# *Palaeontology, palaeobiology and evolution*

**K-T (K-Pg) event: can the cavilling stop now, please? (*February 2013*)**

Artist's impression of the Chicxulub impact

Since 1980, when Alvarez *père et fils* discovered signs of a globe-affecting impact event in rocks marking the stratigraphic boundary at the end of the Mesozoic Era –between the Cretaceous and Palaeogene Periods – there has been continual bickering over the cause of the mass extinction at that time. Unlike other mass extinctions that one marked the end of an Era dominated in the popular mind by the iconic dinosaurs. Besides that focus, many geologists have been averse to external, 'wham-bam-thank-you-ma'am' explanations for shifts in the fossil record: a sort of Lyellian view that geological change had to be at the pace of the humble tortoise and must be due to something in the Earth system itself. Then a majority, this conservative faction looked instead to the effects of the voluminous basalt flood that had affected western India at around the same time. Incidentally, that apparent match to the end-Mesozoic extinction sparked an interest in volcanic associations with other mass extinctions.

Discovery by geophysicists of evidence for a large almost completely buried impact basin, about 180 km across, centred in the Caribbean off Mexico's Yucatan Peninsula swayed opinion towards an extraterrestrial cause when it became clear that the impact had occurred around the time of the K-Pg boundary, then placed at 65 Ma. Soon there were claims that the Deccan Traps had erupted in less than a million years at that time, together with doubts cast on the actual age of the Chicxulub crater. The time-spread of the Deccan volcanism enlarged with more dating to between 68 and 60 Ma; and so the to-ing and fro-ing continued, gleaning sizeable grants for entrepreneurial geoscientists keen on one or other of what were becoming bandwagon topics. Then the 'golden spike' marking the time of the mass extinction became the subject of controversy. A means of precise dating is to examine signs in sediments of cyclical climate change using the Milankovich approach, although before 50 Ma only the 405 ka cyclicity predicted from astronomy is readily detected. Using well-dated volcanic horizons to calibrate such a stratigraphic dating method might be the key, but it became apparent that 65.3, 65.7 or 66.1 Ma all seemed to have the same likelihood.

The two kill mechanisms that had been proposed are in fact very different, not merely in terms of what might have happened to atmospheric chemistry, climate, photosynthesis and so on, but concerning their timing. Repeated episodes of major basalt eruption every 100 ka or so would have had a chronic and perhaps cumulative effect on the Earth's biota; i.e. even a 10 Ma spread for Deccan basalt floods bracketing the actual die-off would be acceptable as a cause. An impact however takes no more than a second to occur, because of the hypersonic speed induced by Earth's gravity as well as that of the asteroid through the Solar System. All its immediate effects – entry flash; crater excavation; debris fall-out; atmospheric dust and toxic gas accumulation; climate change; acid rain and tsunamis – would have been done and dusted over a matter of a few thousand years. The Chicxulub impact would have been a catastrophe that was instantaneous in geological terms. Its occurrence would need to bear the same date as the mass extinction itself to be seen as incontrovertible; well, at least to the majority of geoscientists. That point seems to have been reached.

As well as the crater, Chicxulub scattered molten rock far and wide to appear in the 'boundary layer' as glass spherules, which are dateable using radiometric means. So too is the timing of the mass extinction itself, provided suitable materials can be found above and below the strata across which fossil abundances change so dramatically. Paul Renne of the University of California, Riverside, and colleagues from the US, the Netherlands and Britain dated impact glasses from Haiti and volcanic ash from the late Cretaceous to early Palaeogene terrestrial sediments of Montana, USA that bracket the extinction event using multiple argon-isotope studies and the $^{40}$Ar-$^{39}$Ar method (Renne, p.r. and 8 others 2013. Time scales of critical events around the Cretaceous-Paleogene boundary. *Science*, v. **339**, p.684-687. The glasses come out at 66.038$\pm$0.049 Ma, while the Ar-Ar age of volcanic ash just above the carbon-isotope anomaly that marks the world-wide disappearance of a large proportion of living biomass is 66.019$\pm$0.021 Ma. As they say, the ages are 'within error' and the error is very small indeed.

So, does this work mark the end of the K-Pg controversy? Probably not, as very large sums of grant money are still tied up with on-going studies. Perhaps to assuage the fears of all those still financially addicted to answering 'what killed the dinosaurs?', The abstract of the paper reads thus' 'The Chicxulub impact likely triggered a state shift of ecosystems already under near-critical stress'.

Artist's impression of the common ancestor of placental mammals (Credit: Science magazine)

Interestingly, in the very same issue of *Science* came a research article that reexamines taxonomy of 86 key living and fossil placental mammals in the light of genetic sequencing, to locate startigraphically their earliest common ancestor (O'Leary, M.A. and 22 others 2013. The placental mammal ancestor and the post-K-Pg radiation of placentals. *Science*, v. **339**, p. 662-667). That seems to wrap up, for now, another controversy; did diminutive placental mammals arise unnoticed beneath the gaze of mighty dinosaurs, or what? It seems that some precursor mammals were able to diversify and produce a line whose foetuses grow and are nourished in the mothers uterus attached to a placenta, before live birth at an advanced stage of development, once opportunities for diversification emerged after the K-Pg event. Morphologically, the ancestor of everything from a naked mole rat to a blue whale and, of course, ourselves, seems to have been a sneaky-looking little beast with a long nose and pointy teeth. It does look like it, or its predecessor, could have scuttled unscathed amongst the leaf litter as dinosaurs engaged in their death prance…

**Related articles:** Rebuilding Our Extinct Ancestor (ribosometranslation.wordpress.com)

**Pushing back the origin of photosynthesis (*February 2013*)**

Sample from a banded iron formation (BIF) from the Barberton Greenstone Belt, South Africa. (credit: K. Lehmann and J.D. Kramers)

More than a decade ago the oldest sedimentary rocks in the world at Isua in West Greenland hit the headlines, and not for the first time. Inclusions of graphite in crystals of the mineral apatite from the Isua supracrustals had yielded carbon isotopes unusually deficient in $^{13}C$ relative to $^{12}C$, which is often regarded as a sign that life was involved in the carbon cycle at the time. The Isua rocks have been reliably dated at around 3.8 billion years (Ga) so that added over 400 Ma to the time at which life was present on Earth. Sedimentary rocks formed at 3.4 Ga contain the first tangible signs in the form of stromatolites thought to have been secreted by biofilms of blue-green bacteria which are oxygen-generating photosynthesisers. Sadly, limestones at Isua, indeed all the putative sedimentary rocks there were metamorphosed and deformed plastically so that such features, if they were ever present, had been obliterated. Apatite was thought to be so strong and resistant to heating that carbon within its crystals would have preserved original isotopic 'signatures'. Detailed studies to test this hypothesis refuted the early age for life, which reverted back to around

3.4 Ga. But Isua presents too good an opportunity for its geochemical secrets to be left uninvestigated.

The latest targets are its iron isotopes. Isua includes metamorphosed banded ironstones composed largely of magnetite and quartz. Magnetite is iron oxide ($Fe_3O_4$) and begs the question of how such an oxygen-rich mineral formed in such volumes in sediment if photosynthesizing life had not made elemental oxygen available. That would oxidize soluble ferrous ions ($Fe^{2+}$) to the insoluble ferric form ($Fe^{3+}$) in order for iron oxide to precipitate from sea water in large amounts. There is no other means known for oxygen to be produced in a planet's surface environment. A team at the University of Wisconsin's NASA Astrobiology Institute, led by Andrew Czaja and joined by Stephen Moorbath of the University of Oxford, who set the entire West Greenland story rolling by leading its geochronological investigation since the early 1970s, have made a breakthrough (Czaja, A.D. et al. 2013. Biological Fe oxidation controlled deposition of banded iron formation in the ca. 3770 Ma Isua Supracrustal Belt (West Greenland). *Earth and Planetary Science Letters*, v. **363**, p. 192-203; DOI: 10.1016/j.epsl.2012.12.025).

Any element that has more than one naturally occurring isotope offers the possibility of studying various kinds of chemical process by looking for changes to the relative proportions of the different isotopes. Having different relative atomic masses isotopes of an element have slightly different chemical properties so that one is likely to be more favoured in a reaction than another. In the case of iron, the most important reactions in surface processes are those that depend on reducing and oxidising conditions, i.e. producing soluble $Fe^{2+}$ and insoluble $Fe^{3+}$ respectively. Oxidation and precipitation of iron oxides and hydroxides tend to favour the heavier isotope $^{56}Fe$ over the more common $^{54}Fe$ resulting in an increase in the $^{56}Fe/^{54}Fe$ ratio ($\delta^{56}Fe$). This is found throughout the Isua ironstones, but may again reflect metamorphism. However, such was the detail of this study that $\delta^{56}Fe$ values were measured for many individual bands. Instead of showing roughly the same values throughout the rock, each band had a different value. That strongly suggests that values produced during sedimentation had been preserved. It seems that a bacterial mechanism of oxidation was involved. Moreover, by comparing the 3.8 Ga Isua ironstones with examples dated at 2.5 Ga from Australia the team found different isotopic values that implicates different kinds of bacteria involved in producing apparently similar rock types. The twist is that the most likely bacterial type involved at Isua may have been a photosynthesiser, but not of the kind that releases elemental oxygen instead transferring it from water to combine directly with the ions of iron that its photosynthesis  had oxidised. The younger ironstones seem more likely to have involved cyanobacteria that do excrete oxygen; shortly after their formation the Earth's surface increasingly became oxygen-bearing.

Throughout the Precambrian, BIFs appear and then vanish from the record only to reappear when geologist least expect them, for instance around the time of the Snowball Earth events in the Neoproterozoic Era. Iron isotopes could well become handy tools to probe the processes that formed them.

### Is end-Triassic mass extinction linked to CAMP flood basalts? (*June 2013*)

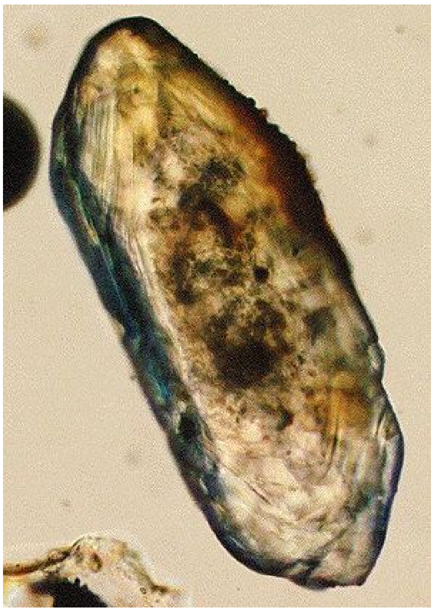
Mass extinctions and smaller but significant die-offs in the marine and terrestrial domains have been linked in the geoscientific imagination with many things: asteroid impacts; gamma-ray bursts from distant supernovae; belches of methane from the sea floor;

emissions of hydrogen sulfide gas from seawater during ocean anoxia events; sea-level changes and more. The most intriguing, since it suggests a causal link between the core-mantle boundary and the biosphere, is the influence of flood basalt events and the gases, both greenhouse and toxic, that they undoubtedly released.

The famous K-T extinction (now K-Pg since the Palaeogene became the Period following the Cretaceous rather than the Tertiary) has swayed back and forth between the Chicxulub impact in Mexico's Yucatán Peninsula and the flood basalts of the Deccan Traps in western India as likely mechanisms, Chicxulub currently being in pole position. The equally devastating event at the close of the Triassic Period (at 201 Ma) that presaged the rise of the dinosaurs has had a similar external versus internal causality controversy, both the Rochechouarte impact crater and the Central Atlantic Magmatic Province (CAMP) being candidates.

CAMP flood basalts in Morocco (credit: Wikipedia)

Rochechouarte, however, resulted from nowhere near as energetic an event as the Chicxulub impact. The problem, as with all events for which the weight of evidence points to geologically very short time scales (of the order of tens to hundreds of thousand years), is the dating of candidate causes. Rochechouarte happened at 201±2 Ma: it may or may not have coincided with faunal change. Yet timing of the CAMP flood basalts has hitherto been even more coarsely tagged. This imprecision is not unconnected with the choice of radiometric dating methods, the $^{40}Ar/^{39}Ar$ approach being 'easy' and hence popular, but limited in its precision and accuracy. The 'gold standard' is zircon U-Pb geochronology that depends on the far greater reluctance of the host mineral to lose either parent or daughter isotopes compared with the feldspars, micas and amphiboles used in many other methods. Zircon still in its igneous parent is crucial. Yet basalts contain few zircons.



Zircon crystal about 250 µm long

Zircon geochronology has now been accomplished for the CAMP flood basalts of eastern Canada, the Atlantic seaboard of the US and that of Morocco, and has a precision of around 30 ka, one to two orders of magnitude better than other methods (Blackburn, T.J. and 8 others 2013. Zircon U-Pb geochronology links the end-Triassic extinction with the Central Atlantic Magmatic Province. *Science*, v. **340**, p. 941-945; DOI: 10.1126/science.1234204). The extinction is defined most readily by a sudden change in fossil pollen and spores, possibly within less than 10 ka, as well as extinction of Triassic marine fauna and large numbers of terrestrial reptile and amphibian taxa followed by diversification of early Jurassic dinosaurs. The oldest CAMP basalts are from Morocco immediately above spores of clearly Triassic age; i.e. before the extinction, whereas the basalt flows in Canada and the eastern US (a mere 3 to 13 ka younger) are above the turnover. So, the start of the CAMP flood volcanism brackets the extinction.

But did CAMP cause, indeed could it have caused the extinction? Blackburn and colleagues cannot be certain. A negative carbon-isotope spike associated with the extinction is estimated to have required almost a million km$^3$ of magma to have been erupted almost instantaneously to inject excess $CO_2$ into the atmosphere. The dating suggests four major pulses of eruption in the areas studied spread over around 600 ka, the last three being associated with biological diversification and recovery in the earliest Jurassic. In fact the research seems merely to suggest strongly that flood volcanism accompanied the extinction, but leaves its causing the death toll still an open question.

The CAMP events marked the beginning of Pangaea's break-up and the formation of Tethys separating Eurasia and North America from the old Gondwana continental mass. That tropical seaway became the site of massive production of marine carbonates, presumably drawing down excess carbon dioxide from the atmosphere.

**Related article:** What really happens in a flood basalt eruption (geolsoc.org)

**Pushing back DNA sequencing: a Spanish cave bear (*September 2013*)**

At the time, only 3 years ago, publication of the first full Neanderthal genome seemed miraculous (See *Yes, it seems that they did* Human evolution 2010). Yet the apparent magic proved repeatable, including for an obscure but distinct group of extinct humans – the Denisovans – known only from their DNA in a single pinkie bone. These advances astonished the world by showing that anatomically modern humans were capable of interbreeding with both groups, and did, so that many people now living outside of Africa carry the genetic evidence. But the samples analysed for DNA were little more than 40 thousand years old. Older fossils of extinct animals have given up their genetic features, such as the wooly mammoth and a horse about 700 ka old, but only from samples frozen into permafrost at high northern latitudes.

The degradation of DNA over time seemed destined to limit palaeo-genetics, even when slowed down by natural freezing. The degradation breaks down any surviving genetic material into shorter and shorter fragments of the DNA molecule, ultimately to its atoms being recombined in new molecules of totally unrelated compounds through the chemical processes of fossilisation. Reassembling the fragments correctly becomes increasingly difficult the smaller they are. Few outside of a highly skilled specialists were optimistic of breaking the 100 ka barrier, even using frozen fossils. Unsurprisingly, having had such dramatic successes, the specialists continue to ride their luck and their ingenuity.

Excavations at Gran Dolina, in Atapuerca, Spain

The cave complex of the Atapuerca Mountains in northern Spain, whose sediments range in age from almost a million years ago to recent times, contain rich accumulations of human remains, including the pre-Neanderthal *Homo heidelbergensis* and *H. antecessor* dating back to more than 800 ka. If ever there was a magnet for archaeo-geneticists Atapuerca is definitely one. Moreover, physical anthropologists seem never to stop disputing their interpretations. Jesse Dabney of the now famous Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany, and co-workers from Britain, New Zealand, Spain and Australia are now beginning to report results. The first are from a cave bear (probably *Ursos deningeri*) known to be older than 300 ka (Dabney, J. and 10 others 2013. Complete mitochondrial genome sequence of a Middle Pleistocene cave bear reconstructed from ultrashort DNA fragments in one of its foreleg bones. *Proceedings of the National Academy of Sciences*, v. **110**, DOI: 10.1073/pnas.1314445110). The bear's mitochondrial DNA was pieced together from fragments as small as 50 base pairs, and shows its ancestry to cave bears (*U. spelaeus*) from the later Pleistocene that became extinct at about 28 ka.

Reconstruction of a European cave bear (Ursus spelaeus)

It may be only a matter of time before human DNA emerges from the rich Atapuerca fossil hoard; indeed the authors strongly hint that they are working on that now.

## Could volcanism have spread organisms? (*November 2013*)

Recently there have been worrying accounts about pathogens being transported for thousands of kilometres in dust storms, for instance, viruses that cause foot and mouth disease, influenza and the sheep disease bluetongue carried by tiny midge. They raise the question of whether or not in the past organisms small enough to be carried by winds in aerosol suspension might have helped colonise regions distant from where they evolved.

The 600 square kilometre caldera lake of Taupo on New Zealand's North Island.

Studies of volcanic ash thought to have been transported at high latitudes in the Southern Hemisphere from a 25 thousand-year old major volcanic eruption on the North Island of New Zealand add volcanic activity to violent meteorological phenomena as a possible means of transport (Van Eaton, A.R. *et al*. 2013. High-flying diatoms: Widespread dispersal of microorganisms in an explosive volcanic eruption. *Geology*, v. **41**, p. 1187-1190; DOI: 10.1130/G34829.1). Ash from as far as 850 km from the volcano turns out to incorporate abundant remains of diatoms – species of algae that secrete distinctively intricate skeletons made from silica. The volcano, Taupo, erupted from beneath a lake bed, explaining the diatoms' origin in lake muds and lake water. Even details of the organisms' soft parts and pigmentation are preserved in the ash, suggesting that at least some of them might have been transported alive. Astonishingly, the New Zealand authors' counts of organic material in the ash suggest that as much as 0.6 $km^3$ of diatom remains were dispersed during the eruption.

Assorted species of diatoms on a microscope slide (credit: Wikipedia)

Violent sub-aqueous eruptions can entrain liquid water as spray as well as water vapour and glassy magma shards, carrying the mixture into the stratosphere, far above wind belts in the lower atmosphere. At such altitudes transport can spread fine aerosols through an entire hemisphere because they remain in suspension for long periods.

Different species of diatom live in subtly different environments, so that their relative proportions and presence or absence in ash provide a 'fingerprint' for the volcano responsible. So the discovery by the team from the Victoria University of Wellington (a 'first') presents a new tool for identifying the source of ash layers in the volcanic record that came from other volcanoes associated with caldera lakes – common for those capable of launching huge volumes of material aloft, such as Toba that erupted in Sumatra at around 74 ka and may have influenced the first modern human migrants from Africa. But could minute organisms survive both the volcanic heat and blast and a traverse through the dry stratosphere to result in colonisation? If that were possible it would have significant implications for the spread of early life forms during the far more volcanically active Hadean and Archaean Eons of Earth's history.

Commenting on the article, Jennifer Pike of Cardiff University, UK (Pike, J. 2013. Of volcanoes and diatoms. *Geology*, v. **41**, p. 1199-2000; DOI: 10.1130/focus112013.1) surmises that diatoms might survive drying out in the stratosphere, provided they were in the form of spores encased in silica. Such spores were not found in the Taupo ash, but who is to say that they will not be discovered in other ancient volcanic ash layers? Spores are extremely durable and other micro-organisms than diatoms produce them and have done in the past.

**Related articles;** Super-Eruption Launched Algae Army Into the Sky (livescience.com)