact, a dust cloud initially described by Alvarez et al. (1980) blocked the sun for up to two years. Pitch black conditions would occur from one to six months followed by a twilight conditions for up to two years before clearing (http://www.lpi.usra.edu). In addition to killing plankton, Earth would have cooled for a brief period. After the dust settled, Earth entered into an extended warming period as the increased amount of gases lead to a greenhouse effect. The amount of CO_2 released into the atmosphere from the impact alone doubled the concentration.

Final Thoughts

Frank Kyte, a researcher from the University of California, Los Angeles, analyzed a small piece of meteorite recovered from KTB sediments. The geochemical analysis indicates that the object was a carbonaceous chondrite rather than a comet (Kyte 1998). In a recent study by Bottke et al. (2007) it is suggested that a collision in the asteroid belt 160 Mya led to fragments whose orbital paths cross the inner planets. They believe one of these fragments was the asteroid that formed the Chicxulub crater. Recent studies by Gerta Keller of Princeton University suggest the Chicxulub impact may have occurred 300,000 years before the KTB (http://www.daviddarling.info). She believes there that there may have been another asteroid that struck Earth at approximately 65 Mya which led to the extinctions (Keller 2006). However, her work has not been confirmed by other labs as of this writing. Whatever the case, one asteroid or several, the arguments are no longer whether the dinosaurs went extinct gradually nor are there any disagreements as to the major triggering event. An extraterrestrial object or objects certainly was the doomsday device for the extinctions that ended the Cretaceous.

In summary, an idea about how dinosaurs went extinct was tested. Based on high concentrations of iridium, a hypothesis is formulated. Over the years, a preponderance of additional evidence including isotopes, impact related minerals, wildfires, tsunamis, and extraterrestrial amino acids supported this hypothesis. Finally, after a decade an impact crater was discovered further solidifying the hypothesis. Research collected since the discovery of the Chicxulub crater has only strengthened the hypothesis leading it to the realm of theory.

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