**Dinosaur Extinction: A Scientific Controversy**

The science in your textbooks is what Thomas Kuhn calls “Normal Science”; that is, it teaches you science based on the current paradigms. But all knowledge claims in Science are contingent; that is inherent in a discipline that is fundamentally empirical.

I vividly remember the publications that argued that at least some dinosaurs were warm blooded, not the slow moving, cold blooded super-lizards I read about as a child. I also vividly remember when the Alvarezes (father and son) published their theory that an asteroid strike off the coast of Yucatan caused dinosaur extinction. That theory gained widespread acceptance among paleontologists.

Fairly recently, Gerta Keller of Princeton University has challenged that orthodoxy. Her arguments have been controversial, and some of the programs I have seen make it clear that personal antagonism and professional jealousy play a role in the controversy (in both directions; I may be a Princeton grad, but I take no position on the merits of the controversy; I am not sufficiently knowledgeable in the discipline to have a meaningful opinion). That, unfortunately, is also a part of Science. Scientists are prone to all of the same foibles that other humans are prone to.

I have put together four articles I found on the internet to illustrate the debate. The first is from *The Daily Princetonian*, the second from the web site *Space Daily*; the third from the *Princeton Weekly Bulletin*, and the last is from a science blog published by Gred Laden.

My main point with these articles is that the progress of Scientific knowledge is not linear; it is marked by new theories, abandoned theories, false starts, dead ends, and controversy.

I copied each article and pasted it directly into my word processor.

**Keller: Volcanoes, not asteroid, caused mass extinction**

By Lauren Christensen  
Staff Writer  
Published: Wednesday, May 6th, 2009  
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Geosciences professor Gerta Keller  
For decades, it has been the predominant theory among scientists that dinosaurs began to die off when an asteroid collided with the Earth 65 million years ago. But a new study by geosciences professor Gerta Keller suggests that the mass extinction of life on Earth actually occurred 300,000 years after the collision and was likely due to volcanic activity in modern-day India.

Keller based her controversial findings on studies of rock formations from the K-T boundary — the transition between the Cretaceous and Tertiary periods — which marks Earth’s development from being dominated by reptiles to being occupied by mammals. Keller looked at formations
from around the world, including some in the United States, India and Mexico. Her research included examining ossified remains of various organisms that indicate a delay between when the asteroid hit the Earth and the extinction of the dinosaurs.

“For thirty years many scientists have taken it for granted that the K-T mass extinction was caused by an asteroid impact,” Keller said in an e-mail to The Daily Princetonian. “The search for the real culprit must now begin in earnest.”

Keller’s work contributes to the debate about the true cause of the extinction of the dinosaurs. For years, scientists have theorized that the Chicxulub asteroid event, whose crater was discovered in northeastern Mexico in the late 1970s, precipitated the demise of the dinosaur population, as well as more than half of all living organisms on Earth.

Part of Keller’s research, however, looks at “the cores from the impact crater on Yucatan” and shows that the Chicxulub impact — the earliest known asteroid event in northeastern Mexico — actually occurred hundreds of thousands of years before the first evidence of mass dinosaur extinction, she said.

“Our work shows that the long-held belief that a large asteroid impact on the Yucatan caused the mass extinction some 65 million years ago is not supported by critical evidence,” Keller explained.

Keller added that the Chicxulub asteroid did not even cause any significant damage to the planet’s environment or fragile marine species either.

Keller emphasized her confidence in her research, especially in light of its enormous impact on the scientific community.

“Challenging the established and popular impact theory requires extraordinary proof,” she said. “We have provided that proof in triplicate.”

Keller conducted a significant portion of her research at El Penon, a trench site in northeastern Mexico. Several Princeton students assisted with the excavation.

Brian Gertsch GS, who has been working with Keller, said he was currently studying the biotic effects of Deccan volcanism in marine environments in northeast India.

“The main results show that very high stress conditions in marine environments correlate with a major volcanic episode in the terminal Cretaceous [period] in India,” he said in an e-mail.

Gertsch added that his work with Keller points to a significant, direct impact of the Deccan volcanic phase at the K-T boundary on the environment, both on land and in the oceans.

“This scenario provides a better view of the K-T mass extinction mechanism where extraterrestrial impact had no influence on the faunal mass extinction,” Gertsch explained.
Keller noted that there is room for further research in the field, explaining that since the Chicxulub asteroid event should no longer be considered the cause of the mass extinction of the organisms which populated the Earth during the Cretaceous period, the cause of their extinction remains to be determined.

Keller and her team have already begun to work on answering this question, she said.

“We have already discovered that the main volcanic phase [of huge-scale volcanic activity in modern-day India] coincided with the mass extinction,” she said. “The next step is to find out how these volcanic eruptions caused the global mass extinction.”
Princeton Paleontologist Produces Evidence For New Theory On Dinosaur Extinction


Sep. 26, 2003 — As a paleontologist, Gerta Keller has studied many aspects of the history of life on Earth. But the question capturing her attention lately is one so basic it has passed the lips of generations of 6-year-olds: What killed the dinosaurs? Share This: 9 Related Ads:

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Cretaceous

The answers she has been uncovering for the last decade have stirred an adult-sized debate that puts Keller at odds with many scientists who study the question. Keller, a professor in Princeton's Department of Geosciences, is among a minority of scientists who believe that the story of the dinosaurs' demise is much more complicated than the familiar and dominant theory that a single asteroid hit Earth 65 million years ago and caused the mass extinction known as the Cretaceous-Tertiary, or K/T, boundary.

Keller and a growing number of colleagues around the world are turning up evidence that, rather than a single event, an intensive period of volcanic eruptions as well as a series of asteroid
impacts are likely to have stressed the world ecosystem to the breaking point. Although an asteroid or comet probably struck Earth at the time of the dinosaur extinction, it most likely was, as Keller says, "the straw that broke the camel's back" and not the sole cause.

Perhaps more controversially, Keller and colleagues contend that the "straw" -- that final impact -- is probably not what most scientists believe it is. For more than a decade, the prevailing theory has centered on a massive impact crater in Mexico. In 1990, scientists proposed that the Chicxulub crater, as it became known, was the remnant of the fateful dinosaur-killing event and that theory has since become dogma.

Keller has accumulated evidence, including results released this year, suggesting that the Chicxulub crater probably did not coincide with the K/T boundary. Instead, the impact that caused the Chicxulub crater was likely smaller than originally believed and probably occurred 300,000 years before the mass extinction. The final dinosaur-killer probably struck Earth somewhere else and remains undiscovered, said Keller.

These views have not made Keller a popular figure at meteorite impact meetings. "For a long time she's been in a very uncomfortable minority," said Vincent Courtillot, a geological physicist at Université Paris 7. The view that there was anything more than a single impact at work in the mass extinction of 65 million years ago "has been battered meeting after meeting by a majority of very renowned scientists," said Courtillot.

The implications of Keller's ideas extend beyond the downfall of ankylosaurus and company. Reviving an emphasis on volcanism, which was the leading hypothesis before the asteroid theory, could influence the way scientists think about the Earth's many episodes of greenhouse warming, which mostly have been caused by periods of volcanic eruptions. In addition, if the majority of scientists eventually reduce their estimates of the damage done by a single asteroid, that shift in thinking could influence the current-day debate on how much attention should be given to tracking and diverting Earth-bound asteroids and comets in the future.

Keller does not work with big fossils such as dinosaur bones commonly associated with paleontology. Instead, her expertise is in one-celled organisms, called foraminifera, which pervade the oceans and evolved rapidly through geologic periods. Some species exist for only a couple hundred thousand years before others replace them, so the fossil remains of short-lived species constitute a timeline by which surrounding geologic features can be dated. In a series of field trips to Mexico and other parts of the world, Keller has accumulated several lines of evidence to support her view of the K/T extinction. She has found, for example, populations of pre-K/T foraminifera that lived on top of the impact fallout from Chicxulub. (The fallout is visible as a layer of glassy beads of molten rock that rained down after the impact.) These fossils indicate that this impact came about 300,000 years before the mass extinction.

The latest evidence came last year from an expedition by an international team of scientists who drilled 1,511 meters into the Chicxulub crater looking for definitive evidence of its size and age. Although interpretations of the drilling samples vary, Keller contends that the results contradict
nearly every established assumption about Chicxulub and confirm that the Cretaceous period persistied for 300,000 years after the impact. In addition, the Chicxulub crater appears to be much smaller than originally thought -- less than 120 kilometers in diameter compared with the original estimates of 180 to 300 kilometers.

Keller and colleagues are now studying the effects of powerful volcanic eruptions that began more than 500,000 years before the K/T boundary and caused a period of global warming. At sites in the Indian Ocean, Madagascar, Israel and Egypt, they are finding evidence that volcanism caused biotic stress almost as severe as the K/T mass extinction itself. These results suggest that asteroid impacts and volcanism may be hard to distinguish based on their effects on plant and animal life and that the K/T mass extinction could be the result of both, said Keller.

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Note: A longer version of this news release appeared in the Princeton Weekly Bulletin (http://www.princeton.edu/pr/pwb/03/0922/).

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Dinosaur dust-up
Princeton paleontologist produces evidence for new theory on extinction

By Steven Schultz

http://www.princeton.edu/pr/pwb/03/0922/

Princeton NJ -- As a paleontologist, Gerta Keller has studied many aspects of the history of life on Earth. But the question capturing her attention lately is one so basic it has passed the lips of generations of 6-year-olds: What killed the dinosaurs?

Gerta Keller, professor of geosciences, has spent the last decade investigating the demise of dinosaurs. Rather than working with dinosaur bones, like these in Guyot Hall, she conducts research on one-celled organisms.

The answers she has been uncovering for the last decade have stirred an adult-sized debate that puts Keller at odds with many scientists who study the question. Keller, a professor in Princeton's Department of Geosciences, is among a minority of scientists who believe that the story of the dinosaurs' demise is much more complicated than the familiar and dominant theory that a single asteroid hit Earth 65 million years ago and caused a mass extinction.

Keller and a growing number of colleagues around the world are turning up evidence that, rather than a single event, an intensive period of volcanic eruptions as well as a series of asteroid impacts are likely to have stressed the world ecosystem to the breaking point. Although an asteroid or comet probably struck Earth at the time of the dinosaur extinction, it most likely was, as Keller says, "the straw that broke the camel's back" and not the sole cause.

Perhaps more controversially, Keller and colleagues contend that the "straw" -- that final impact -- is probably not what most scientists believe it is. For more than a decade, the prevailing theory has centered on a massive impact crater in Mexico. In 1990, scientists proposed that the Chicxulub crater, as it became known, was the remnant of the fateful dinosaur-killing event and that theory has since become dogma.

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very renowned scientists," said Courtillot.

The implications of Keller's ideas extend beyond the downfall of ankylosaurus and company. Reviving an emphasis on volcanism, which was the leading hypothesis before the asteroid theory, could influence the way scientists think about the Earth's many episodes of greenhouse warming, which mostly have been caused by periods of volcanic eruptions. In addition, if the majority of scientists eventually reduce their estimates of the damage done by a single asteroid, that shift in thinking could influence the current-day debate on how much attention should be given to tracking and diverting Earth-bound asteroids and comets in the future.

Working back in time

Unlike many children today who lap up a steady diet of dinosaur-related books, toys and television programs, Keller knew nothing of the creatures when growing up in Liechtenstein and Switzerland. She became interested in paleontology in the 1970s as a graduate student in earth sciences at Stanford University and began studying the periodic episodes of extinctions and abrupt climate changes that punctuate Earth's 4 billion years.

"I am interested in major events in Earth's history," said Keller. "How did they change life on Earth? What caused the big changes in evolution?"

Keller does not work with big fossils such as dinosaur bones commonly associated with paleontology. Instead, her expertise is in one-celled organisms, called foraminifera, which pervade the oceans and evolved rapidly through geologic periods. Some species exist for only a couple hundred thousand years before others replace them, so the fossil remains of short-lived species constitute a timeline by which surrounding geologic features can be dated.

Princeton geophysicist Jason Morgan said Keller's detailed analysis of these microorganisms gives her work real credibility. "It's not like finding an isolated dinosaur bone," said Morgan. "You have thousands of organisms in a single sample. You can do real statistics on them."

Keller first used fossilized foraminifera to study climate changes in the last several hundred thousand years. Then, going to work for the U.S. Geological Survey, she became interested in earlier periods and began working her way backward in time. "I'm now down to 100 million years and can't go much further," she said, noting that these microorganism records extend back only about 200 million years.

The time of the dinosaur extinction is known as the Cretaceous-Tertiary boundary, or K/T for short. In addition to dinosaurs, many other forms of life were wiped out, including all tropical and subtropical species of foraminifera. Looking at ocean sediments from before and after the K/T boundary "is like day and night," Keller said, because so much life disappeared.

At many locations around the world, the K/T boundary is clearly visible in rock formations, which contain a thin layer of clay rich in the element iridium. Because iridium is more common in asteroids and comets than on Earth, scientists, led by father and son Luis and Walter Alvarez, proposed in 1980 that an asteroid or comet must have struck Earth just at the K/T boundary.
When the Chicxulub impact crater was discovered in 1990, it appeared to be a likely source for the iridium and seemed to confirm the hypothesis. Several lines of evidence

Keller began studying the K/T boundary several years after coming to Princeton in 1984 and soon suspected that the story might not be so straightforward. In a series of field trips to Mexico and other parts of the world, she has accumulated several lines of evidence. She has found, for example, populations of pre-K/T foraminifera that lived on top of the impact fallout from Chicxulub. (The fallout is visible as a layer of glassy beads of molten rock that rained down after the impact.) These fossils indicate that this impact came about 300,000 years before the mass extinction.

In other studies spread across a range of excavation sites, Keller has found evidence that the ecological disruption caused by the Chicxulub impact may not have been as severe as originally thought. She found normal marine sediments lying directly on top of the fallout layer, suggesting that there were no tsunami waves or other major disturbances.

In addition, Keller and her students conducted studies throughout Mexico, Guatemala and Haiti (see related story below) that revealed signs of as many as three meteorite impacts: the Chicxulub impact, evidenced by the fallout of glass beads; the K/T impact with its iridium layer and mass extinction; and probably a third smaller impact, evidenced by another iridium layer about 100,000 years after the mass extinction.

The latest evidence came last year from an expedition by an international team of scientists who drilled 1,511 meters into the Chicxulub crater looking for definitive evidence of its size and age. Although interpretations of the drilling samples vary, Keller contends that the results contradict nearly every established assumption about Chicxulub and confirm that the Cretaceous period persisted for 300,000 years after the impact. In addition, the Chicxulub crater appears to be much smaller than originally thought -- less than 120 kilometers in diameter compared with the original estimates of 180 to 300 kilometers.

Keller and colleagues are now studying the effects of powerful volcanic eruptions that began more than 500,000 years before the K/T boundary and caused a period of global warming. At sites in the Indian Ocean, Madagascar, Israel and Egypt, they are finding evidence that volcanism caused biotic stress almost as severe as the K/T mass extinction itself. These results suggest that asteroid impacts and volcanism may be hard to distinguish based on their effects on plant and animal life and that the K/T mass extinction could be the result of both, said Keller.

Softening opposition

Because her results are among the first to quantify the biotic effects of volcanism, they may also help other scientists understand the likely effects of greenhouse warming resulting from volcanism or other causes, Keller said.

Together Keller's results give her hope that her ideas may gain greater recognition, but she remains cautious about how many people she is likely to convince. "When you have such a large
group of scientists who became famous based on the idea that a single impact at Chicxulub
caused the K/T mass extinction, you can't easily change their minds," she said.

Courtillot, whose views largely concur with Keller's, is optimistic that the opposition may be
softening, particularly concerning the role of volcanism in the K/T extinction. "Recent years are
vindicating our minority views -- at least I hope that is the case," he said.

In the meantime, Keller has further studies planned, including trips to extract sediments from
Brazil, the Indian Ocean and the Middle East. She hopes these samples could broaden and clarify
the story of the last days of the dinosaurs. "We want to nail it down as far away from Chicxulub
as possible," she said.
Gerta Keller goes after impact theory again
Posted by Greg Laden on May 5, 2009

http://scienceblogs.com/gregladen/2009/05/05/gerta-keller-goes-after-impact/

Keller has been one of the leading voices opposing the impact KT boundary extinction hypothesis. According to a press release from her university, she has more on this matter.

Press Release:

Gerta Keller, whose studies of rock formations at many sites in the United States, Mexico and India have led her to conclude that volcanoes, not a vast meteorite, were the more likely culprits in the demise of the Earth’s giant reptiles, is producing new data supporting her claim.

Keller, a Princeton professor of geosciences, and several co-authors lay out the case in a paper published April 27 in the Journal of the Geological Society of London. Examinations at several new sites have produced “biotic evidence” — the fossilized traces of plants and animals tied to the period in question — indicating that a massive die-off did not occur directly after the strike but much later.

In addition, Keller and other researchers have found “aftermath” sediments that remained undisturbed and showed signs of active life, with burrows formed by creatures colonizing the ocean floor. This would quash a theory advanced by some that a massive tsunami followed the impact, Keller said.

“Careful documentation of results that are reproducible and verifiable will uncover what really happened,” Keller said. “This study takes an important step in that direction.”

Much of the new data comes from a trench dug out of low-lying hills in northeastern Mexico at a site called El Peñon. A group of Princeton undergraduates accompanying Keller on a field trip to Mexico in 2004 excavated the area and uncovered the new evidence. Keller and her team have been analyzing that evidence for the last several years.

Understanding what caused the dinosaurs to disappear remains a great mystery. Theories attempting to explain it include asteroid or cometary impacts, volcanoes, global climate change, rising sea levels and supernova explosions. Scientists know that at a point about 65 million years ago, some phenomenon triggered mass extinctions on the land and oceans.

This event defines the boundary between the older Mesozoic Era, the “Age of Reptiles,” and the modern Cenozoic Era, the “Age of Mammals.” On a finer geological scale, the disappearances occurred between the Cretaceous (K) period and the Tertiary (T) period. As a result, scientists refer to this time as the K-T boundary.

At many locations, the K-T boundary is clearly visible in rock formations, which contain a thin
layer of clay rich in the element iridium. Because iridium is more common in asteroids and comets than on Earth, scientists proposed in 1980 that an asteroid or comet must have struck Earth just at the boundary and caused the mass extinction of dinosaurs and many other animals. They thought they had found the culprit when they discovered the Chicxulub impact crater in Mexico’s northern Yucatan.

Keller began studying the K-T boundary in 1984 — the year she arrived at Princeton. She discovered that the evidence for the asteroid theory was not so clear. In field investigations, she and her team of students and collaborators found populations of Cretaceous age foraminifera, one-celled ocean organisms that evolved rapidly during select geological periods, living on top of the impact fallout from Chicxulub. The fallout from the asteroid that struck Chicxulub is visible as a layer of glassy beads of molten rock that rained down after the impact. If this impact caused the mass extinction, then the foraminifera above the impact glass beads should have been the newly evolved species of the Tertiary age.

Using these fossil remains to construct a timeline, she and her team were able to date the surrounding geologic features and begin to piece together proof that the impact occurred 300,000 years before the great extinction.

Over the years, Keller’s group has amassed evidence for as many as four major events widely separated in time in that area of Mexico as well as in Texas. The oldest of the four events is the Chicxulub impact, seen by the fallout of glass beads. The second is about 150,000 years later and seen in a layer of sandstone with Chicxulub impact glass beads that were transported from shallow shore areas into deep waters during a sea level fall and was commonly interpreted as a tsunami generated by the Chicxulub impact. About 100,000 to 150,000 years later, the third event struck at the time of the K-T boundary with its iridium layer and mass extinction. This event may represent a second large impact or massive volcanism. The fourth event is possibly a smaller impact as evidenced by another iridium layer about 100,000 years after the mass extinction.

Advocates of the Chicxulub impact theory suggest that the impact crater and the mass extinction event only appear far apart in the sedimentary record because an earthquake or tsunami caused slumps and mixing of sediments surrounding the Gulf of Mexico. To date no evidence of major disturbance has been found in the sediments.

Keller says her team’s newest research, however, confirms what she has found in earlier studies — that the sandstone complex that overlays the impact layer was not deposited over hours or days by a tsunami but over a long time period. From El Peñon in Mexico and other sites listed in the new study, the scientists were able to calculate that between 13 and 30 feet of sediments were deposited at a rate of about an inch per thousand years after the impact. These sediments separating the impact layer from the sandstone complex and the overlying mass extinction were formed by normal processes. There is evidence of erosion and transportation of sediments in the sandstone layers, but no evidence of structural disturbance, Keller said.

Also at El Peñon, the researchers found 52 species present in sediments below the impact layer
and counted all 52 still present in the layer above it, indicating that the impact has not had the devastating biotic effect on species diversity as has been suggested. “Not a single species went extinct as a result of the Chicxulub impact,” Keller said.

In contrast, she noted, at a nearby site known as La Sierrita where the K-T boundary, iridium anomaly and mass extinction are recorded, 31 out of 44 species disappeared from the fossil record at the K-T boundary.

“Keller and colleagues continue to amass detailed stratigraphic information supporting new thinking about the Chicxulub impact and the mass extinction at the end of the Cretaceous,” said Richard Lane, program director in the National Science Foundation’s division of earth sciences, which funded the research. “The two may not be linked after all.”

Keller suggests that the massive volcanic eruptions at the Deccan Traps in India may be responsible for the extinction, releasing massive amounts of dust and gases that could have blocked sunlight, altered climate and caused acid rain. The fact that the Chicxulub impact seems to have had no effect on biota, she said, despite its 6-mile-in-diameter size, indicates that even large asteroid impacts may not be as deadly as imagined.

She regards the latest evidence as sufficiently convincing and compelling to allow her to move on and investigate further the evidence for Deccan volcanism as being at the root of dinosaur extinction. But she does not expect her teams’ present work will stop the raging debate at the heart of this controversy.

“The decades-old controversy over the cause of the K-T mass extinction will never achieve consensus,” Keller said. But consensus, she added, is not a precondition to advancing science and unraveling truth. “What is necessary is careful documentation of results that are reproducible and verifiable,” she said.

Co-authors of the paper are Thierry Adatte of the University of Lausanne in Switzerland; Alfonso Pardo Juez of the CES Fundación San Valero in Spain, who earned a Ph.D. from Princeton in 1995; and José Lopes-Oliva of the University of Nueva León in Mexico, who earned a Ph.D. from Princeton in 1996. The journal is published by the Geological Society of London. The research was funded by the National Science Foundation and the Swiss National Fund.

Keywords: dinosaur extinction; kt boundary; impact theory