CURRENT ISSUES IN EVOLUTION: MASS EXTINCTIONS

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I. INTRODUCTION

Abrupt appearances and disappearances are characteristic of the fossil record. As one moves through the stratigraphic column, one finds different species and higher taxa present at different levels. The well-known missing-link problem deals with abrupt appearances of species. Abrupt disappearance is also a significant feature of the fossil record. The last appearance of a species in the fossil record is interpreted to indicate the extinction of that species. Simultaneous extinctions of many species characterize most boundaries between geologic periods. The Cretaceous-Tertiary (KT) mass extinction has generated the most interest and the most controversy.

A great deal of effort is presently being given to study the possible role of **catastrophes** in mass extinctions. At one time, the rate of sedimentation was assumed to be more or less constant throughout geologic time. Abrupt appearances and disappearances were explained as the result of interruptions in deposition. More recently it has been recognized that uniform sedimentation rates cannot explain the features of the fossil record, and the role of catastrophes in earth history is increasingly recognized. A catastrophe can rapidly deposit significant amounts of sediment in a short time, and it is more likely that the record of such events will be preserved over time than for ordinary, gradual processes. Therefore, the stratigraphic column may be largely a record of unusual events. A large amount of research is presently being conducted in an effort to identify the nature and causes of catastrophes in the fossil record.

II. ISSUES IN MASS EXTINCTIONS

Several lines of evidence must be considered in order to reach an understanding of the present discussion over the KT boundary extinction. These include paleontology, geochemistry, biology and even astronomy.

A. Cretaceous Faunal Extinctions

The first issue to be addressed is to confirm that a **mass extinction** truly did occur. About 60-76% of all marine species (Crutzen 1987), including 90% of coccolithophorid genera and planktonic foraminifera (McLean 1985) died out at the end of the Cretaceous, in addition to the well-known extinctions of the ammonites and dinosaurs. Thus there is considerable extinction across the KT boundary. However, there have been questions as to whether this level of extinction is real, and whether it qualifies as an unusual event in the geologic record.

One challenge to the conclusion that a mass extinction occurred at the KT boundary is based on **taxonomic** considerations (Patterson and Smith 1987, 1989). Echinoderms and marine fishes make up about 20% of the data used to substantiate the KT mass extinction. In these two groups, only 25% of the family level extinctions are considered to be real, the other 75% due to faulty taxonomy, mistaken dating, the inclusion of rare species, and other factors. At the generic level, less than 12% of the extinctions were valid. Patterson and Smith (1989) suggest that periodic peaks in diversity and apparent extinction may have a purely **taphonomic** basis.

A second challenge to the reality of mass extinctions is that mass extinctions are **not statistically distinguishable** from background extinction rates (Benton 1985, McKinney 1987). Instead, apparent mass extinctions are the result of low origination rates combined with extinction rates only slightly higher than background rates. Despite the challenge, dramatic faunal changes do occur across some stratigraphic boundaries, and scientific investigation seems justified.

An important feature of the KT boundary extinction is its **selectivity** (Jablonski 1986, McKinney 1987, Officer et al. 1987). Marine families suffered the highest rates of extinction, with less effect on terrestrial groups. Freshwater communities were almost unaffected (Crutzen 1987, Hutchinson and Archibald 1986), as were insects (Whalley 1987). Among plants, deciduous trees survived better than evergreen taxa (Wolfe and Upchurch 1987), and a sudden change from angiosperm pollen to fern pollen has been recorded at the boundary (Saito, Yamanoi and Kaiho 1986).

B. The Impact Hypothesis

Geologic features of the KT boundary present interesting evidence relating to possible causes of the mass extinction. These features include the presence of a clay layer at several widely spaced localities (Alvarez et al. 1980). The widespread existence of the boundary clay has been interpreted as evidence for a worldwide event at the boundary. Unusually high levels of iridium are associated with the clay (Alvarez et al. 1980). Iridium is found in higher concentrations in meteorites than in rocks of the earth's crust, and its presence in high concentrations has been interpreted to be the result of a collision between the earth and either an asteroid or a comet. Shocked quartz grains are also found at the boundary (Bohor et al. 1984), and high levels of carbon, mainly soot (Wolbach et al. 1988). The production of shocked quartz grains requires an event of considerable force, such as a nuclear explosion or meteoric impact. The soot is explained as possibly the result of a global fire triggered by heat from a meteoric or asteroidal impact. Together, these features have led to the development of the impact hypothesis as a cause of mass extinctions.

According to the impact hypothesis (Alvarez et al. 1980), an **extraterrestrial object** about 10 km in diameter struck the earth at the close of the Cretaceous. The resulting dust cloud obscured the sun for several months, causing prolonged darkness, cooling, and acid rain (Crutzen 1987, Diamond 1983). Many species could not cope with such alterations of the environment and became extinct. Species resistant to the environmental disturbance would be more likely to survive, explaining the selective nature of the extinctions. Few hypotheses in recent years have stimulated as much research and provoked as much controversy in science as has the impact hypothesis.

The impact of a 10-km diameter asteroid would be a catastrophe almost beyond our ability to envision. The energy of the impact would have been about 10^{23}-10^{24} J (Crutzen 1987) (1 J= 10^7 ergs). The **results** of such an impact (Clube and Napier 1982) might include a blast wave that would kill off any life over half the world, with an air temperature of 500°C and windspeed of about 2500 km/hr. Nitric oxides produced in the fireball would destroy the earth's ozone level, exposing survivors to life-threatening UV light. Global earthquakes with ground waves 10 m high would result. If the comet hit the ocean, it could generate waves as high as 500-1000 m at a distance of 2000 km from the impact target. The earth's core would be disrupted, possibly producing magnetic reversals. Plate movement would be accelerated, opening cracks 10-100 km wide in the earth's crust, and causing rapid mountain-building and worldwide vulcanism. It is difficult to understand how any significant number of species could survive such an event. It is amazing that the geological community, so steeped in the uniformitarian tradition, could become so excited over such a far-out hypothesis. Yet there is more.

C. Impact Cycles

Analysis of extinction rates suggests that mass extinctions may have occurred repeatedly in the stratigraphic column, being fairly typical of geological period boundaries. The greatest mass extinction occurred at the Permian-Triassic boundary (Erwin 1989). At least 95% of marine species became extinct at the end of the Permian, and the nature of the fauna changed from predominantly sessile epifaunal groups to more mobile types. Further analysis of the timing of mass extinctions has led to the proposal that such extinctions are periodic (Raup and Sepkoski 1984, 1988; Fox 1987), occurring on average about every 25-26 MA (million years). A mechanism for periodicity has been proposed (Clube and Napier 1982, Napier and Clube 1979), relating periodic comet showers to the capture of material by the solar system as it crosses roughly equally spaced regions of the Milky Way galaxy where matter is denser.

D. Vulcanism Hypothesis

Challenges have been presented against both the periodicity of the mass extinctions and their causation by extraterrestrial impacts. The **periodicity** of mass extinctions has been variously described as statistically unjustified (Benton 1985, McKinney 1987) or a statistical artefact of arbitrary decisions concerning the dating of stratigraphical boundaries, the average time for a "stage" and the definition of mass extinction (Hoffman 1985, Benton 1985). Another area of attack is the accuracy of the extinction data when a check of the data revealed that only about 25% of the data for families of marine fish and echinoderms is valid (Patterson and Smith 1987, 1989). Another argument has been that most mass extinction are not associated with evidence for extraterrestrial impacts (Erwin 1989, Kyte and Wasson 1986, Quinn and Signor 1989), although they have been implicated in some other mass extinctions (Jansa and Pe-Piper 1987; Kyte, Zhou and Wasson 1988; Olsen, Shubin and Anders 1987).

The **impact hypothesis** of mass extinction has also been attacked. One of the chief points of attack has been the purported stepwise character of the extinctions. If mass extinctions were caused by an extraterrestrial impact they should occur simultaneously in the fossil record. However, the extinctions occurred gradually for such groups as ammonites and rudist bivalves (Donovan 1987), and dinosaurs (Rigby et al. 1987, Sloan et al. 1986), although the Paleocene dinosaurs may be reworked (Eaton, Kirkland and Doi 1989, Fastovsky 1987). In any case, dinosaurs might be cold resistant, since they have been found in Australia during the early Cretaceous when Australia is believed to have been within the Antarctic Circle (80°S) (Rich et al. 1988). The stepwise nature of the mass extinction may be explainable as the result of a comet "shower" rather than a single impact (Hut et al. 1987).

Additional challenges include the lack of evidence of extraterrestrial material at some KT boundary sections (Rampino and Reynolds 1983, Officer et al. 1987) and its presence in places other than the boundary (Officer and Drake 1983, Officer et al. 1987). McLean (1985) sees no evidence for global darkening, cooling or catastrophe. Van Valen (1984) points to the absence of turbidites at the boundary as ruling out an oceanic impact, and the absence of a suitable crater as ruling out a terrestrial impact.
An alternative terrestrial hypothesis of mass extinction is that the paleontological and geological phenomena associated with mass extinctions can be explained as the result of terrestrial processes such as **vulcanism** and tectonism. Iridium concentrations are not periodic (Kyte and Wasson 1986), and have been found in dust from Krakotoa (Officer and Drake 1983) and the Hawaiian Kilauea volcano (Zoller, Parrington and Kotra 1983), along with other elements more typical of the earth's mantle than of extraterrestrial material (Gilmore et al. 1984; Zoller, Parrington and Kotra 1983). The boundary clay in some sections is not lithologically unusual (Rampino and Reynolds 1983). Shocked quartz grains can be accounted for by volcanism better than by impact, because the particles would have been transported out of the atmosphere by an impact and should have lost their shock features on reentry (Officer et al. 1987). Marine KT boundaries do not appear to be synchronous (Officer and Drake 1983), and have not been successfully correlated with terrestrial KT boundaries (McLean 1985).

Correlated periodicities of mass extinctions, and continental flood basalt volcanism have been noted by Rampino and Stothers (1988), who suggest that the volcanism may be caused by periodic showers of comets. Both mass extinctions and flood basalt volcanism have been linked to increased frequencies of geomagnetic reversals (Loper, McCartney and Buzyna 1988), with the suggestion that mantle activity may be causally related to all three phenomena. Unusual tectonism, together with the Deccan Traps flood basalts, sea-floor spreading and sea level changes occurred at the KT boundary, and there is no need to invoke an extraterrestrial impact (Moses 1989). The Deccan Traps would have released about 5 x 1017 moles of carbon dioxide, which is about 9 times the total of the modem atmosphere (McLean 1985). The ocean seems to have been dead at the time of the KT boundary, possibly due to the activity of the Deccan Traps.

Most of these points, together with a few others, are reviewed by Van Valen (1984), who tends to favor the volcanic hypothesis. In evaluating the discussion, he states: "I conclude that selective use of the available evidence can prove either gradualism or catastrophism, and that neither kind of evidence seriously affects the other."

III. SIGNIFICANCE TO CREATIONISM

It is clear that many species are now extinct. Creationists would attribute most extinctions to be the result of a worldwide flood that produced most of the sediments in the geologic column. The stepwise character of extinctions can be interpreted as the result of different source areas and differential sorting by the waters of the flood. The time involved for all the various mass extinctions would be reduced from hundreds of millions of years down to one or a few years. This scenario requires major catastrophic action, but few creationists have considered events as catastrophic as those currently being discussed in the evolutionary community. The debate over catastrophism will continue to generate more research into the nature of the processes responsible for deposition of the geologic column. Although creationists cannot expect evolutionists to validate the flood model, it is likely that much research will be done to investigate the role of catastrophic activity in earth history. This should be helpful in the development of a flood model. Whether such a model will include one or more extraterrestrial impacts cannot be determined at this time, but they do offer at least a theoretical possibility for the source of energy required to break up the crust of the earth and release the fountains of the deep.

IV. SUMMARY

Recognition of mass extinctions, linked stratigraphically with unusual geologic activity and geochemical features, has resulted in two competing hypotheses to explain mass extinctions. The impact hypothesis states that the earth has collided with one or more asteroids, each collision raising a dust cloud which induced such environmental changes that an abrupt global mass extinction occurred. The volcanic hypothesis states that the mass extinctions have been caused by episodes of flood basalt volcanism, producing global environmental changes. Under these conditions mass extinctions would have occurred over longer periods of time, although still relatively abrupt on a geological timescale. A strong debate among advocates of the opposing viewpoints has ensued, with neither side able to convincingly disprove the other hypothesis. This is an interesting example of scientific debate which helps to demonstrate the nature of scientific inquiry.

LITERATURE CITED

Alvarez, L.W., W. Alvarez, F. Asaro, and H.V. Michel. 1980. Extraterrestrial cause for the Cretaceous-Tertiary extinction. Science 208:1095-1108.

Benton, M.J. 1985. Mass extinction among non-marine tetrapods. Nature 316:811-814.

Bohor, B.F., et al. 1984. Mineralogic evidence for an impact event at the Cretaceous-Tertiary boundary. Science 224:867-869.

Clube, V. and B. Napier. 1982. Close encounters with a million comets. New Scientist 95:148-151.

Crutzen, P.J. 1987. Acid rain at the KT boundary. Nature 330:108-109. (News and Views)

Diamond, J.M. 1983. Extinctions, catastrophic and gradual. Nature 304:396-397. (News and Views)

Donovan, S.K. 1987. How sudden is sudden? Nature 328:109. (News and Views)

Eaton, J.G., J.I. Kirkland and K. Doi. 1989. Evidence of reworked Cretaceous fossils and their bearing on the existence of Tertiary dinosaurs. Palaios 4:281-286.

Erwin, D.H. 1989. The end-Permian mass extinction: what really happened and did it matter? Trends in Ecology and Evolution 4:225-229.

Fastovsky, D.E. 1987. Paleoenvironments of vertebrate-bearing strata during the Cretaceous-Paleogene transition, eastern Montana and western North Dakota. Palaios 2:282-295.

Fox, W.T. 1987. Harmonic analysis of periodic extinctions. Paleobiology 13:257-271.

Gilmore, J.S. et al. 1984. Trace element patterns at a non-marine Cretaceous-Tertiary boundary. Nature 307:224-228.

Hoffman, A. 1985. Patterns of family extinction depend on definition and geological timescale. Nature 315:659-662.

Hut, P. et al. 1987. Comet showers as a cause of mass extinctions. Nature 329:118-126.

Hutchinson, J.H. and J.D. Archibald. 1986. Diversity of turtles across the Cretaceous/Tertiary boundary in northeastern Montana. Palaeo. Palaeo. Palaeo. 55:1-22.

Jablonski, D. 1986. Background and mass extinctions: the alternation of macroevolutionary regimes. Science 231:129-133.

Jansa, L.F. and G. Pe-Piper. 1987. Identification of an underwater extraterrestrial impact crater. Nature 327:612-614.

Kyte, F.T. and J.T. Wasson. 1986. Accretion rate of extraterrestrial matter: iridium deposited 33 to 67 million years ago. Science 232:1225-1229.

Kyte, F.T., L. Zhou, and J.T. Wasson. 1988. New evidence on the size and possible effects of a Late Pliocene oceanic asteroid impact. Science 241:63-65.

Loper, D.E., K. McCartney and G. Buzyna. 1988. A model of correlated espisodicity in magnetic-field reversals, climate, and mass extinctions. J. Geology 96:1-15.

McKinney, M.L. 1987. Taxonomic selectivity and continuous variation in mass and background extinctions of marine taxa. Nature 325:143-145.

McLean, D.M. 1985. Mantle degassing unification of the trans- K-T geobiological record. (M.K. Hecht, B. Wallace, and G.T. Prance, eds.) Evol. Biol. 19:287-313.

Moses, C.O. 1989. A geochemical perspective on the causes and periodicity of mass extinctions. Ecology 70:812-823.

Napier, W.M. and S.V.M. Clube. 1979. A theory of terrestrial catastrophism. Nature 282:455-459.

Officer, C.B. and C.L. Drake. 1983. The Cretaceous-Tertiary transition. Science 219:1383-1390.

Officer, C.B., A. Hallam, C.L. Drake, and J.D. Devine. 1987. Late Cretaceous and paroxysmal Cretaceous/Tertiary extinctions. Nature 326:143-149.

Olsen, P.E., N.H. Shubin, and M.H. Anders. 1987. New Early Jurassic tetrapod assemblages constrain Triassic-Jurassic tetrapod extinction event. Science 237:1025-1029.

Patterson, C. and A.B. Smith. 1987. Is the periodicity of extinctions a taxonomic artefact? Nature 330:248-252.

Patterson, C. and A.B. Smith. 1989. Periodicity in extinction: the role of systematics. Ecology 70:802-811.

Quinn, J.F. and P.W. Signor. 1989. Death stars, ecology, and mass extinction. Ecology 70:824-834.

Rampino, M.R. and R.C. Reynolds. 1983. Clay minerology of the Cretaceous-Tertiary boundary clay. Science 219:495-498.

Rampino, M.R. and R.B. Stothers. 1988. Flood basalt volcanism during the past 250 million years. Science 241:663-668.

Raup, D.M. and J.J. Sepkoski. 1984. Periodicity of extinctions in the geologic past. Proc. Nat. Acad. Sci. (USA) 81:801-805.

Raup, D.M. and J.J. Sepkoski. 1988. Periodic extinction of families and genera. Science 231:833-836.

Rich, P.V. et al. 1988. Evidence for low temperatures and biologic diversity in Cretaceous high latitudes of Australia. Science 242:1403-1406.

Rigby, R.K. et al. 1987. Dinosaurs from the Paleocene part of the Hell Creek Formation, McCone County, Montana. Palaios 2:296-302.

Saito, T., T. Yamanoi and K. Kaiho. 1986. End-Cretaceous devastation of terrestrial flora in the boreal Far East. Nature 323:253-255.

Sloan, R.E., J.K. Rigby, L.M. Van Valen, D. Gabriel. 1986. Gradual dinosaur extinction and simultaneous ungulate radiation in the Hell Creek Formation. Science 232:629-633.

Van Valen, L.M. 1984. Catastrophes, expectations, and the evidence. Paleobiology 10:121-137.

Whalley, P. 1987. Insects and Cretaceous mass extinction. (letter) Science 327:562.

Wolbach, W. et al. 1988. Global fire at the Cretaceous-Tertiary boundary. Nature 3334:665-669.

Wolfe, J.A. and G.R. Upchurch. 1987. Leaf assemblages across the Cretaceous-Tertiary boundary in the Raton Basin, New Mexico and Colorado. PNAS 84:5096-5100.

Zoller, W.H., J.R. Parrington, and J.M. Phelan Kotra. 1983. Iridium enrichment in airborne particles from Kilauea volcano: January 1983. Science 222:1181-1121.