Dinosaur Extinction: Changing Views

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If you played a word association game with people and asked them to respond with the first word that popped into their heads, more than likely, the response for "fossil" would be "dinosaur." If you asked them "what killed the dinosaurs" more than likely they would say "an asteroid." Just as there are many unanswered questions about how dinosaurs lived, so too there are many unanswered questions about how they died. Before we can address the specific question of dinosaur extinction, we must examine the general topic of extinction.

Extinction: No One Gets Out of Here Alive

Before the beginning of the 19th century the idea that species could become extinct was not widely believed. In the western culture, it was believed that all species of plants and animals were perfectly created in a matter of days. Certainly a creator would not allow his creations to disappear from Earth. The work of the renowned French paleontologist, Georges Cuvier soon showed that some species have disappeared. He compared the teeth of the two species of living elephants with those of fossil elephants and their relatives. The teeth of fossil mastodons and mammoths were so different from those of the two living species that Cuvier concluded that the mastodons and mammoths no longer existed. Very soon the work of Cuvier and others showed that not only had extinction occurred, but that it had been a very common event throughout Earth's history.

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>
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Scientists even began to use extinction to measure geological time. Probably best known for this kind of work is the English geologist Charles Lyell. Lyell compared collections of modern marine invertebrates (clams, snails, etc.) to collections of fossil marine invertebrates from different aged rocks and places in Europe. He found that the older and more different the collections of fossil invertebrates were from modern invertebrates, the more extinction had occurred.

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Lyell was measuring the fact that, over long periods of geological time, as species evolved others became extinct.

Today, we know that not only does extinction occur, but that of all the species that ever lived, well over 99 percent are now extinct. This figure is not an exact percentage, but rather it is an approximation, based on three factors: (a) the age of the Earth, (b) the number of species alive at any given time, and (c) an estimate of how long the average species exists.

a) Paleontologic evidence points to the origin of life on Earth at about 3.5 billion years.

b) For the number of species alive at any given time, we can use estimates of E.O. Wilson, who placed the number of known species alive today at 1.4 million, while judging that the number may be anywhere from 10 to 100 million.[1] To be conservative, we can use the lower estimate of 10 million for the number of species alive at any given time. This number overestimates the number of species alive early in the history of life, but underestimates the number of species alive later in geological time.

c) In the late 1980s Niles Eldredge estimated how long a variety of species survived. An average duration for a species based on his various estimates was 12.4 million years.[1]

We now need to make a few calculations. If we use the estimate that the number of species at any given time is about 10 million, that each species lasts about 12.4 million years, and that life originated 3.5 billion years ago, we arrive at the staggering figure of over 2.8 trillion species that have lived on Earth! If only 10 million are alive today, this means that only one in every 280,000 species that has ever lived is alive today. Thus, 99.99 percent are extinct. This total may seem like a shocking number, but it is clear that the fate of most species is extinction rather than further evolution. Because most species become extinct, only a small percentage of species provides the future diversity. Extinction is so common that it is the rule rather than the exception. Just as evolution is an ongoing process adding new species, extinction is an ongoing process that eliminates species.

Armed with this information, we might think that the extinction of species that we humans are causing today is normal or even common. Such an assumption would be wrong. The great many extinctions occurring today because of human activity fall into an extremely rare category known as mass extinction. In the past 540 million years, during the Phanerozoic Era, there have been five times when the numbers and rates of extinction became so high that they stand out from all other times in the geological past (Fig. 1). A sixth mass extinction is now underway, but this time humans are the culprits.

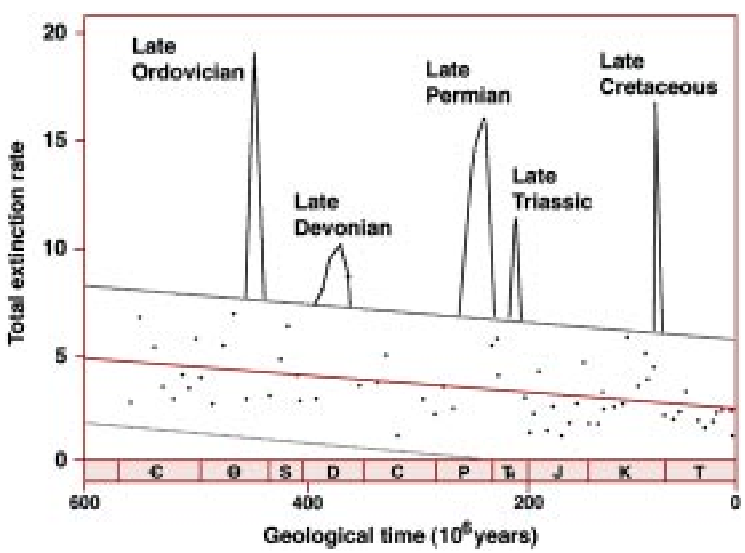

Fig. 1. The five major mass extinctions in the past 540 million years as demonstrated by extinctions of marine invertebrates and vertebrates. From Archibald (1996) after Raup and Sepkoski (1982).[1]

In Fig. 1, each point on the graph represents the number of extinctions per million years for families of marine invertebrates and vertebrates for that particular interval of geological time. The solid line is called a regression line and can be thought of as showing the average extinction rate through geological time. The dashed lines surround 95 percent of all the points shown on the graph. Each of the five spikes falls well outside the 95 percent interval, indicating much higher rates of extinction five times in the past. These five spikes are generally recognized as times of mass extinction.

When we add up all the extinctions that have occurred in the past, we find that mass extinctions probably account for no more than about 10 percent of all extinctions. The other 90 percent or more are normal or background extinctions that are the counterpart to evolution. Although the five mass extinctions comprise a relatively small percentage of total extinctions during Earth history, each represents a major reorganization of the Earth's biota. The severest of the big five reorganizations occurred at the end of the Permian some 250 mya (million years ago). There was over 90 percent species extinction, although this is not obvious from Fig. 1.

The most famous mass extinction, however, is the one that included the last of the dinosaurs, the terminal Cretaceous mass extinction 65 mya.[2] This mass extinction wiped out the dominant land vertebrates and opened the evolutionary way for mammals that until that time were no larger than a small cat. Although the terminal Cretaceous mass extinction is the most famous, we still cannot say what happened with certainty in part because of the relatively poor record of its best-known victims—the dinosaurs.

The K/T Extinction

The Late Cretaceous (from about 100–65mya) is not only the last geological time interval from which dinosaurs are definitely known, it is also one of the best sampled for dinosaurs. The name K/T comes from a combination of the names Cretaceous, in which we find fossils of dinosaurs, and Tertiary, the time in which we see the first appearance of modern groups of mammals (the K comes from Kreide, the German word for "chalk," deposits of which are common at this time in Europe; Cretaceous means "chalk-bearing").

Around the world there are literally hundreds of Late Cretaceous dinosaur sites, including such seemingly unlikely places as Antarctica and New Zealand (Fig. 2, A). One of the best-known areas for Late Cretaceous dinosaurs is in the northern part of western North America. In this area, we know that the number of genera of dinosaurs dropped from 32 to 19 during the last 10 million years of the Late Cretaceous. In other words, some 40 percent of dinosaur genera were lost in this region during that time. Whatever killed the last species of dinosaur, the record shows that they were declining during the last 10 million years

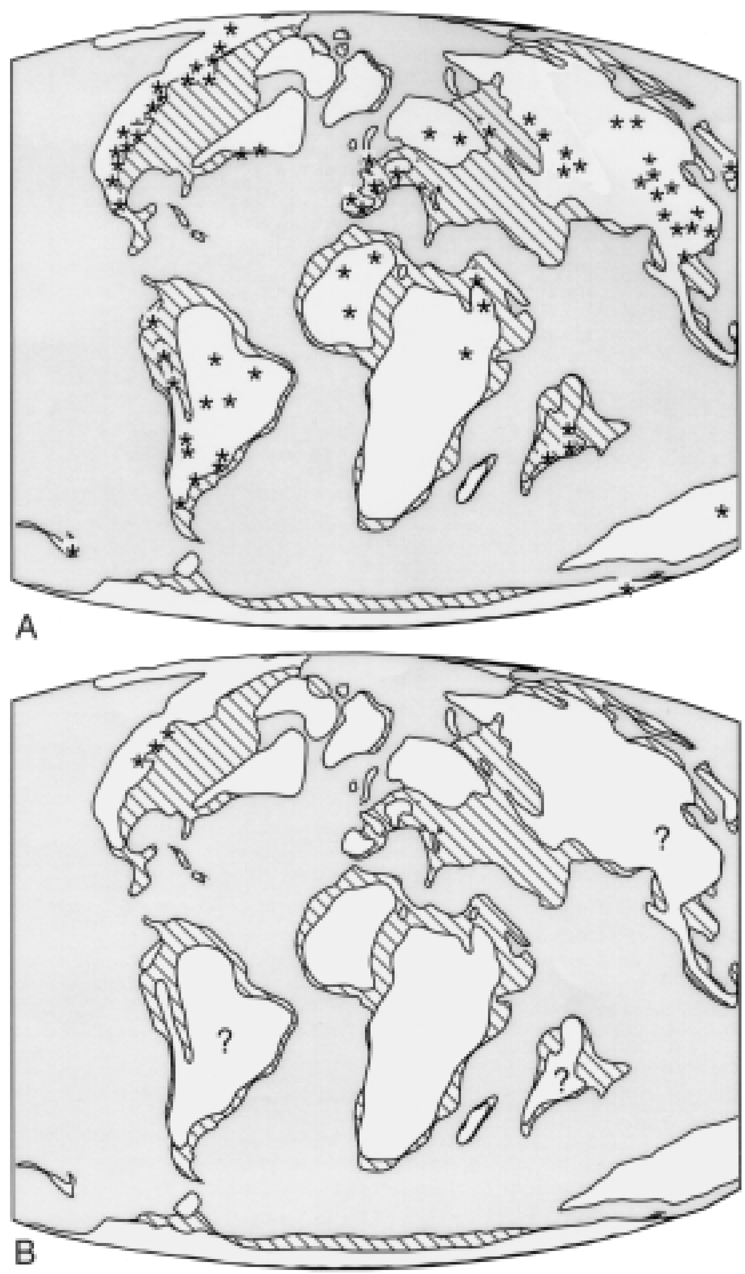

Fig. 2. A. Important dinosaur sites (black stars) for the Late Cretaceous (100 to 65 mya). **B.** Important vertebrate faunas spanning the K/T boundary. More recently discovered possible K/T boundary vertebrate faunas are indicated by a question mark. From Archibald (1996)[1] using data mostly from Weishampel (1990) and map after Smith et al. (1994).

of the Cretaceous, at least in the western part of North America.

Unfortunately, as one examines the rocks representing the end of the Cretaceous, the fossil record of dinosaurs gets worse. Only a handful of places in the world have a nearly continuous fossil record of vertebrates across the K/T boundary. The one area where we do have an adequate record of dinosaurs very near the K/T boundary is in western North America. Recently discovered sites in China, South America, and India offer hope in the future for an even better K/T record of vertebrates (Fig. 2, B).

What this means is that the vertebrate (and dinosaur) fossil record at the K/T boundary is far poorer than is usually realized. Most importantly, this means that at least for now, we cannot say anything about how fast dinosaur extinction occurred. The record is simply too poor to address this issue. Fortunately, the record is good enough that we can say something about how many species of dinosaurs and other vertebrates became extinct and how many survived. We can also say something about what is called the selectivity of these extinctions. This means that we can ask whether all kinds of species of vertebrates from bony fish to turtles were equally or unequally affected during the change from the Cretaceous to the Tertiary. In order to ask such questions we need a fossil record of vertebrate species other than dinosaurs. Indeed, we have such a record, once again in the western portion of North America. As we examine this record, keep in mind questions such as: Why did this dinosaur extinction occur? Was it only the dinosaurs that went extinct? Which other groups of animals survived?

Other Vertebrate Species Living with the Last Dinosaurs

Our K/T sites for vertebrate fossils are found in eastern Montana. It has been well documented that at least 107 species of vertebrates existed here during the closing million or so years of the Cretaceous. These species belong to 12 major groups, which are listed in Table 1. It may be surprising that of these 107 species only 19 are dinosaurs. You may also notice that pterosaurs (flying relatives of dinosaurs) and birds are not included in this table, even though fossil evidence indicates their existence at this time.[3] These two groups are not included because their fragile skeletons make them poor candidates for fossilization compared to most other vertebrates. Of the 107 remaining species of vertebrates, 49 percent (52 species) survived, or 51 percent became extinct.[1] Even though only about half of these species of vertebrates became extinct, the overall biological effect on the land was profound. Dinosaurs had been the dominant land vertebrates throughout the Mesozoic. Although mammals had been around for almost the same amount of time, it was only after the dinosaurs were gone that mammals truly began to flourish. More importantly, we can use the survival data in Table 1 to test the various theories of dinosaur extinction.

The Three Most Popular Theories of Dinosaur Extinction

Soon after the discovery and naming of the first known dinosaurs in the early 19th century, people began to speculate on what had happened to them. By the 1980s, there were over 80 dinosaur extinction theories, more than for any other group of animals. With so many theories, it is no wonder that they ranged from the highly reasonable to the absurd, e.g., overhunting by aliens.[4, 3] Given so many theories of extinction, only the three best explained and testable of these will be discussed here. All three theories, to one degree or another, argue that changes in climate, whether sudden and drastic or slow and cumulative, caused the extinctions. It is important to keep in mind that none of the three theories is mutually exclusive, that is, any combination of the three may have happened. The most important question is which theory, or part of a theory, is best supported by the fossil evidence. Before testing these theories against the vertebrate fossil record, they first must be described. They are described in the order of the length of the time intervals over which they are thought to have acted, beginning with the longest.

The Deccan Traps

Massive eruptions of flood basalts on the Indian subcontinent, called the Deccan Traps, occurred at the time of the K-T boundary. Flood basalts flow from great fissures and volcanoes with moderate amounts of explosive power. They are more like the lava flows of the Hawaiian Islands than the explosive eruption of Mount St. Helens, which literally blew the mountain apart. However, the Deccan Traps erupted over four or more million years and produced enough lava to cover both Alaska and Texas to a depth of 2000 ft (610 m). The effects of such massive volcanism have not been as well studied as the effects proposed in other extinction theories. It is clear, however, that such eruptions would greatly increase the amount of very fine-grained material in the atmosphere. This “dust” would decrease the amount of sunlight reaching the Earth’s surface, which would in turn lead to long-term global cooling. Both cooling and a decrease of sun reaching the Earth’s surface would, over this long time interval, change the vegetation and thus, affect the animals feeding upon it.

Table 1. Survival and extinction of vertebrate species across the K/T boundary in the western part of North America.

Sharks and relatives	0/5	(0%)
Bony fish	9/15	(60%)
Amphibians	8/8	(100%)
Mammals		
Rodent-like multituberculates	5/10	(50%)
Placentals	6/6	(100%)
Marsupials	1/11	(9%)
Reptiles		
Turtles	15/17	(88%)
Lizards	3/10	(30%)
Crocodile-like champsosaurs	1/1	(100%)
Crocodilians	4/5	(80%)
Dinosaurs		
Ornithischia (bird-hipped)	0/10	(0%)
Saurischia (reptile-hipped) except birds	0/9	(0%)
Total number and percent survival	52/107	(49%)

The first number is the number of species that survive the K/T boundary extinction. The second number is the number of species known from the Late Cretaceous. Percent is percent survival.

Marine Regression

The second theory relates extinction to marine regression, which is the process whereby very shallow seas that covered much of the low-lying areas of continents drain away, back into the deeper ocean basins.[1] One of the greatest such marine regressions is recorded in rocks near the end of the Cretaceous Period, some 65 mya. Unlike the eruption of the Deccan Traps, which took place over millions of years, the terminal Cretaceous marine regression occurred over a much shorter period of time, only tens or hundreds of thousands of years. Estimates suggest that 11.2 million square miles of land were exposed during this interval, more than twice the next largest such addition of land during the past 250 million years. The landmass that was exposed is approximately equal to the area of modern day Africa. As these continent-sized shallow seas drained away, great areas of low, coastal habitat were fragmented into smaller and more isolated areas. As these habitats for terrestrial coastal species shrank and became more distant from one another, population sizes would have decreased. Furthermore, as land emerged from the sea, land bridges were exposed, such as the Bering land bridge between Asia and North America. This new land would allow migration of terrestrial vertebrates and the potential for increased competition among previously separated species. River systems that had once flowed over relatively short distances grew in length as the shoreline receded further and further and provided greater habitat for many fresh water organisms. As new land areas were exposed with the regression of the great interior seaways, the climate cooled and climatic extremes increased, further stressing an already stressed environment.

Asteroid Impact

The argument presented in this theory is that a 6-mile wide asteroid struck Earth 65 mya, spewing very fine material high into the atmosphere where it spread around the globe.[5] The major result was the blockage of many of the sun’s rays. This blockage greatly reduced or possibly stopped photosynthesis. Many individual plants would have been stunted or killed, and many plant species would have become extinct. Herbivorous dinosaurs and other vertebrates that fed upon these plants would have disappeared, which in turn would have caused the extinction of the carnivorous dinosaurs that fed upon the herbivores. This process appears to have taken only a few thousand years at the most.

Evidence for the asteroid impact comes from three sources:

The crater The probable crater for this impact has been located near the tip of the Yucatan Peninsula in Central America. It was appropriately named Chicxulub, which means the devil's horns in a local dialect. At 110 miles (180 km) across, it was originally thought to be the second largest such structure on Earth. More recent studies argue that it is more on the order of 60 mi (100 km), or possibly even smaller.

An increase in the element iridium at the Cretaceous/Tertiary (K/T) boundary A high level of iridium found in rocks from this time period in many places on the Earth is a strong indication of an extraterrestrial source for the iridium, such as from an asteroid striking the Earth. Iridium, a very heavy element, like gold, is rare at the surface of the Earth except where concentrated in a small area by very deep volcanoes.

Shocked quartz Quartz grains, showing shocked lamellae (or parallel layers) in two directions at a microscopic level, indicate a great amount of rapidly applied pressure—such as might be caused by the impact of an asteroid.

Following the publication of the asteroid impact theory in 1980, a number of other possible consequences were suggested, such as acid rain, globe wildfire, sudden temperature increases and/or decreases, tsunamis, and superhurricanes. Each of these is argued to have had consequences on the world's plants and animals.[5] Some of these consequences can be tested using the fossil vertebrate record, but others cannot, notably tsunamis, and superhurricanes. We now turn to examining and testing the various theories using mostly information from the fossil record of vertebrates.

Using the Vertebrate Record To Test Theories of Dinosaur Extinction

The most obvious pattern of extinction among the major vertebrate groups listed in Table 1 is that extinctions were concentrated in only five of these groups: sharks and their relatives, lizards, marsupials, ornithischian dinosaurs, and saurischian dinosaurs. Species in these five groups account for 75 percent of the extinctions. This pattern demonstrates that the K/T extinctions were highly selective and any theory of extinction must account for this selectivity. Because the biotic effects of volcanic eruption have not been explored extensively, but the effects are considered to be similar to the effects of an asteroid impact, these two theories will be discussed together under the asteroid impact.[1] We will start with the marine regression theory.

Marine Regression

Global marine regression began in the last few million years of the Cretaceous. As this occurred, tremendous new tracts of dry land were added. Dinosaurs may well have lived away from the seacoast near the end of the Cretaceous, but their habitats would not have been affected. The well-known dinosaur-bearing vertebrate localities near the K/T boundary, however, come from coastal plain habitats. Thus, it is from this information that we should draw our inferences of what may have occurred.

As indicated in Table 1, the fossil record shows a 0 percent survival for both dinosaurs and sharks and their relatives. With marine regression, the coastal plain habitats were being drastically reduced, stranding dinosaurs in ever-smaller areas—this is similar to what humans are doing to the habitats of large mammals in Africa today. The loss of habitat stressed the dinosaur populations, setting them up for any other biotic insults such as that from even a small asteroid impact or from massive volcanism. At the same time, the coastlines were retreating away from the Western Interior taking the sharks and relatives with them.

Sharks could follow freshwater courses up to a few hundreds of miles or kilometers, but not thousands of miles or kilometers. Their marine connections were severed. Much larger and longer rivers replaced the small coastal streams, which continued to support many species of freshwater fish, turtles, amphibians, and crocodilians. This too is supported by the evidence shown in Table 1. In fact, freshwater species did very well, with descendants such as paddlefish, sturgeon, gar, snapping turtles, and alligators still plying the Missouri-Mississippi river systems.[1]

The lowering of sea level reconnected once separated landmasses, such as eastern Asia and western North America. The fossil record shows that the earliest relatives of what would later evolve into hoofed mammals and whales probably reached North America at this time (65 mya)—their possible ancestors being placental mammals known in Asia 20 million years earlier. These new North American placental mammals had teeth that resembled those of the opossum-like marsupials living in North America at this same time. The marsupials arose in North America over 100 mya and were very common for at least the 20 million years leading up to the K/T boundary 65 mya. It seems likely that the appearance of these new placental mammals in North America spelled competitive doom for the marsupials. Interestingly, when both groups appear in South America a few million years after the K/T boundary, they do not compete. Rather, the placentals became more strictly herbivorous, while the marsupials became omnivorous and carnivorous, including large saber-toothed marsupial cats. The one group whose fossil record cannot be explained by marine regression is the lizards, which underwent a drastic reduction, at least in western North America. A possible explanation is that when the climate became wetter in this area following the K/T boundary, the more dry-adapted lizards could not tolerate the changes.

Asteroid Impact

We can start testing the asteroid impact theory by examining the effects of such possibly related events as acid rain, sharp temperature decrease, and global wildfire.[5]

a) We know from work on living species and habitats that among vertebrates, acid rain hurts aquatic organisms most, killing both adults and eggs laid in the water. Among the aquatic organisms, however, only sharks and their relatives show very high levels of extinction. Other aquatic species did very well through the K/T transition, thus acid rain was probably not a major factor.

b) If a sharp drop in temperature had occurred, the species that should have been most affected would have been cold-blooded (ectothermic) vertebrates that spend at least part of their time out of water—this is why today we see far fewer species of amphibians and reptiles (except warm-blooded or endothermic birds) in the far northern and far southern regions of the world. Yet, most of these ectotherms, except lizards, did well through the K/T boundary. Whether dinosaurs should be considered as endotherms, ectotherms, or as having another kind of physiology remains controversial (see de Ricqlès, page 79).

c) Finally, a global wildfire is argued to have consumed 25 percent of all above ground burnable material. Geological evidence for wildfire has been presented based on large amounts of carbon and other compounds occurring at the K/T boundary. Some paleontologists argue that such a global wildfire would have transported great quantities of detritus (very small fragments of plants and animals) into the streams, which would have favored the survival of aquatic animals that eat such material.[4] Other scientists argue that a global wildfire would have been an equal opportunity killer: terrestrial creatures would have been burned on land, and aquatic vertebrates would have suffocated from all the burned material dumped into their environments. Thus, depending upon how the fossil information is interpreted, global wildfire could have been either a significant or unimportant event at the K/T boundary.

Volcanism and Asteroid Impact

One probable result of an asteroid impact or high levels of volcanic activity would have been the blocking of sunlight, either around the globe or in more restricted areas. Blocking sunlight would have caused the reduction or even cessation of photosynthesis among green plants. The fossil record of land plants in the northern part of western North America suggests an extinction of at least 80 percent, which tends to support the hypothesis that photosynthesis was suppressed. Reduced photosynthesis would have had a devastating effect on large herbivores, especially if they were already stressed by other events such as marine regression. Unfortunately, more recent studies have questioned just how much dust really would have been spread around the world from such an impact. Thus, more studies are necessary before we can resolve this question.

Summary

When using the vertebrate fossil record to test the various theories of dinosaur extinction, it appears that marine regression explains more of the highly selective pattern of extinctions and survivals through the K/T transition in western North America than do either an asteroid impact or massive volcanism. When combined with evidence from plants and marine species, it appears that marine regression, an asteroid impact, and massive volcanism each probably played a significant role in what is the best known mass extinction in Earth's history. These three theories, plus other causes that we still do not know, each may have been necessary, but clearly were not enough individually to cause the extinctions that we see at the end of the Cretaceous.

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Both hypotheses of dinosaur extinction take into account some of the evidence while ignoring some. For example, if either hypothesis is correct and there is a 60+ million-year gap between man and dinosaur, how then do we explain petroglyphs and other forms of ancient art that depict humans interacting with such familiar dinosaurs as the triceratops, stegosaurus, tyrannosaurus, and the sauropods?Â Climate change can be very destructive to ecosystems in general, and we tend to kill or drive out all of our major competition in particular.Â In our view, this incredulity is wrong. Science should involve the impartial investigation of evidence without prejudice, not an arbitrary human effort to prop up flawed, theoretical histories of the earth.