Indian dinosaurs revisited*

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During the last three decades, research has shown the scientific potential, significance and uniqueness of the Indian record of dinosaurs in a global context. Known from several localities throughout the subcontinent, it is the Gondwana rocks of the Pranhita–Godavari and Narmada valleys that hold the key in answering questions regarding dinosaur origins, their rise to giganticism, nesting behaviour, dietary preferences and the contiguity of land masses in the past. This potential however is being realized slowly: there are only two mounted skeletons in the country, but several incomplete specimens suggest a great diversity for Indian dinosaurs.

DINOSAUR bones were reported as early as 1828 from Jabalpur Cantonment by an army officer Captain W. H. Sleeman (Figure 1), only four years after the first description of *Megalosaurus* by William Buckland, a Professor at Oxford University in 1824. In fact, some of these collections housed in the British Museum, London helped Sir Richard Owen to formally establish 'Dinosauria' as a group of large extinct reptiles later in 1842. The dinosaurs of India have thus been studied for the past 175 years and these studies provide unique scientific information on: the origin of dinosaurs and the evolution of their gigantic size; their nesting environments and behaviour; and dietary preferences as inferred by remains of dinosaur dung or coprolites. Relationships to contiguous land masses of Madagascar, Australia, Antarctica and South America based on geodynamic plate tectonic models can also be inferred. In addition, attention has focused on extinction scenarios involving the asteroid impact fallout at two localities in Kutch and Meghalaya, and the concurrent outpouring of the Deccan lava flows, one of the most intensive and extensive continental flood basalt activities known on planet Earth at precisely the same time as the dinosaur extinction event.

The dinosaurs of India known by about 15 to 20 genera form only a small component of the less than 300 valid taxa known worldwide[1]. This group of highly successful and diverse reptiles survived for about 165 million years (m.y.) and occupied diverse ecological niches ranging from tropical rainforests (as in the Cretaceous of North and South America), sandy deserts of Mongolia and the polar regions of Alaska and Australia. In this great latitudinal distribution, these reptiles were helped by a long-term greenhouse with temperatures significantly elevated above the global mean annual present-day temperature of 15°C (Figure 2).

*Dedicated to Prof. S. Ramaseshan on his 80th birthday.

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Indian dinosaur localities

Early discoveries were made in central India in the 19th Century by soldiers, surveyors and priests, one of the most famous being Reverend Stephen Hislop of Nagpur. Most of the dinosaur localities are in central India, along the Pranhita–Godavari (PG) Valley[2] and along the Narmada river[3], and are associated with Gondwana rocks or with sedimentary sequences interfingering with the Deccan basaltic flows (Figure 3). However, there are some notable exceptions: ONGC scientists have described Jurassic dinosaurs from northern Kutch along India's border with Pakistan; while Cretaceous finds include the Tiruchirapalli region in south India; the Barkhan locality, east of Quetta in Pakistan[4], and some sites in Meghalaya described by scientists of the Geological Survey of India[5].

Some important Indian taxa

Although there has been much discussion regarding the extinction of dinosaurs and other biotas at the end of the

Figure 1. Captain (later General) W. H. Sleeman found the first dinosaur bones at Jabalpur.

Cretaceous, there has been relatively less attention paid to the origination of this group. In fact, the rise of the dinosaurs was just one other instance of accelerated evolution that took place after one of the most destructive biotic mass extinction episodes on earth some 245 m.y. ago. During this extinction event over 90% of marine life and over 80% of life on land perished. It was as one palaeontologist put it – 'The day the earth nearly died!' Life on earth as we know it now, consists of the 10–15% survivors of this catastrophe. Among the survivors were the thecodonts which, within a span of 30 m.y., gave rise to the first dinosaurs. Much is now known of the earliest (Triassic) dinosaurs from the work of the Argentinian scientist Fernando Novas, who has described some excellent specimens from Patagonia. In India as well, some little material has been assigned to a putative dinosaur, *Alwalkeria maleriensis* from Nehal village, in the PG Valley[6]. Triassic dinosaurs, including *Alwalkeria* were slender, nimble, bipedal creatures that soon took over the role of a top carnivore.

Barapasaurus and Kotasaurus and the origin of the giants

One of the earliest mounted and best preserved dinosaur skeletons, *Barapasaurus tagorei*[2] is on display at the Indian Statistical Institute, Kolkata (Figure 4). Recently, another skeleton of *Kotasaurus* has been exhibited at the Birla Science Centre, Hyderabad[7]. Both these genera found in Lower Jurassic rocks are unique not only because they represent one of the best examples of the early sauropod giants, but they also throw light on India as a possible centre of origin. No other specimen at this early stage of dinosaur evolution is as complete. In fact, the potential of the Indian dinosaur fossil record is yet to be realized.

The Jurassic sauropods gave rise to even larger sauropods in the Cretaceous for which an appropriate name *Titanosaurus* has been given, based initially on material from India. Titanosaurids have now been reported from several localities in the Cretaceous of southern France and Spain as well as in several localities in South America, implying a slow but steady faunal exchange between these land masses. Jain and Bandopadhyay[8] have described a partial skeleton of *Titanosaurus* from the Lameta Formations near Wardha. Sauropod bones are found in most Indian Cretaceous localities extending from Kutch in the west through most of peninsular India to the east in Jabalpur and south of Nagpur. The ectothermic nature of these giants has been inferred on the basis of several physiological factors[9], but the high vascularity of their

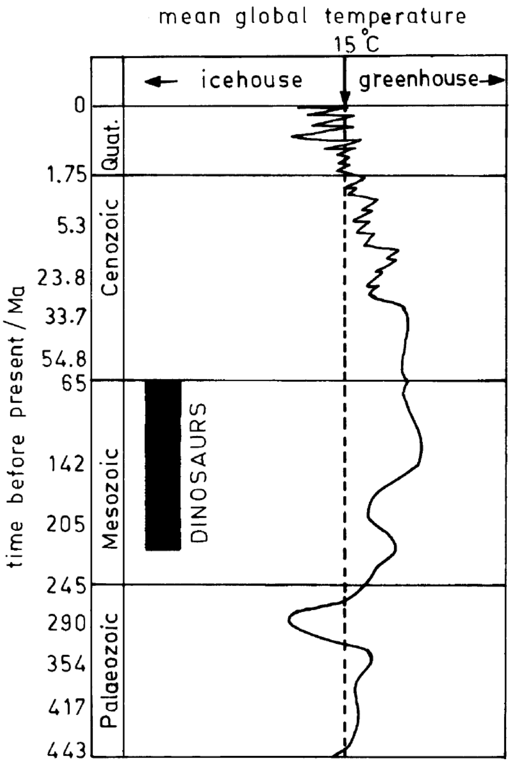

Figure 2. Greenhouse earth during the time of the dinosaurs.

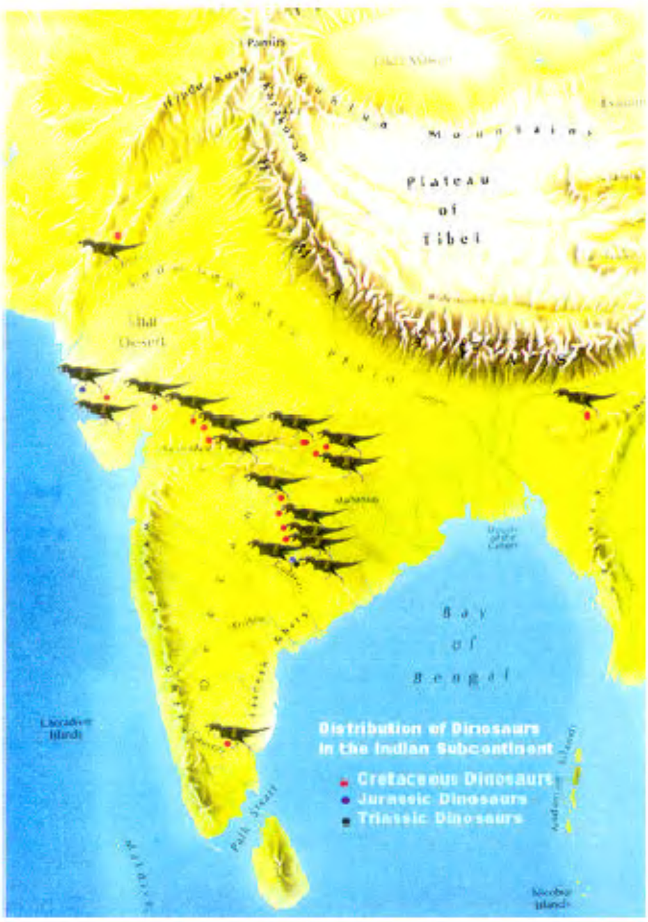

Figure 3. Distribution of dinosaurs in the Indian subcontinent.

Figure 4. Skeleton of *Barapasaurus tagorei* on display at the Indian Statistical Institute, Kolkata. (Photo: Courtesy Palaeontology Museum.)

bones as exemplified by the cross-section of a sauropod bone from Anjar, Kutch points to osteological similarities with endotherms (Figure 5). The cross-section shows remodelled bone in active growth with well-preserved osteons, having an average diameter of 25 μm. In fact, this well-preserved specimen shows blood-capillary canals similar to those found in recent mammalian endotherms.

Figure 5. Cross-section of sauropod bone from Anjar showing growth and well-preserved osteons marked by arrows. Osteon diameters are about 25 μm.

Indosuchus raptorius

Comparable in size to the better known *Tyrannosaurus rex* of North America, but distinct from it taxonomically at the familial level is *Indosuchus raptorius* (Abelisauridae). *Indosuchus* was first described by Von Huene and Matley in 1933 (ref. 10) based on material quarried from Jabalpur and other localities in Madhya Pradesh. By studying specimens collected by Barnum Brown in 1922 from Jabalpur and now housed in the American Museum of Natural History at New York, Chatterjee[11] has described the skull and mandible of this giant carnivore. He is also in the process of describing a much larger dinosaur assemblage from the Lameta Formation of Balasinor and Rahioli, situated east of Ahmedabad[12]. These forms include a stegosaur and an ankylosaur.

Dinosaur nesting sites

During the last two decades, one of the biggest gains in dinosaur research in the country has been the documentation of sauropod nesting sites in an area excess of 10,000 km^2 across most of peninsula India[3]. The nesting sites comprise of hundreds of nests and thousands of eggs

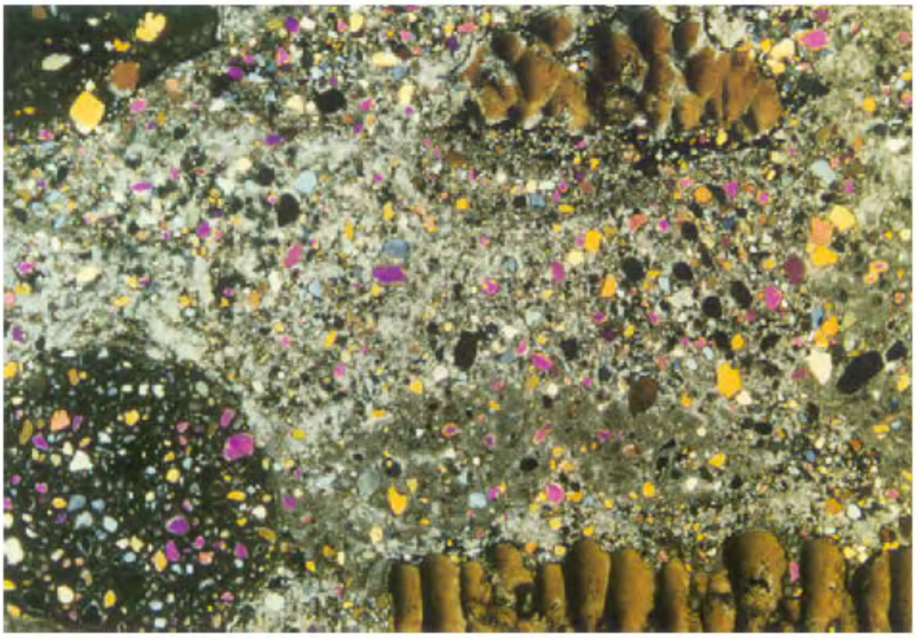

Figure 6. Thin section of eggs (brown colour) in pedogenically modified calcareous sandstones. Rounded caliche nodule to the left is 1 cm in diameter.

both complete and fragmented, representing the largest dinosaur hatchery known worldwide from a single lithological unit, a calcareous sandstone comparable to the Lower Limestone of the Lameta Type Section. Figure 6 illustrates eggshell fragments represented as brown-coloured spheroliths surrounded by sand grains and caliche nodules gradually undergoing replacement by calcareous material.

Some of the best dinosaur eggshell material was obtained initially from the ACC Limestone Quarry at Balasinor. The 'Limestone' represents a regolith which was formed under semi-arid conditions by pedogenesis of fluvial deposited sandstone[13]. The horizon was preserved when the Deccan lava flows covered the horizon and sealed it from further weathering and erosion. Some of the stages in the preservation of nests and bones at Jabalpur are shown in Figure 7, where living habitats of dinosaurs near lakes and rivers became the sites of fosslization of their bones and eggs, only to be later covered by Deccan basaltic flows.

Sauropod nests and eggs comprise of up to 10 to 12 spherical eggs ranging in diameter from about 15 to 20 cm (Figure 8 *a*, *b*). They have been grouped under the parataxon, *Megaloolithus* and have 6 to 7 distinct morphostructural units[14,15]. The cross-section of a typical sauropod eggshell shows the development of cylindrical spheroliths of calcite with air canals penetrating the thickness of the eggshell which may vary from about 2 to 4 mm. It is important to understand that embryos require the basic necessities for life, including oxygen, nutrients and waste disposal which the amniote egg provides in an efficient manner (Figure 9). The under-surface (mammillary layer) of the dinosaur eggshell provides significant information regarding whether the embryo was growing within the egg or not, depending on the amount of

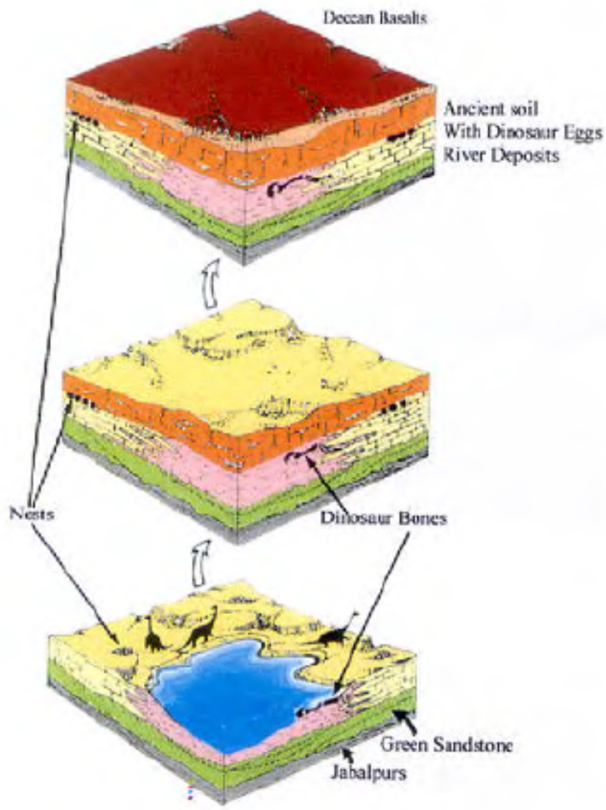

Figure 7. Stages in the preservation of eggs, nests and bones at Jabalpur.

calcium resorbtion taking place. Indian sauropod eggshells studied by electron microscopy suggest that a large proportion of embryos were growing and hatching out, as the mammillary surface shows cratered pits. Another rare eggshell type consists of elongated eggs named *Elongatoolithus* and this is believed to have been laid by carnivorous (theropod) dinosaurs.

Dinosaur dung

Some of the rarest preserved dinosaur material pertains to dung or coprolites (Figure 10). Matley[16] was one of the first to systematically describe coprolites from the Pisdura area situated not far from Nagpur. On-going collaborative work by several institutions such as the Physical Research Laboratory (PRL), Birbal Sahni Institute of Palaeobotany, Geological Survey of India and Panjab University is documenting isotopic and dietary signatures of herbivorous dinosaurs. A variety of coprolitic segments have yielded woody tissue, cuticles, pollen and water-ingested micro-organisms such as diatoms. This study is providing greater insights into the physiological processes of large sauropod dinosaurs which were presumably ectothermic and had rudimentary peg-like teeth. One of the main questions being addressed is the degree of gut (bacterial) fermentation taking place.

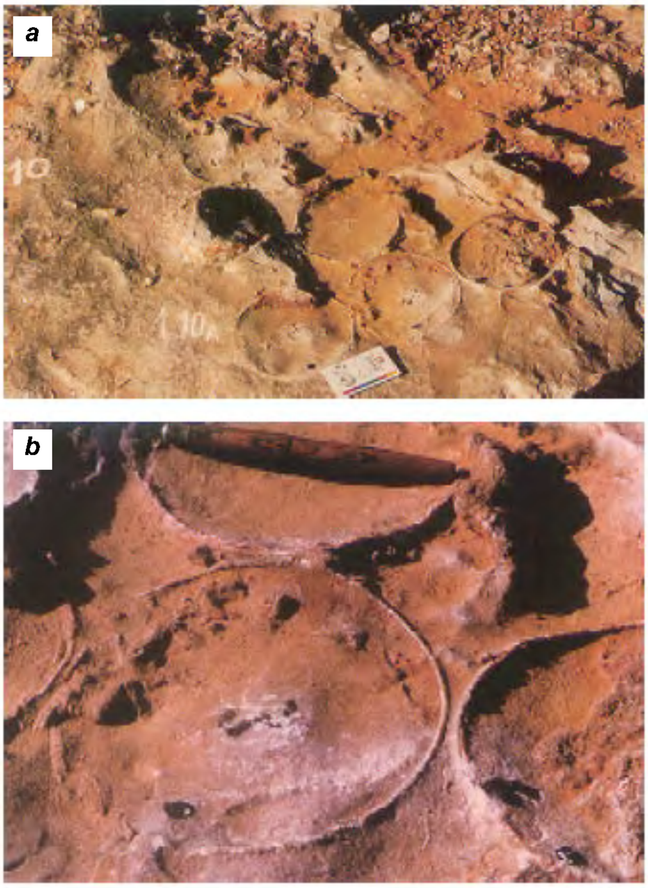

Figure 8. ***a***, Well-preserved nest at Rahioli; ***b***, Close-up of some eggs in the nest. Pen for scale.

Environments and associated biotas

The palaeoenvironments in which Indian Triassic, Jurassic and Cretaceous dinosaurs lived have been discussed at length previously[17]. Of greater interest is the biodiversity of life during the Mesozoic, at the time that dinosaurs were the dominant animals[18]. Cretaceous biodiversity during the outpouring of the Deccan basalts has been the best studied and it will be elaborated here, to give some idea of the other life forms that lived alongside the dinosaurs. Vegetation was diverse, dominated by palm trees and other plants requiring high precipitation. Lakes were dominated by algal charophytes and siliceous diatoms. The Goghuwa Fossil Park situated to the east of Jabalpur displays some of the land plants present during the Cretaceous. On land, the main faunal communities consisted of fishes, frogs, snakes, lizards, crocodiles, turtles and dinosaurs[18]. Mammals were then small and arboreal, and formed an insignificant part of this community[19]. No Cretaceous bird has yet been reported from India. Invertebrates comprised of pulmonate gastropods, unionid pelecypods and ostracodes. The seas teemed with a host of forms dominated by the molluscan ammonites, best seen in the Tiruchirapalli sections. These sea giants also met the same fate as the dinosaurs some 65 m.y. ago.

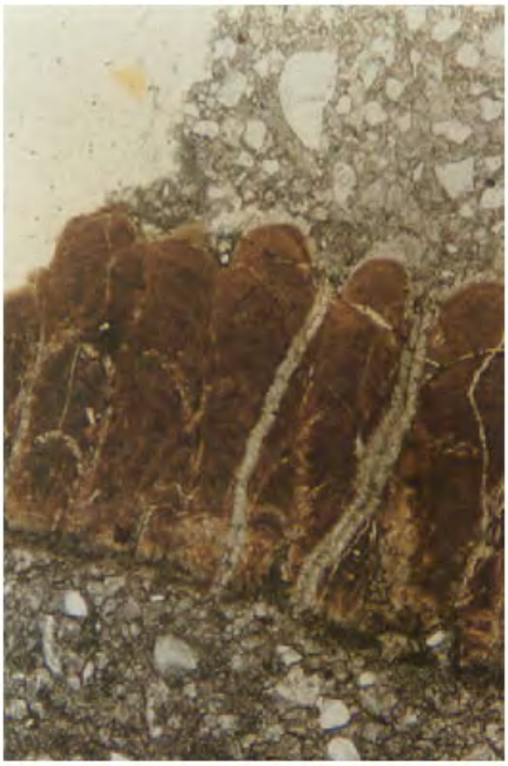

Figure 9. Thin section of sauropod eggshell showing calcitic spheroliths and air canals running through the shell. Shell thickness about 2.5 mm.

Extinction scenarios

There are three main competing hypotheses to explain the mass extinction that occurred at the end of the Cretaceous, 65 m.y. ago. Over 65–70% of species (including dinosaurs) in all environments: marine, brackish and freshwater perished suddenly and it is only from the small percentage of survivors which included mammals, that present-day life has originated.

Extinction theories can be grouped into two main classes depending upon whether they are slow processes such as sea-level changes with prolonged, cumulative effect ultimately causing breakdown of the ecosystem; or more short-term events such as the outpouring of the Deccan Lavas (3 to 5 m.y.) or geologically instantaneous ones such as asteroid impacts (days to months). It is also possible that one or more causes as listed above could have worked in tandem to enhance the catastrophic effect.

Fluctuations involving fall in sea levels have been tied to extinction events[20]. Explained in simplistic terms: as the sea-level falls, surface area of continents enlarges and aridity increases, as moisture-laden winds cannot penetrate deep inland. It is interesting to note that present-day sea levels are the lowest that they have been in the last 500 m.y., and are comparable to low levels at the Permian/Triassic boundary when the greatest mass extinction took place[20]. Coincidentally at this very time, an extensive volcanic activity was underway in Siberia and a causal relationship between vulcanicity and mass extinction has long been held[21]. Similarly, the Deccan basalts are dated to a major lava outpouring episode at 65 m.y., which coincides precisely with the demise of dinosaurs and other organisms. In fact, the last record of an Indian dinosaur is from sedimentary beds which lie between two lava flows (Figure 11).

Figure 10. Cross-section of dinosaur dung showing concentric layering and air vesicles. Natural size.

Figure 11. Dinosaur bones in thin Cretaceous lake deposits sandwiched between lava flows, Ranipur, southeast of Jabalpur.

Figure 12. Section at Um Shorengkew in Meghalaya showing iridium-enriched layer marking (with arrow) the fallout of the asteroid impact. (Photo: Courtesy Bhandari *et al.*[22]).

However at present, on the basis of physical and geochemical markers, the asteroid hypothesis has gained ground. In over 100 localities around the world, enhanced iridium levels (in ng/g range) are confined to thin layers which not only mark a major biotic turn-over at the Cretaceous/Tertiary boundary (KTB), but also host a suite of impact-related minerals such as stishovite, microdiamonds and fullerenes (the latter originating from wildfires that swept the globe after the impact). Bhandari and co-workers from the PRL have documented two widely-separated sites in India, one at Anjar, Kutch[22] and the other at Um Shorengkew (Figure 12) in Meghalaya, where the iridium anomaly has been observed.

Conclusion

Indian dinosaurs form a small but important component in understanding dinosaur palaeobiology and evolution. They also contribute significantly to aspects dealing with origins of the giant sauropods, reproductive and digestive physiology as well as faunal relationships in land masses that were at one time contiguous. Dinosaurs form part of India's rich fossil heritage and deserve to be protected for our future generations. At present, there is urgent need for enactment of legislation that will allow scientific study of fossils, including dinosaurs, but will firmly deal with intentional acts of vandalism and commercialism.

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