Chapter Eight

Our Hazy View of Time at the K-T Boundary

From the perspective of geologic time, the K-T boundary lies 65 million years in the past. In reality, events at that boundary occurred fairly recently in relation to events like the origin of the Earth (4.5 billion years ago) or even the origin of dinosaurs (around 240 million years ago). Nonetheless, trying to tell time 65 million years ago represents a significant challenge for paleontologists and geologists. More importantly, our ability to tell time precisely will directly affect our ability to establish whether the K-T extinction happened very quickly, as predicted by the impact hypothesis, or more gradually, as suggested by scenarios involving volcanic activity and the retreat of shallow seaways.

There are two common ways to tell geologic time. The first is termed "relative" geologic time. Basically, all one is trying to do is decide whether a particular event happened earlier or later than another event. No judgement is made about how much earlier or later that event occurred. As mentioned in earlier chapters, this concept is based on the law of superposition, which generally states that layers of rocks and fossils that lie lower in a sequence are older than layers and fossils that lie higher in the sequence. This is because layers are laid down one on top of the other.

The other common way to tell geologic time is termed "scaled" or "absolute" geologic time. Here, instead of simply trying to determine whether one event occurred earlier or later than another, one tries to estimate how much earlier or later in terms of years. The only way to reliably scale time in terms of years-before-the-present is through radioisotopic dating. The basic concept was explained in Chapter 1. It's through this means, for example, that the age of the K-T impact has been estimated to be 64.98 million $\pm$ 50,000 years, as noted in Chapter 6. Other geologic time scales exist, such as the previously mentioned time scale based on the reversals of the Earth's magnetic field. But, these time scales ultimately depend on radioisotopic dates in order to be calibrated in terms of years before the present.

In terms of the debate between proponents of the impact and volcanic extinction scenarions, how does our ability to tell time through these relative and scaled methods affect our ability to assign resonsibility for the extinctons to the two competing hypotheses?

Chapter 8 from: *The Mistaken Extinction - Dinosaur Evolution and the Origin of Birds*, by Lowell Dingus and Timothy Rowe, 1998. W. H. Freeman, New York.

Stepwise Extinctions and Multiple or "Smeared" Iridium Anomalies

In its original form, the impact hypothesis posited a single catastrophic blast as the cause of the terminal Cretaceous extinctions. However, in the last half of the 1980s several researchers began to argue that the large iridium enrichment associated with the boundary clay and the last appearances of typical Cretaceous organisms could not explain the detailed pattern of last occurrences of extinguished organisms seen in the rock layers leading up to the K-T boundary. Instead, a series of steplike extinction events is apparently seen to occur in the layers just below the boundary clay containing the major iridium enrichment (fig. 7.12)[39]. In some sequences spanning the K-T boundary, the high concentrations of iridium are not restricted to the boundary clay itself. On the contrary, the iridium enrichment appears to more gradually diminish in intensity as one moves either up from or down from the boundary clay over distances of a few meters. These are termed "smeared" anomalies. Occasionally, subsidiary peaks of iridium concentration are associated with these smeared enrichments and are interpreted by some to represent multiple anomalies.

Correlated with the alleged stepwise extinction events below the boundary are significant changes in the ratios different forms of carbon, oxygen, and osmium atoms, called isotopes. These are interpreted by Jeffrey Mount of the University of California at Davis and his colleagues to represent significant environmental and/or climatic changes during an extended period of the K-T transition. Taken as a whole, the picture seems to suggest that a series of small extinction events occurred over a period of several hundreds of thousands or even a few million years before the major impact.

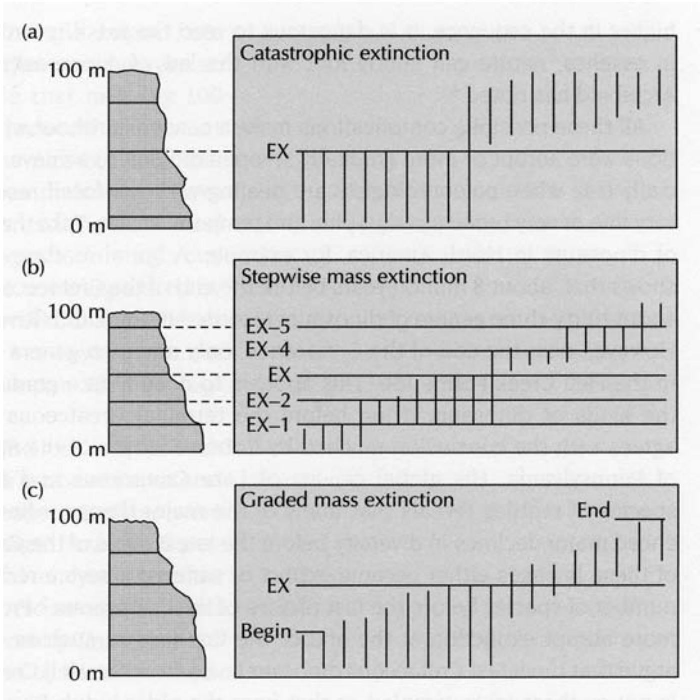

figure 8.01 These diagrams illustrate how different patterns of extinction might look in the geologic record. Three different hypothetical stratigraphic sections are shown on the left. Each section is 100 meters thick and contains several layers of rock. To the right, the vertical ranges of several kinds of fossil animals are plotted. In other words, each kind of animal is found throughout the interval of rock layers corresponding to the height of the vertical line. In (a), many kinds of animals disappear at the same level in the sequence of rocks, suggesting a catastrophic extinction. In (b), different kinds of animals disappear at five different levels within the sequence of layers, suggesting a stepwise pattern of extinction. In (c), almost every kind of animal disappears at a different level in the sequence, suggesting a more gradual pattern of extinction.

Not surprisingly, proponents of impact scenarios have distinctly different interpretations of what these stepwise extinctions represent than do proponents of volcanically based scenarios. To proponents of impact, the stepwise extinctions and the multiple or smeared iridium enrichments are documentation of multiple impacts as might be predicted by belief that the extinctions were caused by a swarm of comets that lasted less that a couple of million years. To proponents of volcanic scenarios, the stepwise extinctions and iridium anomalies document the major pulses of volcanic activity and associated environmental havoc resulting from the eruptions that formed the Deccan Traps and other terminal Cretaceous volcanic activity.

In large part, these differences of opinion result from differing approaches to interpreting the superpositional relationships of the fossils present in the sequence of rock layers spanning the K-T boundary. One problem, pointed out by Phil Signor of the

University of California at Davis and Jere Lipps of UC Berkeley, is that organisms that were relatively rare elements in these faunas are not likely to be preserved as often as more abundant members of the faunas[40]. Consequently, the less common organisms may *appear* to drop out of the fossil record well below the boundary, even though they may have lived right up to the last moment of the Cretaceous. They appear to disappear because we have yet to find them preserved as fossils close to the boundary. This sampling or preservational phenomena might make one large extinction event look more gradual or "stepped" in the geologic record.

In contrast, because gaps in time may be present between different layers of rocks containing the fossils, artificially large numbers of organisms can appear to disappear from the record abruptly. Some of these animals that appear to drop out might have actually lived longer, but there are not layers of sediment to document their existence.

Similarly, as David Jablonski of the University of Chicago and Karl Flessa pointed out, there are instances in which a fossil organism appears to drop out of the record temporarily, only to reappear several layers higher up in the sequence[41]. Such a pattern might be interpreted to mean that the organism was temporarily not living in the local area but survived in other regions before returning to the original habitat.

Finally, due to the fact that layers of sediment and enclosed fossils can be eroded from their original position in the sequence and redeposited later into younger layers higher in the sequence, it is dangerous to read the fossil record too literally. In essence, nature can subtly fool with the law of superposition, as David Archibald has noted[42].

All of these possibilities make a consensus about whether extinctions were abrupt or more gradually stepped difficult to achieve when paleontologists are dealing with the fossil record on either very fine or coarse stratigraphic and temporal scales. Take the fossil record of dinosaurs in North America, for example. A literal reading of the record shows that, about eight million years before the end of the Cretaceous, there were about 33 genera of dinosaurs recorded from North America. However, near the end of the Cretaceous, only 19 genera were present, suggesting a gradual decline in the kinds of dinosaurs living before the terminal Createceous events[43]. Proponents of a more abrupt extinction at the end of the Cretaceous, such as Dale Russell, argue that the latest Cretaceous dinosaur fauna from the Hell Creek Formation is not as thoroughly sampled as that from the older Judith River Formation. However, after fairly intensive collecting in both areas for the last 100 years, this seems like a fairly weak argument.

Another study has been conducted within the Hell Creek Formation itself to estimate whether the diversity of dinosaurs was declining before the terminal Createceous events. Peter Sheehan, David Fastovsky of the University of Rhode Island and their colleagues divided the 300-foot-thick formation into three parts--the lowest 100 feet, the middle 100 feet and the upper 100 feet[44]. Then they recorded where they found fossils of different kinds of dinosaurs. They tracked 14 different genera of dinosaurs that belonged to eight different families and concluded that there was no statistically significant change in diversity from the bottom to the top of the formation.

Unfortunately, the Hell Creek Formation is widely noted for its paleoriver channels that are capable of reworking fossils from the original position in which they were deposited. A simple assignment of fossils to one of the three levels within the formation ignores the possibility of reworking. Other paleontologists, such as Archibald, have argued that the statistical approach used by Sheehan and his colleagues is not truly able to measure whether the diversity of dinosaurs actually declined or remained constant[45]. Consequently, the conclusion that dinosaur diversity did not decline until the last moments of the Cretaceous is still very controversial.

How Precisely Can We Really Tell Time at the K-T Boundary?

Regardless of whether one favors a more gradual, terrestrial scenario or a more catastrophic extraterrestrial scenario, the question of how well we can "tell time" at the end of the Age of Dinosaurs directly affects our ability to test these competing hypotheses.

The extinction mechanisms associated with any single impact are thought to have operated over a period of less than 50 years and maybe as little as several months. This means that in any marine or continental boundary sequence that we want to use as a test, our youngest fossils at the end of the Age of Dinosaurs and our oldest fossils at the beginning of the Age of Mammals would have had to have lived no more than 50 years and perhaps as little as several months apart in order to truly test the predictions in a rigorous scientific sense[46]. Also, those same samples would have to be separated by less than 100,000 years to test the more gradual, terrestrial hypotheses associated with volcanism and the retreat of shallow seaways or the net effects of multiple impacts. Can we tell time during this period of geologic history that precisely?

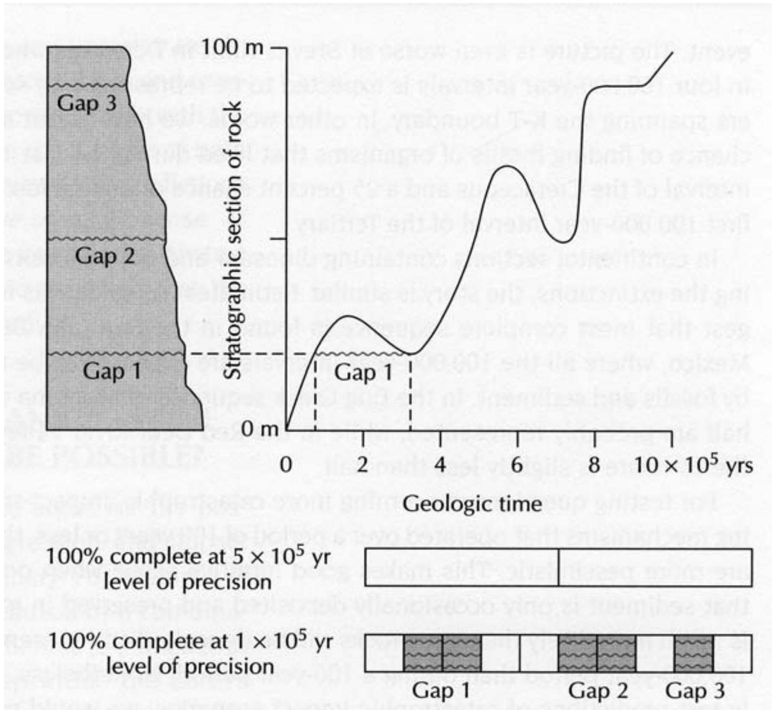

figure 8.02 The graph illustrates how gaps not represented by sediment in a section of rocks can affect our ability to read the fossil record at short time scales. Basically, the record is revealed to be less and less complete as one tries to read the fossil record at increasingly finer time scales.

The only direct way to tell how many years old rocks and fossils are is by isotopic age determinations, also called radiometric dates. As discussed earlier, these estimates are based on atomic processes of radioactive decay. Until recently, they have generally been thought to be accurate to within ± 5% of the true age. However, 5% of 65 million is a little over 3 million years. If several analyses are run on the same rock, we were sometimes reduce the error factor down to several hundred thousand years. New technology utilizing lasers has improved our precision to between ±10 and 100 thousand years, as shown by the dates associated with the boundary that were discussed previously.

Yet clearly, these error factors currently prohibit us from rigorously testing the predictions made by these competing hypotheses at the required catastrophic time scales of months or centuries. Also, to test adequately, we would have to have rocks that we could date at catastrophic levels of precision just below the youngest fossils from the Age of Dinosaurs and just above the oldest fossils from the Age of Mammals. No such marine sections exist, and only one terrestrial section is presently known. The error factors associated with the dates in that one terrestrial Canadian section (± 400 thousand years) are much too great for definitive testing, especially of catastrophic killing mechanisms lasting less than 50 years.

How Completeness of the Geologic Record Affects Our Ability to Decide Whether the Extinctions Were Gradual or Catastrophic

If we ignore or neglect the error factors associated with radioisotopic dates, as well as other error factors associated with estimating the duration of the period of reversed polarity during which the extinctions occurred, we can approach the question another way. Geologists, especially Peter Sadler of the University of California at Riverside, have developed a method to estimate how often sediment and fossils are preserved in sedimentary sections[47].

Layers of rock intermittently record the passage of geologic time. Gaps of various duration often exist between different layers of sediment that contain fossils (fig. 7.13). These gaps can result either from the fact that sediment was not being deposited during the intervening period between layers or from the fact that sediment was originally deposited between two layers, but was later eroded away by the actions of water or wind. Since few beds can be radioisotopically dated, there is no way to determine the duration and position of all the time gaps in a given sequence of layers spanning the K-T boundary. Yet, by compiling and contrasting how fast sediment builds up in other sections deposited in similar environments (i.e. modern sections being deposited on floodplains, deltas, lakes, near-shore continental shelves, and deep ocean floors), we can estimate how often sediment and fossils were preserved in sections where we cannot tell time with radioisotopic dates. One of us performed such a test as part of our graduate studies at UC Berkeley[46].

For testing questions concerning more gradual volcanic scenarios, we must estimate how many 100,000-year intervals at the end of the Age of Dinosaurs and the beginning of the Age of Mammals are represented by sediment and fossils. Again, this is because the killing mechanisms for these scenarios are thought to have operated over time intervals of about 100,000 years. So, to test the associated ideas about whether volcanic eruptions were responsible for the extinctions, we would need to have had sediment preserved during each 100,000-year period during the K-T transition. By the same reasoning, to test the catastrophic effects of an impact, we would have to have sediment and fossils preserved during the last 100-year interval before the extinction event and during the first 100-year interval after the boundary. This is because most of the "killing mechanisms" associated with the impact are thought to have operated at time scales less than 100 years. So, we need to convince ourselves that we are truly seeing the effects of these short term mechanisms.

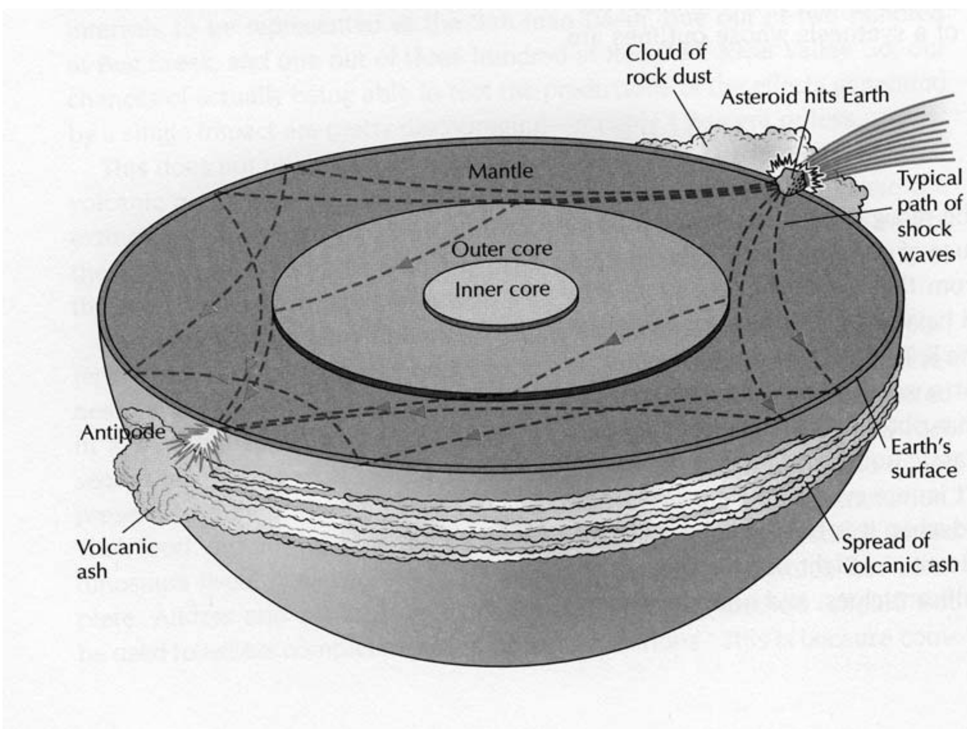

figure 8.03 This illustration shows how an massive impact on one side of the Earth might trigger extensive volcanic eruptions on the opposite side. Such a mechanism has been advocated by some scientists to be responsible for both the Chicxulub Crater and the Deccan Traps. (from Broad, W. J., Dec. 27, 1994, New theory would reconcile rival views on dinosaur's demise, New York Times)

This might seem like a trivial point, but in fact, it is anything but trivial. To illustrate why, let's briefly consider a depressing hypothetical analogy involving human history. Imagine that you are an archaeologist in the 45th century trying to interpret the relative number of deaths caused by World War II and longer term environmental pollution that occurred during the 20th and 21st centuries. Most records detailing deaths during the 20th and 21st centuries were forever destroyed during global wars at the end of the 21st century; however, some sketchy records remain of these events. It's known that World War II happened during a five to seven year period in the middle of the 20th century, and that environmental pollution caused numerous deaths during both centuries. In your research, you are trying to interpret whether a large cemetery--essentially a bone bed--that you've excavated in Europe represents the effects of war casualties that occurred during World War II or deaths that resulted from environmental pollution. If you could find a way to tell time on the scale of decades, you could at least decide whether the bones in the cemetery represented individuals that died during the decade in which World War II was fought. However, if your ability to tell time was limited to establishing that these deaths occurred sometime during the 20th or 21st centuries, you could not be sure whether the deaths were the result of casualties during World War II or the result of that era's environmental pollution.

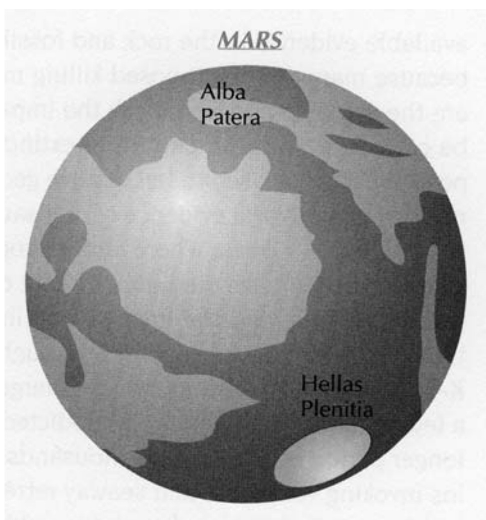

figure 8.04 The maniifestations of antipoda volcanism seem to be clearly demonstrated on Mars. The largest known volcano in the solar system is located at the opposite point on the planet from where a large impact occurred, creating the crater, Hellas Plenitia. (from Broad, W. J., Dec. 27, 1994, New theory would reconcile rival views on dinosaur's demise, New York Times)

Now let's take that concept and apply it to extinction events that happened 65 million years ago during the K-T transition. First, we'll look at the completeness of the fossil record in deep marine sections containing the fossils used to document the extinction of microscopic plankton. The latest estimates suggest that we can expect many 100,000-year intervals spanning the K-T transition to be complete in these sections; in other words many of the 100,000-year intervals during the transition can be expected to be represented by sediment. For example, in the Spanish K-T boundary sequence at Caravaca, all the 100,000-year intervals are thought to be represented; in other words, it is complete at the 100,000-year time scale. This is very encouraging because this estimate is telling us that we can expect to find fossils and sediment deposited during the last 100,000-year period before the extinction event and from the first 100,000-year period after the extinction. However, in the Italian sequence at Gubbio, where the iridium enrichment was first discovered, slightly more than half of the 100,000-year intervals are expected to be represented by fossils or sediment. So, we have about a 50% chance of not having fossils from the last 100,000-year interval before the extinction event and a 50% chance of not having a fossil record from the first 100,000-year interval after the extinction event. The picture is even worse at Stevns Klint in Denmark, where only one in four 100,000-year intervals is expected to be represented by sediment layers spanning the K-T boundary. In other words, we have about a 25% chance of finding fossils of organisms that lived during the last 100,000-year interval of the Cretaceous and a 25% chance of finding fossils from the first 100,000-year interval of the Tertiary.

In continental sections containing dinosaur and pollen fossils documenting the extinctions, the story is similar. The most complete sequence is found in the San Juan Basin of New Mexico, where all the 100,000-year intervals are expected to be represented by fossils and sediment. In the Bug Creek sequence of Montana, slightly over half are probably represented, while in the Red Deer Valley in Canada, the estimate is slightly less than half.

For testing questions concerning more catastrophic, impact-triggered killing mechanisms that operated over a period of 100 years or less, the estimates are more pessimistic. This makes good intuitive sense when one considers that sediment is only occasionally deposited and preserved in rock layers; for, it is much more likely that some rocks will be deposited over a 100,000-year period than over a 100-year period. Nonetheless, to rigorously test predictions of catastrophic impact scenarios, we would need to have had sediment preserved during each 100-year period at the end of the Age of Dinosaurs and the beginning of the Age of Mammals. What are our chances?

In the same marine sections we examined before, we can expect only three out of four 100-year intervals to be represented by sediment at Caravaca. So, we have a 75% chance of finding fossils that lived during the last century of the Cretaceous and the first century of the Tertiary. Only about one out of ten 100-year intervals can be expected to be represented at Stevns Klint and Gubbio. So, our chances of actually documenting the effects of a catastrophic impact in these sections is quite low. In the continental sections where the last large dinosaurs lived, we can expect about one out of 70 100-year intervals to be represented at the San Juan Basin, one out of 200 at Bug Creek and one out of 300 at Red Deer Valley. So, our chances of actually being able to test the predictions of the effects generated by a single impact are pretty discouraging--roughly 1% or less.

This does not mean that an impact did not cause the extinctions, nor that volcanic activity associated with the retreat of seaways did not cause the extinctions. It means that given our limited ability to tell time at the end of the Age of Dinosaurs, we probably can't distinguish between the effects of the two processes, at least for now.

Some critics have noted that the statistical base or framework for making these estimates of completeness in geological sequences spanning the K-Tboundary may not be strong or refined enough to place much faith in the results. However, this only reinforces the point that we can't really test the predictions of short-term, catastrophic scenarios in a truly definitive scientific sense. At this point, therefore, we can *believe* what we *want* to believe, but we can't adequately test these hypotheses about dinosaurian extinction to establish their scientific validity in a temporal context.

Could a Combination of the Volcanic/Marine Regression and Impact Scenarios Be Possible?

Not surprisingly, some scientists are now beginning to argue for the possibility that a combination of the volcanic/marine regression and impact scenarios caused the mass extinctions at the K-T boundary. For example, F. L. Sutherland, has suggested that the extinctions were caused by a combination of environmental effects generated by the monumental K-T impact at Chicxulub and the hot-spot volcanism originating deep within the Earth's mantle that created the Deccan Traps and other K-T volcanic deposits[36].

Since the early 1980s, even some of the staunchest proponents of the impact and volcanic secnarios have softened their stances a bit. Walter Alvarez and Frank Asaro, original members of the team that proposed the impact hypothesis, wrote[48]: "In the past few years the debate between supporters of each scenario has become polarized: impact proponents have tended to ignore the Deccan Traps as irrelevant, while volcano backers have tried to explain away evidence for the impact by suggesting that it is also compatible with volcanism. Our sense is that the argument is a Hegelian one, with an impact thesis and a volcanic antithesis in search of a synthesis whose outlines are yet unclear." On the other side, Vincent Courtillot now beleives that between 1/3 and 1/2 of late Cretaceous extinctions resulted from the asteroid impact[49]. David Archibald, based on the analysis described above, concluded that the extinctions were probably a combination of causes related to marine regression and impact; however, he was less convinced that volcanism had much to do with it[37]. Nonetheless, given that four of the twelve groups of vertebrates that he studied fit the expected pattern for extinctions resulting from sudden cooling and acid rain, it's clear that volcanism could have played some role.

Some scientists, including Mark Boslough of Sandia National Laboratory and John Hagstrum of the U. S. Geological Survey, have even gone so far as to propose that the impact served as the trigger for the plume volcanism that catalyzed the eruptions that formed the Deccan Traps[38]. This scenario suggests that the impact at Chicxulub generated a force equivalent to the simultaneous explosion of millions of hydrogen bombs, which, in turn, is calculated to have generated an earthquake of an unprecedented magnitude--13 on the Richter scale. The shock waves from the impact would have traveled through the Earth, which would have acted like a lens to refocus the energy of the shock waves at the point on the Earth directly opposite the point of impact--the antipode (fig. 7.10). This focusing effect is somewhat like the way sound travels through a domed chamber like those found in many state capitol buildings. As opposed to the smoke-filled, rectangular caucus chambers, a whisper on one side of a relatively quiet rotunda can often be clearly heard on the opposite side of the room because the sound waves reflect off the dome to be focused on the area directly opposite the point of origin. Based on one computer simulation of the impact, the shock waves focused at the antipode would have caused the ground to flex as much as 60 feet (18 m), opening a network of huge cracks in the Earth's surface, heating the rocks in the upper 100 miles (about 150 km) of the crust and mantle, and catalyzing massive floods of basalt. To provide some scale for comparison, the earthquake that rocked San Francisco in 1906 is though to have generated shock waves that lifted the ground surface only about three feet (1 m) or so.

Although not well documented on the Earth, evidence for antipodal volcanism appears to exist on other rocky planets in our solar system, as noted by David Williams and Ronald Greeley of Arizona State University. The largest-known impact crater visible on the surface of Mars, named Hellas Plenitia, is located at the antipode for the lava flows, christened Alba Patera. These flows extend across about 1,000 miles (1,500 km) of the planet's surface and were erupted from the largest-known volcano in the solar system (fig. 7.11). It is estimated that the cracks opened by the shock waves generated by the impact that formed Hellas Plenitia may have been as much as 10 miles (15 km) deep.

However, within the context of the Deccan Traps and the one well documented K-T crater at Chicxulub, they did not appear to have been at opposite points on the Earth 65 million years ago, leaving proponents of antipodal volcanism to search for the impact source of the Deccan Traps volcanics in the eastern Pacific. Although John Hagstrum of the U. S. Geological Survey feels that there may be geologic evidence in that area for an impact, no clear evidence has yet been documented and published. At this point, therefore, the existence of impact-generated antipodal volcanism on Earth and its possible connection to K-T events must be considered to be rather speculative.

In addition, most, but not all, experts in flood basalt volcanism argue that the amount of energy required to have produced the half-million-year-long flows of magma that characterized the most copious eruptions of the Deccan Traps would have greatly exceeded that generated by the Chicxulub impact. Thus, the Deccan eruptions must have arisen from a more powerful source of energy deep within the Earth itself. Furthermore, the Deccan Trap volcanism began about 68 million years ago, and continued to erupt material in several major pulses until about 65 million years ago. However, the impact at Chicxulub did not occur until right at the end of the Deccan volcanism, not right at the start. So any antipodal relationship between the two most well documented geological features associated with these two scenarios seems completely unfounded.

So, Where Do We Stand?

The murder mystery at the end of the Cretaceous remains a fascination for scientists and public alike. In essence, the jury composed of members of the scientific community is still out. Despite an abundance of clues, the case of whether the extinction of large dinosaurs was caused by volcanic eruptions or impact(s) is far from closed. Perhaps at this point, the situation within the scientific community is anaogous to having a hung jury. But, regardless of what caused it, events surrounding those moments of evolutonary history during the K-T transition radically changed the course of life on this planet. No longer did dinosaurs, as we commonly recognize them, play the dominant role on land that they had for over 165 million years. No longer did beasts like *Tyrannosaurus* and *Triceratops* roam the continents. Why? To us as authors and jurors, the mystery remains unresolved, but we have tried to lay out the evidence so that you have the opportunity to act as a juror in the case and decide for yourself.

Although the verdict of the scientific community has not been rendered, we have progressed in terms of the historical debate between catastrophists and uniformitarianists or gradualists. As a result of the contemporary extinction debates, the concept of uniformitarianism has now been expanded to encompass a kind of natural geologic event that was originally deemed to be unacceptable. Large extraterrestrial impacts are now clearly established as a normal, if relatively rare, geological process. As such, they have been incorporated into the methodological uniformitarian repertory of natural processes that can be considered in explaining Earth-based events, including extinctions.

It's the question of how this new process in the uniformitarian repertory affects the extinction and evolution of life on Earth that is still at issue. In retrospect, even the volcanic scenario based on plumes of magma rising from the mantle is rather catastrophic in terms of geologic time in relation to the uniform, gradual, stately rate of evolutionary change originally envisioned by proponents of substantive uniformitarianism.

It really should not be too surprising to us that a consensus has not developed among scientists on what extinguished all the large dinosaurs at the end of the Cretaceous. We have similar problems in modern murder cases. Take the assassination of President Kennedy, for example. There was a lot of evidence to help us decide exactly how it happened, including photos and even home movies taken at the moment of the shooting. However, controversy still abounds about many aspects of the case. Was there just one gunman or more? Was there a conspiracy involved? This assassination even happened within our lifetime in front of dozens of eye witnesses, yet we still can't all agree about the exact sequence of events and their causes. Extrapolate these kinds of problems back 65 million years into the past and you get some sense of how difficult it is to be certain about what caused the extinction of *Tyrannosaurus*--the king of the dinosaurs.

Yet, recall that our charge in this book is to examine all the evidence in the rock and fossil records involving dinosaur extinction, and that requires us to investigate another basic question. Ironically, despite over a decade of debate concerning what caused the extinction of dinosaurs 65 million years ago, another line of evolutionary research has rendered the main point moot. It is true that neither *Tyrannosaurus* nor *Triceratops* roams our world anymore, but in a very important sense, the extinction debate has been focused on the wrong question. Scientists participating in this debate have been asking, "What caused the extinction of all dinosaurs about 65 million years ago?" But amazingly, an equally appropriate question to ask is, "Did all the dinosaurs really go extinct 65 million years ago?" That investigation, which revolves around the search for living descendants of the dinosaurs, is the focus of the next part of this book.

Chapter 8 from: *The Mistaken Extinction - Dinosaur Evolution and the Origin of Birds*, by Lowell Dingus and Timothy Rowe, 1998. W. H. Freeman, New York.