What is the K/T boundary?

Subject: Geology

Grade Level: 9th – 11th

Rational or Purpose: This lesson is designed to let students take a more in depth look at the K/T boundary, and see if there are any clues to identify the cause of the extinction of dinosaurs. This lesson requires students to read articles (included in lesson plan) from books and scientific journals. They will analyze the information given, and decide whether the evidence is enough to support the hypothesis that the massive K/T extinction was caused by meteorites.

Materials: Student worksheet

Lesson Duration: 60 minutes

Sources:
Alvarez, L.W., et al. "Extraterrestrial Cause for the Cretaceous-Tertiary Extinction." Science, Vol. 208 (1980) pp. 1095.

Kring, D.A., "Impact Events and Their Effect on the Origin, Evolution, and Distribution of Life." GSA Today. Vol. 10, No. 8 (2000) pp. 1.

Melosh, H J. Impact Cratering: a Geologic Process. New York: Oxford UP, 1989.

TEKS Objectives:
112.49. Geology, Meteorology, and Oceanography.
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Background Information:
There are several suggested proposals for dinosaur extinction. Some propose that it was caused by massive meteor strike. Others claim that it was a dust layer created by violent volcanic activities, which blocked the sunlight, causing the extinction of dinosaurs. In either case, we should be able to look at evidence from rock samples, and analyze the chemical content of the rock layers to obtain information. The time period in which the dinosaur extinction occurred was the transition from the Cretaceous (K) Period to the Tertiary (T) Period. The rock layer that contains materials at this transition is called the K/T boundary.

Procedure:

1. Teacher should poll students to identify what they believe caused dinosaur extinction. Students can spend 2-3 minutes to explain their thoughts.

2. Give students 3 minutes to brainstorm any physical evidence that can be found today to support the cause of dinosaur extinction. This task can be done in groups of 4 students.

3. After a brief group and class discussion, the teacher will give each group a selection of articles that are included in this lesson plan. Each group should read carefully and note any additional information to analyze the helps to explain the cause of massive extinction. There are several articles from different sources that point toward the cause of extinction by extraterrestrial material, possibly meteorites. Students will exchange articles to gather additional information to form their conclusion for this lesson. (Each excerpt is ended with a citation in parentheses.)

4. In the lesson, teacher may include the process of rock formation and the rock cycle to assist students in understanding the Iridium content found in rocks. The teacher is also encouraged to use the PowerPoint from this CD-ROM and WebCast online to help students explore the knowledge in this matter.

5. To conclude this activity, each student will write a short essay, or mini-research paper, stating their findings from the articles. Be sure to remind students to cite specific readings to support their statement in the essay.

Required Article Excerpts for Group Activities

Melosh, H J. Impact Cratering: a Geologic Process. New York: Oxford UP, 1989.

Most recently, the discovery of shocked quartz in the Cretaceous-Tertiary boundary clays lends support to the belief that the Cretaceous era was ended by the impact of a 10-km diameter asteroid or comet. **(Melosh, H J. Impact Cratering: a Geologic Process. New York: Oxford UP, 1989. pp.8)**

The most famous shock indicators in quartz-rich rocks are Coesite and Stishovite. These dense phases of silica were first found in nature at Meteor Crater, Arizona, and provided important confirmatory evidence of that crater's impact origin, since volcanic explosions cannot approach the pressures at which Stishovite and Coesite form (greater than 15 and 30 GPa, respectively). Subsequent discovery of Stishovite and Coesite at the Ries Crater in Germany was also accepted as proof of that structure's impact origin. Most recently, the discovery of shock quartz in the Cretaceous-Tertiary boundary clay in Montana lends increased weight to the hypothesis that the Cretaceous Era was brought to a close by a major impact event. **(Melosh, H J. Impact Cratering: a Geologic Process. New York: Oxford UP, 1989. pp.41)**

Although the reality of a large impact at the end of the Cretaceous continues to be argued, an impressive amount of evidence has been found to support the hypothesis. Iridium anomalies at the Cretaceous-Tertiary boundary have been found at 75 cities around the world, in both marine and terrestrial sediments. Other siderophile elements such as gold, osmium, and platinum are associated with the iridium in approximately chondritic ratios. In addition, sanidine spherules, which may be equivalent to microtektites, have been found in many locations. Perhaps the most telling evidence is the discovery of shocked quartz grains (up to the size of find sand) in the boundary clay at widely separated localities. There is no natural process other than impact that is capable of producing these shock features. The wide distribution of the shocked quartz argues for a large event. Recently, large concentrations of carbon soot have been found in boundary clays, suggesting that the impact may also have ignited global wildfires. The only piece of evidence lacking to prove the case for a large impact is the crater itself. In spite of much effort neither the crater nor even any clues to its general location have yet been found. An impact of the required size should have produce a crater 100 km or more in diameter, and such a crater should not be difficult to find. One possibility is that the impact occurred in an ocean (which is, of course, more probable than an impact on land) in an area where the seafloor has been subducted since the Cretaceous. **(Melosh, H J. Impact Cratering: a Geologic Process. New York: Oxford UP, 1989. pp.222-223)**

Alvarez, L.W., et al. "Extraterrestrial Cause for the Cretaceous-Tertiary Extinction." Science, Vol. 208 (1980) pp. 1095.

Identification of Extraterrestrial Platinum Metals in Deep-Sea Sediments
This study began with the realization that the platinum group elements (platinum, iridium, osmium, and rhodium) are much less abundant in the earth's crust and upper mantle than they are in chondritic meteorites and average solar system material. Depletion of the platinum group elements in the earth's crust and upper mantle is probably the result of concentration of these elements in the earth's core. (**Alvarez, L.W., et al. "Extraterrestrial Cause for the Cretaceous-Tertiary Extinction." Science, Vol. 208 (1980) pp. 1095.**)

A Sudden Influx of Extraterrestrial
To test whether the anomalous iridium at the C-T boundary in the Gubbio sections is of extraterrestrial origin, we considered the increases in 27 of the 28 elements measured by NAA that would be expected if the iridium in excess of the background level came from a source with the average composition of the earth's crust. The crustal Ir abundance, less than 0.1 ppb, is too small to be a worldwide source for material with an Ir abundance of 6.3 ppb, as found near Gubbio. Extraterrestrial sources with Ir levels of hundreds of parts per billion or higher are more likely to have produced the Ir anomaly. (**Alvarez, L.W., et al. "Extraterrestrial Cause for the Cretaceous-Tertiary Extinction." Science, Vol. 208 (1980) pp. 1095.**)

The Danish boundary layer, which has much more Ir than the Italian C-T clay, is even less likely to have had a crustal origin. Rocks from the upper mantle (which has more Ir than the crust) have
less than 20 ppb and are therefore an unlikely worldwide source. There are, however, localized terrestrial sources with much higher Ir abundances; for example, nickel sulfide and chromite ores have Ir levels of hundreds and thousands of parts per billion, respectively…There is prima facie evidence for an abnormal influx in the observations that the excess iridium occurs exactly at the time of one of the extinctions; that the extinctions were extraordinary events, which may well indicate an extraordinary cause; that the extinctions were clearly worldwide; and that the iridium
anomaly is now known from two different areas in western Europe and in New Zealand. (**Alvarez, L.W., et al. "Extraterrestrial Cause for the Cretaceous-Tertiary Extinction." Science, Vol. 208 (1980) pp. 1095.**)

The Asteroid Impact Hypothesis
After obtaining negative results in our tests of the supernova hypothesis, we were left with the question of what extraterrestrial source within the solar system could supply the observed iridium and also cause the extinctions. We considered and rejected a number of hypotheses; finally, we found that an extension of the meteorite impact hypothesis provided a scenario that explains most or all of the biological and physical evidence. In brief, our hypothesis suggests that an asteroid struck the earth, formed an impact crater, and some of the dust-sized material ejected from the crater reached the stratosphere and was spread around the globe. This dust effectively prevented sunlight from reaching the surface for a period of several years, until the dust settled to earth. Loss of

sunlight suppressed photosynthesis, and as a result most food chains collapsed and the extinctions resulted. Several lines of evidence support this hypothesis, as discussed in the next few sections. The size of the impacting object can be calculated from four independent sets of observations, with good agreement among the four different diameter estimates. (**Alvarez, L.W., et al. "Extraterrestrial Cause for the Cretaceous-Tertiary Extinction." Science, Vol. 208 (1980) pp. 1095.**)

Biological Effects

A temporary absence of sunlight would effectively shut off photosynthesis and thus attack food chains at their origins. In a general way the effects to be expected from such an event are what one sees in the paleontological record of the extinction.

The food chain in the open ocean is based on microscopic floating plants, such as the coccolith-producing algae, which show a nearly complete extinction. The animals at successively higher levels in this food chain were also very strongly affected, with nearly total extinction of the foraminifera and complete disappearance of the belemnites, ammonites, and marine reptiles.

A second food chain is based on land plants. Among these plants, existing individuals would die, or at least stop producing new growth, during an interval of darkness, but after light returned they would regenerate from seeds, spores, and existing root systems. However, the large herbivorous and carnivorous animals that were directly or indirectly dependent on this vegetation would become extinct. Russell states that "no terrestrial vertebrate heavier than about 25 kg is known to have survived the extinctions." Many smaller terrestrial vertebrates did survive, including the ancestral mammals, and they may have been able to do this by feeding on insects and decaying vegetation.

The situation among shallow marine bottom-dwelling invertebrates is less clear; some groups became extinct and others survived. A possible base for a temporary food chain in this environment is nutrients originating from decaying land plants and animals and brought by rivers to the shallow marine waters. (**Alvarez, L.W., et al. "Extraterrestrial Cause for the Cretaceous-Tertiary Extinction." Science, Vol. 208 (1980) pp. 1095.**)

Kring, D.A., “Impact Events and Their Effect on the Origin, Evolution, and Distribution of Life.” GSA Today. Vol. 10, No. 8 (2000) pp. 1.

THE CHICXULUB IMPACT EVENT

Regional Effects

The Chicxulub impact occurred on a shallow carbonate shelf that is now part of the Yucatán Peninsula. In the immediate vicinity of the crater, the shock wave, air blast, and heat produced by the impact explosion killed many plants and animals. The air blast, for example, flattened any forests within a 1000–2000 km diameter region, which would have included the highlands of Chiapas, central Mexico, and the gulf states of the United States. Tsunamis also radiated across the Gulf of Mexico basin, producing reworked or unusually high energy sediments along the latest Cretaceous coastline. Tsunamis were 100–300 m high as they crashed onto the gulf coast and ripped up seafloor sediments down to depths of 500 m. The backwash of these waves was tremendous, depositing forest debris in 400–500 m of water. The abyssal portion of the Gulf of Mexico basin, the neighboring proto-Caribbean, and Atlantic Ocean were also affected by the splashdown of impact ejecta, density currents, and seismically induced slumping of coastal margins following magnitude 10 earthquakes. Within a few hundred kilometers of the Chicxulub crater, the thick blanket of ejecta was sufficient to exterminate life. (**Kring, D.A., “Impact Events and Their Effect on the Origin, Evolution, and Distribution of Life.” GSA Today. Vol. 10, No. 8 (2000) pp. 1.**)

Global Effects

While these effects devastated organisms in the Gulf of Mexico region, the most significant environmental perturbations were the direct and indirect result of ejected debris that rained through the atmosphere, as first postulated by L.W. Alvarez et al. (1980). This material was
carried in a vapor-rich plume that rose through the atmosphere into space. Once above the atmosphere, it expanded on ballistic trajectories, enveloping the whole Earth as it fell back into the atmosphere. The impact ejecta was distributed globally in a pattern much different from that of volcanic plumes, which simply rise into the stratosphere and then spread into latitudinal bands. Calculations indicate that most of this material reaccreted to the top of the atmosphere over a three-day period, where it then settled to the ground over a longer period of time, depending on grain size. If a substantial portion of this dust was submicron in size, model calculations suggest the dust may have made it too dark to see for one to six months and too dark for photosynthesis for two months to one year, seriously disrupting marine and continental food chains and decreasing continental surface temperatures. (**Kring, D.A., “Impact Events and Their Effect on the Origin, Evolution, and Distribution of Life.” GSA Today. Vol. 10, No. 8 (2000) pp. 1.**)

In addition to the dust in the vaporrich plume of ejecta, several important gas species were entrained. The Yucatán Peninsula, near the Chicxulub impact site, consists of carbonate and anhydrite deposits that overlie a crystalline silicate basement, so the impact produced several climatically active gas components, including aerosol-

producing SO_2 and SO_3, greenhouse-warming CO_2 and H_2O, and ozone-depleting Cl and Br. The worst appears to have been the
S species, which enhanced stratospheric S on the order of 105–106 times relative to modern abundances. (**Kring, D.A., "Impact Events and Their Effect on the Origin, Evolution, and Distribution of Life." GSA Today. Vol. 10, No. 8 (2000) pp. 1.**)

The biological consequence of the Chicxulub impact was the collapse of entire ecosystems; cascading effects destroyed the infrastructure of the biosphere (e.g., collapse of food chains, loss of habitat), compounding the initial direct environmental effects. Thus, while the physical effects of the impact event may have been relatively short-lived, the time needed to reestablish chemical gradients, repair food chains, and rebuild integrated ecosystems was much greater. The details of the biologic crisis and its recovery are difficult to tease from the geologic record, but some progress is being made. Impact cratering theory suggests the crisis was global and, indeed, marine bivalve extinction intensities are global without any latitudinal or geographic variations. In both marine and continental settings, organisms with dormant or resting states faired better through the crisis. For example, planktonic diatoms that produce resting spores specialized to persist in benthic or deep-pelagic environments of low- to nolight conditions, and, during periods of stress, had a high survival rate. It has also been suggested that the loss of primary productivity and the subsequent collapse of food chains had much less an effect on organisms that were detritus feeders or starvation resistant. The recovery of these survival species, however, did not represent the full recovery of the ecosystem with robust food chains and attendant biochemical gradients. For example, it appears that while marine production may have recovered relatively quickly (albeit with a completely different population of organisms), the flux of organics to the deep sea took approximately three million years to recover. (**Kring, D.A., "Impact Events and Their Effect on the Origin, Evolution, and Distribution of Life." GSA Today. Vol. 10, No. 8 (2000) pp. 1.**)