The Mistaken Extinction

Chapter Six

The Search for the Smoking Gun: The Direct Evidence for a K-T Impact

Throughout the 1980s, proponents of an impact scenario for the extinctions at the end of the Cretaceous searched feverishly through geologic data and satellite imagery. They were looking for the "smoking gun" or, more appropriately, the "festering wound" inflicted on the Earth's crust by the alleged impact. The Earth has long been bombarded by extraterrestrial objects, although the rate of impacts appears to have decreased over the last 4.5 billion years since the Earth first formed.

Nonetheless, extraterrestrial objects large enough to pass through the atmosphere without burning up continue to occasionally hit the Earth with tremendous force. Scars from some recent impacts remain clearly visible, such as Arizona's Meteor Crater. It formed when a meteorite hit the Earth between 50,000 and 25,000 years ago, creating a bowl-shaped depression about three-quarters of a mile (1.2 km) across[1]. An iron meteorite between 80 and 200 feet (25 and 60 m) across is believed to have been responsible. The impact released between 10^{16} and 10^{17} joules of kinetic energy--about the same amount as would be released by the explosion of 4-60 megatons of dynamite. Estimates of crater impact frequency suggest that a meteor large enough to leave a crater six miles (ten km) across hits the Earth about once every 100,000 years[2].

Even in the 20th century, an apparent explosion of a comet or meteorite devastated a large area of Siberia. This near-impact, called the Tunguska event, leveled 1000 square miles (2,600 square kilometers) of forested land on June 30, 1908[3]. The devestated region was equivalent to a square about 32 miles on each side. The explosion, which released energy equivalent to 15 megaton nuclear bomb[4], was heard as far away as Moscow. The Tunguska event is thought to have been the result of a object that exploded between 4 and 6 miles (6 and 10 km) above the Siberian landscape. Debate has ensued as to whether the explosion was caused by a comet, between 300 and 625 feet (90 to 190 meters) across, or by a carbon-rich asteroid between 164 and 328 feet (50 to 100 meters) across. It is estimated that the body was traveling between 7.5 and 12.5 miles per second (12 and 20 km/sec), which would be equivalent to between 27,000 and 45,000 miles per hour. The impact would have generated shock layer temperatures of somewhat less than 36,000 degrees F (20,000 degrees C). In 1956, one student of that event, M. W. De Laubenfels, went so far as to suggest that a similar but

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larger impact could have been responsible for the extinction of dinosaurs[5].

But these relatively recent events are dwarfed by what was proposed to have happened at the end of the Cretaceous. An asteroid or comet large enough to have caused the K-T extinctions should have left a truly enormous crater (fig. 6.01). One early estimate suggested that the collision would have generated a crater about 31 miles (50 km) deep that extended across an area of almost 5,800 square miles (15,000 square km)[23]. This would represent a crater with a diameter of almost 90 miles (140 km). But the question remained, where is that crater?

A K-T Impact Crater

For several years, no one could find a crater of the right size and age. Many potential explanations were offered by impact proponents, such as Walter Alvarez and Frank Asaro, as to why[24]. They pointed out that the crater might have been eroded away by subsequent geologic weathering or even destroyed by the recycling of crust at subduction zones. Alternatively, it might now be too deeply buried under subsequently deposited sediment to be easily recognizable. However, the opposition favoring volcanic extinction scenarios countered that it seemed highly unlikely that we would not have found at least one crater, especially if multiple impacts had occurred, as some impact advocates had begun to suggest by the mid-1980s.

One proposed candidate for the K-T impact crater was the Manson Crater located in Iowa. However, it is only about 22 miles (35 km) across. This is much too small to have caused the observed global thickness of debris and iridium concentration found in the boundary layer[6]. One sure test of whether the Manson crater was a legitimate candidate would be to date the rock that had been melted at the time of its impact. Such a test should yield an age of about 65 million years. Initial radiosiotopic evidence developed by Michael Kunk of the U. S. Geological Survey suggested that it was about the right age--65.7 million years old. In 1993, however, further tests conducted by Kunk in conjunction Glen Izett and others from the U. S. Geological Survey established that the Manson Crater is about 74 million years. The crater was much too old to have had any role in the K-T extinctions[7].

Another serious candidate was actually discovered as the result of exploration for oil in 1981[8]. However, little attention was paid to the announcement by Glen Penfield and his colleagues because it was before the search for the K-T impact crater had actually begun. In an ironic twist of fate, most of the drilling-core samples that documented the geologic evidence at this site were destroyed by a fire in the warehouse where they were stored. Consequently, the crater's possible existence

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and relationship to the scenarios involving the K-T extinctions only came to light in the early 1990s. Studies by Alan Hildebrand of the Geological Survey of Canada and his colleagues, as well as research by Kevin Pope of Geo Eco Arc Research and his colleagues[9,] brought this geologic structure to the attention of the scientific community.

This site is located near the town of Chicxulub (fig. 6.02). It lies partly on the northwest corner of the Yucatan Peninsula and extends into the adjacent Gulf of Mexico. On land, the form of the buried crater can be seen, to some degree, on topographic maps and aerial photos[10]. They reveal a semicircular ring of sink holes that correlate well in position with the margin of the crater that was identified at first by anomalous readings of gravity. These sink holes range from about 160 to 1600 feet (50 to 500 m) in diameter and are from six to 400 feet (2 to 120 m) deep. Apparently, the edge of the crater formed a barrier to the later migration of groundwater under the surface of the Earth. This caused an increased flow of subsurface water, which dissolved the limestone layers underneath the ground. Then, a collapse of the limestone around the boundary of the crater formed the sink holes.

Chicxulub is truly enormous, whether you believe scientists that advocate a mind-boggling diameter of almost 200 miles (300 km) or those who propose a more modest, but still daunting, figure of about 110 miles (180 km). The conflicting dimensions were reported in different studies published in 1993 and 1995. Virgil Sharpton of the Lunar Planetary Institute and his co-authors published the earlier study, which argued for the larger diameter[11]. Alan Hildebrand and his co-authors published the later study[12]. In both papers, the estimated diameter of the crater was based on interpretations derived from gravity measurements taken at the site. Although it would seem to be an easy job to determine the crater's size by measuring the diameter of the crater rim, the job is made more difficult by the fact that the crater's full topography is no longer clearly expressed at the surface of the Earth. Since the actual crater formed, it has been buried by between 1,000 and 3,300 feet (300 and 1,000 m) of sediments (fig. 6.03). But the gravity measurements allow geophysicists to "see" through the overlying sediments deposited on the land and on the seafloor to interpret the underlying structure of the crater.

The process of crater formation is fairly well understood as the result of ballistic experiments in the laboratory and obervations of craters on the Earth, moon, and planets[13,14]. Upon impact, shock waves compress and accelerate the target rocks downward and outward to velocities of a couple of miles (several km) per second (fig. 6.04). Then, rebound changes the direction of movement to upward and outward for target material near the surface. These two phases of movement excavate a transient crater by moving target material downward and out from the point of impact, then upward and out of the crater, to create a layer of debris ejected outside the crater in the form of fallout. Calculations indicate that the great majority of material in the impacting object is blasted upward at high velocities as ejecta. In addition, a mass of target rock equal to about 10-100 times the mass of the meteorite is exploded out of the crater along similar paths.

Relatively large craters on Earth have a central peak surrounded by a series of concentric terraces. These formed as large, unstable blocks of surrounding rock, propelled by gravity, slid down into the crater's cavity soon after it formed. The floor of the crater is formed by a layer of rock that was melted by the impact. Some of this melted material was blasted out of the crater. In terms of the Chicxulub impact scenario, this material is thought to have formed the glassy, spherical and globular droplets of melted impact debris found in some boundary clays. These are called tektites. The layer of melted rock on the crater floor overlies a layer of fractured rock including fragments of the target rock. Some of the fractured target rock is thought to have been blasted into orbit as part of the dust cloud. Smaller fractured fragments eventually settled out of the atmosphere as the badly fractured crystals of quartz and other minerals discussed in the last chapter.

Within the largest craters on Earth the large central peak is represented instead by a tall ring of mountains. These are formed by uplifting movements after the initial downward and outward forces reverse in the center of the crater to generate upward and inward motions as a result of rebound and the collapse of the crater rim. The process seems to be kind of like watching a slow-motion movie of a drop of water hitting the surface of a bowl of water, but obviously, water is much less viscous. Such large craters are more easily seen on the Moon where erosion and subsequent deposition have been minimal due to the lack of rain and wind. An example is the crater that forms the Oriental Basin, which has five stupendous concentric rings that range in diameter from 200-800 miles (320-1300 km).

Some of the crater rings were generated by gravitational collapse after an initial crater, shaped like a hemisphere, is created by the impact. The depth of the crater continues to grow until the pull of gravity becomes too weak to pull the material forming the floor further down. The resulting hole is termed the transient crater, and it has a ratio of depth/diameter of about 1:3. The fractured walls of the transient crater are not stable because their slopes are too steep. Consequently, they collapse under the force of gravity to form additional rings, as well as the layer of fractured material in the bottom of the crater (fig. 6.05). So, the game is to identify the diameter of transient crater so that the force of the impact can be estimated.

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On gravity surveys, the Chicxulub crater shows up as a basin almost 125 miles (200 km) in diameter that contains two ring-shaped structures (fig. 6.06) with diameters of 65 and 96 miles (104 and 154 km). One of these may correspond to the central ring of mountains seen in large lunar craters. The 1993 study by Sharpton and his colleagues argued for the presence of a fourth ring with a diameter of about 175 miles (280 km). This suggested to those researchers that the transient crater was about 106 miles (170 km) across [15]. However, using the same gravitational data supplemented with other new data and a slightly different method of analysis, the 1995 study by Hildebrand and his colleagues failed to confirm the presence of the outside ring . This later study concluded that the 125-mile-diameter ring represented the rim of the collapsed crater and that the transient crater was only 50-56 miles (80-90 km) in diameter[16].

If the interpretation of the 1993 paper is correct, the estimated force of the impact may have been one of the largest in the last four billion years within the inner part of the solar system. The impact--by one estimate judged to be equivalent to simultaneously detonating 1,000 times the number of nuclear weapons present in all of today's arsenals--would have excavated a crater about 35 miles (56 km) deep. This results from the calculating the depth based on the depth to diameter ratio of about 1/3. If the 1995 study is correct, the depth of the crater would have been about 18 miles (28 km). No matter which estimate is considered valid, the impact was obviously an event of staggering proportions.

But what geologic and paleontologic evidence is there to suggest that Chicxulub is, in fact, the crater left by the impact at the K-T boundary? One test would be to date the meltrock in the crater radioisotopically to see if it yields the same age as the tektites preserved in K-T boundary sections in other areas. This is what Carl Swisher and his team of colleagues did. Their radioisotopic dating of the melted rock within the Chicxulub crater formed at the time of the impact has established its age at 64.98 million ± 50,000 years[17]. The microscopic glassy tektites at the boundary found in Haiti and at Arroyo El Mimbral, Mexico have been dated by the same laboratory to be 65.01 million years ± 80,000 years and 65.07 million ± 10,000 years old. These radioisotopic ages represent strong geologic evidence that these tektites, found at the K-T boundary where the change in microscopic marine organisms occurs, were at least formed at the same time as the Chicxulub impact.

The geographic location of this impact crater on the coastline of the ancient Gulf of Mexico is also significant. Some chemical analyses of boundary clay suggested that the impact had occurred in the crust of the

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ocean because the tektites and other boundary material were of similar composition[18]. One such study was conducted by Don De Paulo and Frank Kyte of the Univeristy of California at Los Angeles and their colleagues. Other analyses by Michael Owens and Mark Anders suggested that the impact had occurred in the crust of a continent[18]. Since the Chicxulub crater extends across both continental and marine crust, these seemingly contradictory results could be explained by the fact that the crater straddles the shoreline.

More definitive geologic evidence comes from geochemical "fingerprinting"--a method whose name sounds especially appropriate for solving mysteries related to a scientific detective story. As mentioned in the previous chapter, geochemical fingerprinting involves analyzing the chemical composition of elements in different rock material at different sites to see if they might represent rocks formed by the same event. In this case, scientists compared the chemical composition of tektites from the boundary layer near Beloc, Haiti with the chemical composition of the rocks in the crater at Chicxulub.

Haraldur Sigurdsson and his colleagues found that the boundary layer at Beloc contains two principal kinds of spherules thought to represent tektites that were blasted out of the crater during the impact[19]. One is composed of black glass and the other is composed of black glass covered by a coating of yellow glass. The black glass is rich in silica and has a chemical composition similar to that of a particular kind of volcanic rock called andesite, which is commonly erupted along the edges of continental plates. More impressively, the chemical composition of this black glass is almost exactly like that of some andesites found in Mexico, and andesite is present in the Chicxulub area.

Analyses of the yellow glass coatings, however, reveal a distinctly different chemistry. The yellow glass is depleted in rare earth elements, but it is enriched in atoms of calcium and magnesium. To try and recreate the composition of the yellow glass, the Sigurdsson and a second group of colleagues melted minerals such as gypsum and anhydrite--common in the magnesium-rich, limy sediments along the Mexican coast near Chicxulub--with andesite[19]. The temperature in the experimental melting tubes made of platinum was raised to between 2200 and 2500 degrees F (1200 and 1400 degrees C). The result, upon cooling, was the formation of a yellow glass enriched in calcium, similar to that found coating the Haitian tektites.

In 1993, another piece of mineralogical "fingerprinting" evidence was discovered by Thomas Krogh of the Royal Ontario Museum and his colleagues. In the Raton Basin of Colorado, the boundary layer was found to contain microscopic crystals of the mineral zircon weighing from one to four one-millionths of a gram[20] (one pound=454 grams). Zircon is very durable and often contains in its crystal structure atoms of uranium that naturally decay to atoms of lead. Zircon can, therefore, be used for radioisotopic dating. Such age analyses on these crystals established that they had originally been formed 544.5 ± 4.7 million years ago, then reheated 65 million years ago. At Chicxulub, fragmented target rock from the crater created by the impact also contains crystals of zircon. When they were analyzed, they were found to have an original age of formation of 544 ± 5 million years. Similar age relationships have been found for microscopic zircon crystals separated from the boundary clay in Haiti. What makes this evidence compelling is that 545 million year old rocks are very rare in North America. Consequently, the presence of such zircon crystals at the impact site and at these two other geographically widespread localities is very difficult to explain without invoking the Chicxulub impact and its globally distributed fall-out layer.

Other Potential K-T Impact Craters

There is now no shortage of other large impact craters that potentially could have been created at the same time as the Chicxulub crater. They range in location from Siberia, to the Black Sea region, to northern Africa, to Alaska[21]. One example is the 60-mile-diameter (96 km) Popigay crater in eastern Siberia Based on its size in relation to the Chicxulub crater, only about one tenth the amount of material is thought to have been ejected from this smaller crater. Yet, based on modeling, the Popigay impact alone would have generated a dust cloud thick enough to cut off light from the Sun to the Earth for three months. However, radioisotopic dates indicate that it is around 39 ± 9 million years old. So, it is much too young to have been involved in the K-T extinctions.

Some scientists have argued that several potential K-T impact craters tend to line up on a single great arc that extends across the surface of the Earth[22]. This implies that they may represent the break-up of a single large extraterrestrial body into several smaller bodies that impacted in a "machine-gun" like barrage. One example of such a barrage was witnessed in the summer of 1994 when the comet Shoemaker-Levy broke up into several pieces before pummeling Jupiter.

At this point, however, such claims that more than one K-T impact occurred represent a significant leap of faith. The age of these other craters is not tightly constrained by published radioisotopic dating in the way that the age of the Chicxulub crater is.

Although not all proponents of the volcanic extinction scenario would probably agree, it appears to us that there is now good geologic evidence to demonstrate that an extraterrestrial impact of huge proportions did occur at the end of the Cretaceous. But can effects of the

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potential killing mechanisms from the impact at Chicxulub be distinguished from the potential killing mechanisms of the volcanic activity? To see, we must closely examine clues present in the fossil record spanning the K-T boundary, paying special attention to the kinds of organisms that perished and survived. That exercise is the subject of the next chapter.

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Captions for figures in Chapter 6

fig.6.01
This is an artist's conception of what the Chicxulub Crater mighthave looked like soon after it was formed by the impact of a comet or asteroid about 65 million years ago.

(from Kerr, R., 1993, Death knell for the dinosaurs, Science, v. 261, p. 1518; illustration credited to William K. Hartmann)

fig. 6.02
The map shows the location of the Chicxulub Crater. It occupies a corner of the Yucatan Penninsula in Mexico, as well as forming some of the bed for the adjacent Gulf of Mexico.

(from Pope, K. O., et al, 1991, Mexican site for K/T impact crater?, Nature, v. 351, p.105)

fig. 6.03
A generalized cross section of the Chicxulub Crater illustrates both the rock units that form the crater and its contents, as well as the younger units on top that have buried it since it was formed.

(from Swisher, et al., 1992, Coeval ^{40}Ar/^{39}Ar ages of 65.0 million years ago from Chicxulub crater melt rock and Cretaceous-Tertiary boundary tektites, Science, v. 257, p. 955)

fig. 6.04
This schematic diagram illustrates how the transient crater is formed by the impact, as well as the subsequent rebound and collapse of the crater rim.

(from Grieve, R. A. F., 1989. Hypervelocity impact cratering: A Catastrophic geologic process, In Alvarez, W., et al. Catastrophes and Evolution: Astronomical Foundations, Cambridge Univ. Press, Cambridge, p. 64)

fig. 6.05
The final form of the crater takes shape after the collapse of the unstable walls of the transient crater.

(from from Grieve, R. A. F., 1989. Hypervelocity impact cratering: A Catastrophic geologic process, In Alvarez, W., et al. Catastrophes and

Evolution: Astronomical Foundations, Cambridge Univ. Press, Cambridge, p. 65)

fig. 6.06

The image on the right has been developed from studies analying the force of gravity around the impact site at Chicxulub. The image shows the rough outline of the crater and its concentic rigns. The map on the right documents the curved line of sinkholes (black dots) delineating the circular outline of the crater.

(Hildebrand, et al., 1995, Size and structure of the Chicxulub Crater reveale by horizontal gravity gradients and cenotes, Nature, v. 376, p. 415)