GENERAL SCIENCE NOTES

A CATASTROPHE WITH AN IMPACT

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INTRODUCTION

As one moves up or down through the stratigraphic column, the types of fossil organisms often change abruptly. The boundary dividing Permian and Triassic sediments is an example. An estimated 96% of all fossil species found below this boundary are not found above it (Raup 1979, Sepkoski 1989). The sudden change from the presence of a particular type of fossil to its absence in overlying strata is called an extinction. Extinction of many species at approximately the same stratigraphic boundary is termed a mass extinction. The greatest mass extinction occurred at the boundary between the Permian and the Triassic, and is used to divide Paleozoic from Mesozoic sediments.

Another mass extinction occurred at the boundary between the Cretaceous and the Tertiary, dividing Mesozoic and Cenozoic sediments. Because this latter extinction includes the dinosaurs, it is of considerable interest both to scientists and the public. The cause for the extinction of the dinosaurs remains a puzzle. Dinosaur fossils are commonly found in Mesozoic sediments, but not in the overlying Tertiary sediments. A few reports of Tertiary dinosaurs have been claimed (e.g., Sloan et al. 1986, Rigby et al. 1987, Van Valen 1988), but these are rare and controversial. Although the dinosaurs are the most famous example, abrupt faunal change is a common feature of the stratigraphic column.

In 1980, a team of researchers reported (Alvarez et al. 1980) the finding of an unusually high concentration of iridium in a clay band at the boundary between the Cretaceous and the Tertiary. This iridium anomaly, as it was called, has been found in several localities in Europe, North America and New Zealand. Iridium is rare in the crust of the earth, but is more common in meteorites and in the mantle of the earth. The Alvarez team suggested that the source for the iridium was a very large meteorite that had collided with the earth. Such an impact might also have upset the ecological balance of the earth, causing many species to become extinct. This might explain the disappearance of the dinosaurs, along with many other groups that are not found in sediments above the Cretaceous.

The impact hypothesis has generated a great amount of interest among scientists. Although the idea of an extraterrestrial impact had been suggested earlier (e.g., McLaren 1970), the iridium anomaly was the first evidence that made such an explanation seem worth investigating. Not only geologists and paleontologists have become interested, but also astronomers, oceanographers, and biologists from many disciplines. The number of scientific papers on this topic has already probably exceeded that for any other geological hypothesis of this century except for that of plate tectonics (Glen 1989).

QUESTIONS CONCERNING THE END-CRETACEOUS EXTINCTION

Before considering the impact hypothesis in detail, the reality of a mass extinction should be established. About 60-76% of all Cretaceous marine species (Crutzen 1987), including 90% of coccolithophorid genera and planktonic foraminifera (McLean 1985) are not found in sediments above the Cretaceous. Other groups found in the Cretaceous but not in overlying strata include the dinosaurs, ichthyosaurs, pterosaurs, ammonites, and several groups of invertebrates. Thus there is considerable extinction across the Cretaceous-Tertiary (KT) boundary.

Some have questioned whether so-called mass extinctions are truly different from the extinction rates characteristic of other portions of the geologic column (Benson 1985, McKinney 1987). It is claimed that apparent mass extinctions may be the result of low origination rates combined with extinction rates only slightly higher than background rates. Despite this challenge, dramatic faunal changes do occur across some stratigraphic boundaries, and scientific investigation seems justified.

Any hypothesis proposed to explain the KT boundary mass extinction must also explain the selectivity of the extinctions. Marine families suffered the highest rates of extinction, with less effect on terrestrial groups (Jablonski 1986, McKinney 1987, Officer et al. 1987). Freshwater communities were almost unaffected (Crutzen 1987, Hutchinson & Archibald 1986), as were insects (Whalley 1987). Among plants, deciduous trees survived better than evergreen taxa (Wolfe & Upchurch 1987), and a sudden change from angiosperm pollen to fern pollen has been recorded at the boundary in Japan (Saito, Yamanoi & Kaiho 1986) and in Canada (Nichols et al. 1986).

The extinctions may also have been influenced by geography. A major floral turnover is reported from Siberia and western North America, but not from the southern hemisphere (Collinson 1986). Similarly, marsupials were reportedly more affected in North American than in South America (Case & Woodburne 1986, but see Van Valen 1988). Having considered some of the features of the extinctions of the KT boundary, we can now examine the impact hypothesis itself.

THE IMPACT HYPOTHESIS

Geologic features of the KT boundary present interesting evidence relating to possible causes of the mass extinction. The widespread existence of the boundary clay has been interpreted as evidence for a worldwide event at the boundary. In addition to the high iridium levels, shocked quartz grains are also found at the boundary (Bohor et al. 1984), and high levels of carbon, mainly soot (Wolbach et al. 1988). Together, these features have led to the development of the impact hypothesis as a cause of mass extinctions. The production of shocked quartz grains requires an event of considerable force, such as a nuclear explosion or meteorite impact. The soot is explained as possibly the result of a global fire triggered by heat from an impact by a meteorite or asteroid. But how large would such an object have been, and what would be the results of such an impact? And is there any other evidence for an impact, such as an appropriate crater?

The size of the impact object can be extrapolated from the amount of iridium in the boundary clay compared to that in extraterrestrial material. Based on this extrapolation, the extraterrestrial object is hypothesized to have been about 10 km in diameter. Such an object would have a mass of about 5×10^{15} kg and a velocity of perhaps 2×10^{4} m/sec. The energy dissipated at the impact would have been about 10^{23}-10^{24} Joules (Crutzen 1987). This is roughly equivalent to one million times the amount of energy released by the 1964 Alaska earthquake.

The impact of a 10-km diameter asteroid would cause a catastrophe beyond our ability to envision. The results of such an impact (Clube and Napier 1982, Albritton 1989) might include a blast wave that would kill off any life over half the world, with an air temperature of 500° and windspeed of about 2500 km/hr. The heat of the impact might ignite widespread forest fires, accounting for the layer of soot found in New Zealand, Europe and North America (Melosh et al. 1990). Nitric oxides produced in the fireball would destroy the earth's ozone level, exposing survivors to life-threatening ultraviolet light. Global earthquakes with ground waves 10 m high would result. If the comet hit the ocean, it could generate waves 500-1000 m high 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 volcanism (Clube & Napier 1982). It is difficult to understand how any significant number of species could survive such an event.

The resulting dust cloud would obscure 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 would become extinct. Species resistant to the environmental disturbance would be more likely to survive, explaining the selective nature of the extinctions. In view of its spectacular nature, it is no wonder that the impact hypothesis has generated so much interest.

HAVE THERE BEEN MULTIPLE IMPACTS?

Analysis of extinction rates has been interpreted to suggest 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. Not only did most of the Paleozoic species become extinct across that boundary, but the fossils seem to represent different ecological conditions. Paleozoic marine fossils are said to be predominantly from sessile epifaunal groups, while more mobile types predominate in the Mesozoic sediments (Erwin 1989).

Further analysis of mass extinctions has led to the proposal that such extinctions are periodic (Raup & Sepkoski 1984, 1988; Fox 1987), occurring on average about every 25-26 Ma (million years). A mechanism for periodicity has been proposed (Clube & Napier 1982, Napier & 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.

Challenges have been presented to 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 (Benson 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. Only about 25% of the extinction data for families of marine fish and echinoderms is considered to be valid (Patterson & Smith 1987, 1989). At the genus level, less than 12% of the extinctions were judged valid. Patterson and Smith (1989) suggest that purported periodic peaks in diversity and apparent extinction may be related to the depositional history (taphonomy) of the fossils rather than to faunal changes. Another argument has been that most mass extinctions are not associated with evidence for extraterrestrial impacts (Erwin 1989, Kyte & Wasson 1986, Quinn & Signor 1989). Impacts have been plausibly linked to only a few mass extinctions other than the end-Cretaceous extinction (Jansa & Pe-Piper 1987; Kyte, Zhou & Wasson 1988; Olsen, Shubin & Anders 1987).

CRITICISMS OF THE IMPACT HYPOTHESIS

The impact hypothesis for the end-Cretaceous 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 allegedly occurred in steps 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 from Cretaceous sediments (Eaton, Kirkland & Doi 1989, Fastovsky 1987). In any case, dinosaurs might have been resistant to the cold weather supposedly produced by the impact, since they have been found in Australia during the early Cretaceous. According to plate tectonic reconstruction, Australia is believed to have been within the Antarctic Circle (80°) in the early Cretaceous (Rich et al. 1988). It may be possible to reconcile the stepwise nature of the mass extinction with the impact hypothesis by proposing a "shower" of comets rather than a single very large impact (Hut et al. 1987).

Additional challenges to the impact hypothesis for the end-Cretaceous extinction include claims that evidence of purported extraterrestrial material is lacking at some KT boundary sections (Rampino & Reynolds 1983, Officer et al. 1987), while it is sometimes found in places other than the boundary (Officer & 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 large enough to cause the end-Cretaceous extinctions.

VOLCANISM: AN ALTERNATIVE HYPOTHESIS

An alternative hypothesis of the cause of mass extinctions is that they were caused by terrestrial processes such as volcanism and tectonism. High iridium concentrations are not found in a periodic manner in the geologic column (Kyte & Wasson 1986), as should be the case if extinctions are caused by periodic extraterrestrial impacts. Iridium has been found in volcanic dust from Krakotoa (Officer & Drake 1983) and the Hawaiian Kilauea volcano (Zoller, Parrington & Kotra 1983), suggesting volcanism as a possible source for the iridium. Other elements more typical of the earth's mantle than of extraterrestrial material have reportedly also been found in the boundary clay at some locations (Gilmore et al. 1984; Zoller, Parrington & Kotra 1983). The boundary clay in some sections is not lithologically unusual (Rampino & Reynolds 1983). It is claimed that shocked quartz grains may 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 & 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 proposed (Rampino 1987, Rampino & Stothers 1988). Episodes of large-scale volcanism are suggested to have been caused by periodic showers of comets, with both factors contributing to mass extinctions. Mass extinctions and flood basalt volcanism have both been linked to increased frequencies of geomagnetic reversals (Loper, McCartney & Buzyna 1988), with the suggestion that mantle activity may be causally related to all three phenomena.

The Deccan Traps in India are a very large volcanic outpouring, covering at least 500,000 km^2 (Rampino & Stothers 1988), and occurring across the KT boundary (Jaeger et al. 1989). Unusual tectonism, seafloor spreading and major sea level changes also occurred at or about the KT boundary, and there seems to be no need to invoke an extraterrestrial impact (Moses 1989). The Deccan Traps would have released about 5×10^{17} moles of carbon dioxide, which is about 9 times the total of the modern atmosphere (McLean 1985). This is suggested as an explanation for the apparent lack of life in the ocean at the time of the KT boundary.

Many 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.” It may be that scientific conclusions are influenced by the philosophical views of the scientist nearly as much as by the data.

SIGNIFICANCE TO CREATIONISM

The discussion of mass extinctions and their possible causes should be of great interest to creationists. Investigations of the nature of species changes through the stratigraphic column could lead to better understanding of the causes of stratigraphic sorting of fossils. The stepwise character of extinctions might be the result of different source areas and differential sorting by the waters of the flood. One observation that may be useful is that marine fossils trend from predominantly sessile types in Paleozoic sediments to more mobile types in Mesozoic sediments (Erwin 1989). Other ideas to investigate include stratigraphic trends in paleobiogeographic relationships, lithologies, and paleocurrents.

Discussions of the possible effects of volcanism and meteoric impacts are also of interest to creationists. Large volcanic flows (Rampino & Stothers 1988) and numerous craters apparently caused by extraterrestrial impacts (Napier & Clube 1979, Grieve 1990) are found within the layers of the stratigraphic column, indicating their occurrence during the accumulation of the sediments. The occurrence of all or most of these events within the relatively short period of the biblical flood implies a catastrophe of unprecedented magnitude. Despite this, few creationists have seriously studied the possibility of events as catastrophic as those currently being discussed in the evolutionary community. The possibility that a large extraterrestrial impact was an important energy source for the break-up of the earth’s crust and release of the “fountains of the deep” that occurred during the flood should be considered.

The present discussion should not be interpreted as demonstrating the validity of the biblical flood story. However, although geologists generally take great care to emphasize that they do not accept the story of the biblical flood, the current discussion of the geological and paleontological evidence seem to enhance the respectability of such a worldwide catastrophe. More importantly, the on-going debate provides new data and new ideas that creationists may be able to utilize in developing a better understanding of processes that may have occurred during the flood.

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. The focus on catastrophic activity may be useful in developing models of the worldwide flood described in the scriptures.

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