Extinction!

The death of the dinosaurs wasn’t unique. There have been 17 major extinctions of life during the past 600 million years. And, in most cases, an asteroid probably wasn’t to blame. The answer may lie in great volcanic eruptions.

by Norman MacLeod

Extinction has always been a controversial subject. Even after decades of intense study, researchers are still arguing over the cause of the best-known mass extinction, the ‘death of the dinosaurs.’ And there’s a topical slant in the idea that - even today - species are regarded as "endangered" if they are relatively susceptible to extinction. Then too, what thinking person could have avoided wondering whether our own species is slated for extinction and, if so, how long we have before we meet our fate?

The disappearing mammoth

Two centuries ago extinction held centre-stage in an even more fundamental debate: whether the Bible should be interpreted literally. The bones of a very large fossil elephant (a ‘Mammoth’) had been collected in the then new world of North America. Discussing the Mammoth at the National Institute of Sciences and Arts in Paris in 1796, the French anatomist Baron Georges Cuvier argued that the bones belonged to a unique species of which no living examples were known. It was extremely unlikely that such a large animal could have gone undetected if its descendants had survived to the present day, so Cuvier pronounced the species extinct.

This conclusion contradicted religious dogma of the time. A benevolent creator, it was assumed, would not allow any of his creation to disappear from the Earth. In this way, Cuvier fired off one of the first salvos in a debate between theologians and natural historians that culminated 60 years later with the writings of Charles Darwin - and still continues in some quarters of society to this day.

Observing extinctions

Since Cuvier's time, extinctions have studied primarily by palaeontologists - scientists who investigate the remains of ancient life. For all that is said in popular books, articles and television programmes, the study of extinction is a surprisingly problematic and young field of inquiry. Extinction is one of the most common observations in palaeontology, but it remains very difficult to understand precisely why a particular ancient plant or animal species went extinct.

Much of this difficulty stems from the way that scientists ‘observe’ an extinction. Stated rather badly, we study extinction by observing what isn’t there. When we collect a fossil from a rock deposit, we assume that the species represented by this fossil lived at the place and time the rock was formed. If we sample a younger deposit and find that the species is not present, and if it never reappears in still younger deposits, we assume the species has become extinct, and that the time of extinction corresponds to the date of the youngest observed fossils.

But there may be other explanations for the absence of the species in younger deposits. For example, the species may have become extinct in this particular region, but survived to later times in other areas. Or the younger deposits may record an environment in which the species never occurred in the first place. A third possibility is that natural selection changed the appearance of the species to such an extent that palaeontologists mistakenly assign younger members to a different species.

A chart of extinctions

These problems mean that we are only just beginning to compile reliable data on how extinctions have varied over time. And such data is essential if we want to test different hypotheses on what has caused extinctions.

Figure 1 shows one of the latest summaries of extinction data. It concentrates on invertebrates - such as snails, clams and coral species - that lived in ancient oceans. The graph shows the number of extinctions that occurred within successive small subdivisions of geological time - called stages - which are typically a few million years in duration.

There are two particularly noteworthy features. First, there is a general decline in the number of extinctions over the last 600 million years. Secondly, there are several major ‘peaks’ of extinction, which are roughly evenly spaced. Both of these features are spurring a vigorous debate among palaeontologists.

Extinctions on the decline

The overall trend in Figure 1 shows the number of extinctions decreasing with time. At face value, it means that a species existing in the past was more likely to be wiped out than a species existing now. Is this really the case, and - if so - why?

There are currently three explanations.

The first suggests that the effect isn’t real. It occurs because palaeontologists are more

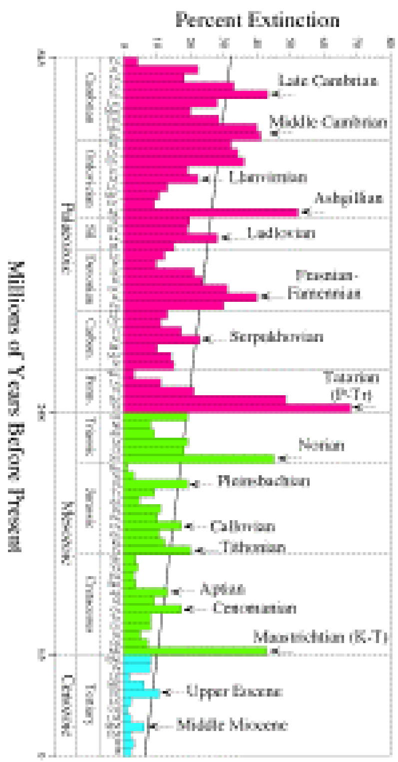

Figure 1. Figure 1. Extinctions over the past 600 million years - mass extinctions show up as peaks superimposed on a general decline in extinctions (diagonal line). The mass extinction marked as 'Maastrichtian' was the death of the dinosaurs. Reference: Sepkoski, JJ, Jr. 1994. Extinction and the fossil record. Geotimes March 15 - 17

familiar with modern marine organisms than with species from the remote past. When dealing with recent fossils, palaeontologists can be fairly confident that they are classifying them correctly into different species and groups of species (genera). When they look back to more ancient and unfamiliar fossils, they are more likely to be fooled into separating them out into many more genera. So there’s a higher chance that one of these - artificially small - ancient genera would become extinct.

The second invokes marine organisms moving from the general ocean into ‘marginal’ environments, for example around the edges of continents. Here, they might be sheltered from environmental changes, and so suffer less extinctions. On the other hand, the marginal environment might play the opposite role. It could be so extreme that the species had to evolve into a hardier form, which was then immune to all but the most profound episodes of global environmental change.

The third (and most recent) explanation argues that conditions in the world's oceans have become progressively more favourable for marine life. In 1994, Prof. Ron Martin of The University of Delaware summerized geochemical evidence that the oceans themselves have changed over geological time, by studying isotopes of elements such as sulphur-34, strontium-87 and carbon-13. These trends match the declining extinction curve.

Ocean changes

In Martin's model, the oceans of 600 million years ago were very different from those of today. Their circulation was sluggish, with large areas of the ocean floor covered by waters with little or no dissolved oxygen. They received large amounts of nutrient washed off from the barren continents (plants and soils had not yet evolved). And ocean plankton was relatively ineffi synthesis.

Figure 2. Extinct Fossil Fish.

As time went by, the oceans became more dynamic as plate tectonics pushed the continents around. Life on land trapped the nutrients that once ran off into the seas. As a result, the oceans became host to a greater diversity of plankton. This, in turn, meant they could support a diverse array of species, increasing the stability of marine ecosystems - and decreasing the probability of extinction.

Mass extinctions: the three culprits

The second important pattern we can see in Figure 1 are ‘peaks,’ where large numbers of species (up to 90%) become extinct within a short period of time. These are termed mass extinctions. The most famous - though not the most severe - involved the ‘death of the dinosaurs’ about 65 million years ago.

Scientists have proposed many different mechanisms to account for the pattern of mass extinctions over the last 600 million years. Currently, the most popular are: a fall in sea level; vast eruptions of basalt; and the impact of an asteroid or comet.

Interestingly, it’s not the direct effects that cause the damage. In all three cases, researchers explain the extinctions through subsequent drastic changes in the environment. For example, they may cool the Earth by promoting the formation of clouds, or lead to global warming as greenhouse gases are released. Nitrogen and sulphur compounds thrown into the atmosphere may produce acid rain, and also destroy the ozone layer.

Patterns of extinction

Generally, it’s difficult link any particular catastrophic event to a subsequent mass extinction. Instead palaeontologists comparing the pattern of mass extinctions as a whole with the patterns of each of the three possible mechanisms. Figure 2 compares the record of mass extinctions with geological records of sea-level falls, flood-basalt eruptions, and impacts of bolides (asteroids or comets).

Looking at Figure 2, it is clear that impacts show the worst record of association with mass extinction events. Sizeable impacts are as likely to have occurred during low-extinction stages as during high-extinction stages. In fact, there’s only one compelling example of an association between a large impact and a major extinction event. The Chicxulub event of 65 million years ago was the largest impact of the last 600 million years, and third largest in the known history of our planet. It blasted out a large crater in Mexico. At the same time, we find the Maastrichtian mass extinction event, also known as the K/T mass extinction. This was the disaster in which the dinosaurs perished, and it is ranked as the third to fifth largest extinction event of the last 600 million years.

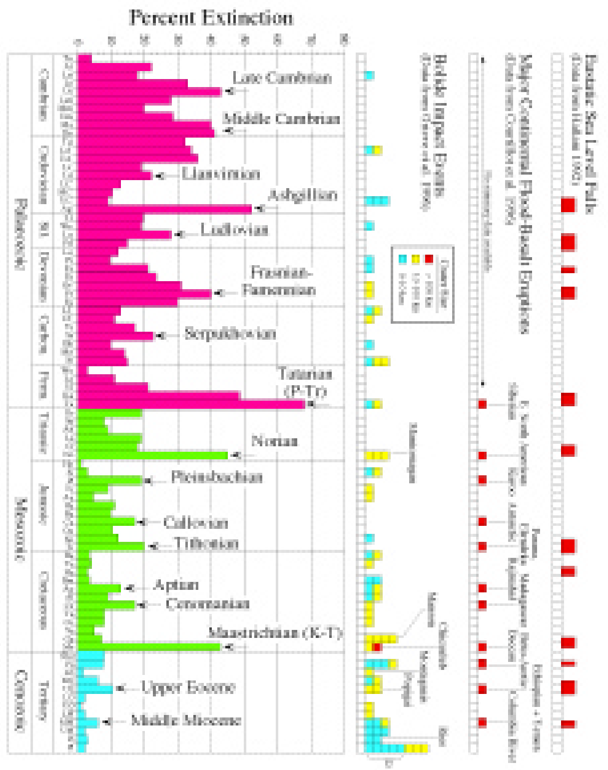

Figure 3. Figure 2. The record of extinctions (bottom), compared with - from top - major sea-level changes, giant eruptions of basalt, and impact craters.

Moving on to the second possible mechanism, abrupt falls in sea level show a rather better level of association with extinctions. Each of the three largest mass extinctions during the last 250 million years (the time interval for which we have the most accurate time resolution) corresponds to a major sea-level change. This supports the idea that rapid falls in sea level have a detrimental effect on the diversity of marine invertebrates.

Giant eruptions

But the strongest association - by far - comes with the third prospective extinction mechanism, as seen in the record of continental flood-basalt eruptions. These are vast outpourings of basaltic lava, similar to the eruptions responsible for the Hawaiian Island chain, but taking place entirely on land.

Perhaps the best known is the series of eruptions that took place on the Indian subcontinent beginning at the very end of the Maastrichtian stage, 66.5-64.5 million years ago. They poured out over one million cubic kilometres of lava in just over one million years, forming the vast Deccan Traps. The eruption did not take place continuously over the entire million years, but episodically in massive lava flows that have no counterpart in human history.

Since we have no direct experience of such cataclysmic eruptions, it is difficult to imagine (much less model) the climatic effects. Regardless, the close association between the flood-basalt record and the pattern of extinction events is very difficult to explain away as mere coincidence. In addition, it’s worth noting that the three largest extinctions of the last 250 million years took place during times of combined sea-level fall and flood-basalt eruption. Of course, the Maastrichtian event is also associated with the Chicxulub impact. However, this event is by no means the largest mass extinction to have occurred and, according to available data on the timing and magnitudes of impacts, several extinction events of equal and greater magnitude are not associated with large asteroid impacts.

Weighing up the evidence

As far as any single extinction event is concerned, in all probability we will never know all the factors involved. Nevertheless, the existing data provide an insight into the factors that are repeatedly associated with extinction events in the geological record.

A simple statistical analysis of the data in Figure 2 reveals the relative strength of the association between each type of catastrophe and mass extinctions as follows:

sea-level change 7 out of 14 continental flood basalt eruptions (over the last 250 million years) 10 out of 10 asteroid impact 1 out of 17.

Based on current data, tectonic factors - giving rise to flood-basalt volcanism and sea-level fall - appear to exhibit the greatest level of association with large-scale extinction events over the course of the last 600 million years.

Extraterrestrial impacts - current darlings of the media coverage of extinctions - have certainly played an important role in Earth history and may have enhanced the ‘death of the dinosaurs.’ However, asteroid impacts do not appear to be the primary agents responsible for the overall patterns in the geological extinction record.

Dr Norman MacLeod is an international expert in the study of extinctions. After a BSc in geology from the University of Missouri, he received an MSc from the Southern Methodist University and a PhD from the University of Texas, both in palaeontology. Norm MacLeod has researched at the University of Michigan and Princeton University, and is now a member of the Palaeontology Department at The Natural History Museum, London. As well as extinctions, his research interests include the quantitative analysis of morphology and the analysis of evolutionary patterns.

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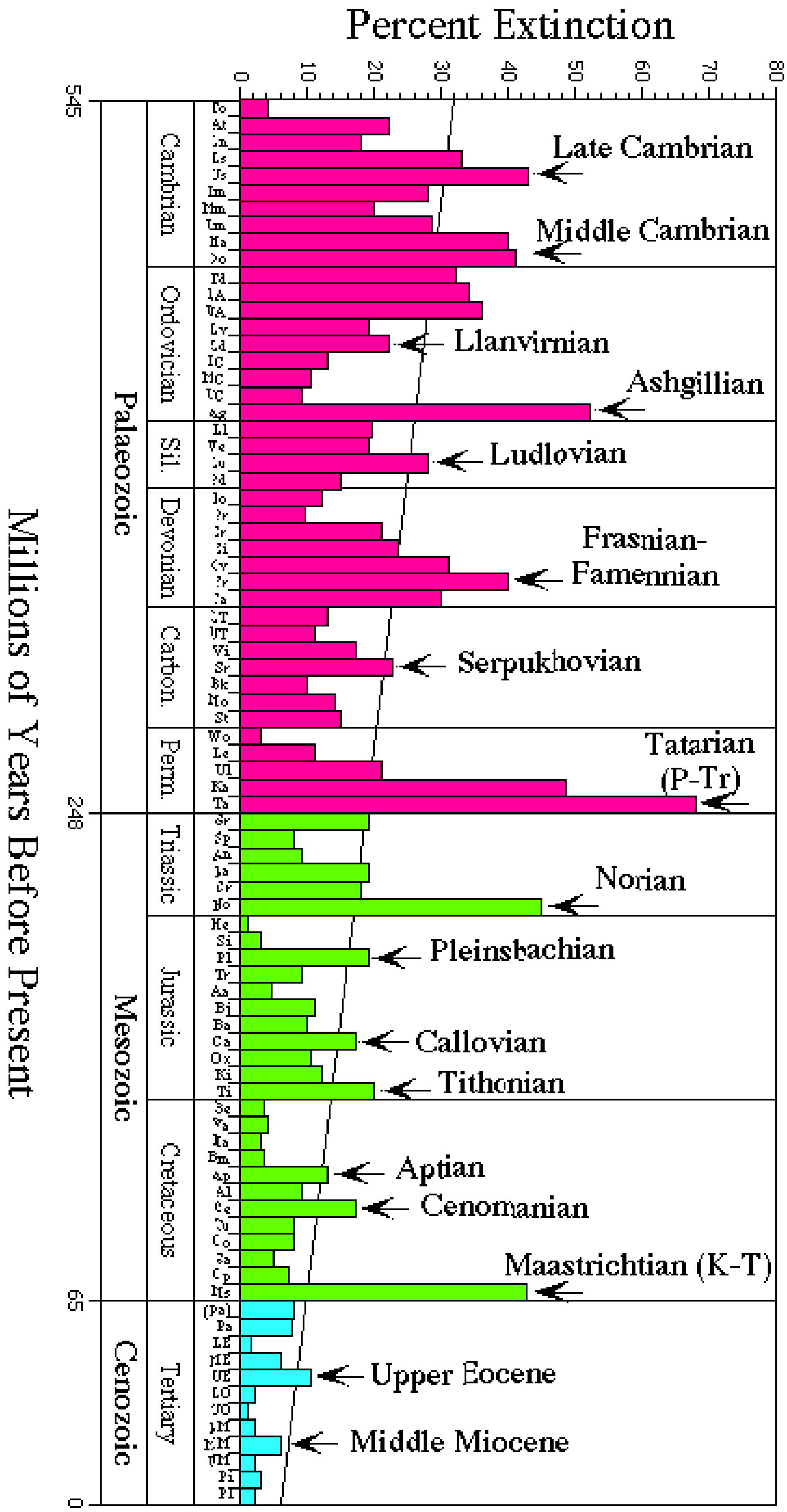

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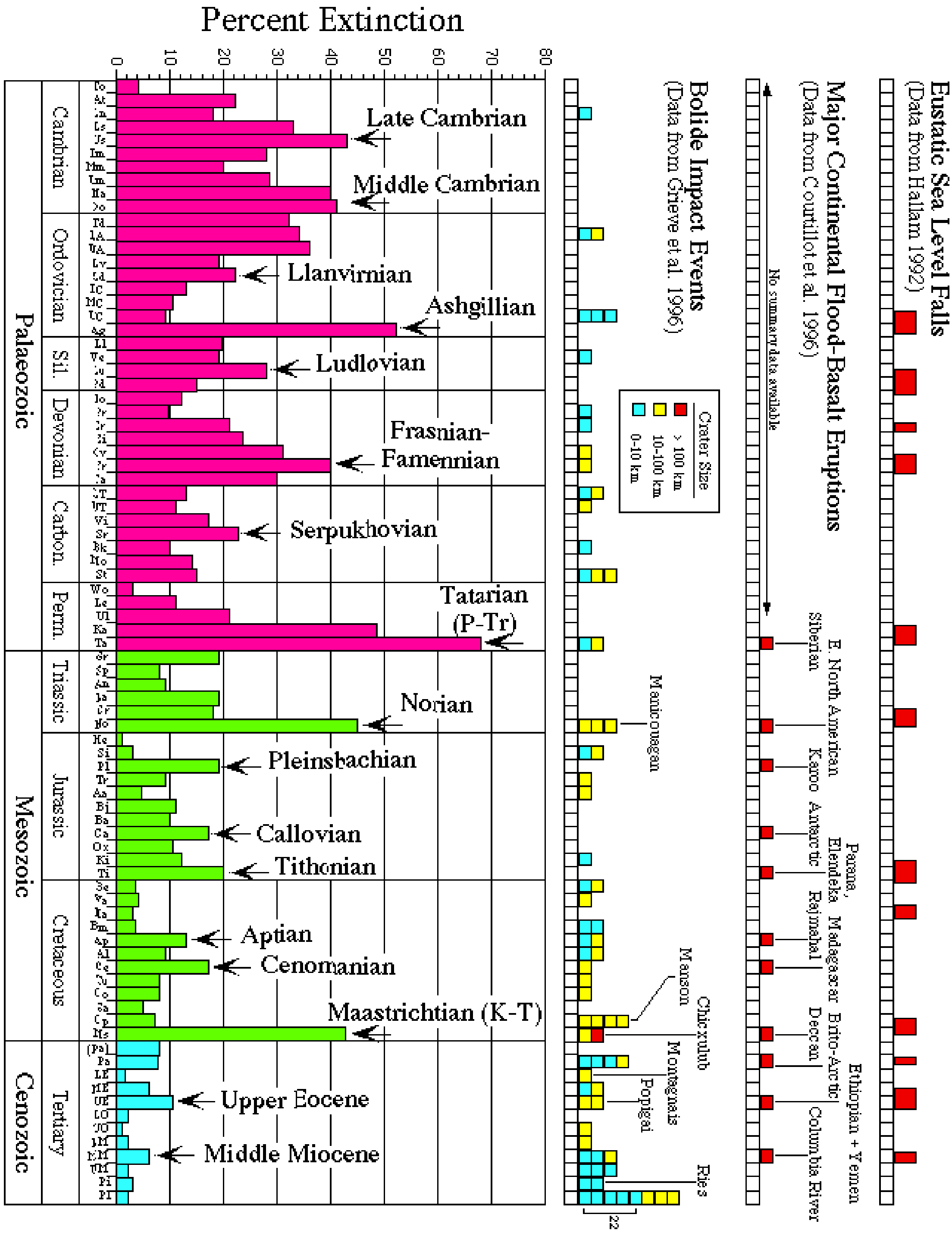

Figure 4. Figure 2. The record of extinctions (bottom), compared with - from top - major sea-level changes, giant eruptions of basalt, and impact craters.