Late Triassic Extinctions and the Origin of the Dinosaurs

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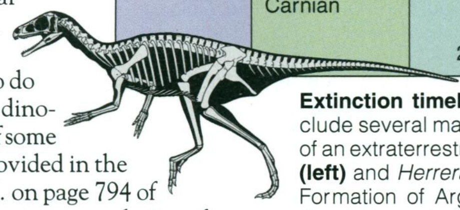
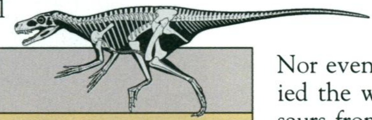
There have been many mass extinctions in the history of life, some equal in magnitude to, or greater than, the famous Cretaceous-Tertiary (K-T) event 65 million years ago (Ma), when the dinosaurs died out. Much recent research has focused on mass extinction events during the Late Triassic, some 150 million years earlier, close to the time of the origin of the dinosaurs. During this time, 20% or more of families of animals died out, eliminating some 50% of species and matching the severity of the K-T event (*1*). What is not clear is whether there was a single extinction event in the Late Triassic or more than one, whether the events were catastrophic and caused by a major extraterrestrial impact or not, and whether the extinctions had anything to do with the rise of the dinosaurs. Clarification of some of these matters is provided in the report by Rogers *et al.* on page 794 of this issue, which presents argon dating of an important dinosaur assemblage (*2*).





Period	Stage	Boundary date (Ma)	Events
Jurassic	Hettangian		
Late Triassic	Norian	202	Triassic-Jurassic mass extinction
			214-Ma Manicouagan impact
		220	Carnian-Norian mass extinction
	Carnian		228-Ma Ischigualasto dinosaurs
		230	

Extinction timeline: Important events in the Late Triassic include several mass extinctions and a major catastrophic impact of an extraterrestrial object. The first dinosaurs, such as *Eoraptor* **(left)** and *Herrerasaurus* **(above)**, come from the Ischigualasto Formation of Argentina. [Skeletal reconstructions courtesy of Carol Abraczinskas and Paul Sereno, University of Chicago]

There is no question that there was a mass extinction at the very end of the Triassic period, 202 Ma at the Triassic-Jurassic (Tr-J) boundary. It is well documented that ammonoids and bivalves were decimated and that the conodonts finally disappeared (*1*). On land, several families of reptiles disappeared, particularly the last of the basal archosaurs ("thecodontians"), the group that includes the ancestors of dinosaurs and crocodilians, and some mammal-like reptiles, the group that includes the ancestors of the mammals.

Recent work on earliest Jurassic vertebrate faunas has led to the claim (*3–5*) that this Tr-J event was instrumental in triggering the radiation and huge success of the dinosaurs. In addition, a major impact crater site, the Manicouagan structure in Quebec, has been identified as the smoking gun for a catastrophic extraterrestrial impact at the Tr-J boundary (*3, 4*). Elevated levels of iridium have been reported from a Tr-J boundary section in Austria (*6*), and shocked quartz has been found at a Tr-J boundary section in Italy (*7*). High levels of iridium in K-T boundary clays worldwide and shocked quartz in many such sections are, of course, taken as key evidence for a major impact 65 Ma. The story for the Tr-J mass extinction event seemed to be firming up, with clear evidence for considerable loss of diversity, corresponding to an impact crater of suitable size and iridium and shocked quartz. Over the past 10 years, supporters of extraterrestrial catastrophic extinction have sought clear geological evidence for additional events that match the quality of the data for the K-T event but without much success. Could the Tr-J extinction event be the elusive second best documented catastrophic extinction event they were looking for?

The case is far from certain. Later authors (*5*) failed to find the iridium anomaly in the Austrian section, and the nature of the lamellae in the shocked quartz was not adequate to rule out other explanations, such as a volcanic source for the material (*7*). Further, the Manicouagan impact structure has been redated (*8*) away from the Tr-J boundary (202 Ma), falling closer to the Carnian-Norian boundary, well down in the Late Triassic, about 220 Ma. This redating may or may not be significant in the attempt to unravel the controversial earlier Late Triassic extinction event.

It had been well known to paleontologists for decades that a major faunal turnover took place on land during the Late Triassic. Various long-established groups, sometimes termed paleotetrapods (mammal-like reptiles, thecodontians, temnospondyl amphibians, rhynchosaurs, prolacertiforms, and procolophonids) were replaced by new reptilian types, sometimes termed neotetrapods (turtles, crocodilians, dinosaurs, pterosaurs, lepidosaurs, and mammals). It had long been assumed that this replacement was a long, drawn-out affair that involved competition between the "primitive" paleotetrapods and the "advanced neotetrapods" (*9*), but this has been questioned.

The opposing view (*10–12*), which focused particularly on the origin of the dinosaurs, was that there was no such competitive replacement but that the dinosaurs radiated after a mass extinction of other reptile groups at about the Carnian-Norian boundary, the Crn-Nor extinction event.

The new work by Rogers *et al.* (*2*) clarifies the detail of the run-up to the Crn-Nor event. They have studied the world's oldest dinosaurs from the Ischigualasto Formation of Argentina in an attempt to unravel through the rock sequence just what was going on. Rogers and colleagues (*2*) have established a radiometric date of 228 Ma for the lower part of the Ischigualasto Formation which, they argue, places it in the middle of the Carnian stage.

The Ischigualasto fauna was dominated by the rhynchosaur *Scaphonyx*, a pig-sized grubbing herbivore, and *Exaeretodon*, a medium-sized herbivorous cynodont mammal-like reptile. Other rarer elements of the fauna include the bulky herbivorous dicynodont mammal-like reptile *Ischigualastia*; the basal archosaurs *Aetosauroides* (a herbivore), *Proterochampsa* (a piscivore), and *Saurosuchus* (a carnivore), as well as the dinosaurs *Eoraptor* (*13*) and *Herrerasaurus* (*14*) (both carnivorous theropods), and *Pisanosaurus* (*15*), a herbivorous ornithischian. Out of a sample of 228 tetrapod specimens collected in this study, only 13 (5.7%) were dinosaurian.

The new study confirms the view that there was no long-term ecological replacement of paleotetrapods by neotetrapods because members of both assemblages cohabit side by side without evidence of a decline of the former and a rise of the latter. This pattern is confirmed in a coarser-scale worldwide census of Late Triassic tetrapod faunas (*11,12*). During Carnian times, in areas as far apart as Argentina, Scotland, India, Morocco, and New Mexico, terrestrial faunas were dominated by rhynchosaurs, mammal-like reptiles, and basal archosaurs but with rare dinosaurs present worldwide, representing 1 to 6% of the faunas.

Although specimens are rare, new studies of these very early dinosaurs (*13–15*) have

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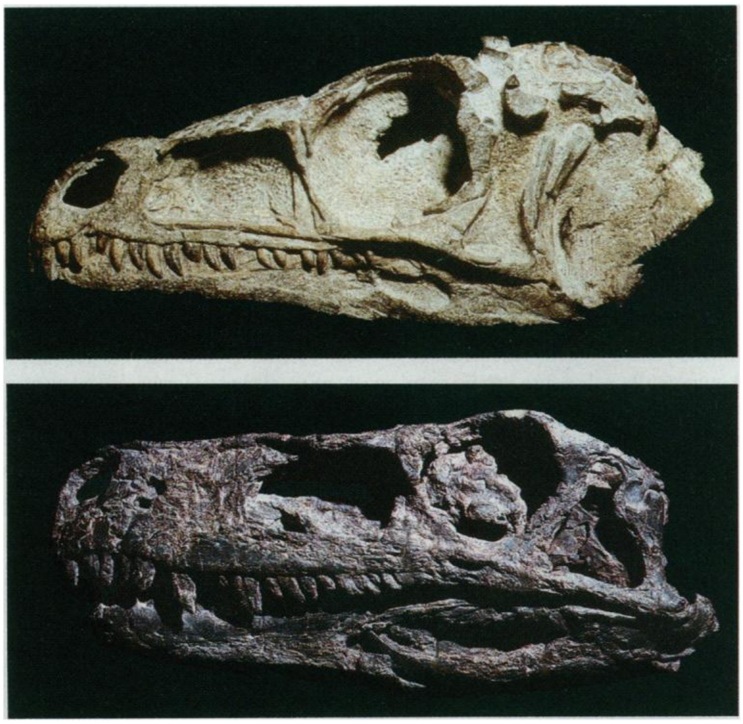
shown that the main lines of dinosaurian evolution were already laid down during Carnian times, with representatives of all three major lineages, the theropods, sauropodomorphs, and ornithischians, already present. These three lines had apparently diverged from a single common ancestor within only a few million years. The Carnian dinosaurs in all lineages were moderately sized animals, all light-weight bipeds less than 6 m long.

If the origin and early evolution of the dinosaurs was seemingly a low-key affair and the first dinosaurs were small and rather insignificant in their faunas, the situation was seemingly quite different a few million years later, after the proposed Crn-Nor extinction event. The rhynchosaurs and most of the mammal-like reptiles and basal archosaurs had either disappeared or become extremely rare, and the dinosaurs had diversified and become abundant (*10–12*).

For the first time, mass accumulations of dinosaur skeletons are found; for example, the famous death assemblage of several hundred individuals of the theropod *Coelophysis* at Ghost Ranch, New Mexico, in the early Norian Upper Petrified Forest Member of the Chinle Formation. For the first time too, dinosaurs became relatively diverse, and they began to exhibit that feature for which the group is famous: large size. Specimens of *Plateosaurus* from the Norian Stubensandstein and Knollenmergel of Germany reached lengths of 6 to 8 m. Overall, dinosaurs had switched from being minor players in the Carnian, at faunal abundances of less than 6%, to being the dominant land reptiles, with abundances of 25 to 60% in the Norian (*10,12*).



Old bones. These 228-million-year-old dinosaur skulls were recovered from the Ischigaulasto Formation in northwest Argentina, which contains the world's oldest dinosaur bones. **(Top)** The early dinosaur *Eoraptor* and **(bottom)** *Herrerasaurus*. [Photos courtesy of Paul Sereno, University of Chicago]

Was the postulated Crn-Nor extinction event (225 Ma) restricted to nonmarine vertebrates and a minor blip in the diversification of life compared to the Tr-J event (202 Ma), a commonly expressed view (*3–5*)? Recent studies of marine fossil records (*1, 16*) have indicated that the foraminifera, ammonoids, bivalves, bryozoans, conodonts, coral reefs, echinoids, and crinoids all experienced global-scale extinctions either during the Carnian or at the Crn-Nor boundary.

The Late Triassic extinction events are significant for several current strands of research in paleobiology and in geology in general. The early evolution of dinosaurs, and the explosive rise to dominance of the group during Late Triassic times, is a prelude to the later success of the group and their dominance of terrestrial habitats for 160 million years (much longer than the reign of the mammals, so far). It is striking how little paleobiologists know of this remarkable group and of their early history.

The nature of the Late Triassic events has a direct bearing on current debates about catastrophism in the history of the Earth. A strong body of opinion accepts that there have been many major extraterrestrial impacts on the Earth and that these impacts may have recurred at regular intervals. Identification of mass extinction events, and their dates, is crucial: One Late Triassic event fits the periodic pattern; two events do not. One event could be part of the periodic impact cycle, and one the result of some other set of circumstances (*1*). Further, in support of periodic catastrophes, some more physical evidence of impacts is required for extinction events other than the K-T event. The Tr-J mass extinction looked like a good second case study, but convincing evidence for impact is proving elusive.

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