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Fatal impact

the asteroid that wiped out the dinosaurs

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Introduction

Sixty-five million years ago an asteroid the size of Wellington Harbour crashed into the shallow seas off the Yucatan Peninsula, Mexico, and caused the greatest catastrophe of the last 250 million years. The impact caused the extinction of the dinosaurs – the dominant animals of the previous 150 million years – along with about half of all species of plants and animals then alive. Evolution of new species and the recovery of ecosystems on land and in the sea took thousands, possibly millions of years.

Impact!

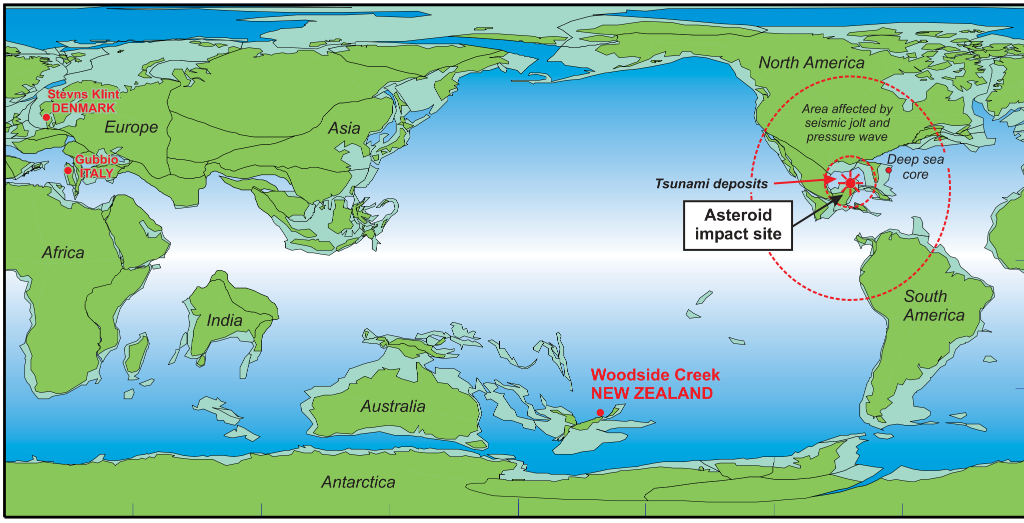
The global distribution of a centimetre-thick layer of meteorite dust and an impact crater almost 200 km in diameter imply that the asteroid was about 10 km in diameter. An asteroid of this size, travelling at 70,000 km per hour, would have hit the Earth with the explosive force of 100,000 billion tonnes of TNT. That's about 10,000 times the destructive power of the entire global nuclear arsenal at the peak of the cold war!

Initial effects of this impact would have been a seismic jolt of magnitude 12, which is 1000 times greater than the largest recorded earthquake. Shock waves would have been generated with hurricane-force winds of 250 km per hour. The earthquake and winds would have flattened forests throughout North America. A blast of heat from the impact may have generated a huge fireball, possibly causing the waters of the Gulf of Mexico to boil. Displacement of water in the shallow seas would have generated a giant tidal wave or mega-tsunami, reaching 150 m in height along the coast of the Gulf of Mexico and affecting coastal areas further afield, perhaps as far away as New Zealand.

Earthquake, atmospheric blast, mega-tsunami, fiery hailstorm, global darkness, freezing cold, acid rain and greenhouse warming. *Source for artwork on this and cover pages: NASA, artist Don Davis*

Although these initial effects would have devastated much of North America, it is the following series of events that are believed to have led to mass extinction.

First, about 90,000 cubic kilometres of rock and other debris would have been ejected into the atmosphere at ballistic velocities. Some material would have punched through the atmosphere before re-entering at high speeds. The huge volume of re-entering ejecta may have heated the atmosphere sufficiently to cause global forest fires. Some estimates suggest that the atmosphere was heated to 1000°C, although it is difficult to see how any life would have survived if that were the case. Once most of the ejecta had settled, fine particles of dust would have remained in the atmosphere, blanketing out the sun and causing total darkness for up to two months. Light levels would have been too low for photosynthesis to occur for up to six months. This, combined with a severe drop in temperature, is likely to have caused a near complete collapse of the food chain and ultimately mass extinction of the dominant herbivores and carnivores on land and in the sea – dinosaurs, pterosaurs, plesiosaurs, mosasaurs and ammonites.



Map showing distribution of landmasses 65 million years ago, with the effects of continental drift removed, and the asteroid impact site on Yucatan Peninsula, Mexico. Tsunami deposits are recorded throughout the Gulf of Mexico and the shock wave is predicted to have flattened forests over much of North America. Fallout from the impact is recorded as far away as Italy, Denmark and New Zealand (map produced with ATLAS computer program).

Other effects were specifically related to the geological composition of the rock at the impact site. Because this target rock was primarily limestone and gypsum-rich evaporite, it contained large amounts of carbon and sulphur. Up to 100 billion tonnes of sulphur and 10,000 billion tonnes of carbon may have been injected into the atmosphere. These elements were vaporised on impact to form carbon dioxide and sulphate aerosols. Sulphate aerosols in the atmosphere act like dust particles blacking out the sun, and initially contributing to global cooling. They would have stayed in the atmosphere for several years before falling as acid rain. Carbon dioxide would have remained in the atmosphere for several hundred years. Once the cooling effects of dust and sulphate aerosols were gone, carbon dioxide levels two to three times greater than normal would have caused global warming, perhaps by as much as 10°C for several hundred years. It is possible that some groups of plants and animals that survived prolonged darkness and freezing temperatures immediately following the asteroid impact were then killed off by extreme greenhouse conditions.

The evidence

Many theories have been proposed to explain the extinction of the dinosaurs. These range from the improbable – hay-fever following the evolution of flowering plants – to the more conventional – a period of intense volcanic activity or long-term changes in climate.

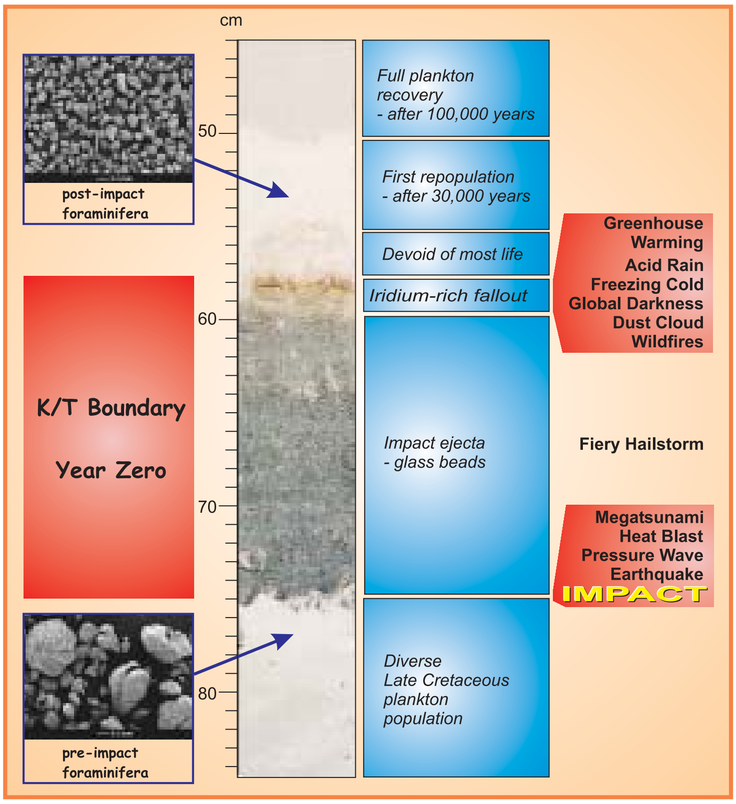
However, there is now little doubt that the main cause of mass extinction at the end of the Cretaceous Period* was the impact of a giant asteroid. The evidence is found in the fossil record, distinctive features of a thin layer of clay that marks the extinctions, and the physical record of the impact crater.

The fossil record shows that mass extinction of dinosaurs, marine reptiles, ammonites and many other animal and plant species occurred at the K/T boundary. The best evidence is found in deep-sea cores of marine mud or equivalent strata uplifted on land where the abrupt disappearance of many species of marine plankton occurs immediately below the K/T boundary.

Until a few years ago, debate raged over how suddenly the dinosaurs and other groups died out. The problem is that the fossil record is very patchy, especially for large land animals. Plants and animals most likely to be preserved as fossils are those that live in marine or lake environments where sediments gently cover their remains.

Source: Canadian Museum of Nature, artist Eleanor Kish

* The end of the Cretaceous, or the boundary between the Cretaceous and Tertiary Periods, is referred to as the K/T boundary (the K referring to the German word for Cretaceous, Kreidehaltig).



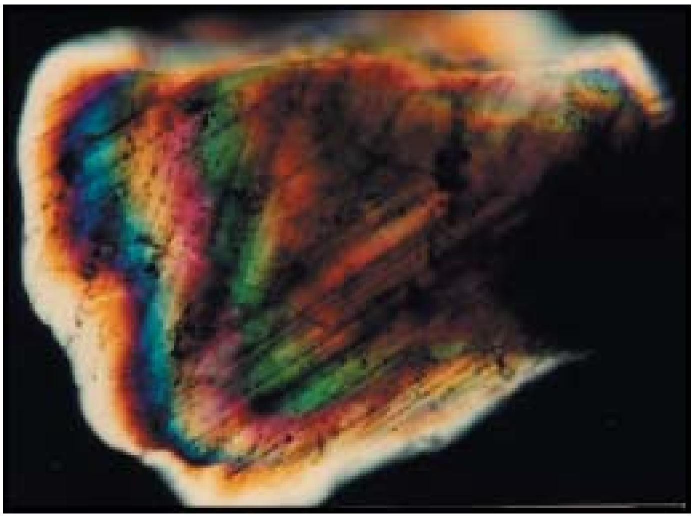
A deep-sea sediment core from offshore Florida, western Atlantic Ocean, shows remarkable evidence for extinction amongst marine plankton – in this case fossil foraminifera – at the time of asteroid impact. The impact is recorded by a 15 cm thick layer of glass beads, which are condensation droplets formed from vaporised particles of meteorite and target rock, overlain by a thin layer of impact dust *Source: Brian Huber, Smithsonian Institution.*

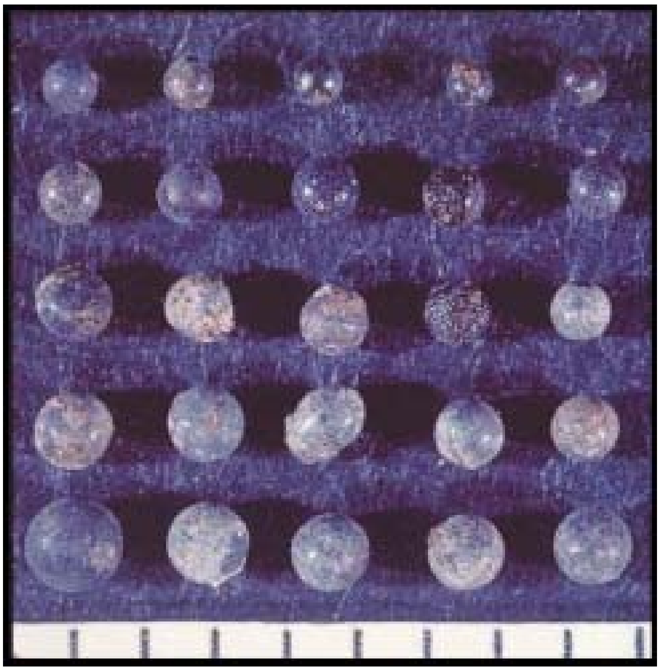
Small plants and animals are also more likely to produce more fossils simply because there tend to be more of them. Thus, the shells of microscopic marine plankton provide the most convincing evidence for sudden mass extinction. Two groups of plankton – planktonic foraminifera and calcareous nanoplankton – that occur in vast abundance in ocean mud, suffered near complete extinction at the K/T boundary. But for two of the main groups linked to the K/T mass extinction – the dinosaurs and the Nautilus-like ammonites – the fossil evidence suggested they may have declined in abundance and diversity gradually through the last few million years of the Cretaceous. However, in recent studies involving very intensive fossil collecting in the cliffs of Spain (for ammonites) and in the Montana badlands (for dinosaurs), paleontologists have now shown that the diversity of ammonite and dinosaur species remained stable until the very end of the Cretaceous.

A thin layer of clay found at K/T boundary sites worldwide contains extremely high amounts of elements such as iridium that are normally rare on Earth but are abundant in meteorites. This boundary clay also contains impact-shocked mineral grains and droplets of impact glass.

The initial evidence for an extraterrestrial impact at the K/T boundary was the discovery in 1980, by a team led by father and son Luis and Walter Alvarez, of extremely high concentrations of the element iridium in the boundary clay at three widely separated localities in Italy, Denmark and New Zealand. Iridium is an element that is much more abundant in extraterrestrial bodies than in the Earth's crust. There are now over 100 sites worldwide, including seven in New Zealand, with iridium-rich boundary clays.

Woodside Creek was the first K/T boundary site to be identified in New Zealand. After Percy Strong pinpointed the boundary in a 1977 study of fossil foraminifera, a team of Canadian scientists, led by dinosaur expert Dale Russell, took a large suite of core samples in an attempt to study the magnetic properties of the boundary zone. Although the study was unsuccessful due to the very weak magnetic signal, the samples were passed on to the Alvarez team who went on to make their landmark discovery of iridium enrichment in boundary clays from Woodside Creek, Gubbio in Italy and Stevns Klint in Denmark. Most of the drill-holes present in the K/T boundary site today were made by the Canadian team.





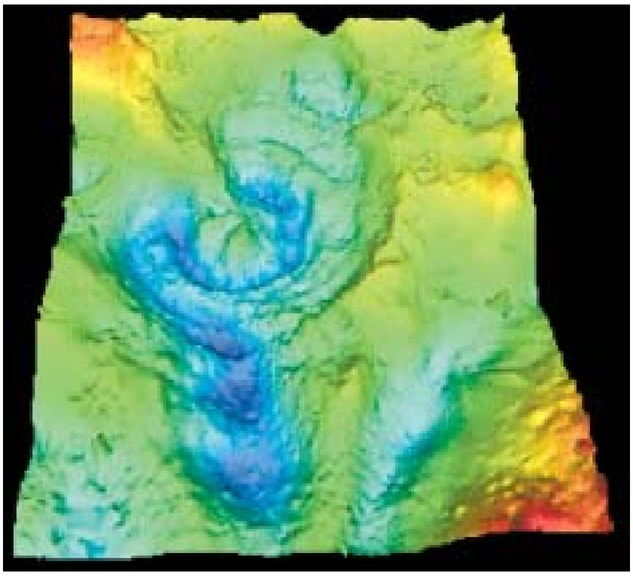
An impact-shocked quartz grain (above) and glass beads (right) from the K/T boundary in Yucatan and Wyoming.
Source: Alan Hildebrand, University of Calgary

The abundance of iridium, chromium and nickel is consistent with the composition of chondritic meteorites, most of which originate in the asteroid belt between Mars and Jupiter. The global abundance of iridium in the boundary layer provided the initial basis for estimating the diameter of the impacting object at around 10 km.

Physical components of the boundary clay also provide evidence for a large meteorite impact. Small grains of the mineral quartz have been found with distinctive fracture lines criss-crossing the surface. Such grains are known to be formed by high-pressure shock and are found at nuclear bomb sites and in known meteorite craters. Small glass beads in the boundary clay are the remains of condensation droplets that formed from vaporised particles of meteorite and target rock.

The impact crater is identified as a 180 km wide circular structure at Chicxulub, on the Yucatan Peninsula, Mexico. Subsequent studies of rock outcrops in this region have identified extensive tsunami deposits at K/T boundary sites throughout the Gulf of Mexico.

The clinching evidence for the impact hypothesis was the discovery in 1991 of a likely impact crater in the Yucatan Peninsula. The buried crater was identified by aerial surveys of the magnetic and gravitational fields in the region after some K/T boundary sediments in nearby Haiti were interpreted as tsunami deposits. Tsunami deposits linked to the impact are now recorded throughout the Gulf of Mexico and Caribbean region and as far away as Spain and Brazil.



The buried Chicxulub impact crater is seen as a 180 km wide circular negative gravity anomaly (blue and green colours), representing a crater in which dense continental rocks were vaporised. The crater was then filled with low density debris from the impact.
Source: Alan Hildebrand, University of Calgary

New Zealand's record of the K/T boundary event

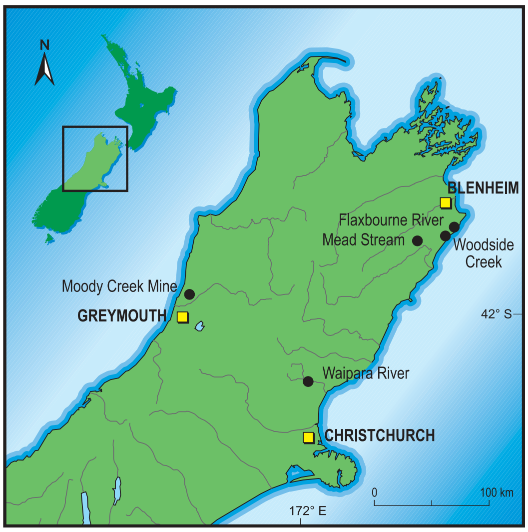
Through detailed studies of fossil foraminifera, micropaleontologist Percy Strong has pinpointed the K/T boundary in seven sites in New Zealand.

New Zealand has been prominent in the K/T boundary debate ever since the Alvarez team first used samples from Woodside Creek in eastern Marlborough to demonstrate the global distribution of iridium enrichment. The Woodside Creek K/T boundary was discovered by Percy Strong in 1975. Since that time, Percy has found six more K/T localities in the northern South Island. These sites provide remarkably complete records of the K/T boundary event. As well as the iridium anomaly, the boundary clay contains shocked quartz and impact glasses. In addition, the discovery of abundant soot and complex carbon molecules called fullerenes, which form in intense fires, provide compelling evidence that the impact ignited global forest fires.

New Zealand is an important region for K/T boundary research. It provides a good record of the K/T event far from the impact site. Being in a region that was close to the South Pole, plants and animals may have been more able to withstand months of darkness and freezing conditions produced by the global dust cloud.

Until recently, there was little evidence for what happened on land in New Zealand at the K/T boundary. All the sites in the eastern South Island were in marine rocks laid down in water depths of 50 to 200 m or more. In 2001, the first non-marine K/T boundary was discovered in coal deposits near Greymouth. Detailed study of fossil spores and pollen grains provided remarkable evidence for massive destruction of forests precisely at the level of the iridium-rich layer. This latest discovery is very important. The destruction of forests was thought to have been confined to North America. With similar devastation now recorded in small and distant New Zealand, the role of the asteroid impact in ending the reign of the dinosaurs becomes much clearer. Global destruction of forests and of many groups of marine phytoplankton would have destroyed the foundation of the food chain and resulted in widespread extinctions, especially among large herbivores and carnivores.

What has yet to be resolved is what killed the forests? Was it the prolonged darkness and freezing conditions produced by the global dust cloud and sulphate aerosols? Or was it global wildfires caused by super-heated impact ejecta re-entering the atmosphere at ballistic velocities?



The five most complete K/T boundary sites in New Zealand are all located in the northern South Island. Flaxbourne, Woodside and Mead sites are in deep marine limestone. The Waipara site is in shallow marine sandstone. The Moody Creek Mine site is the only record of the K/T boundary event in the non-marine sediments (in this case coal and sandstone) in the Southern Hemisphere.

The survivors' tale

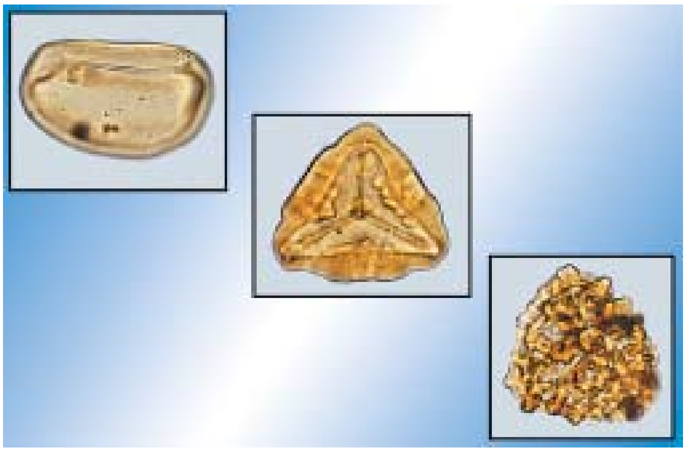
In any extinction event there is an up side. If the dinosaurs were not wiped out by the meteorite impact, would humans have evolved?

Dinosaurs and mammals lived side by side for many millions of years without mammals replacing dinosaurs as the dominant life form. The main evolutionary diversification, including appearance of the primates, occurred between 10 and 15 million years after the K/T boundary event.

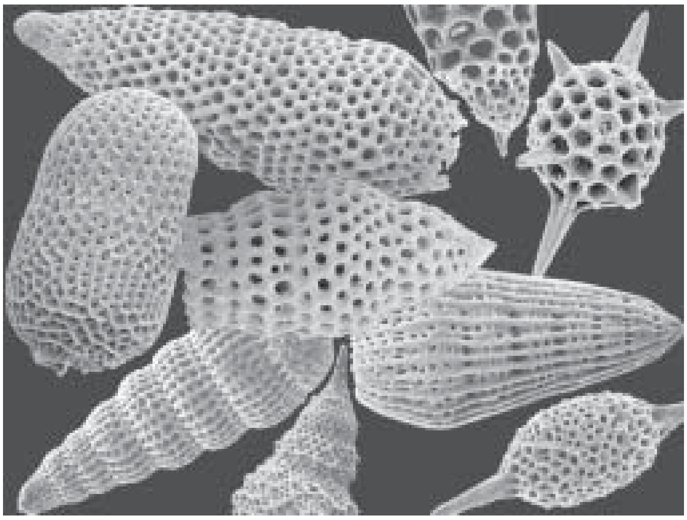
Why did the mammals survive? What can we learn about the K/T event by examining the record of survivors?

The surviving plants and animals provide good evidence supporting the asteroid impact. For example, generally the impact winter theory holds true because warm climate species fared worse than cool climate species.

For land plants, we now know that the broad pattern of recovery was the same worldwide. The first plants to colonise the post-impact landmass were small ground ferns. Modern relatives of these ferns are colonisers of open ground, especially water-logged and acidic soils. The interesting feature of the New Zealand discovery is that these ferns remained dominant for a long period of time, possibly for as long as 10,000 years. If the primary killing mechanism was mass burning associated with global wildfires, we'd expect a more rapid recovery. On the other hand, if the impact winter was the main killer, perhaps cool climatic conditions prevailed for considerably longer than the few years it would have taken for the dust and sulphate aerosols to settle out of the atmosphere. Fluctuations in the abundance climate indicator fossils, from both land and sea environments around New Zealand, indicate that climate may have been very unstable for millions of years after the impact. This probably reflects the important role that stable ecosystems play in regulating global climate.



Microscopic fossil spores from ferns that dominated the New Zealand landscape for at least 10,000 years after the asteroid impact. *Source: Vivi Vajda, Lund University*



Microscopic shells of species of marine plankton (radiolarians) that were tolerant of cool climatic conditions and therefore survived the effects of the asteroid impact in seas off eastern New Zealand.

Four good reasons to study the K/T boundary mass extinction

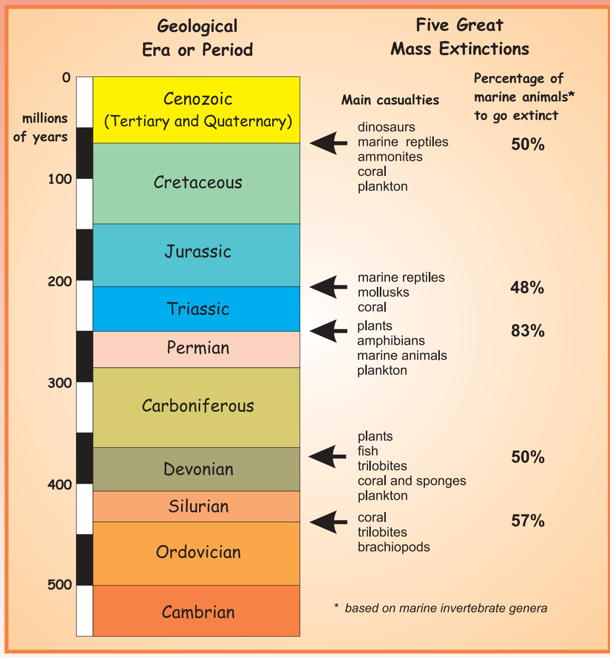
1. It's very interesting! This amazing story helps to explain our place in the world – why humans are running things now and not dinosaurs.

2. It might happen again. Large extraterrestrial impacts are predicted to occur every hundred million years. Just this year a 70 m wide asteroid with the explosive capability of a four megatonne nuclear bomb passed within 500,000 km of Earth. NASA scientists predict that there is a small chance that it will collide with Earth in 2093 on its return orbit.

3. It's a guide to the effects of nuclear war. Comparing the explosive force of meteorite impacts with nuclear bombs is not simply for dramatic effect. Initial research on the K/T impact theory was carried out during a time when the threat of wholesale nuclear war was a real possibility. In part, understanding the catastrophic effects of the impact helped governments appreciate the real risks that a nuclear winter posed for life on this planet.

4. It's a guide to the effects of global climate change. With all the greenhouse gases humans are pumping into the atmosphere, it's unlikely that within the next few hundred years the planet will experience freezing conditions comparable to the impact winter (unless there is another major impact or a nuclear war). However, the greenhouse event that followed the impact winter is a very good model for our current climate crisis. The K/T event is one of very few episodes in Earth's history where greenhouse gas levels and global temperatures may have risen at a rate similar to that predicted for the next 200 years.

The K/T boundary mass extinction is the last of five great mass extinctions known in the history of life. These events are loosely defined as brief episodes in geological time when around half or more marine genera (= natural groupings of species) became extinct. Apart from the K/T event the causes of these mass extinctions are still poorly understood. Some would argue that we are now in the grip of the sixth great extinction with over half of the many major groups of species becoming extinct in the last 1000 years. In this case, there is little doubt of the cause - it is us!



Further Reading

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Cox, G. & Wiffen, J. 2002. Dinosaur New Zealand. HarperCollins, Auckland. 39 p.

Frankel, C. 1999. The end of the dinosaurs: Chicxulub Crater and mass extinctions. Cambridge University Press, Cambridge. 223 p.

Gould, S. J. 1996. Dinosaur in a haystack. Penguin, London. 480 p. (especially Chapters 12 and 13.)

Powell, J. L. 1998. Night comes to the Cretaceous: Dinosaur extinction and the transformation of modern geology. W. H. Freeman, New York. 250 p.

Web Resources

- Enchanted Learning – http://www.enchantedlearning.com/subjects/dinosaurs/extinction/Asteroid.html
- Department of Paleobiology, National Museum of Natural History, Smithsonian Institution – http://www.nmnh.si.edu/paleo/ (Dinosaur exhibits, "A blast from the past")
- Museum of Paleontology, University of California, Berkeley – http://www.ucmp.berkeley.edu/diapsids/dinobuzz.html (The Dinobuzz)
- University of Arizona – http://www.lpl.arizona.edu/SIC/news/chicxulub2.html (Impact generated wildfires)
- NASA Ames Research Center, Asteroid and Comet Impact Hazards – http://impact.arc.nasa.gov/
- Meteorite and Impacts Advisory Committee (MIAC) to the Canadian Space Agency – http://miac.uqac.ca/MIAC/chicxulub.htm (Chicxulub Crater, Mexico, and the K/T boundary)
- Earth History, Institute of Geological and Nuclear Sciences – http://www.gns.cri.nz/what/earthhist/

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