The “Great Extinction” that never happened: the demise of the dinosaurs considered

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Abstract: The concept of a sudden extinction of the dinosaurs, consequent upon the impact of some extraterrestrial object, is so dramatic that it has taken hold upon the imaginations of many scientists, as well as of the general public. The evidence for an impact, at approximately the level of the Cretaceous–Tertiary boundary, is impressive. Whether it was the cause for the iridium concentrations, so widely distributed at that level, remains disputable. The wave of extinctions, so often attributed to the impact, is equally disputable. It is now evident that no clear line can be drawn between the smaller theropod dinosaurs and the birds. In that sense, the dinosaurs are not extinct. The dating of the extinction of the larger saurischians and of the ornithischians, based as it is upon evidence from only one small corner of the globe, is equally disputable. Whenever it happened, that extinction appears to have been the product of natural causes — a slow decline, occasioned by environmental changes, and not an extraterrestrially induced catastrophe. Whether the impact had any effect at all upon the dinosaurs is questionable; if so, it appears to have been not worldwide, but confined to a limited region of the Americas.

Résumé : Le concept d’une extinction soudaine des dinosaures, à la suite de la chute d’un objet extraterrestre, est si dramatique qu’il a saisi l’imagination de plusieurs scientifiques ainsi que du grand public. L’évidence d’un impact, approximativement à la limite Crétacé–Tertiaire, est impressionnante. Cependant, il reste discutable que cela ait été la cause des concentrations en iridium, si grandement répandues à ce niveau. La vague d’extinctions si souvent attribuée à cet impact est également discutable. Il est maintenant évident qu’on ne peut tracer de ligne exacte entre les plus petits dinosaures théropodes et les oiseaux. En ce sens, les dinosaures ne sont pas disparus. Puisqu’elle est fondée sur de l’évidence d’un seul petit coin du globe, la date de l’extinction des grands saurischiens et des ornithischiens est aussi discutable. Peu importe le moment où c’est arrivé, cette extinction semble avoir été produite par des causes naturelles - un dépérissement lent occasionné par des changements environnementaux et non pas par une catastrophe extraterrestre. Beaucoup de questions sont soulevées à savoir si cela a eu un effet quelconque sur les dinosaures et, si c’est le cas, cela semble être limité à une région des Amériques et non pas étendu à l’échelle mondiale.

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Introduction

Around 65 million years ago, or so the story goes, an extraterrestrial object hit our earth. That impact wrought havoc upon the animals and plants, in particular wiping out the group then dominant on land, the dinosaurs. It is a colourful, dramatic concept. For many people — yes, even many scientists — it has become an article of faith, so firmly accepted as to be no longer questioned. When a geological colleague, Dr. Judith Lentin, lectured at the University of Arizona a few years back and dared to question that concept, one of the Geology faculty said to her afterwards: “How can you claim that there wasn’t a catastrophic extinction, when everyone *knows* there was?”

Yet this concept is not a unity; instead, it has four components. First of all, was there such an impact at that time? Secondly, did it have worldwide, catastrophic effects on the biological community? Thirdly, are the dinosaurs truly extinct? Fourthly, if so, did the extinction of the dinosaurs coincide with that impact?

Cyril Galvin, in a recent essay review (Galvin 1998, p. 52), observed that

> In the late twentieth century, the impact theory drives research into what happened on the surface of the earth about 65 million years ago. As a result, there is now a much better idea of the paleontology of K–T time, and of extinction in general, than there was 20 years ago.

The literature on this theme is indeed vast. A selective bibliography on the Cretaceous–Tertiary (K–T) boundary event to 1989 (Tokaryk et al. 1992) listed 645 papers; in the ensuing decade, the number of relevant papers must have at least doubled and several books have been published, with titles that indicate their opposing views — for example on the pro-impact side, Powell’s *Night Comes to the Cretaceous* (1998) and, on the contrary viewpoint, Dingus and Rowe’s *The Mistaken Extinction* (1998). In preparing this epitome of the evidence, we cannot claim to have read all of this vast

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literature but, since we doubt whether anyone else has, we are not apologetic!

An impact and its consequences

Though the reality of the "extraterrestrial event" has been questioned (e.g., Paul 1989), we concur that there are excellent reasons to believe that one did indeed occur during the later Cretaceous period. Geophysical techniques have generated the image of a large crater at Chicxulub, in the Yucatán Peninsula, Mexico (Hildebrand and Penfield 1990; Hildebrand et al. (1991, 1995, 1998). This has been variously considered to result from the impact of an asteroid, a large meteorite or, just possibly, a comet or comet shower (Hut et al. 1987). In the adjacent Gulf of Mexico, a "boundary cocktail" consisting of impact materials, lithic fragments, and reworked microfossils has been reported, apparently deposited by giant sediment flows resulting from the impact (Bralower et al. 1998), while a brownish "fireball layer," succeeded by a layer rich in green globules of glauconite or altered glass, has been found off the east coast of Florida and excitedly characterized by discoverer Richard Norris as "the smoking gun" that killed the dinosaurs (Recer 1997). One of the discoverers of the Yucatán crater, Alan Hildebrand (1993, p. 112), evoked a truly apocalyptic vision:

> The K/T impact turned the Earth's surface into a living hell, a dark, burning, sulphurous world where all the rules governing survival of the fittest changed in minutes. The dinosaurs never had a chance.

A display on "Dinosaur Extinction" in a current, self-proclaimedly educational web site, designed by Enchanted Learning Software, states flatly that all animals over 55 lbs (25 kg approx.) weight were exterminated worldwide by the impact, along with half of all other life forms (see << www.enchantedlearning.com/subjects/dinosaurs/extinction/index.html >> and accompanying pages).

However, few persons nowadays would make such sweeping claims. The idea of a "wild fire" causing a massive burning of the Earth's biomass (Ivany and Salawich 1993*a*, 1993*b*) was swiftly countered (Keller and MacLeod 1993) and has long since been jettisoned. The contrary concept of impact-generated ice clouds, nearly worldwide in extent and having a disastrous effect on the vegetation and whole biota (McKay and Thomas 1982), is intriguing but unsupported by evidence.

The impact, then, apparently had effects in the adjacent oceanic regions. How much further did those effects extend? Smit et al. (1994) claimed that clastic sediments in northeastern Mexico were a product of the impact, but this interpretation was swiftly challenged by other scientists, who showed that these deposits were the product of a much longer time period and, indeed, predate the Cretaceous–Tertiary boundary (Stinnesbeck et al. 1994; Keller et al. 1997). Comparable claims regarding sand deposits in Alabama have been decisively refuted on the basis of trace-fossil evidence (Savrda 1993).

If the impact generated a dust cloud that spread around the Earth's atmosphere, the effects on the biota would certainly have been drastic (Toon et al. 1982). Though those authors would not have supported the suggestion on the abovementioned "educational web site," that the dust cloud might have suffocated "those organisms which were unable to cope with the lower oxygen levels" — an occurrence which would have required an impossibly high level of dust density — it is perfectly conceivable that such a cloud might have impeded photosynthesis. The questions are: have we any evidence of such a dust cloud and, if so, was it necessarily the product of an impact?

The existence of an iridium layer in terminal Cretaceous sediments, at many localities worldwide (terrestrial and submarine), has been considered significant in this regard. Though the presence of that element in comets is doubtful (Tatum 1998), iridium is regularly brought to the earth in meteorites and meteoritic debris. In consequence, the advocates of impact-induced devastation have seized delightedly upon it as evidence for their ideas (e.g., Alvarez et al. 1980).

However, as Hoffman (1989, p. 29) has pointed out, the presence of iridium cannot be regarded as unequivocal proof of global impact effects. First of all, there is not always a single, precisely defined iridium layer but quite often, instead, a broad iridium-enriched zone in the sediments. Restudies of the sites in Italy from which the iridium layer was originally reported (Crocket et al. 1988; Rocchia et al. 1990), have shown that there was not a single iridium "spike," but merely a horizon of peak values within a sequence of iridium-enriched clays approximately 4 m thick — a result scarcely supporting the concept of genesis resulting from impact.

It was already being realized that these levels of iridium enrichment might have terrestrial causes. Rampino had earlier demonstrated (1982) that the dissolution of normal pelagic limestones may produce an insoluble clay residue containing iridium-rich meteoritic material — material not derived from any single massive impact or the enclosing of the Earth within a comet's tail, but from the normal, day-to-day and year-by-year rain of meteoritic debris from space. Similar processes of concentration might well also occur in the terrestrial realm.

Alternatively, a dust cloud giving rise to the iridium concentrations may have been a product of volcanic activity. A major phase of vulcanism, the "Deccan traps" volcanic episode, had begun in India in the late Maastrichtian, too early to have been triggered by that extraterrestrial impact. As McLean (1982) has pointed out, this volcanic episode might well have caused dust clouds spreading as widely as, and persisting more prolongedly than, those produced by the catastrophic eruption of Krakatoa, Indonesia, in 1883. In certain areas, although a layer rich in iridium was identified, the concentrations of other elements were not considered consistent with that found in meteorites (e.g., Bhandari et al. 1994).

In summary, there is definite evidence of impact by an extraterrestrial object or objects in Yucatán and reasonably convincing evidence that it affected the Caribbean region, extending as far as the present southeastern North Atlantic Ocean. There is an iridium-enriched layer of variable thickness, sufficiently widespread globally that it is nowadays being taken as defining the Cretaceous–Tertiary boundary. However, its relation to the Chicxulub impact cannot be considered established beyond doubt, since the stratigraphical control for dating the impact is insufficient to prove its exact age (Ward et al. 1995). Even if the iridium "layer" is admitted as correlating with the impact, the question remains whether its direct effects, or the effects of mantle degassing and a dust cloud resulting from unusual volcanic activity (McLean 1985*a*, 1985*b*), had any drastic effect on the biota.

The evidence of the fossils

In Late Cretaceous times, the terrestrial realm was richly populous. Though gymnosperms remained abundant and a number of other plant groups persisted, the flowering plants (angiosperms) were becoming the predominant plant group in many regions. With their spreading, the last major groups of insects — the bees, wasps, butterflies, and moths — had appeared. In addition to the dinosaurs, a whole array of animal groups were flourishing — frogs and salamanders, crocodiles, lizards, turtles, and snakes were all abundant, and many of the modern groups of birds had appeared. Recent discoveries have shown that large flightless birds, the ratites, were already present (Buffetaut and LeLoeuff 1998). The mammals, for so long tiny creatures living in the shadow of the dinosaurs, were becoming bigger and more varied; indeed, there is increasing evidence that the first ungulates — the hoofed herbivores — may have been competing for food with the herbivorous dinosaurs (Van Valen and Sloan 1977; Sloan et al. 1986; Archibald 1996*b*).

How did this terrestrial biota fare at the Cretaceous–Tertiary transition? Was it as drastically decimated as Hildebrand (1993) conceived? If it was adversely affected by the impact, did that happen over the whole globe or only in the region close to the impact — Central America, the Caribbean and the southern and central regions of North America?

The investigation of these questions is made difficult by the scarcity of terrestrial sediment sequences spanning the Cretaceous–Tertiary boundary. Until the recognition of the iridium layer, this boundary had been established by different means in different regions, most often by the occurrence or nonoccurrence of dinosaur remains or by microfloristic evidence (see Jeletzsky 1962; Russell and Singh 1978; Lerbekmo et al. 1987). Despite a tacit international acceptance that the iridium layer could conveniently be employed to define the boundary in both the terrestrial and the marine realms, the problem has eased only in regions where that layer can be identified with confidence. In such regions, moreover, the new boundary does not usually coincide with the one set earlier, being most often slightly or considerable higher than the last occurrence of dinosaur remains (Archibald 1996*a*, pp. 42–45; Sarjeant 1996, p. 162). Moreover, the existence in some regions of multiple layers calls into question the precision of the boundary, as identified by this means.

In cross-boundary terrestrial sequences where no iridium layer can be recognized, the problem of boundary definition remains. In the San Juan Basin of New Mexico, for example, it was either never deposited or was removed by erosion, the single small iridium "spike" being considered a product of geochemical enrichment processes (Orth et al. 1982).

To assess the extent of terrestrial extinctions, therefore, one must consider evidence from localities where there is a hiatus at that level, where fossil plants or animals are found at lower (late Maastrichtian) or higher (early Paleocene) horizons. What does such a comparison tell us? First of all, as MacLeod (1998, p. 418) stated flatly: "No major terrestrial plant group became extinct at the K/T boundary anywhere."

In the northern Great Plains of the United States and western Canada, there is indeed a floristic turnover (Lerbekmo et al. 1979, 1987; Johnson and Hickey 1990; Srivastava 1994). Though this is probably attributable to long-term environmental processes, the short-term effects of the Yucatán impact may have also been a factor. However, as MacLeod (1998, p. 416) points out

> …this extinction event, along with the fern spike [seen in those regions] greatly diminishes in northern U.S., and Canadian localities. No comparable K/T floristic perturbation is known from any other continent.

Thus it seems that while, yes, the impact may have had some regional effect on the flora, it had no global effect. As for the insects, so directly dependent upon plants, they suffered no extraordinary extinctions at that level (Jarzembowski 1989; Labandiera 1992).

The evidence concerning terrestrial vertebrates has been reviewed at length by several authors, notably Colbert 1986; Sullivan 1987; Bryant 1989; Hoffman 1989; Sarjeant 1990, 1996; Archibald 1996*a*; MacLeod et al. 1997. The amphibians, turtles, lizards and snakes, crocodiles, and even that primitive aquatic group, the champsosaurs, all pass the boundary without suffering any abnormal extinctions, the 70% reduction in lizard numbers in North America being, as Archibald (1996*a*, p. 160) points out, a direct consequence of the shift from a more arid to a wetter environment. The crocodilians, in contrast, were actively diversifying, a point of significance since, after the dinosaurs, these included the largest terrestrial animals. The birds were diversifying at great speed from latest Cretaceous to Paleocene, the mammals at a somewhat lesser rate, with all four major groups — monotremes, marsupials, multituberculates and placentals — present on both sides of the boundary, though there was a quite rapid expansion in the number of condylarths in North America and a corresponding reduction of the marsupials with which they were competing (Archibald 1996*a*, p. 160). One group of freshwater sharks failed to survive into the Paleocene; otherwise, the aquatic terrestrial fauna — the other freshwater fishes, the molluscs and crustaceans — suffered no significant diminution in numbers or variety (Patterson and Smith 1987). Only the pterodactyls, a group increasingly affected by avian competition, faded out before the end of the Cretaceous; their extinction requires no other cause, global or extraterrestrial.

The availability of cross-boundary marine sedimentary sequences was considered at length by MacLeod and Keller (1991). Summarizing the information from 28 sections examined, they reported (p.1439)

> …systematic differences between continental-shelf and deep-sea depositional environments. The lower Danian [earliest Paleocene] interval immediately following the K/T boundary….is typically missing from the deep sea, whereas boundary sections deposited in shallower middle-neritic to upper-slope environments are in most cases complete across the K/T boundary. These shallow, neritic boundary sections, however, are in many instances disrupted by hiatuses. These differential patterns of hiatus distribution between deep-sea and continental-shelf

> depositional settings appear to be linked to sea-level fluctuations.

Such constraints mean that, while the cross-boundary marine sedimentary record is much better than the terrestrial, there are difficulties in interpreting the pattern of extinctions. Moreover, a tacit assumption made by many geologists — that the climate of the later Cretaceous was stable and equable — has been challenged by Barrera (1994), who demonstrated that there were considerable eustatic sea-level fluctuations and that the lowest marine temperatures of the Late Cretaceous occurred during the middle Maastrichtian, not at its end. His conclusions have been in part supported, in part contradicted by work in Tunisia (Keller et al. 1995; Liangquan Li et al. 1999, 2000) and on submarine cores from the South Atlantic (Liangquan Li and Keller 1998*a*, 1998*b*). These later works confirm the existence of considerable climatic fluctuations in the Late Cretaceous, but indicate a cooling in the last 100 000 years of the Maastrichtian

The evidence concerning marine extinctions has been considered in regional terms by Kauffman (1982) and in general terms by a variety of authors, notably Hoffman 1989; Sarjeant 1990, 1996; Archibald 1996*a*; MacLeod et al. 1997; Hudson 1998 (with response by MacLeod 1998). In addition, a large number of authors have examined the biostratigraphical record of particular groups. It is clear that the marine extinctions were nonsynchronous. The inoceramid bivalves, a characteristic late Mesozoic group, vanished at the end of the lower Maastrichtian, while the rudistids and ammonites, although becoming extinct during the late Maastrichtian, did so well before its end (Ward et al. 1986; Jablonski and Raup 1995; Johnson and Kauffman 1996). The belemnites were in deep decline during the Late Cretaceous, becoming restricted to high latitudes; by the end of the Maastrichtian, only one family survived — and continued to survive, according to W.A. Cobban (personal communication, quoted in Sarjeant 1990, p. 103), well into the Cenozoic, perhaps as late as the Eocene.

The other groups of bivalves, the echinoderms, the marine arthropods, the scleractinid corals, the bryozoans and even the nautiloids show only the normal levels of extinction across this boundary, while the gastropods were rapidly expanding (MacLeod et al. 1997). The position concerning bryozoans and brachiopods is less clear, but the evidence for any major extinctions is, at best, dubious. Among the fishes, there was a rapid turnover of elasmobranchs (sharks and rays) during the Maastrichtian, but this was balanced by a high rate of origination (Capetta 1987). The actinopterygians (by the Late Cretaceous, predominantly teleosts) show no significant diminution in number and variety (MacLeod et al. 1997, p. 280). The mosasaurs appear to have been in decline during the late Maastrichtian and gone before its end, the last elasmosaur somewhat earlier. These extinctions may have been a consequence either of the fading out of the ammonites, perhaps their principal prey, or of the radiation of the sharks; there is no need to involve impact to explain them.

Concerning the evidence for a boundary event presented by the marine microbiota, there has been much argument. This has concerned, in particular, the foraminifera and the calcareous nannoplankton (coccospheres). Concerning the former, some authors have claimed a major, and virtually synchronous, extinction of both planktic and benthic foraminifera (e.g., Smit 1982), whereas others have seen it as a progressive extinction (Keller 1988, 1993) or even recognize no such event (e.g., Widmark and Malmgren 1992; Khunt and Kaminski 1993; Coccioni and Galeotti 1994). Indeed, MacLeod and Keller suggested (1991, p. 1439) that the apparently sudden extinctions of the planktic foraminifera were merely “artifacts of a temporally incomplete deep-sea stratigraphic record.” Their conclusion is essentially endorsed by recent studies, which not only indicate a pattern of sea-level changes and temperature fluctuations in the late Campanian and Maastrichtian, but also demonstrate that such extinctions as occurred could result from environmental stresses, without recourse to any extraterrestrial event (Keller et al. 1995; Liangquan Li and Keller 1998*a*, 1998*b*; Liangquan Li et al. 1999, 2000).

The calcareous nannoplankton have also been a focus for controversy: Hudson’s assertion that “a major extinction occurred right at the boundary” (1998 p. 143) contradicts that of Pospichal (1996, pp. 352–353), who stated

> …nowhere are the Cretaceous species shown to disappear completely at the K–T boundary. Specimens are always present in variable amounts…and there is always a gradual decline through these zones.

This picture, of a steady decline rather than a sudden extinction, is endorsed by Gartner (1996) and indicates an environmental shift, rather than an impact-induced disaster, thus paralleling the information gained from recent studies of foraminifera.

Of the other microfossil groups, the radiolaria show no unusual extinction rates, seeming indeed to increase during that time (MacLeod et al. 1997, pp. 270–271). Among diatoms, there was a substantial turnover between the Santonian stage of the Late Cretaceous and the Late Paleocene, especially among benthic species; but this does not correlate with any short-term event (MacLeod et al. 1997, pp. 269–270). The dinoflagellates were left virtually unscathed in the passing of the boundary: Paleocene high-latitude assemblages, in particular, are so like those of the late Maastrichtian that even differentiating them is difficult (Sarjeant 1990, pp. 104–105; 1996, p. 163). The silicoflagellates were quite unaffected (Tappan 1979).

The dinosaurs themselves

It has long been taken as gospel that, at the end of the Cretaceous, the greatest land animals of all time — the dinosaurs — quite suddenly and abruptly vanished from the Earth. Attempts to explain this happening have ranged from the reasonable to the wildly unreasonable; the late Alan Charig (1993) identified over ninety such theories, and there have been more since. Yet it remains to be established whether they did truly become extinct and, if so, when.

Recently, there has been a proliferation of evidence from China and elsewhere that calls their extinction into question. Discoveries of small “dinosaurs,” either with a cover of feathers over their whole bodies or with a few feathers at extremities only (Ji et al. 1998), and of much larger theropods (perhaps *Dilophosaurus*; see Gierlínski 1997) with an overall cloak of feathers, have so blurred the distinction between dinosaurs and birds as to mean that the Class Dinosauria of Owen and the Class Aves of Linnaeus must arguably become one (Gauthier 1986). Even the distinguishing phrase "non-avian dinosaurs," employed by MacLeod et al. (1997), evokes an image hard to define. Fundamentally, the evolution of birds from dinosaurs is well documented by a step-by-step progression of changes. Birds are now classified by most palaeontologists as part of the Dinosauria (Padian and Chiappe 1998*a*, 1998*b*). If their approach is correct, then dinosaurs are still alive and well today.

However, if one accepts the conventional definition of dinosaurs as meaning, in particular, a group of reptiles of great size then, yes, there remains an extinction to be explained. It was an extinction of all ornithosuchian lineages, of the sauropods and the larger theropods.

Was this extinction rapid or was it progressive? This is hard to decide from direct evidence since, though earlier Maastrichtian deposits with dinosaurs are to be found in several regions — France, Spain, Romania, India, and possibly China — the *only* region in which terrestrial deposits bridging the boundary have unquestionably been found is the Great Plains of the west-central United States and the Canadian provinces of Saskatchewan and Alberta.

It is unwarranted to assume that the position of the last discovered dinosaur bones in this small (on the world scale) region indicates the timing of a worldwide extinction. In that same region, the last bones of marsupials in North America are found, though in the early Tertiary rather than the latest Cretaceous. One might equally conclude, from similar regional evidence, that the marsupials became extinct worldwide early in Tertiary times; yet marsupials survived elsewhere in the world, in abundance until recently in Australia and in comparable abundance until the Neogene in South America (from which continent some species, notably the opossums, were able to re-invade Central and North America early in the Neogene).

There are persistent stories of the survival of dinosaurs through to the present day. The late Alan Charig examined these in some detail (1993, pp. 310–312), pointing out that the reports were always from tropical jungles and always of sauropods. The fact that the tropical forest environments — and especially rain forests — are so inimical to the survival of fossils means that we simply do not know what dinosaurs lived in those environments during the Mesozoic; they might indeed have been the optimal sauropod habitat. In the absence of evidence from fossils, their survival in such environments, long after the Cretaceous boundary "event," cannot be discounted. Nevertheless, the present authors concur with Charig's judgement (1993, p. 312) that "we may safely regard the dinosaurs as extinct," even if we cannot be sure when, on a global scale, that extinction finally occurred.

In terms of events in North America, one must note that in the most fully studied cross-boundary section — that at Hell Creek, Montana — there are no bones of dinosaurs in the uppermost 2–3 m of Late Cretaceous strata (taking the iridium layer as defining the boundary), except in ancient stream channels where, as Retallack et al. (1987, p. 1093) reported, "assemblages of Cretaceous and Paleocene mammals and of dinosaurs…are so thoroughly mixed that they are difficult to interpret." Those authors concluded that the absence of dinosaur bones in the undisturbed sediments is a consequence of acid dissolution of bones and teeth in the palaeosols; others (e.g., Padian 1995) have concluded instead that, by the time of the Yucatán impact, the large dinosaurs were already extinct. As noted earlier (p. 246), the timing of that impact is in any case uncertain.

A related question is whether, up to the presumed time of their extinction, the dinosaurs were a flourishing group or whether they were already in deep decline. Sheehan et al. (1991) claimed that the Hell Creek section presented no statistically meaningful evidence of decline, but their evidence was reexamined by Williams (1994), who concluded (p.189)

> The decline in both numbers and kinds of dinosaurs suggested by the combined evidence of the channels and the sparseness of the last few meters of the Hell Creek Formation are consistent with a gradual decline (however steep) or possibly an accelerating decline, but not a catastrophic one.

Though Hurlburt and Archibald (1995) have pointed out the difficulties in statistically distinguishing, on the basis of the fossil record, between a gradual and sudden extinction, most vertebrate palaeontologists now concur that the decline of the dinosaurs was gradual and that, by the late Maastrichtian, only a low number of genera and species (ceratopsians, ankylosaurs, and theropods) survived.

On a broader scale, it is clear that within the Western Interior Basin of North America, there is a decline in dinosaur diversity between Campanian and Maastrichtian times. Three successive faunas of dinosaurs found along the Red Deer River of Alberta document this decline. The Campanian fossils of the Dinosaur Park Formation indicate the presence of more than 35 species of dinosaurs, one of the richest records in the world. The succeeding Horseshoe Canyon Formation has produced only 20 species, in spite of the fact that a great diversity of habitats is evident in the sediments. Finally, the Scollard Formation has yielded only 14 species of dinosaurs. Even if one counts all of the dinosaurs recovered from the intensely prospected Hell Creek Formation of the northern U.S.A. (Archibald 1996*a*), dinosaurian diversity never reaches the levels seen during Campanian times; moreover, as noted above, the last dinosaur remains occur considerably below the iridium layer, a matter of significance if that is taken as marking the boundary. It is evident that, in this region of the world, dinosaurs were undergoing a reduction in diversity — a happening that cannot be attributed to a catastrophic extraterrestrial event at the end of the Cretaceous. In all likelihood, as Charig (1993), Taquet (1993), Officer and Page (1996), and many others have concluded, the extinction of the dinosaurs (or of such of them as became extinct) must be attributed to more than one cause.

Elsewhere it seems that decline was not ended at the level of the iridium layers. In India, at least, there is good evidence that the theropod dinosaurs persisted past that level, on the basis of eggshell fragments in sediments showing no evidences of reworking (Bajpai and Prasad 2000).

Conclusions

The evidence for an extraterrestrial impact in Yucatán appears conclusive. Whether or not this impact generated — or even coincided with — the very widespread iridium layer, or whether that layer was a product of volcanic activity, remains arguable, as does its suitability, as a means for recognizing the Cretaceous–Paleocene boundary.

In contrast, the evidence from terrestrial and marine fossils affords no support for any worldwide holocaust. The patterns of extinction across the boundary are, as Sims (1997) points out, difficult to determine. However, whilst extinction rates fluctuate in different groups, they do so in such normal fashion that the concept of a "Great Extinction" — so dear to newspaper reporters and the uninformed general public — should be jettisoned.

The fact that our present information on dinosaur distribution in the latest Maastrichtian is restricted to a single, relatively small area of the Earth's surface makes it difficult to establish exactly when the larger dinosaurs did become extinct. Since the occurrence of dinosaur bones has been used so regularly as evidence of a Cretaceous age for the containing strata, it is difficult to assess claims that there are dinosaur bones, unreworked, in the Paleocene. Similarly, the very presence of mammal bones — especially of ungulates — in a stratum has been considered to be evidence for an early Tertiary date. Yet, as noted earlier (p. 247), there are indications that primitive ungulates were present, and potentially competing with the dinosaurs, in later Maastrichtian times.

The environmental changes in North America during the Late Cretaceous were considerable. The inland sea, whose margins had provided so congenial a habitation for the big dinosaurs, was gone; before the end of the Maastrichtian, the vegetation and the climate were changing drastically (Kerr 1988; Sweet et al. 1990). Concerning the extinction of those monster creatures, Sims (1997, p. 16) may be quoted:

> The cause of the biotic turmoil at the K–T boundary is likely to prove as difficult to pin down as the pattern of the extinctions. The complexity of the extinctions suggests that one explanation will not suffice. The convergence of sea level fall, restructuring of oceanic circulation, and fluctuating marine temperatures…during the Late Cretaceous would have provided considerable environmental stress. Closer to the boundary, the intense volcanic activity associated with the Deccan Traps will have accentuated this stress. The evidence for meteoritic impact is strong and this too may have played a role in the extinctions near the boundary. A process of accelerated stress towards the boundary may correlate with a pattern of accelerated extinctions.

We are less convinced than Sims of "biotic turmoil" at that time and consider that any effects of the extraterrestrial impact would have been limited only to Central America and the south and central regions of North America. Even so, we believe this is a good summation. Birkelund and Haukansson (1982) justly called the extinction a "multicausal event," a judgement echoed by MacLeod (1996).

The concept of the Great Extinction is nowadays receding from science into science fiction, where it belongs. Whilst still unsure quite when, or where, that last sound was uttered, we believe with Clemens et. al (1981), Dodson (1996, pp. 279–280), and others, that the history of the big dinosaurs ended, not with a bang, but a whimper. We are grateful that those smaller dinosaurs that we call "birds" remain with us in such variety and abundance.

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