Chapter Two

Death and Taxes?

Earlier Hypotheses Explaining Dinosaur Extinction

When it comes to dinosaur extinction, paleontologists have long tried to console their readers with some simple "facts of life." We really shouldn't feel too badly about the extinction of dinosaurs because it's well known that they majestically "ruled the land" for over 150 million years. Given that we humans have been on the verge of annihilating our species after only about 100,000 years, it's not as though dinosaurs got cheated. Conventional paleontological wisdom teaches that extinction is as inevitable as death and taxes. Looking back at the fossil record, paleontologists point out that less than one percent of all the species that have ever lived are probably still alive today. So, with a stiff upper lip, paleontologists have not only come to accept the extinction of dinosaurs but revel in their mysterious disappearance.

This revelry has long constituted one of the most entertaining, intriguing, and controversial pursuits in science. In trying to solve the mystery, hundreds of scientists from paleontologists to astrophysicists have paid their money and taken their chance by putting their hypotheses in print. Some of the earlier explanations seemed rather fanciful, whereas others appeared more reasonable. Most earlier hypotheses were predicated on relatively gradual, Earth-based causes. However, some have been related to relatively sudden, extraterrestrial events. Investigations into dinosaur extinction intensified in 1980, when scientists at Berkeley proposed that the impact of an extraterrestrial body was responsible. But before tackling the more demanding technical evidence involving impacts and volcanic events, let's ease into the topic by informally evaluating a small sample of earlier explanations. Then, we'll focus on the hypotheses involved in the more recent debate.

It is not our intention deal with all the hypotheses that have been proposed to explain dinosaur extinction or to criticize the individuals that proposed these earlier ideas. Consequently, personal references are not provided. A more comprehensive listing of these and other early extinction hypotheses can be found in the references listed in the back of the book[1]. The goal here is to illustrate how the scientific method of proposing and testing ideas actually works.

Throughout the review of extinction hypotheses, our emphasis as scientific detectives of ancient history will be on two questions: First, *how can we scientifically test these hypotheses for the extinction of dinosaurs with the evidence available in the rock and fossil records?* Second, *which hypotheses are refuted and which are supported by most of that evidence?* The first question can be used to separate scientific explanations from unscientific ones. Because, if we're going to assume the role of scientific detectives in solving this mystery, we must propose ideas or hypotheses that we can test with the evidence available in the geologic and paleontologic records. The second question must be applied to decide which alleged cause of extinction is the most likely culprit. That will be the one that explains the most evidence found in the rock and fossil records. In the end, it is impossible to *prove* which, if any, of these hypotheses is correct. However, it is possible to show which hypotheses are inconsistent, or fail to explain, the available geologic and paleontologic evidence. Now, let's get on to the allegations and the evidence in the case.

The following scenarios exemplify extinction hypotheses that are almost impossible to test directly with the clues available in the rock and fossil records. Thus, whether they actually happened or not, they remain unsatisfying explanations to the scientific community.

All Filled Up, But No Way To Go?

The Cretaceous, or last period of the Age of Dinosaurs, saw the rise and proliferation of angiosperms--more commonly known as flowering plants (fig. 2.01). Along with this evolutionary burst came a decrease in the predominance of ferns. One dietary ramification of this floral change might have been a decrease of fern oil in the diet of plant-eating or herbivorous dinosaurs. This could have led to acute constipation which exterminated all the herbivorous dinosaurs. In turn, the meat-eating or carnivorous dinosaurs may have died out after the extinction of their herbivorous prey, which presumably had served as their primary food source.

Can we test this idea with evidence from the fossil record? The stomach contents of dinosaurs are not usually preserved inside fossil skeletons. So, we cannot directly track dietary changes through time with any degree of continuity. Another way to get at the question would be to study fossilized dinosaur dung, or coprolites. This is an active area of contemporary dinosaur research that has the potential to shed new light on the diet of dinosaurs. To date, however, research on coprolites has been limited, and they are often difficult to attribute to a particular kind of dinosaur. Consequently, this hypothesis is almost impossible to test with the currrently available fossil evidence...whether or not it's true.

Figure 2.01 The rise of flowering plants in the Cretaceous Period has been implicated in the extinction of dinosaurs through causing both consitpation and hayfever. However, testing these ideas is not possible with the evidence preserved in the fossil record. (from Mark Hallett in Zoo Books: Dinosaurs, 1985, v. 1, no. 9).

Terminal Sneezes and Sniffles?

Another hypothesis has been associated with the proliferation of flowering plants, but it was offered more in jest. The idea is that more flowers meant more pollen, and more pollen meant more hay fever--so much so that all the dinosaurs died from it. Allergic drowning would indeed have been a terrible fate for such Herculean life-forms.

Like stomach contents, however, the nasal tissues of dinosaurs are not preserved as fossils. So, no direct evidence for judging the hypothesis exists in the rock and fossil records.

Even if one assumes that hay fever was the cause, however, those of us with allergies might wonder why our mammalian ancestors and other late Cretaceous reptiles were not similarly afflicted? Besides, many groups of herbivorous dinosaurs, such as duckbills and horned dinosaurs, were proliferating during toward the end of the Age of Dinosaurs, apparently undaunted by the increased levels of pollen. So again, the idea is not directly testable with any fossil evidence related to sinus problems, and what little indirect evidence there is refutes the hypothesis.

More Maladies

Plagues have long haunted humanity and, presumably, life in general. Even today, we are again being reminded of our vulnerability through the rapid spread of AIDS. So, it comes as no surprise that epidemics have often been implicated in the demise of the dinosaurs (fig. 2.02).

But problems exist with testing this scenario scientifically. The most significant problem is finding evidence of diseases in fossil organisms. Most diseases affect the soft anatomy, such as organs, muscles, nerves, and the circulatory system. However, the symptoms of diseases that would have affected the soft anatomy of dinosaurs are not evident in the fossil record because soft tissues are not preserved. Only the harder parts of the body, such as bones and teeth, are commonly fossilized. Some diseases, such as arthritis and bone cancer, do leave their mark on the fossilized bones. But there is no evidence in the late Cretaceous bones or teeth of dinosaurs to indicate such a pandemic cause of extinction. So, diseases may well have played a role in the death of some individual dinosaurs. However, we cannot directly test whether some disease of the soft anatomy caused the extinction of dinosaurs.

Nonetheless, diseases within the soft tissues of vertebrates tend to be pretty specific. They usually attack only one species or a few closely related species. Just in the mid-continent of North America, fossils representing 19 species and at least eight major lineages of dinosaurs have been recovered from rocks deposited just before the end of the Cretaceous[2]. Indirectly, therefore, it seems unlikely that one massive epidemic could eradicate a group as diverse as the late Cretaceous dinosaurs.

An Eye For An Eye?

This hypothesis suggests that dinosaurs became plagued with cataracts, which rendered them blind and led to their extinction. This assertion is both hard to believe and impossible to test directly, because no fossilized cataracts from dinosaurs are known.

A Matter of Degree?

The sex of baby alligators, which are close living relatives of dinosaurs, is determined by the temperature at which the egg incubates in the nest. A temperature of less than 86 degrees Fahrenheit (16 degrees Centigrade) results in a female. A temperature of greater than 93 degrees F (20 degrees C) results in a male...which leaves a curious "no man's land" in the middle. Consequently, a climatic change at the end of the Age of Dinosaurs might have resulted in the birth of all male or all female dinosaurs. This, obviously, would have posed some serious problems for reproduction.

Unfortunately, the temperature of the climate in which the dinosaurs lived is difficult to determine that precisely, especially the temperature inside a nest. Evidence from fossil plants suggests a warming trend at the end of the Cretaceous, at least in the middle of North America[3]. Yet, precise temperatures can't be determined, making this scenario impossible to evaluate directly with the available rock and fossil evidence.

If this hypothesis were true, however, one has to wonder why so many dinosaurs died out, while some late Cretaceous crocodiles survived. Indirectly, this hypothesis fails to account for the survival of some similarly adapted animals that were alive at the time.

Those Little Things?

Paleontologists who study fossil mammals are often proud to implicate their "pets" within the context of dinosaur extinction (fig. 2.03). This hypothesis suggests that dinosaurs were eradicated by early mammals, either through direct competition for resources or because the mammals ate all their eggs.

This idea impossible to test directly with available geologic and paleontologic evidence. Such complex ecological scenarios are often difficult for contemporary ecologists to get a handle on. What's more, modern ecologists usually work in local settings with living species that they can observe--not on a global scale requiring analyses of a very incomplete fossil record that is 65 million-years-old. We have no direct evidence about what late Cretaceous mammals ate or how they affected the balance of resources.

figure 2.02 Epidemics have been cited as another possible cause of dinosaur extintion. However, no evidence for such epidemics is preserved in the fossil skeletons. (from Mark Hallett in Zoo Books: Dinosaurs, 1985, v. 1, no. 9)

Indirectly, fossils show that all the known forms of late Cretaceous mammals were no larger than modern beavers. So, it's a bit hard to imagine them being a seriously competitive threat to large contemporary dinosaurs, such as *Tyrannosaurus* and *Triceratops*. Even if they were, mammals had co-existed with dinosaurs for at least 100 million years before the end of the Cretaceous. So, the dinosaurs had more than demonstrated their ability to cope with small mammals over the long-run. Finally, one is left wondering, "If those little, rat-sized mammals were so rough on the dinosaurs and their eggs, how did crocodiles, lizards, turtles and other reptiles survive?" Thus, the available indirect evidence appears to exhonerate our early relatives.

Proposals that dinosaurs became sexually frustrated, became suicidal, or succumbed competitively to leaf-eating caterpillars represent other hypotheses that are difficult, if not impossible, to test with the available geologic and paleontologic evidence. In contrast, many hypotheses seeking to explain dinosaur extinctions have been directly tested and apparently refuted. A small sample follows:

Big, Bigger, Biggest...Boom?

One, for example, was the idea that dinosaurs just got too big for their own good and became extinct as a result of their enormous size. This doesn't jibe with the known fossil record for a couple of reasons. First, most of the largest dinosaurs known lived and died long before the end of the Cretaceous (fig. 2.04). These were the Jurassic sauropods, including *Apatosaurus, Brachiosaurus, Ultrasaurus, Supersaurus,* and *Seismosaurus.* They lived about 150 million years ago. The largest dinosaurs that lived at the end of the Cretaceous, such as *Tyrannosaurus, Anatotitan, Triceratops,* and *Pachycephalosaurus,* were not nearly as large as the Jurassic sauropods. The only known exception was *Argentinosaurus*, an enormous sauropod from the late Cretaceous of South America. So, there wasn't a generally progressive increase in size up to the end of the Cretaceous.

Another piece of fossil evidence refuting this hypothesis is that many, relatively small kinds of dinosaurs continued to thrive in the latest Creatceous, especially small carnivorous dinosaurs such as *Dromaeosaurus*, *Troodon,* and *Saurornithoides* (fig. 2.05).

Thin, Thinner, Thinnest...Crack?

Eggs of the late Cretaceous sauropod, *Hypselosaurus,* had unusually thin shells (fig. 2.06). Similar suggestions have been made for the rich fossil record of eggs at the end of the Cretaceous in southeastern China and possibly India. Did the egg shells of all dinosaurs get so thin toward the end of the Cretaceous that they became inviable, causing the extinction of the whole group?

Within the last fifteen years, many spectacular discoveries of late Cretaceous eggs and nests of several types of dinosaurs have been made in Montana, Canada, Argentina, China, India and Mongolia (fig. 2.07). Nests, eggs and embryonic remains have been found for duckbills, hypsilophodonts, troodontids, therizinosaurids and even one carnivorous species related to *Oviraptor*. The newly discovered eggs are found in nests that also preserve skeletons representing embryos and hatchlings. Adolescents were also found near the nests. Thus, the eggs for these species appear to have been quite viable.

figure 2.03 Saurornithoides, a small carnivorous dinosaur from Asia, is a fairly close relative of Troodon, Velociraptor, and Dromaeosaurus. It lived near the end of the Cretaceous, about 72 million years ago. Its skull was only about 7.5 inches long.

Death by Dipoles?

Throughout the known history of the Earth, our planet's magnetic poles have reversed direction such that the magnetic end of the compass pointing North today would have pointed South. The reason for these reversals is not well understood, although some ideas will be mentioned in later chapters. Nonetheless, the history or sequence of these reversals has been recorded in, and can be read from, many of the rocks that make up the Earth's crust. Some recent data suggests that when the poles reverse direction, it can happen in a period of as little as a few hundred years[4]. There is some evidence that the Earth's magnetic field plays a role in the migration of some animals, such as monarch butterflies and various birds. Was one of these reversals to blame for the extinction of the dinosaurs.

The available evidence refutes this idea. First, the last dinosaur fossils in many different geographic areas consistently occur near the middle of a stable interval when the Earth's magnetic poles were reversed--not near a boundary when the poles were in the process of reversing position. In addition, the Earth's magnetic poles are known to have reversed themselves over 100 times during the Age of Dinosaurs[5], so why didn't one of those other reversals knock the dinosaurs out? Finally, why would this reversal extinguish dinosaurs and leave other reptiles, such as crocodiles, turtles, and lizards, unscathed? This evidence suggests that a reversal of the magnetic poles was not the culprit.

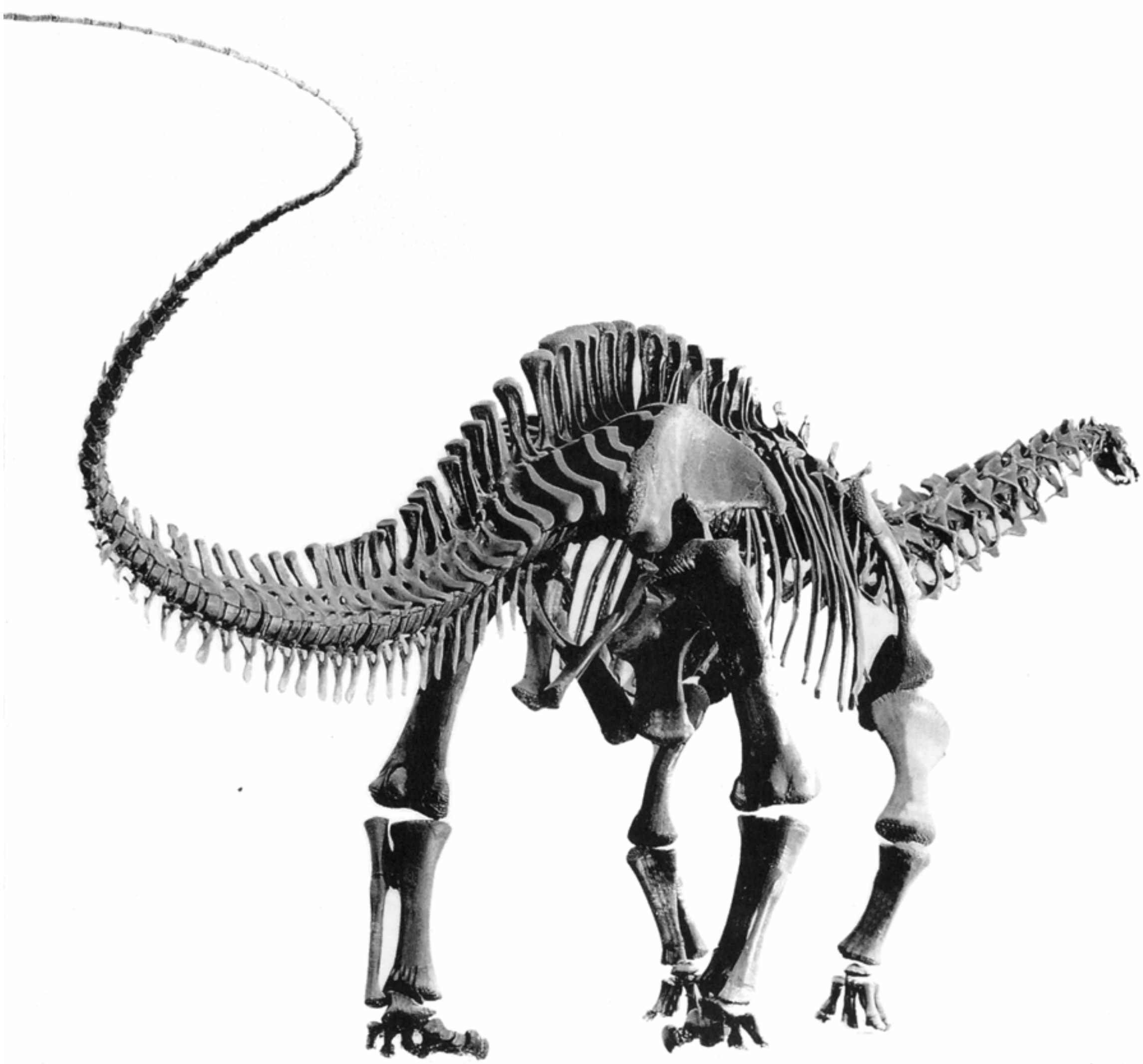

figure 2.04 *Apatosaurus*, one of the large sauropods, reached lengths of almost 90 feet (30 meters). It lived in what is now Utah, Wyoming, and Colorado about 140 million years ago--long before the end of the Cretaceous. (from Dingus, et al., 1995, The Halls of Dinosaurs, AMNH, p. 14).

The preceding examples do not constitute an exhaustive list of extinction hypotheses that can be tested and refuted. Others **include the idea** that too many predatory types evolved. **This** can be refuted by examining the ratio between herbivorous and carnivorous dinosaurs through time. This brings us up to the event that was most commonly thought to be the cause of dinosaur extinction before the debate over extraterrestrial impacts and volcanic eruptions began in 1980.

Tried and True?

Before the debate about dinosaur extinction focused on impacts and volcanism, conventional wisdom had long held that their eradication was due to climatic changes associated with changes in the configuration of the Earth's seas. Throughout the last part of the Age of Dinosaurs, shallow seaways covered extensive areas of the continents, especially across Europe and North America (fig. 2.08). North America was essentially cut in half by a sea that extended from the Gulf of Mexico north to the Arctic Ocean. It is now called the Western Interior Seaway. Most of our evidence of dinosaurs and other animals that lived on North America during the Cretaceous comes from fossils preserved in sediments that were laid down by rivers along the floodplains adjacent to this seaway. The floodplain stretched from the eastern flank of the ancestral Rocky Mountains on the west to the shallow sea on the east[6]. The subsequent uplift of the Rocky Mountains, coupled with erosion by rivers running out of the Rockies, has exposed these ancient sediments across a wide swath of the western Great Plains.

figure. 2.05 The eggs of the sauropod, *Hypselosaurus*, have thin shells for such a large egg. The egg is nine inches in length. (from Dingus, et al., 1995, The Halls of Dinosaurs, AMNH, p. 15)

Evidence from fossil plants is critical to interpreting the ancient climate of the area. As inferred from living relatives of the fossil plants that lived on that floodplain, the climate was subtropical to tropical and quite equable[7]. The days weren't too hot, nor the nights too cold. The summers weren't too warm, nor the winters too frigid. In general, the climate of the Earth was more uniform than it is today, as evidencedby the fact that there were no polar icecaps. Locally in the middle of North America, the seaway also acted like a heat sink to buffer against climatic extremes. Abundant fossil evidence of "cold-blooded" vertebrates, such as crocodiles and amphibians, provide evidence that the temperature didn't drop below freezing, at least for very long. In fact, the climate had gradually warmed over the last million years or so of the Cretaceous[8]. Relatives of palms and Norfolk pines (more typical of late Cretaceous floras found in southern Colorado and New Mexico) migrated north into areas like Montana and North Dakota.

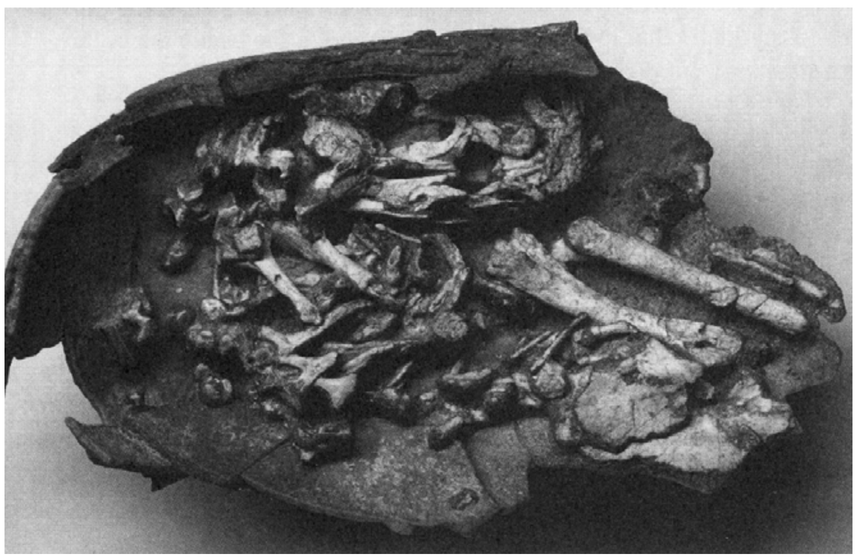

figure 2.06 The embryonic bones of an *Oviraptor*-like dinosaur are preserved within this four-inch-long egg. The bones represent the first embryo of a carnivorous or theropod dinosaur ever found. The egg was laid about 72 million-years-ago, near the end of the Cretaceous Period. (from Dingus, et al., 1995, The Dinosaur Halls, AMNH, p. 48.)

However, at the end of the Cretaceous, the seaways pulled back off the continental margins and lowlands into the major ocean basins (fig. 2.09). No one is exactly sure why, although some ideas will be addressed in later chapters. What is clear is that over a period of about three or four million years, while the seas retreated[9], climates would have become more extreme where the seas once existed (fig. 2.10): warmer days, cooler nights; hotter summers, colder winters.

The conventional wisdom had long held that the cold-blooded dinosaurs could not tolerate these extreme climatic changes and, as a result, suffered total extinction. On the surface, this scenario seems reasonable, but critics have raised a couple of simple counterpoints.

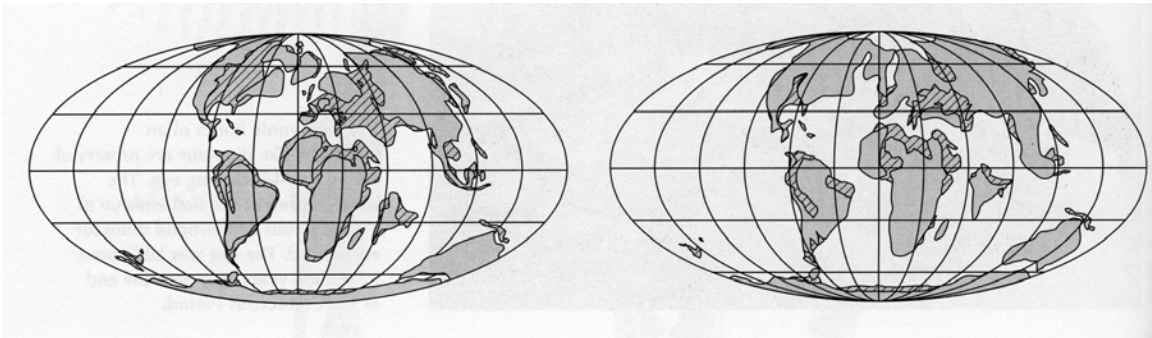

figure 2.07 This map of the Earth shows the distribution of continents (stippled), oceans (white), and shallow continental seaways (hatched) just before the end of the Cretaceous Period. (redraw from Archibald, J. D., 1996, Dinosaur Extinction and the End of an Era, Columbia University Press, p. 149).

First, look at some of the cold-blooded animals that survived: snakes, lizards, turtles, crocodiles. Why didn't the freezing winters and torrid summers knock these animals out? Didn't they also rely on the external climate to maintain a livable body temperature? It's hard to see why the physiology of these vertebrates would not be adversely affected, whereas that of the dinosaurs was rendered too crippled to cope. Besides, many paleontologists now argue that dinosaurs were warm-blooded, not cold-blooded, meaning that they might have been able to maintain a fairly constant body temperature regardless of the temperature outside. This is still a controversial issue, and we are still searching for uneqivocal evidence in the cellular structure of fossil bones or the presence of specialized nasal bones called turbinates that will allow us to decide for sure. Furthermore, critics point out that the shallow continental seaways had retreated and advanced numerous times during the Age of Dinosaurs. So, why did dinosaurs survive the climatic changes that were associated with those earlier fluctuations but not this one? Was it simply more extreme? Some evidence suggests that it may have been, as we will see in Chapter 4.

We have now reviewed a significant number of earlier extinction hypotheses and found them wanting.   They either proved to be untestable or unable to explain all the available geologic and paleontologic evidence. To try and solve the mystery, we must now turn to investigate the two competing hypotheses involved in the more recent extinction debate. But before evaluating all the detailed rock and fossil evidence, let us first provide a better image of what these volcanic and impact events might have been like, assuming that they both occurred. To do so, we will briefly set the late Cretaceous scene just prior to and during these proposed extinction events.

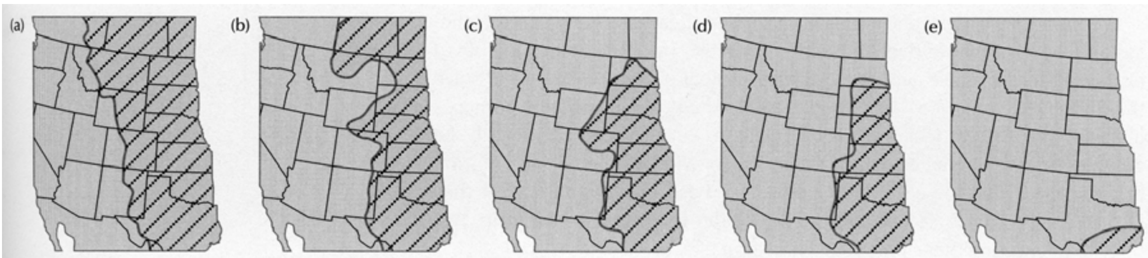

figure 2.08Maps of the western United States Interior illustrating how the Western Interior Seaway retreated to the south and east at the end of the Cretaceous Period. Areas covered by the seaway are cross-hatched. The maps are based on geological evidence showing the geographic extent of marine and floodplain sediments at different times during the Late Cretaceous. All together, the interval represents approximately the last 4 million years of the Cretaceous. The time difference between (d) and (e) is about 1 million years. (from Lillegraven, J. A. and L. M. Ostresh, Late Cretaceous evolution of western shorelines, Western Interior Seaway, Geol. Soc. Am., Sp. Pap. 243, p. 10-11.) .

References and Notes for Chapter 2

1. For a fairly comprehensive listing of published hypothetical causes, see Molnar, R. and M. O'Reagan, 1989, Dinosaur extinctions, Australian Natural History, v.22, p. 563; and Benton, M. J. 1990, Scientific methodologies in collision: the history of the study of the extinction of the dinosaurs, Evol. Biol., 24, 371-400.

2. Archibald, J. D., 1996, Dinosaur Extinction and the End of an Era, Columbia University Press, p. 85.

3. Johnson, K. R. and Hickey, L. J., 1990, Megafloral change across the Cretaceous/Tertiary boundary in the northern Great Plains and Rocky Mountains, U.S.A., Geol. Soc. Am., Sp. Pap. 247, p. 441.

4. Ratcliff, C. D., et al., 1994, Paleomagnetic Record of a Geomagnetic Field Reversal from Late Miocene Mafic Intrusions, Southern Nevada, Science, v. 266, p. 412.

5. Gradstein, F. M., et al., 1994, A Mesozoic Timescale, Jour. Geophys., Res., v. 99, p. 24051-24074.

6. Archibald, J. D., 1996, Dinosaur Extinction and the End of an Era, Columbia University Press, p.16.

7. Hutchison, J. H., and J. D. Archibald, 1986, Diversity of turtles across the Cretaceous/Tertiary boundary in Northeastern Montana, Paleogeog., Paleoclimatol., Paleoecol., v. 55, p. 14-15.

8. Johnson, K. R. and L. J. Hickey, 1990, Megafloral change across the Cretaceous/Tertiary boundary in the nothern Great Plains and Rocky Mountains, U.S.A., Geol. Soc. Am., Sp. Pap. 247, p. 441.

9. Lillegraven, J. A. and L. M. Ostresh, 1990, Latest Cretaceous ...evolution of western shorelines of the...Western Interior Seaway..., Geol. Soc. Am., Sp. Pap. 243, p. 10-11; and Obradovich, J. D. And W. A Cobban, 1975, A timescale for the Late Cretaceous of the Western Interior of North America, In Caldwell. W. G. E., The Cretaceous System of the Western Interior of North America, Geol. Assoc. of Canada, Sp. Pap 13, p. 36.