# G R E S H A M

## C O L L E G E



# DEATH OF THE DINOSAURS
# A GEOCHEMICAL WHODUNNIT

A Lecture by

**PROFESSOR COLIN PILLINGER BSc PhD DSc FRS**
**Gresham Professor of Astronomy**

7 November 1997

# *GRESHAM COLLEGE*

## Policy & Objectives

An independently funded educational institution, Gresham College exists

- to continue the free public lectures which have been given for 400 years, and to reinterpret the 'new learning' of Sir Thomas Gresham's day in contemporary terms;
- to engage in study, teaching and research, particularly in those disciplines represented by the Gresham Professors;
- to foster academic consideration of contemporary problems;
- to challenge those who live or work in the City of London to engage in intellectual debate on those subjects in which the City has a proper concern; and to provide a window on the City for learned societies, both national and international.

Gresham College, Barnard's Inn Hall, Holborn, London EC1N 2HH
Tel: 020 7831 0575 Fax: 020 7831 5208
e-mail: enquiries@gresham.ac.uk

## Death of the Dinosaurs - a geochemical who dunnit

Geologists have never liked change. If they have to accept change then it has to be on a timescale they understand - slow. For this reason geologists embraced with open arms Darwin's origin of species; it seemed to fit exactly with their geological perception of the Earth, a slowly evolving place where accidents of nature occurred at about a constant or uniform rate. Thus arose the philosophy of uniformitarianism introduced by Charles Lyell. Lyell argued that the rate of biological change recorded by fossils had always been and would always remain the same. It seems difficult to see how such a perception could have arisen.

Staring geologists in the face was a geological record which was anything but uniform. The periods in geological history identified in the fossil record had a nasty habit of coming to an abrupt end. There are many examples of when huge numbers of biological species which existed very happily for millenia had suddenly come to a dramatic end. Nevertheless for more than 150 years the uniformitarians or the gradualists had triumphed over the catastrophists. No better explanation existed for the changes observed than the melodramatic statement made to duck the problem that "a higher type of species was now at the threshhold of being". The concept seemed to match that of civilisation itself - one regime or culture past its sell-by-date would shrink away and be superceded before the approaching hordes of a more fashionable enlightened or motivated force. Although the uniformitarians did not have an answer, the catatrophists did not have a weapon to remove them from the centre of the stage they had occupied so successfully for so long.

In the late 1960s, the uniformitarian approach to geology seemed to be finally coming together in a grand theory which explained how the outer crust of the Earth evolved - the theory of plate tectonics was born. Coincidentally unbeknown to them, the catastrophists were about to have their day and the step which was about to be made was the "one small one for [a] man but a giant leap for mankind" far away on the Moon. Amongst the experiments done on the returned lunar soils and breccias not by geologists but meteoriticists were geochemical trace element analyses. It was proving possible by modern analytical methods particularly neutron activation to show that the lunar surface was contaminated by elements which could only have got there from primitive undifferentiated meteorites. All those blemishes on the face of the Moon were craters which had been formed through geological time and indeed were still being formed by impacts.

Real geologists on Earth were not taking much notice they were immersed in their investigation of the new geological panacea plate tectonics. For this reason perhaps they did not notice that a heretic in their midst was a about to unleash a monster to match any that ever roamed the Earth. The subject of the discoveries involved the real, not mythical, monster the dinosaur and the demise of his/her species.

At the end of the geological period called the Cretaceous (abbreviated to K because it was called Kriedzeit in German meaning chalk-time) and the beginning of the Tertiary (abbreviated T), the family of reptiles, the dinosaurs, which had ruled the Earth for $150x10^6$ years suddenly ceased to predominate. Not just the dinosaurs, but 70% of all the species observed in the fossil record slowly evolving for the whole of the Cretaceous period, came to an end in suspcious circumstances. All those lovely creatures so familiar to us the ammonites, the belemnites, the bivalves, all gone in one fail swoop.

Although the K/T boundary event is by no means the most catastrophic seen in the geological record it is by far the most obvious and the most recent being only $65x10^6$ year ago in Earth's history, and of course it had the romance of the dinosaur association. The K/T boundary perplexed geologists for a long time but they had no answer. In 1968 and 1971, in little known papers, dinosaur palaeontologist Dale Russell and astronomer Wallace Tucker made a preposterous suggestion: a nearby supernova could have dramatic biological effects and could even have killed nature's biggest monsters. The majority of geologists were unimpressed by such an upstart theory. Only one or two took any notice - but from that moment the possibility of some extraterrestrial intervention to account for catastrophism was born.

One of those who listened was geophysicist Walter Alvarez, a man who was as interested in the plate tectonics scene as anybody since his forté was measuring the geomagnetic reversals which were the proof of ocean floor spreading. Alvarez was preoccupied in dating events in the tectonic process and one of the ones he wanted information about was the formation of the Appenines in Italy by collision of one geological plate with another. So he tripped the K/T Boundary, as represented by a geological outcrop at Gubbio, Italy, in the best scientific tradition, almost by accident. He was looking for magnetically unaligned fossil beds when he and colleagues came across a narrow band of clay lying between the last limestones of the Cretaceous on the one hand and the first limestones of the Tertiary on the other. Prior to this, it had been tacitly assumed that there must have been some hiatus between the two periods but how long it had lasted was anyone's guess. Carbonates i.e. limestones are notoriously difficult to date radiometrically, at that time it was impossible to obtain ages. But maybe the interspersed layer would provide the opportunity for Alvarez and his companions. If it was laid down slowly not abruptly then the uniformitarians would be right and if fast then catastrophism would have had to have been involved.

There was still a problem how to date the layer which was not straight forward. Walter Alvarez approached his father Luis a nuclear physicist, who suggested that measuring the radioactivity of $^{10}Be$ might give the answer - a good deal of time was wasted on this hypothesis before it was realised that the half-life of $^{10}Be$ had been wrongly measured. It was infact to short to be of any use. But since no one else was particularly interested in the problem of the timescale between the Cretaceous and the Tertiary so what.

Alvarez senior then came up with a new idea, ironically based on the flux of micrometeorites (cosmic dust) from space to Earth; this was hugely imaginative because this subject at that time was not well understood but it could be guessed at from the studies of the lunar surface layers. Meteorites (micrometeorites included) would be rich in platinum group elements whereas the Earth was essentially devoid of species such as iridium which is scavenged out of surface materials into the core. Alvarez proposed two scenarios to date that boundary clay layer: either there would be essential no iridium because the layer was laid down quickly and the dinosaur deaths would have been a catastrophy or there would be some iridium from the accumulating micrometeorite source meaning that the layer was a slowly formed feature. Neither Alvarez, in their wildest dreams, thought about the third alternative: a huge enrichment. The maximum they expected was about 0.1ppb (part per billion) iridium just above detection limits, what they actually found was a hundred times that amount 9ppb concentrated in the clay.

Dating the layer by the technique they proposed was instantaneously forgotten. Where had all the iridium come from? But instead of seeing the obvious answer they embarked on another wild goose chase. Again Alvarez senior's hypotheses were to blame, and the papers by Russell and Tucker which suggested a supernova had killed the dinosaurs was the cause of the mistake. It seemed such a nice idea, that Alvarez father and son strove to prove it. If the iridium at Gubbio came from an exploding star, then it should be accompanied by the radioactively extinct element $^{244}Pu$. This therby was clearly dictated by Alvarez's experience as a nuclear chemist. With appropriate collaborators, they did the required experiments and found among the results exactly the information they wanted. Although they now had a bombshell story on their hands "News Extra Supernova kills dinosaurs" Walter was nervous, and after consultations with the head of the laboratory, all the experiments were repeated. The iridium anomaly was correct whereas the $^{244}Pu$ finding was wrong. The Alvarezes were deflated; the beauty of the supernova hypothesis in their eyes was that it could affect the whole Earth. They had not considered that an impact would be big enough to be global. They thought an impact might exterminate locally but undestroyed species from further afield would simply back collonise the depleted area. It was then that they came up with the idea of a nuclear winter. The impact would saturate the atmosphere with dust which would block out the sun and produce a global effect.

The giant meteorite hypothesis was first thrust upon the world at a conference in Copenhangen in 1979 and published in 1980. Since that time the number of sites where iridium anomalies have been found has multiplied and they can be identifed on all the continents, and in locations when sediments have accumulated on land and under water. There is undoubtedly a world wide occurence of excess iridium which marks the end of the Cretaceous and the onset of the Tertiary. This does not of course prove the giant impact hypothesis, and more over in the mid-1980s, a mechanism concerning how iridium might have been contributed to the atmosphere by terrestrial events was proposed. This concerned the finding that iridium existed in volcanic material erupted from the Hawaiian volcano Kilauea which had sampled deep seated parts of the Earth's mantle. With this information geologists could propose that volcanic eruptions over long periods might have the same effect as an impact. They could even identify lava fields of appropriate age in India, the Deccan traps. Moreover, the impact theory was deficient in that the crater the catastrophists wanted could not be found.

Most of these criticisms of the impact idea can now be overturned in that other indicators of the impact at the K/T boundary have been found, microtektites and shocked quartz species characteristic of explosive events are ubiquitous. Particularly good evidence of this type has been the discovery of tiny diamonds at K/T boundary locations. At first these were interpreted as being direct evidence of the meteorite; some investigators going so far as to identify the type of meteorite which might have been involved. This was however fallacious, the isotopic composition of the diamonds demonstrates that they cannot be first generation meteorite products but must have been synthesised in the plasma generated in the explosion.

Now there is no longer the necessity to rely on just iridium and fortunately a candidate crater which perfectly fits the criteria for the impact hypothesis has been located in the last few years. It is at Chicxulub on the Yucatan Pennisula of Mexico and is 200kms in diameter and 16kms deep suggesting a 10km diameter asteroid hit Earth. The reason it was not apparent previously was that it is filled with sediments and covered by a 1000 metre thick layer. Like in all good detective stories however evidence for its existence has been there all along in the archives of an oil company which geophysically surveyed the area in 1947.

Now that the place of the impact has been located, it is possible to look at the radial distribution of impact evidence. The diamond story is interesting in that the occurence of diamond can be traced through various K/T sites in the United States, the further one gets from the crater the finer the diamonds become. Locations as far as Gubbio in Italy where the first iridium was found show no evidence for diamond. This must surely be evidence for the synthesis in the ionised plasma close to the impact site. Diamond because of its long term persistence must therefore be one of the best indicators of the impact phenomena. A successful search for them has been carried out at a well authenticated crater (e.g. the Ries, in Germany) where they are found in co-existence with silicon carbide again good evidence for the plasma synthesis interpretation. Other craters are currently being searched.

The basic tenet of the Alvarez theory regarding the mass extinctions is that of global environment change induced by effects on the atmosphere. Almost the first indication of a world wide occurrence associated with the K/T boundary was the finding of soot particles which might be taken as evidence of a global wild-fire, the burning of dead or dying vegetation, etc. Soot in the atmosphere would have had a major part to play in extinguishing sunlight. Likewise trace elements liberated by igniting organic matter etc. would have synthesised sulphur and nitrogen oxides which would give rise to another environmental hazard acid rain. Burning of organic matter would lead to large numbers of species in the atmoshpere would have led to dramatically enhanced green house effect immediately following the cold of excluding the sun - either way the dinosaurs and the other trace gases could not win. Another nasty little hazard which has been suggested in the light of the knowledge that the Chicxulub impact occurred in a shallow sea was the generation of giant tidal waves (tsunamis). The Caribbean sea could have been practically emptied for a while before the water flowed back - the effect on shore lines here and elsewhere and to marine creatures would have been formidable.

Detectives are only supposed to gather the evidence - it is for the lawyers to present it and the court to convict or acquit. If there is a reasonable doubt the latter. It is very easy for geologists to still argue that the effects seen in the fossil record would take far too long to have been the direct result of an impact. One thing is for certain an impact occured 65 million years ago and it was orders of magnitude bigger than any other natural event we know about. If it did not kill the dinosaurs directly, it triggered something else that did. By default some of the other extinctions in the fossil record could have been as a result of similar causes although there is no strong evidence that impacts occurred at the appropriate times. Perhaps the occurrence of diamond at appropriate locations, if they are found, will help.



## Books

Fastovsky, D.A. and Weishampel, D.B. (1996) The Evolution and Extinction of the Dinosaurs, Camridge University Press, USA.

Alvarez, W. (1997) T.rex and the Crater of Doom, Princeton University Press, New Jersey.

Hallam, A. and Wignall,P.B. (1997) Mass Extinctions and their Aftermath, Oxford University Press, USA.

## Articles

Alvarez, L.W., Alvarez, W., Azaro, F., and Michel, H.W. (1980) Extraterrestrial cause for the K/T extinction, *Science* **208**, 1095-1108.

Gilmour, I., Russell, S.S., Franchi, I.A., Arden, J.W, Lee, M.R., and Pillinger, C.T. (1992) Terrestrial carbon and nitrogen isotope ratios from K/T boundary nanodiamonds, *Science* **258**, 1624-1625.

Wolbach, W.S., Gilmour, I., Anders, E., Orth, C.J., and Brook, R.R (1988) Global fire at the Cretaceous Tertiary Boundary, *Nature* **334**, 665-669.