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Geology 4 Evolutionary Palaeontology course.

Essay: *Critically assess the evidence which might suggest a causal link between biotic events and extraterrestrial activity at the Cretaceous/Tertiary boundary.*

Introduction.

The past twenty years have seen the slowly increasing acceptance amongst the general public of an idea to the point where it is now an old-hat 'fact': a meteorite impact wiped out the dinosaurs. There this essay could end but for the merest scratching of the surface on this subject. This is all that is necessary to open up one of the most lively cans of worms pertaining to scientific thought at the present time. Debate still rages on all fronts of geology, from the most philosophical meditations concerning the viability of uniformitarianist principals (Marvin, 1990) to fundamental practical considerations such as the limitations of palaeontological temporal resolution. Dig a little bit and the cut and dry meteorite-as-dinosaur-nemesis 'fact' simply crumbles into unconnected ideas. This is not to negate the whole argument, far from it, because many scientific workers are concerned with the valid question belying this unconstrained lay-fact: whether a causal mechanism links extraterrestrial activity and biotic events at the Cretaceous-Tertiary (K/T) boundary.

The important fact underpinning the resolution of this matter is that between the late Cretaceous and the early Tertiary, very large numbers of species became extinct - one of five mass extinction events in the geological record. Estimates vary, but somewhere in the region of 90% of several major marine invertebrate faunal groups, and 50% of terrestrial flora and fauna did not emerge from this period (Ward, 1990; Johnson & Hickey, 1990; Nichols & Fleming, 1990; Archibald & Bryant, 1990; Brothers, 1996). The mass extinction aspect is not in doubt, but the cause(s) and timing of the event is where disparity arises.

Continuous study within this area especially from the 1980's onwards has seen workers divide into a triptych of opinions:

1) Those who support a catastrophic view of events at the boundary. They believe that the evidence shows that extinctions occurred almost instantaneously directly associated with bolide-related events as reflected by the iridium anomaly and high-pressure mineral assemblage. These workers may also advocate a ~30 million year cyclicity of extinctions since the late Permian (Flessa, 1990).

2) Those who support a gradualist view of events. These views are based on the notion that extinctions may well show an increase above background levels well before the K/T boundary and continue well after it. This is reflected in fossil and isotope data indicative of progressive climate change as the boundary is approached. They further hold that the catastrophists evidence for bolide impact can be explained by other terrestrial means such as volcanism, which in turn can explain the observed severe but gradual environmental changes. Selectivity of extinctions is also held to refute catastrophic bombardment, which would have proved far more lethal through global winter, acid rain, tsunamis and fires. Finally other extinctions correlate with low sea level and climate change, and the data for a ~30 million year periodicity appear laundered (Flessa, 1990).

3) The third view is that the evidence suggests that extinctions occurred as a series of discrete steps, neither continuous nor concentrated across the boundary. This is supported by apparent sequential demises such as planktonic foraminifera, followed by marine molluscs followed by conodonts, or tropical specialist species pre-dating geographically widespread generalists. This third opinion is explained as being caused by a shower of comets in tune with a ~30 million year cycle superimposed on a background of general species decline (Flessa, 1990).

These three definitions represent the 3 extremes of current views, many workers opinions actually lie somewhere between. It is now useful to examine the evidence and how it pertains to the argument.

High Pressure Metamorphism.

As mentioned above in the catastrophists and gradualist scenarios, high-pressure metamorphic effects are believed to be an important factor in establishing a causal link. This so called shock metamorphism is a result of rocks being subjected to shock pressures above their Huguenot elastic limit. Some of these effects can be produced during endogenous processes, but a few are uniquely and characteristically the result of extreme shock pressures associated with impact cratering (Sharpton & grieve, 1990). Three types of effect seen in quartz grains are the most common indicators used: microscopic planar deformation features which are readily distinguishable in quartz (due to its abundance and chemical resistance), diaplectic glass associated with these features and/or high pressure polymorphs (usually stishovite or coesite) (Sharpton & Grieve, 1990).

Some authors still hold that explosive volcanism could account for shock metamorphic effects, and some have gone even further by saying that structures widely interpreted as craters may have actually been volcanic cryptoexplosions. These claims are fairly definitely refutable though. One line of evidence is that shock metamorphic effects are associated with some explosive volcanism, but with distinctly different petrological characteristics, a view supported by cathodoluminescence studies of grains (Owen *et al*, 1990). Indeed some authors reckon the origin of the quartz is crucial to models of exogenous versus endogenous causation, and further find that the pressures generated in even the most explosive volcanoes are still orders of magnitude too low for the creation of the shocked features discussed above (de Silva *et al*, 1990). Also important, Huffmann *et al* (1990) concluded that the atmosphere did not have a sufficient mechanism for transportation of observed shocked grains as far as the Western Interior Basin in the United States, requiring a more explosive event. Another line of evidence comes from studies of the morphological pattern seen in all craters in the Solar System. The pattern is one of a shallow rootless structure, central uplift region, ring-shaped trough and raised rim. Surrounding the crater is a downward attenuation of shock pressures and attendant deformation, and lithologically characteristic breccias and surface-rock bearing impact melts containing evidence of superheating (Sharpton & Grieve, 1990).

Geochemical Anomalies.

As discovered by Alvarez *et al* (1980), an iridium rich anomaly exists at the K/T boundary, at the exact same stratigraphic level throughout the globe. As iridium is a highly compatible element, the only sources for it are either the deep mantle or extraterrestrial in-fall. The fact that the only large scale volcanic activity at this time, the Deccan Traps in India, shows low amounts of iridium in its basalts (Finnegan *et al*, 1990) suggests an extraterrestrial source. Further, the chemistry and morphology of platinum grains, spinels, spherules and nickel-rich grains found at Zumaya, Spain in the K/T boundary sediments suggest that they are impact derived (Doehne & Margolis, 1990). Work carried out by Davenport *et al* (1990) further suggests a causal link with the extinctions. They assumed a 10-Km diameter bolide with a chondritic composition and calculated that this would be expected to vaporise completely and distribute ejecta globally. The falling material would have a nickel concentration of between 133 and 1330 parts per million (ppm). Experiments they carried out on the effects of high nickel concentration on particularly hardy radish seeds showed that a level of >40 ppm is sufficient to induce inhibition of chlorophyll production (chlorosis), suggesting a viable near and long term kill mechanism.

Work on carbon isotope anomalies in calcareous plankton skeletons from the K/T boundary showed a zero anomaly for ^{13}C compared with a normally positive value. This suggests a greatly reduced biomass production, and may even reflect surface oceanic waters dominated by respirative processes over normal photosynthetic controls (Hsü & McKenzie, 1990).

At Woodside Creek, New Zealand, work carried out on the K/T boundary revealed a 15-fold increase in kerogen carbon and a 20-fold increase in nitrogen, reflecting a possible sweep-out of plankton and contribution of nitric acid not expected from volcanism (Gilmour *et al*, 1990).

Coincident with the global iridium anomaly and other properties is a layer of charcoal and soot, which may well have been the result of a global fire. The presence of the resinous wood fire hydrocarbon retene and the characteristic isotopic composition of the carbon suggest that the fuel was biomass. Further, the amount of carbon at the boundary requires that much of the Cretaceous biomass burned down (Wolbach *et al*, 1990).

In some cases, models which set out to postulate volcanism as the cause of extinctions ended up falling short of their expectations. A model to evaluate the effects of greenhouse warming from the associated degassing of CO_2, SO_2, and HCl from the Deccan Traps volcanism, concluded that the resultant global temperature increase would have only been around 2°C based on modelling of ocean chemistry and chemical weathering of terrestrial rocks. This value is too low for the observed extinctions, being actually lower than warm periods which have occurred in the Holocene without associated extinctions (Caldeira & Rampino, 1990).

Much of the evidence cited here is taken from an in-depth study of all facets of research into the K/T boundary produced in 1990. Some authors were concluding, based on studies of size distribution of shocked grains, that a locus of origin for an impact crater would be on or very near to the North American continent (Bohor, 1990), and possibly on a continental margin (Sharpton *et al*, 1990). A great breakthrough came in 1992, when a large crater structure was found off the coast of the Yucatan Peninsula in Mexico. This structure called the Chicxulub

Crater was discovered by geophysical techniques and is 200-300 Km wide and 1100 meters below the surface, within upper Cretaceous rocks. Argon and uranium-lead dating revealed that the melt rocks and breccias are the same age as spherules from the K/T boundary found globally (Sharpton, 1995).

Palaeontological Considerations.

The discovery of the Chicxulub Crater together with the other evidence examined above has seen the decreasing prominence of gradualist scenarios in explaining events at this time. Instead attention has become somewhat focussed on the question of the level of severity the impact had. Examination of evidence afforded by the biological record shows a less focussed spectrum of possible conclusions associated with the problem. Unfortunately this in itself seems to be a problem associated with inherent difficulty in achieving necessary resolution in palaeontological techniques of dating.

Evidence from megafloral and palynofloral biostratigraphy in the Western Interior Basin of America shows that there was a high level of turnover in the latest Cretaceous, which culminated at the K/T boundary. Nearly all Late Cretaceous dicotyledonous angiosperms and lesser amounts of conifers and other gymnosperms perished (Nichols & Fleming, 1990), so that only around 20% of flora persisted beyond the time (Johnson & Hickey, 1990). This turnover is marked by discreet stepwise extinctions, which also shows the appearance of northward migration of thermophilous species probably in response to climate warming. Studies of non-marine vertebrate extinctions from the fossil record of Montana volunteered alternative explanations. Sheehan & Fastovsky (1992) compared the pattern of high land-based and low river-dwelling extinctions. Understanding that land dwellers rely on primary productivity as food source, where river-dwellers tend to be more sustained by detritus, they concluded that the pattern showed short-term perturbation consistent with the catastrophic impact model. In contrast, Archibald & Bryant (1990) reckon that low survival percentages are caused by palaeobiogeographical artefacts, rarity of species and differing evolutionary rates. They saw evidence of differential extinction rates and conclude that these are inconsistent with a catastrophic scenario, reflecting marine regression instead. Studies of extinctions in the marine records of Europe, North Africa and the U.S. also revealed alternative interpretations. Working on the same locality in Tunisia, one study came up with a catastrophic explanation for the abrupt discontinuance of up to 97% of planktic foraminifera (forams) exactly at the boundary (Ward, 1990). Keller & Barrera (1990), on the other hand reckoned that the extinctions began about 100 000 years before the boundary and also continued after it. They documented progressive extinctions of large ornate tropical species preceding cosmopolitan generalists.

Several factors must be considered in attempting to resolve these disparities: the usefulness of microfossils, the reality of an extinction horizon, the continuity of the stratigraphy, and the relevance of precursor extinctions.

The microfossil record is used because of considerations of abundance, sampling interval and sampling intensity; i.e. they are small, common and easily collected so that a detailed stratigraphy can be constructed. However, problems with correlating their depositional environment with those of near-shore organisms and the often pronounced effects of bioturbation (a particular problem with coccolithophorids) mean this accuracy can be questioned (Ward, 1990).

Figure 1 shows a representation of how a hiatus can make a gradual pattern of extinctions appear sudden and, conversely, figure 2 shows how a sudden extinction may appear gradual

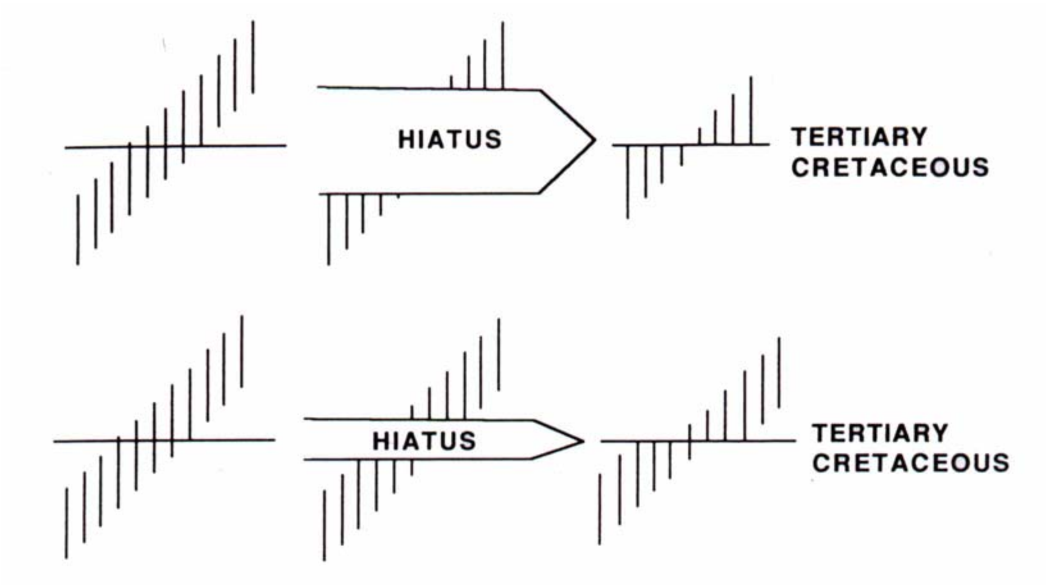

Figure 1. Diagram illustrating how a hiatus (non-depositional or erosion) can change the apparent pattern of species extinction. On the left the ranges of taxa (vertical lines) cross a boundary (horizontal line) without any two extinctions coinciding. If a hiatus occurs at the boundary, however, the preserved pattern of extinctions can look as if several extinctions are simultaneous. In this way a hiatus can make a gradual extinction look sudden. (Ward, 1990)

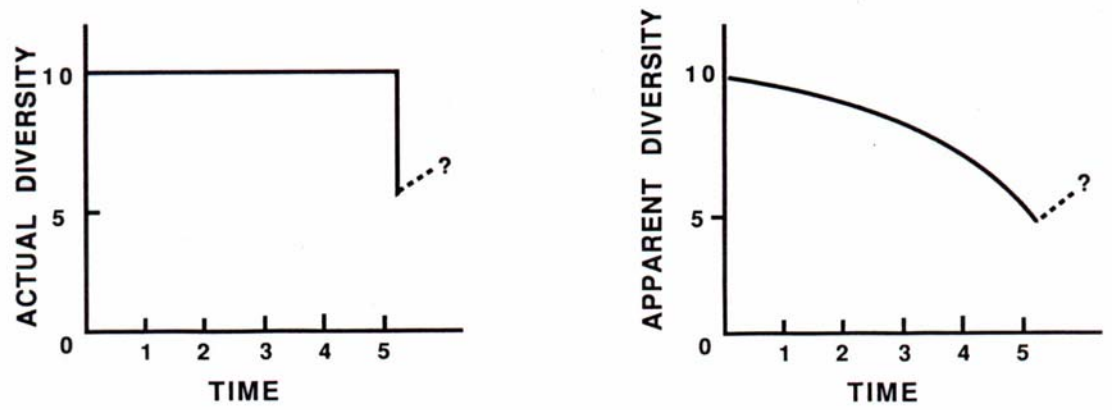

Figure 2. Diagram illustrating how a sudden extinction involving the demise of many taxa simultaneously can appear to be gradual due to sampling problems. In the left hand figure, the actual diversity of taxa is constant through time and then undergoes an instantaneous reduction. The right hand diagram shows how the figure may appear if sampling is incomplete or if the taxa are not commonly preserved (Ward, 1990).

due to sampling deficiencies. These issues are obviously very important as they show that the fossil record may not reflect the actual event. This was demonstrated on real data from Spain which were made to reflect both gradual and sudden extinctions by adding hiatuses of different lengths and positions (Ward, 1990).

Similarly relevant is the question of how complete a section is. Obviously if physical indications of unconformity are present then part of a section is missing, but in many deeper marine sediments, such as marls, shales and limestones, there may well be no such indications that an unconformity exists, thereby creating an incorrect stratigraphy. Also many extinction models deal on timescales that are too short to be recorded in sediments. As suggested earlier, there seems to be a lot of evidence for extinctions occurring before the K/T boundary. Some workers propose stepwise changes with large scale changes occurring 2-3 million years prior, affecting plankton, molluscs, ammonites and benthic molluscs. However it is questionable how well correlated the sedimentary sequences are, and whether some of the extinctions are not just simply the result of the late Maastrichtian marine regression (Ward, 1990).

Conclusion.

Hopefully I have shown by a brief exploration of this live subject that there are many ideas and issues left to be resolved. It is fairly definite that a large extraterrestrial body struck the Earth at the end of the Cretaceous and it is definite that large-scale extinctions, particularly in the marine realm, occurred around this time. I think the evidence shows that the two events are indeed linked but that the causal link falls short of being absolute. Instead the impact was more likely the final stress on an already stressed environment, already subjected to the effects of flood basalt volcanism, temperature change, sea-level change and possible changes in sea water chemistry.

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