Journal of the Palaeontological Society of India
Volume, 56(2), December 2011: 127-135

ISSN 0522-9630

HISTORY OF LATE CRETACEOUS DINOSAUR FINDS IN INDIA AND CURRENT STATUS OF THEIR STUDY*

DHANANJAY M. MOHABEY

GEOLOGICAL SURVEY OF INDIA, PALAEONTOLOGY DIVISION, CENTRAL REGION, SEMINARY HILLS, NAGPUR-440 006
E-mail: d.mohabey@gsi.gov.in

ABSTRACT

The knowledge on the Indian Late Cretaceous dinosaurs is mainly based on the monumental work done prior to independence of India by Richard Lydekker, Charles Alfred Matley and Friedrich von Huene. The early collection of dinosaurs mainly came from the Lameta sediments at Bara Simla and Chhota Simla, Jabalpur in Madhya Pradesh and Pisdura in Maharashtra. The first dinosaur bone in India was discovered by W.H. Sleeman from the Lameta sediments in 1828, but could be identified as of dinosaurs only after 45 years by Lydekker in 1877, who established a new species *Titanosaurus indicus* for it. A major collection mostly came from the excavation by Matley during his expedition to India in 1917-1924 and 1932-33. Huene and Matley jointly worked on the collection during the first expedition from Bara Simla and published their work in 1933. They described four sauropod and eleven species from the collection. After this, it took over 50 years to make new discovery of Late Cretaceous dinosaurs in the Indian subcontinent. The new finds included the discovery of associated abelisaurid-titanosaurid skeletons and their eggs and nest sites from Lameta of the Kheda area in Gujarat in 1981. The new finds from India and its allied southern Gondwana landmasses and emerging phylogenetic information necessitated the taxonomic revision of the Indian dinosaurs. For the Indian titanosaurifome sauropods, the current review accepts only *Isisaurus colberti* and *Jainosaurus septentrionalis* as valid. Amongst theropods presently only three large bodied abelisauridae (*Indosuchus raptorius, Indosaurus matleyi* and *Rajasaurus narmadensis*) and small bodied theropod *Laevisuchus indicus* are recognized. The lack of associated skeletons from the Indian Cretaceous has caused difficulties in establishing phylogenetic relationships amongst the Indian Late Cretaceous dinosaurs. In this context, it becomes important to collect all the missing information on the stratigraphy, horizon and location for the collection made prior to 1933 and removed from India to NMH or AMNH. There is now a need to bring all the collection together and study them for the comparative study amongst the individual and different species for taxonomic study and developing phylogenetic relationships.

Keywords: Late Cretaceous, dinosaurs, History of dinosaur studies, new finds of dinosaurs in India

INTRODUCTION

The study of Indian dinosaur fossils is crucial for understanding their origin and evolution and also the dynamic palaeobiogeography of the Indian subcontinent during Cretaceous in relation to its allied southern Gondwana landmasses. The early collection and the study of dinosaur fossils have mostly remained focused in two main areas. One is around Jabalpur in Madhya Pradesh and the other is Pisdura in Maharashtra (Fig.1). Both these localities have been yielding fossils of dinosaurs from the Lameta Formation of Late Cretaceous age for over one and half a century. The earliest finds of dinosaurs in India were by the Britons who were civil servants, army officers or palaeontologists. The pioneering work on Indian dinosaurs by Richard Lydekker, Charles Alfred Matley and Friedrich Baron von Huene (Fig. 2) laid the foundation for study of dinosaurs in India. Prior to independence of India in 1947, the study of the Indian dinosaurs involved joint efforts of the Geological Survey of India and the British geologists. After 1947, the research on dinosaurs from the Late Cretaceous and pre-Cretaceous Gondwana Group of sediments was keenly pursued by the Indian palaeontologists. A good number of new localities with well-preserved fossils of dinosaurs were located. It includes Triassic and Jurassic sediments of Pranhita and Godavari valleys in Andhra Pradesh and the bordering districts of Maharashtra (Jain *et al.*, 1962, 1975; Jain and Roychowdhari, 1987; Kutty, 1969; Yadagiri *et al.*, 1979; Yadagiri, 1986, 1988; Yadagiri and Rao, 1987) and Late Cretaceous sediments of Kheda (Dwivedi *et al.*, 1982; Mohabey, 1983) and Kutch districts in Gujarat (Fig.1). The first find of dinosaur fossil bones dates back to 1828 but the eggs of dinosaurs were found much later in 1981 after a gap of over 150 years. The early reviews on the finds and status of study of dinosaurs in India have been made by Jain (1989), Sahni (1989) and Mohabey (2001a). However, the reviews lacked information on dinosaur fossils that were excavated by British and American palaeontologists from the Lameta sediments of Jabalpur and were removed to the Natural History Museum (NHM), London and American Natural History Museum (AMNH), New York. Much of this missing information critical to the study of Indian dinosaurs has now been made available by Carrano and others (2010) through a recently published article exhaustively detailing the history of dinosaur collecting in India during 1828 to 1947 and through Archival Source from the NHM. The authors have given a detailed account of the events of the dinosaur finds, the localities, information on the handlers of the specimens, important documents and correspondence concerning the shipment of the specimens from India to London and the status of specimens.

In the present paper, the historical account of dinosaur finds in India both prior to 1947 and after 1947 till has been reviewed and presented based on the available information (Mohabey, 2001a; Caranno *et al.*, 2010) and the current status of their study is discussed.

HISTORICAL ACCOUNT

The Early Finds

The early phase of field collection of dinosaur bones beginning early 1800 to early 1900 (1828-1933) came mostly from the Lameta sediments of two localities at Jabalpur and Pisdura. The collection was handled by a series of people from

*29th M. R. Sahni Memorial Lecture delivered on March 1, 2011

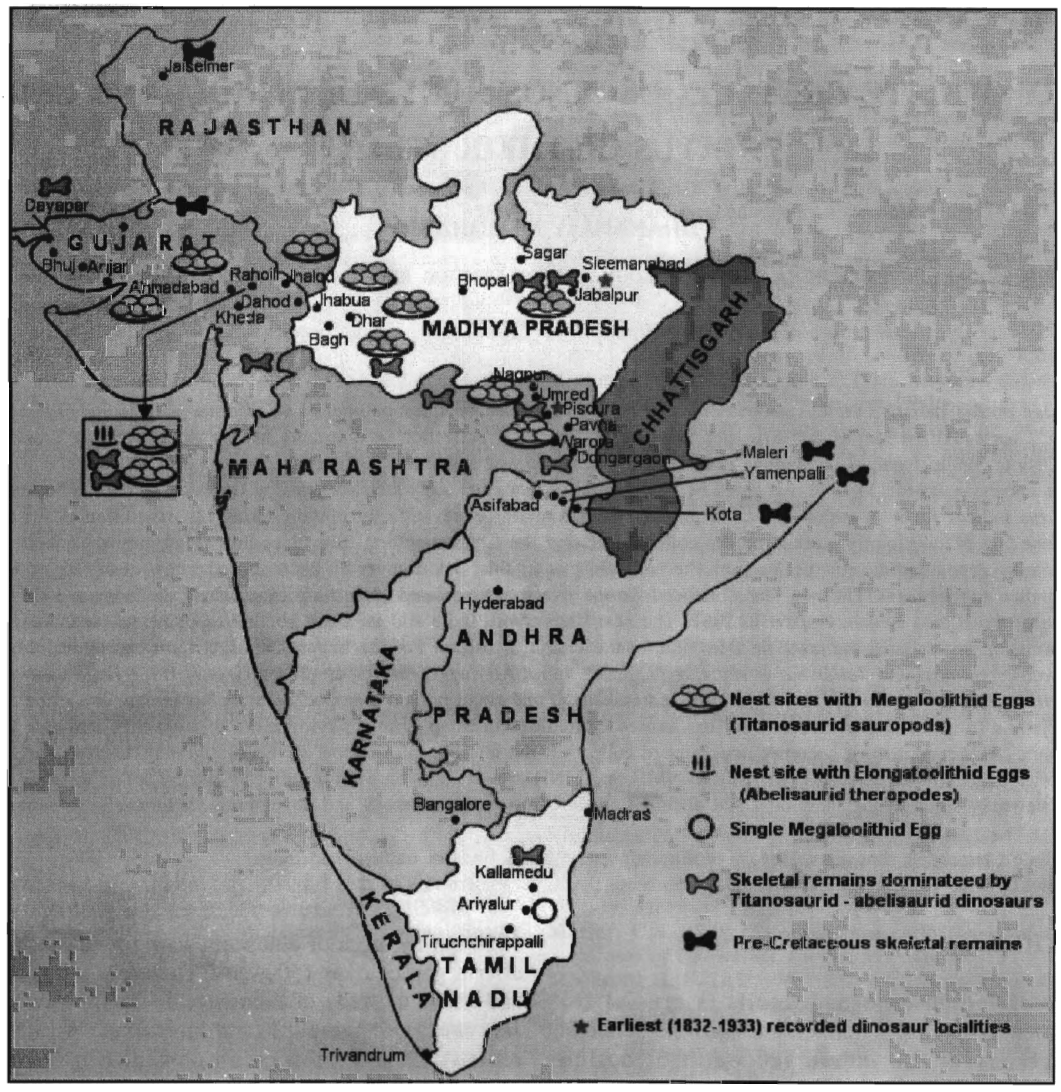

Fig. 1. Showing major Gondwanan (pre-Cretaceous) and Late Cretaceous Dinosaur fossil localities in India.

different disciplines including army persons, civil servants, missionaries, geologists and paleontologists. The specimens passed through many hands over a period of time, sometimes over a couple of decades, before they landed in right hands for their description. It was ironic that in course of the time that lapsed, the critical information on the bone yielding strata, lithology and precise locations were either not recorded or they were lost. The collection, as and when excavated, was shifted from place of their origin - Bara Simla and Chhota Simla at Jabalpur and Pisdura to Geological Survey of India (GSI) Headquarters at Kolkata to NMH, London. for preparation and description.

The history of dinosaur finds in India begins with the first report in 1828 (Princep, 1932) of fossil bones including a vertebra collected from the Lameta sediments of Jabalpur by Captain W.H. Sleeman, a British Officer in the Bengal Army (Sleeman 1844). The bones collected were passed on (Matley, 1921a,b) to a series of learned amateur paleontologists, namely from Dr. G.G. Spilsbury (1837), a medical man to James Princep in 1832 in Kolkata and finally in 1862 to Thomas Oldham - the first Director-General of Geological Survey of India. The bones were further handed over to Hugh Falconer (1868) who identified them as reptilian vertebrae (Falconer, 1868). Lydekkar (1877) studied the vertebrae from Sleeman's collection and established a new genus and species *Titanosaurus indicus* and also included a femur from the Lameta sediments of Bara Simla Hill, Jabalpur collected by Medlicott between 1871-72 (Medlicott, 1872). Lydekker also included in *T. indicus* the vertebrae from the Lameta sediments of Pisdura collected by Blandford. However, Lydekker (1879) redscribed the Blandford's specimen from Pisdura and described the cylindrical caudal vertebrae as new species *Titanosaurus blandfordi* and chevron bones as *Titanosaurus* sp. Thus, it took almost 45 years from its collection in 1828 by Sleeman to its formal description by Lydekkar in 1877 for the first dinosaur to be described from India. Meanwhile, Hislop (1860) also made collection of a few specimens including vertebrae and femur associated with coprolite, turtles and fishes from the Pisdura section. The original caudal vertebrae as collected by Sleeman and described by Lydekker (1877) is not presently traceable in Indian Museum as mentioned by Lydekker that it is deposited in the Indian Museum, Kolkata. The cast (NHM 40867) of the specimen is available in NHM (Carano *et al.*, 2010). A replica of this cast (Fig. 3) has been presented in March 2010 to GSI by Jeffrey

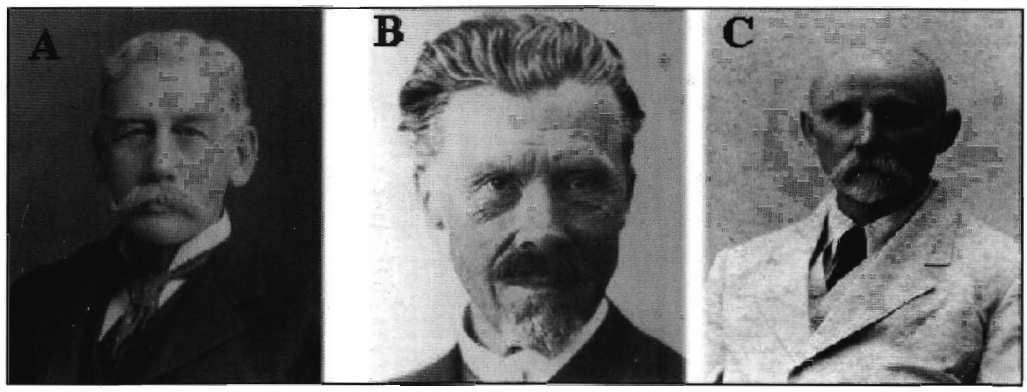

Fig. 2. Pioneering dinosaur researchers in India who, prior to independence of India, made the earliest contributions to the study of Late Cretaceous dinosaur from the Lameta Formation of Jabalpur in Madhya Pradesh and Pisdura in Maharashtra. **A.** Richard Lydekker, **B.** Friedrich Baron von Huene, **C.** Charles Alfred Matley. The classic description of the Indian Cretaceous dinosaurs collected during 1917-1924 was given in the Memoirs of GSI, *Palaeontologia indica*, 1933, Volume XXI, Memoir No. 1 by Huene von and C.A. Matley. Since then, drastic revision to the Indian Late Cretaceous sauropods (titanosauriforme) and theropods (abelisuridae and Noasauridae) has been made.

Wilson of University of Michigan Museum of Palaeontology.

The collection of dinosaur bones by W.T. Blandford from Pisdura has been described by Lydekker (1877) as *T. blandfordi* and *Laplatosaurs madagascariensis*. A single tooth from Takli intertrappean sediments near Nagpur was collected by Rawesi (Hislop, 1860) and was described as *Massospondylus rawesi* by Lydekker (1890) who served the Geological Survey of India from 1874 to 1882. Meanwhile, Hislop (1860) also made collection of a few specimens including vertebrae and femur associated with coprolite, turtles and fishes from the Pisdura section. Hughes (1877) also made a collection of dinosaur bones from the Lameta sediments which were doubtfully assigned to *Titanosaurus* by Lydekker (1879). Blandford during the surveys between the years 1857-1860 also described a bone bed of reptilian affinity from the Ariyalur Group of sediments (Blandford, 1862) near Kallamedu and also reported a single megalosaurid tooth that was referred as *Megalosaurus* (Lydekker, 1879). Narayan Rao and Sheshachar (1927) have made a reference to some carnosaurian dinosaurs from Tiruchirapalli. However, Yadagiri and Ayyasami (1987) on re-examination of the specimens identified them as bovids, perhaps recovered from the Pleistocene horizons. The Kallameddu dinosaurs were subsequently studied by Matley (1929) followed by Yadagiri and Ayyasami (1979, 1987) from the Kallamedu Formation of Late Cretaceous (Maastrichtian age).

Golden Age of Dinosaur Study in India: 1917-1933 was the period when the serious studies on dinosaurs were pursued by Charles Matley and can be described as a Golden Age of dinosaur research in India. Matley carried out a systematic excavation during two expeditions in 1917-1924 and 1932-1933. During first expedition in 1917-1924, Matley (1918, 1919, 1921a,b, 1924) mostly focused in the Lameta sediments around Jabalpur and excavated dinosaur bones mainly from western

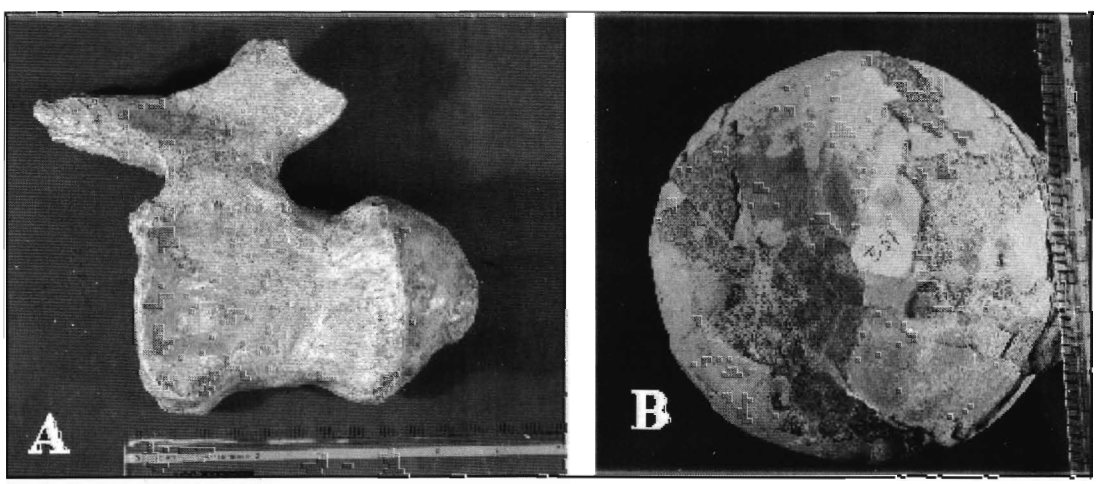

Fig. 3. Photograph of a cast of first dinosaur bone collected by W.H. Sleeman in 1828. The specimen was identified as caudal vertebrae and made a type series of *Titanosurus indicus* by Richard Lydekker (1877). The original specimen has been lost and only the cast presented to Natural History Museum, London (NHM 40867) by Falconer in 1867 is available. The replica made from the original cast has been presented by Jeffrey Wilson of University of Michigan Museum Palaeontology to Geological Survey of India in March 2010. **B.** Showing photograph of the first dinosaur egg discovered in India in January 1981 from the Lameta Formation of Balasinor Quarry of ACC in Kheda District, Gujarat. The eggs were identified as of sauropod dinosaurs in 1982 (Mohabey in 1983). Since then dozens of nest sites of sauropod dinosaur with thousands of eggs have been found in the Lameta sediments in Gujarat, Madhya Pradesh and Maharashtra.

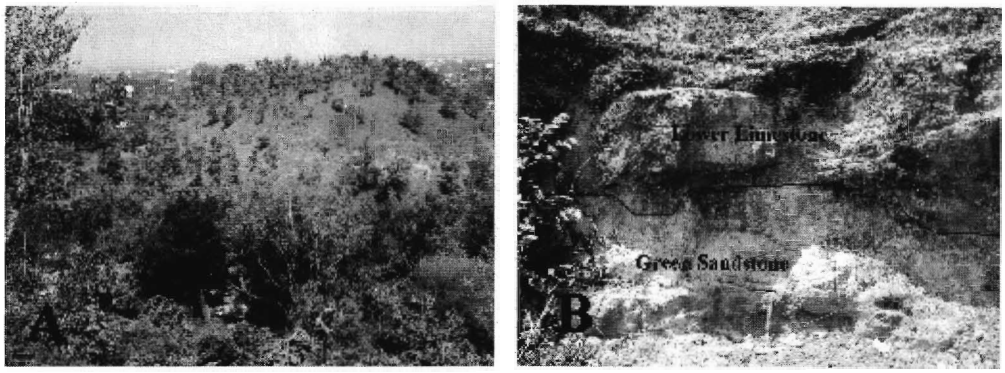

Fig. 4. Showing Chhota Simla Hill at Jabalpur where C.A. Matley in 1932-33 carried out excavation for dinosaur fossil bones in the Lameta Formation on the southwestern slope of the Hillock. **B.** Showing original excavation site of Matley at Chhota Simla. The excavation site could be located in 2008 during a field reconnaissance. The bones were excavated from the topmost part of the Green Sandstone at the contact with the Lower Limestone. Both titanosaurid and abelisaurid dinosaurs were excavated by Matley which were shipped to British Museum, London in 1933.

slope of Bara Simla from three stratigraphic levels - i) Carnosaur Bed at the contact between the Green Sandstone and Lower Limestone, ii) Ossiferous Conglomerate just at the top of the Lower Limestone and iii) Sauropod Bed in the basal part of the Mottled Nodular Bed (Huene and Matley,1933). During this expedition, Matley also visited Pisdura and Dongargaon sections (Fig.1) and collected dinosaur bones including caudal vertebrae of *T. Blandfordi* from the Lameta sediments. Caranno *et al.* (2010) mentioned that most of the sauropod bones from Bara Simla excavated by Matley during this expedition (1917-1924) was retained in India and the majority of the other collection mostly comprising theropods was shipped to London. But it is not clear if all the sauropod material retained in India was deposited with Geological Survey of India. Based on the study of the collection made during 1917-1924, Matley published his monumental work in 1933 jointly with von Huene. The collection was prepared at NMH. They named nine new theropod genera and species including six large to medium-sized theropod and three small-sized theropods (Huene and Matley, 1933). For saurpods, they named at least three genera and four species. The description of the species given by Huene and Matley (1933) is based on the fragmentary material and no associated material was reported for any of the species described. The taxonomy of the specimens from Bara Simla described by Huene and Matley (1933) has been subsequently revised by recent workers (Wilson and Updurch, 2003; Wilson *et al.*, (2003; Novas *et al.*, 2004; Wilson *et al.*, 2009). The revised diagnosis placed all the theropods species from Bara Simla in Abelisauridae excepting *Laevisuchus indicus* that is included in the Noasauridae.

Barnum Brown also visited Bara Simla in 1922 and excavated dinosaur bones from the Carnosaur Bed that was excavated earlier by Matley in 1917-1924. The collection that was removed to American Museum Natural History (AMNH) included skull bones including premaxilla (AMNH 1753), left maxilla (AMNH 1955), right dentary (AMNH 1960) associated with caudal vertebrae of Abelisauridae indet (Novas *et al.*, 2004). He also collected the specimen AMNH 1959 that was originally interpreted as tail club of Lametasaurus indicus by Huene and Matley (1933), However, the recent work on the specimen has interpreted the specimen as titanosaur osteoderm (D'Emic *et al.*, 2009).

Caranno *et al.* (2010) based on the archival documents in Natural History Museum, London, has given an excellent account of the history of the collection of dinosaur bones excavated by Matley during his second expedition to India in 1932-33 as sponsored by Percy Sladden Trust Expedition. During this expedition, Matley carried out excavation at a new locality at Chhota Simla 400 m east of Bara Simla. This was in addition to his collection at the earliest site at Bara Simla and also the collection he made from Pisdura. At Chhota Simla, the excavation was done on the southeast face of the hill around the course of a small nallah coming from the Block House on the Hill. The material excavated included an associated titanosaur skeleton and theropod material (Carrano *et al.*, 2010). During the field work in May 2008, jointly with Jeffrey Wilson and Michael D'Emic, we were able to locate the original site at Chhota Simla from where Matley in 1932-33 excavated the dinosaur bones (Fig. 4). The site was located on the southeast face of Chhota Simla close to the road and near a tomb. The excavation level was within the horizontal beds of the Green Sandstone close to its contact with the Lower Limestone (Fig. 4). We could also collect some pieces of bones from this site. Carrano *et al.* (2010) states that the fossils collected were sent to London in two shipments. Of these, the one shipment comprising 11 packages mostly from Pisdura held under the custody of Director, GSI at Kolkata, was shipped from Kolkata Port on 9th May, 1933. The other shipment consisted of 25 packages (repacked in 18 boxes), left in the care of Superintendent of Gun Carriage Factory, Jabalpur, that were sent through Mumbai Port in July, 1933. The archival documents at NHM (Caranno *et al.*, 2010) shows that all the material removed to NMH has been sent back to India (Kolkata) through a single shipment. The return collection included the type specimens and also casts of some selected specimens. It is obvious that the type specimens came only from the described collection of 1917-1924 from Bara Simla described by Huene and Matley (1933). Of these, type specimens now available in the GSI galleries in the Indian Museum and Curatorial Division, Kolkata, a number of specimens are either not traceable or lost and in a few cases only a part of the specimen is available. Wilson and co-workers (*in press*) have recently described associated post-cranial skeleton of *Jainosaurus septentrionalis* based on the material available at NHM collected by Matley in 1932-33 from Chhota Simla. The specimens were earlier described as *Titanosaurus* sp. by Swinton (1947).

Undescribed Collection by Charles Matley at Indian Museum, Kolkata: In 2007, a collection of bones comprising over 27 specimens was rediscovered in the Sivalik Gallery

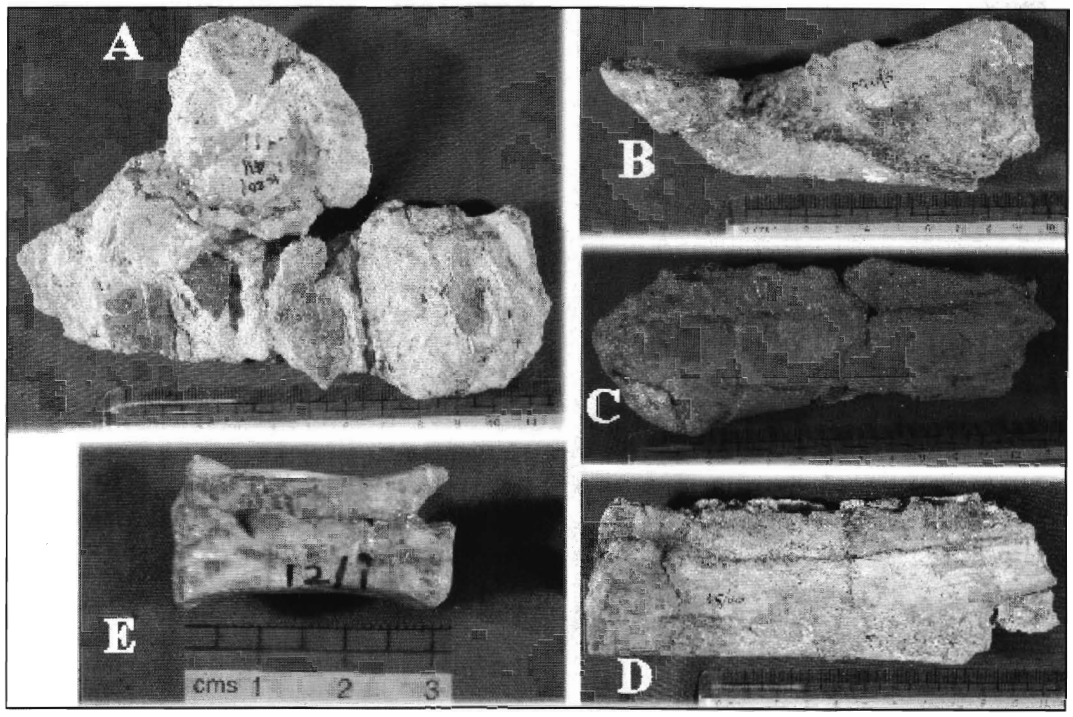

Fig. 5. Showing photographs of some important theropod specimens from the collection of C.A. Matley excavated from Chhota Simla, Jabalpur, possibly during 1932-33. The specimens hitherto not prepared and described were rediscovered in 2007 in the Indian Museum, Kolkata in the Shivalik gallery maintained by GSI. The specimens are now removed to GSI, Nagpur and presently under preparation and description. **A-D**. Abelisauridae. **A.** Left premaxilla in medial view, **B**. Right angular in medial view. **C**. Right dentary in medial view. **D.** Left dentary in medial view. **E**. Caudal vertebrae of small bodied theropod (*Laevisuchus indicus*).

maintained by GSI in the Indian Museum. The specimens include (Fig. 5) skull bones including dentaries, maxilla, premaxilla and angular having Abelisauridae affinity, a series of small vertebrae possibly of Noasauridae and a few phalanges. Majority of the specimens have been labelled under K/20 or D series. The collection from the available records is indicated to be collected by Matley from Chhota Simla during his expedition in 1932-33. The collection has been presently removed to the Palaeontology Division of GSI, Central Region, Nagpur and presently under preparation. The matrix associated with the specimens is exclusively green sand.

Dinosaurs from Gondwana Supergroup of Sediments: Following Matley's work during 1917-1933, research on dinosaur was once again revived by the efforts of Indian Statistical Institute and Geological Survey of India. The near-complete and well-preserved skeletal remains of early-sauropod *Barapasaurus tagori* (Jain *et al.*, 1962, 1975; Jain and Roychowdhari, 1987) were unearthed from the Lower Jurassic Kota Formation of Pranhita-Godavari (P-G) valley from the adjoining areas of Andhra Pradesh and Maharashtra. Its mounted skeleton is displayed in the Indian Statistical Institute (ISI) Museum, Kolkata. This skeleton has been recently redescribed with finer details by Saswati Bandyopadhyay and co-workers (Bandyopadhyay *et al.*, 2010). The authors consider *Barapasaurus* as basal in comparison to *Vulcanodon* and have excluded it from the Eusauropoda

The skeleton of the *Kotasaurus yamenpalliensis* (Yadagiri, 1988) collected from the Kota Formation near Yamenpalli (P-G valley) in Adilabad District of Andhra Pradesh (Yadagiri, 1986; Yadagiri and Rao, 1987; Yadagiri, 1988, 2001) was also reconstructed and mounted in the Birla Science Museum, Hyderabad by GSI. Nearly a complete-skeleton but with the missing skull, morphologically it is characterized by a combination of prosauropoda and sauropoda (Yadagiri, 1988, 2001). Search for dinosaurs in the Gondwana sediments of P-G valley has resulted in documenting fragmentary remains of platerosaurids and thecodontisaurid sauropods from Late Triassic (Narian-Rhaetian) Dharamaram Formation (Kutty, 1969) and a small theropod *Walkeria maleriensis*, perhaps the earliest dinosaur from Asia, from the Lower Triassic (Carnian) Maleri Formation (Chatterjee, 1987). Fragmentary dinosaur skeletal remains have also been reported from the Middle Member of the Jaisalmer Formation of Middle Jurassic (Callovian age) age near Jaisalmer in Rajasthan (Mathur *et al.*, 1985), and the early Middle Jurassic of Kuar Bet in Kutch, Gujarat (Satyanarayana *et al.*, 1999).

NEW FINDS OF DINOSAURS IN INDIAN LATE CRETACEOUS

Associated Titanosaurid-Abelisaurid dinosaurs from Gujarat

In the year 1981, while carrying out the systematic geological mapping as per the Field Season Programme of GSI, Dwivedi and Mohabey (Dwivedi *et al.*, 1982) discovered ossiferous conglomerate bed at the base of the Lameta Formation at Rahioli in Kheda District, Gujarat. This was the third major Late Cretaceous dinosaur locality in India where associated skeletons of titanosaurid and abelisaurid dinosaurs were found. The excavation was subsequently done by GSI and the bones were removed to GSI, Jaipur. From the collection based on the braincase (GSI Type No GSI/21141/1), cervical, dorsal, caudal vertebrae, sacrum, left ilium, left femur, tibia and tarsal (GSI Type 21141/1-31), a new abelisauridae *Rajasaurus*

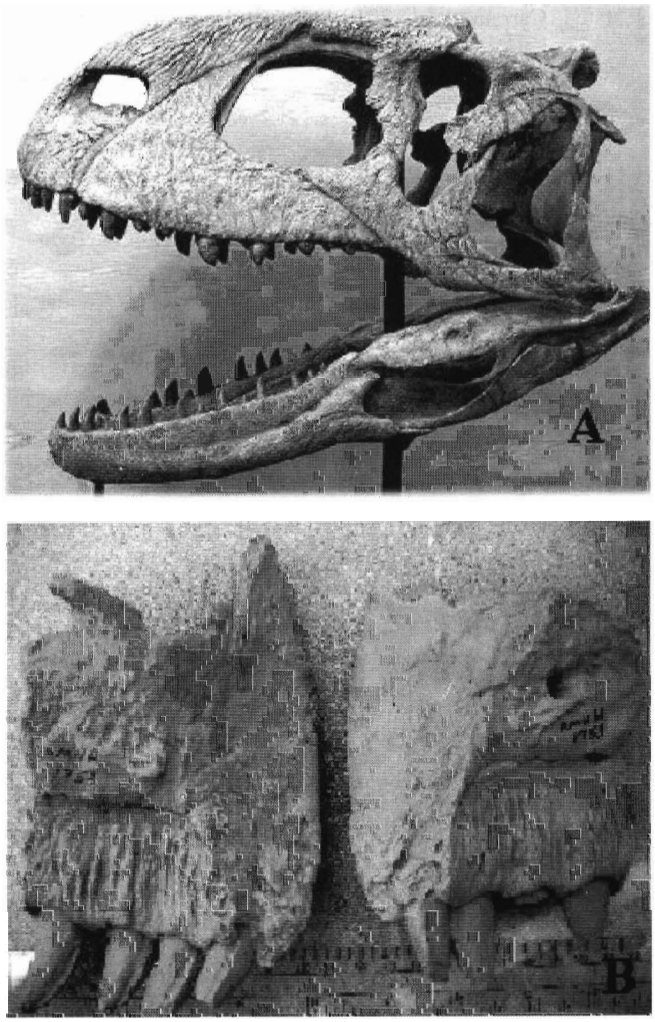

Fig. 6. **A.** Reconstructed skull of *Rajasaurus narmadensis* of a large bodied abalisauridae theropod. The new genus and species was established by Jeffrey Wilson and co-workers based on the material excavated by GSI in 1983-84 from the Lameta sediments of Rahioli in Kheda District, Gujarat. The associated bones (now GSI Type 21411/1-33) were prepared at UMMP, Ann Arbor, for the description. It is the third large bodied abelisauridae theropod described from late Cretaceous of India. **B.** Photograph from the plaster cast of the pair of premaxilla (medial view) of *Indosuchus raptorius* excavated from Lameta Formation at Bara Simla, Jabalpur by Barnum Brown in 1922 from the Carnosaur Bed (Huene and Matley, 1933). The original specimen removed from the site is now in the custody of AMNH (AMNH 1753).

narmadensis (Fig. 6) was described by Jeffrey Wilson and co-workers (Wilson *et al.*, 2003).

Ghevariya (1988) also reported associated post-cranial skeleton of sauropod (Titanosauria) dinosaur from the intertrappean bed at Anjar in Kucth, Gujarat. The dinosaur-bearing intertrappean bed is associated with two anomalous iridium-bearing clay layers at two stratigrahic levels. The sediments were interpreted as straddling the Cretaceous-Tertiary Boundary and the extraterrestrial impact was envisaged (Bhanadari *et al.*, 1995). However, no description could be made for the skeleton excavated from this section. A large collection of sauropod and theropod dinosaur bones of the Lameta sediments of the Nand-Dongargaon (N-D) Basin has also been made in recent years. Jain and Bandyopadyay (1997) have described the associated post-cranial skeleton of *Titanosaurus colberti* from Dongargaon. A Titnosauria axis has also been described from Nand by Wilson and Mohabey (2006). However, most collection from the N-D basin including Pisdura is fragmentary and taxonomic identification is challenging.

Eggs and nest sites: The first discovery of dinosaur eggs and nest sites in India in the year 1981 (Mohabey, 1983) from the Late Cretaceous (Maastrichtian) Lameta Formation in Kheda District, Gujarat resulted in the revival of the dinosaur research in India. The find became more significant as the associated skeletal remains of titanosaurid saurpopds and abelisaurid theropods were also reported from the eggs and nest-bearing sediments (Dwivedi *et al.*, 1982) in the area. A wide diversity was recorded in the Indian dinosaur eggs which were assigned parataxonomically to different oospecies of Megaloolithidae attributed to sauropod dinosaurs (Srivastava *et al.*, 1986; Mohabey, 1996, 1998; Khosla and Sahni, 1995). Nest sites with eggs assigned to *Ellipsoolithus khedaensis* of Elongatoololithidae oofamily assigned to Abelisauridae theropods (Mohabey, 1998; Loyal *et al.*, 1999) were also reported. The occurrence of eggs and nest sites were subsequently recorded from the Lameta Formation of Jabalpur and Bagh valleys, Madhya Pradesh and Nand-Dongargaon Basin in Maharashtra (Mohabey, 1996; Mohabey, 2001; Wilson and Mohabey, 2006). The study of eggs and nest sites suggested that environments offered an ideal niche for the habitat of the titanosaurid-abelisaurid dinosaurs with the acme to breeding and nesting activity during Late Cretaceous (Maastrichtian) in India.

Dinosaur Dung Mass: The first report of coprolite in India goes back to 1857 when Hislop (1960) collected a coprolite specimen from the red clays of the Lameta Formation at Pisdura. Matley (1939) also made collection of over 600 coprolites from this section and described four types of coprolites based on size, shape and morphology. The type A coprolites with diameter between 70-100 mm, ovoid to circular in cross-section with smooth surface and rounded segments were assigned to sauropods. Coprolites were found along with the skeletons of titanosaurid sauropods. No plant tissues were observed by him in any specimens and doubts were always raised (Chin, 1997) on assigning them to sauropods. However, in 1999 a number of Type A coprolites with prolific plant tissues were collected from Pisdura (Mohabey, 2001b). The coprolitic mass comprises comminuted soft plant tissues of gymnosperms, conifers and angiosperms (Mohabey, 2001a, 2005; Ghosh *et al.*, 2003). Wide diversity in plant tissues suggested a multiple source for the sauropod diet which preferably consumed softer plant tissues. Pteridophytic spores, pollen grains of gymnosperms and angiosperms (Mohabey and Samant, 2003) have also been observed in the coprolitic mass (Mohabey and Samant, 2003; Samant and Mohabey, 2009). Diverse morphotypes of phytoliths of grass family (Poaceae) have been recorded from the coprolites by Prasad *et al.* (2005). This indicated that different subclades of Poaceae existed during the Late Cretaceous in India.

Snake-Sauropod Association: An articulated snake fossil within a sauropod nesting ground in association with eggs and a hatchling has been described from the Lameta Formation of Dhori Dungri in Panchmahals District, Gujarat (Wilson *et al.*, 2010). A unique specimen in the world of a Late Cretaceous madtsoiidae (Alethinoophidia) snake *Sanajeh indicus* predating upon hatchling saurpod was excavated from the Lameta Formation of Dhoridungri by Mohabey (1987). The fossil association has provided insight into the feeding ecology of wide-gape early snakes and predation risk on sauropod

dinosaurs. The partial skeleton of the hatchling sauropod, though found in anatomical articulation in association with sauropod (megaloolithid) eggs, is not sufficiently diagnostic for species level identification. Another new species of the snake *Madtsoia* (*Madtsoia pisdurensis* n. sp.) has been described recently from the Lameta sediments of Pisdura (Mohabey *et al.*, 2011). The associated precloacal vertebrae of a large-bodied snake (ca. 5 m long) possess a unique haemal keel morphology with distinct process triangular in ventral view. This constitutes the discovery of fourth species of giant snake *Madtsoia* and provides evidence of trans-Gondwanan distribution of large-bodied madtsooid snakes during the Cretaceous.

DISCUSSION

Knowledge on the Indian Late Cretaceous dinosaurs is mainly based on the monumental work done by Charles Matley on the collection he made from the excavation during his two expeditions to India between 1917-1924 and 1932-33. Most of his collections came from the Lameta Formation at Bara Simla and Chhota Simla, Jabalpur. For the material he excavated during the first expedition at least nine new theropod genera and three sauropod genera were named (Huene and Matley, 1933). The theropod specimens described mostly came from the Carnosaur Bed at Bara Simla. Subsequent taxonomic revision of the theropod specimens by Novas *et al.* (2004) demonstrates that all the material emerging from the Carnosaur Bed can be placed in a single theropod clade - the Abelisauroidea. This include two large-bodied ablisuridae *Indosaurus matleyi and Indosuchus raptorius* (Huene and Matley, 1933; Chatterjee, 1978; Chatterjee and Rudra, 1996). To this list was added the third large-bodied abelisaurid theropod *Rajasaurus narmadensis* by Wilson and co-workers (Wilson *et al.*, 2003) based on the material excavated by GSI from the Lameta sediments of the Kheda area in Gujarat. Of the three small-bodied theropods, *Laevisuchus indicus, Jubbulporuria tenuis and Compososuchus solus* described by Huene and Matley (1933) only *Laevisuchus indicus* is presently considered as valid. A partial dentary from the Lameta Formation of Pisdura has been recently discovered which pertains to *Laevisuchu indicus* or a closely related noasaurid dinosaur, which presently is under description (Mohabey and Wilson, *under preparation*).

Huene and Matley (1933) described three Indian Late Cretaceous sauropod genera (*Titanosaurus*, *Antarctosaurus* and *Laplatosurus*) having closely related species on the southern Gondwanan landmasses. The current review (Wilson and Upchurch, 2003) of the species does not consider *Titanosaurus* as a valid Indian genus and as such is *nomen dubium. Laplatosaurus* is also currently recognized to be restricted to South America and as such the Indian species is invalid. Amongst Indian Titanosauria, only *Isisaurus* (=*Titanosaurus*) *colberti* (Jain and Bandyopadhyay, 1997; Wilson and Upchurch, 2003) and *Jainosaurus septentrionalis* (Huene and Matley, 1933; Hunt *et al.*, 1994; Wilson and Upchurch, 2003; D'Emic *et al.*, 2010; Wilson *et al.*, *in press*) are currently considered as valid having associated with partial skeleton. In many cases, the fragmentary Indian specimens restrict their valid taxonomic identification. A part of the dinosaur collection removed from India during the expeditions by Matley in 1917-1924 and 1932-1933 and Barnum Brown in 1922 is presently available in the NHM and AMNH (PL. V). It is stated (Carrano *et al.*, 2010) that a series of specimens were shipped back to India from London; still there are specimens which are untraceable in the Indian Museum. The collection which is now available in parts in the Indian Museum, Kolkata, NHM and AMNH has come exclusively from two adjoining localities at Bara Simla and Chhota Simla which are geographically separated by a distance less than 400m. It is required that the Indian collection which now stands distributed at three places on three continents are brought together for their better taxonomic study and for comparison amongst the individual and different species. This would be an important exercise for establishing their phylogenetic relationships. If the original Indian specimens from abroad cannot be repatriated back to India, at least the casts of the specimen can be provided to the Indian Museum.

No Titanosauria or Abelisauroid dinosaurs have so far been reported from the Indian Middle Cretaceous or older horizons. Records of their prolific nest sites and eggs of wide diversity and geographic distribution suggest that the Indian titatanosaurs were at the acme of their activity during Indian Late Cretaceous that provided an ideal niche for their habitat. A wide diversity in the Indian eggs (Megaloolithidae) of sauropod affinity is present (Mohabey, 1998). Comparatively, the skeletons found so far indicate presence of fewer species of titanosaurs. This suggests that a couple of species of eggs may be variants laid by the same species of sauropods or possibly corresponding to more species of sauropods existed, the skeletons of which awaits discovery. The study based on the orbital cycles and stable carbon isotopes of the dinosaur-bearing sediments suggests (Hansen *et al.*, 2001, 2005) that the Indian Late Cretaceous Titanosauriform and abelisaurid dinosaurs were introduced during the magnetochron C30N, ca. 500 K before the Cretaceous-Palaeogene (K-Pg B) Boundary and were terminated ca. 350 K before the K-pg-B. The dinosaur fossil evidence suggests that initiation of Deccan Continental Flood Basalt (DCFB) eruption proved fatal for the dinosaur and they struggled hard to survive. The last survivors were the one or two species of Titanosauriforme sauropods, the associated skeleton of which have been found in the intertrappean sediments of DCFB sequences deposited during Maastrichtian magnetochron 29R.

ACKNOWLEDGEMENTS

The author is thankful to the Palaeontological Society of India, Lucknow, for giving an honour of delivering the 29th M.R. Sahni Memorial Lecture. Discussions with Jeffrey Wilson of University of Michigan Museum Paleontology, have benefited the manuscript. The permission by Dr. K. Rajaram, Deputy Director General, Geological Survey of India, Central Region, Nagpur, for publishing the paper is sincerely acknowledged.

REFERENCES

Bandyopadhyay, Saswati, Gillet, D., Ray, S. and Sengupta, D.P. 2010. Osteology of Barapasaurus tagorei (Dinosauria:Sauropoda) from early Jurassic of India. *Journal Vertebrate Paleontology*, **53**(3): 533-569.

Bhanadari, N., Shukla, P.N., Ghevariya, Z.G. and Sunderam, S.M. 1995. Impact did not trigger Deccan volcanism: evidence from Anjar K/T boundary intertrappean sediments. *Geophyical Research Letter*, **22**: 433-436.

Blandford, H.F. 1862. On the Cretaceous and other rocks of south Arcot and Trichnapoly Districts, Madras. *Memoirs of Geological Survey of India*, **IV**(1): 1-217.

Carrano, M.T., Wilson, J.A. and Barrett, P.M. 2010. The history of dinosaur collecting in Central India, p. 1828-1947. In: *Dinosaur and other extinct Saurians: A historical Perspective* (Eds. Moody, R.T.J., Bufftaut, E., Naish, D. and Martill, D.M), *Geological Society, London, Special publications*, **343**.

Chatterjee, S. 1978. *Indosuchus* and *Indosaurus*, Cretaceous carnosaurs from India. *Journal of Paleontology*, **52:** 570–580.

Chatterjee, S. 1987. A theropod dinosaur in India with remarks on the Gondwanan-Laurasian connection in the Late Triassic, p. 183-189 In: *Gondwana Six: Stratigraphy, Sedimentology and Palaeontology* (Ed. Mckenzie, G. D.), Geophysical Monograph, American Geophysical Union, **41**.

Chatterjee, S. and Rudra, D. K. 1996. K T events in India: impact, rifting, volcanism and dinosaur extinction. *Memoirs of the Queensland Museum*, **39:** 489–532.

Chin, K. 1991. Coprolite, p. 147-150. In: *Encyclopedia of Dinosaurs* (Eds. Currie, P. J. and Padian, K.), Academic Press.

D'Emic, M. D., Wilson, J. A. and Chatterjee, S. 2009. The titanosaur (Dinosauria: Sauropoda) osteoderm record: review and first definitive specimen from the Upper Cretaceous of India. *Journal of Vertebrate Paleontology*, **29**: 165–177.

Dwivedi, G.N., Mohabey, D.M. and Bandyopadyay, S. 1982. On the Discovery of vertebrate fossils from Infratrappean Lameta beds, Kheda District, Gujarat. *Current Trends in Geology*, **7**: 79-87.

Falconer, H. 1868. Memorandum of two remarkable vertebrae sent by Dr. Oldham from Jubbulpore–Spilsbury's bed, p. 418-419. In: *Palaeontological Memoirs and Notes of the Late Hugh Falconer.* (Ed. Murchison, C.), Volume I. *Fauna Antiqua Sivalensis.* Robert Hardwicke, London.

Ghevariya, Z.G. 1988. Intertrappean dinosaur fossils from the Anjar area. Kachchh District, Gujarat. *Current Science*, **257**: 248-251.

Ghosh, P., Bhattacharya, S.K., Sahni, A., Kar, R.K., Mohabey, D.M. and Ambwani, K. 2003. Dinosaur coprolites from Late Cretaceous (Maastrichtian) Lameta Formation of India: isotopic and other markers suggesting a C3 plant diet. *Cretaceous Research*, **24**: 743-750.

Hansen, H.J., Mohabey, D.M,. and Toft, P. 2001. No K-T boundary at Anjar, Gujarat,India: evidence from magnetic susceptibility and carbon isotopes. *Proceedings Indian Academy of Sciences (Earth and Planetary Science),* **11:** 133-142

Hansen, H.J., Mohabey, D.M., Lojen, S. and Sarkar, A. 2005. Orbital cycles and stable carbon isiotopes of sediments associated with Deccan volcanic suite, India: implications for stratigraphic correlation and Cretaceous/Tertiary Boundary. *Gondwana Geological Magazine, Special Volume* **8:** 5-28.

Hislop, S. 1860. On the Tertiary deposits, associated with trap-rock, in the East Indies. *Quarterly Journal of the Geological Society, London*, **16**: 154–166.

Hunt, A.G., Lockley, M.G., Lucas, S.G. and Meyer, C.A. 1994. The global sauropod fossil record. *GAIA*, **10:** 262-279.

Huene, F. von and Matley, C. A. 1933. The Cretaceous Saurischia and Ornithischia of the Central Provinces of India. *Memoirs of Geological Survey of India, Palaeontologia Indica,* **21**: 1–72.

Hughes, T. W. H. 1877. The Wardha Valley coal field. *Memoirs of the Geological Survey of India*, **13**: 1–154.

Jain, S.L. 1989. Recent dinosaur discoveries in India. Including eggshells, nests and coprolites, p. 99-108. In: *Dinosaur Tracks and Traces* (Eds. Gillet, D.D. and Lockley, M.G.), *Cambridge University Press.*

Jain, S. L. and Roychowdhari, T. (1987). Fossil vertebrates from Pranhita-Godavari valley (India) and their stratigraphic correlation. *Gondwana Six: Straigraphy, Sedimentology and Palaeontology*, **41**: 219-227.

Jain, S.L. and Bandyopadyay, S. 1997. New titanosurid (Dinosauria:Sauropopda) from the Late Cretaceous of Central India, *Journal of Vertebrate Paleontology*, **17**(1): 114-136.

Jain, S.L., Robinson, P.L. and Roychowdhari, T. 1962. A new vertebrate fauna from the early Jurassic of the Deccan, India. *Nature*, **194**: 755-757.

Jain, S.L., Kutty, T. S., Roychowdhari, T. and Chatterjee, S. 1975. The sauropod dinosaur from the Lower Jurassic Kota Formation of India. *Proceedings Royal Society, London,* **A. 188**: 221-228.

Khosla, A. and Sahni, A. 1995. Parataxonomic classification of the Late Cretaceous dinosaur eggshells from India. *Journal of the Palaeontological Society of India*, **40**: 87-102.

Kutty, T.S. 1969. Some contributions to the stratigraphy of Upper Gondwana formations of Pranhita-Godavari valley, Central India, *Journal of Geological Society of India*, **10**(1): 33-48.

Loyal, R.S., Mohabey, D.M., Khosla, A. and Sahni, A. 1999. Status and paleobiology of the Late Cretaceous Indian theropods with description of new theropod eggshells oogenus *Ellipsoolithus khedaensis* from the Lameta Formation, district Kheda, western India, p. 379-387. In: *Aspects of theropod biology* (Eds. Perez-Moreno B.P., Holtz, A., Sanz, J.L. and Mortella, J.), *GAIA*, **15.**

Lydekker, R. 1877. Notices of new and other Vertebrata from Indian Tertiary and Secondary rocks. *Records of Geological Survey of India*, **10**: 30–43.

Lydekker, R. 1879. Indian Pre-tertiary Vertebrata. 3. Fossil Reptilia and Batrachia. *Memoirs of the Geological Survey of India: Palaeontologia Indica*, Series **4**(1): 1–35.

Lydekker, R. 1890. Note on certain vertebrate remains from the Nagpur district. *Records of Geological Survey of India,* **23**: 21–24.

Mathur, U. B. and Pant, S. C. 1986. Sauropod dinosaur humeri from Lameta Group (Upper Cretaceous–?Palaeocene) of Kheda District, Gujarat. *Journal of the Palaeontological Society of India,* **31**: 22–25.

Mathur, U.B., Pant, S.C., Mehra, S. and Mathur, A.K. 1985. discovery of dinosaur reminbs in the Middle Jurassic of Jaisalmer, Rajasthan, western India. *Bulletin Indian Geologists Association,* **18**(2): 59-65.

Matley, C. A. 1918. Note on some dinosaurian remains recently discovered in the Lameta beds at Jubbulpore. *Journal of Asiatic Society of Bengal*, New Series, **14**: clxxxvi–clxxxvii.

Matley, C. A. 1919. On the remains of carnivorous dinosaurs from the Lameta beds at Jubbulpore. *Journal of the Asiatic Society of Bengal, New Series*, **15**: cxcviii–cxcix.

Matley, C. A. 1921a. On the stratigraphy, fossils and geological relationships of the Lameta Beds of Jubbulpore. *Records of Geological Survey of India*, **53**: 142–164.

Matley, C. A. 1921b. The rocks near Lameta Ghat (Jubbulpore district). *Records of Geological Survey of India*, **53**: 165–169.

Matley, C.A. 1924. Note on an armourd dinosaur from the Lameta Beds of Jubbalpore. *Records of Geological Survey of India*, **55:** 105-109.

Matley, C.A. 1929. On the Cretaceous dinosaurs of Trichnopoly district and the rocks associated with them. *Records of Geological Survey of India*, **61**(4): 337-349.

Matley, C.A. 1939. The coprolites of Pistetdura, Central Province. *Records of Geological Survey of India,* **74**: 535-547.

Medlicott, H. B. 1872. Note on the Lameta or infratrappean formation of Central India. *Records of Geological Survey of India*, **5**: 115–120.

Mohabey, D.M. 1983. On the occurrence of dinosaurian fossil eggs from infratrappean Limestone, Kheda District, Gujarat. *Current Science*, **52**(4): 1194-1195.

Mohabey, D.M. 1987. Juvenile sauropod dinosaur from Upper Cretaceous Lameta Formation of Panchmahals District, Gujarat, India. *Journal of Geological Society of India,* **30**: 210-216.

Mohabey, D.M. 1996. A new specie of Megaloolithus matleyi from the Lameta Formation (Upper Cretaceous) of Chandrapur District, Maharashtra and general remarks on the palaeoenvironment and nesting behaviour of dinosaurs. *Cretaceous Research*, **17**: 183-196.

Mohabey, D.M. 1998. Systematics of Indian Upper Cretaceous dinosaur and chelonian eggshells. *Journal of Vertebrate Paleontology*, **18**(2): 348-362.

Mohabey, D.M. 2001a. Indian Dinosaur Eggs: A review. 2001. *Journal of Geology*, **58**: 479-508.

Mohabey, D.M. 2001b. Dinosaur eggs and dung mass (fecal mass) from Late Cretaceous of Central India: Dietary implications. *Records of Geological Survey of India*, Special Publication, **64:** 605-615.

Mohabey, D.M. 2005. Late Cretaceous (Maastrichtian) nest, eggs and dung mass (coprolites) of sauropods (Titanosaurs) from India, p. 466-489. In: *Thunder Lizards* (Eds. Tidwell, Virginia and Carpenter, Kenneth), Indiana University Press, Bloomington.

Mohabey, D.M. and Samant, B. 2003.Floral remains from Late Cretaceous fecal mass of sauropods from Central India; Implications to their diet and habitat, p. 255-238. In: *Recent developments in micropalaeontology* (Ed. Kundal, P.), *Gondwana Geological Magazine*, Special Volume, **6.**

Mohabey, D.M., Head, J.J. and Wilson, J.A. 2011. A new species of the snake Madtsoia from the Upper Cretaceous of India and its palaeobiogeographic implications. *Journal of Vertebrate Paleontology*, **31**(3): 588-595.

Narayan Rao, C.R. and Sheshachar, B.R. 1927. A short note on certain fossils taken from Ariyalur area, South India, *Journal of Mysore University*, **1**(2): 144-152.

Novas, F. E., Agnolý n, F.L. and Bandyopadhyay, S. 2004. Cretaceous theropods from India: a review of specimens described by Huene and Matley (1933). *Revista del Museo Argentino de Ciencias Naturales*, Nuevo Series, **6**: 67–103.

Prasad, V., Stromberg, C.A.E., Alimohammadia, H. and Sahni, A. 2005. Dinosaur coprolites and early evolution of grasses and grazers. *Science*, **30**: 1177-1180,

Prinsep, J. 1832. Note on the Jabalpur fossil bones. *Journal of the Asiatic Society of Bengal*, **1:** 456–458.

Sahni, A. 1989. Palaeoecology and palaeoenvironments of Late Cretaceous dinosaur eggshell sites fom Peninsular India, p. 179-185. In: *Dinosaur Tracks and Traces* (Ed. Gillet, D.D. and Lockley, M.G)., Cambridge University Press.

Samant, B. and Mohabey, D.M. 2009. Palynoflora from Deccan-volcano-sedimentary sequence (Cretaceous-Palaeogene transition) of central India: implications for spatio-temporal correlation. *Journal Biosciences*, **34**(5): 811-823.

Satyanarayana, K., Dasgupta, D.K., Dave, A. and Das, K.K. 1999. Record of skeletal remains from early Middle Jurassic of Kuar bet, Kutch, Gujara. *Current Science*, **77**(5): 639-641.

Sleeman, W. H. 1844. *Rambles* and *Recollections of an Indian Official. Volume I.* J. Hatchard and Sons, London.

Spilsbury, G. G. 1837. Notice of new sites of fossil deposits in the Nerbudda Valley. *Journal of Asiatic Society of Bengal*, **6**: 487–489.

Srivastava, S.K., Mohabey, D.M., Sahni, A. and Pant, S. 1986. Upper Cretaceous dinosaur egg clutches from Kheda District, Gujarat, India), their distribution, shell ultrastructure and palaeoecology. *Palaeontogrphic*a, **A 193:** 219-233.

Swinton, W.E. 1947. New discoveries of Titanosurus indicus Lyd. *Annals and Magazine of Natural History* **(Series 11), 14:** 112-123.

Wilson, J.A. and Upchurch, P. 2003. A revision of Titanosaurus Lydekker (Dinosauria-Sauropoda), the first dinosaur genus with Gondwanan distribution. *Journal of Systematic Palaeontology*, **1**(3): 125-160.

Wilson, J.A. and Mohabey, D.M. 2006. A Titanosauriform (Dinosauria:Sauropoda) axis from the Lameta Formation (Upper Cretaceous:Maastrichtian) of Nand, Central India. *Journal of Vertebrate Palaeontology*, **26**(2): 471-479.

Wilson, J.A., Sereno, P.C., Srivastava, S., Bhatt, D.K., Khosla, A. and Sahni, A. 2003. A new Abelisaurid (Dinosauria: Theropoda) from the Lameta Formation (Cretaceous: Maastrichtian) of India. *Contributions from the Museum of Palaeontology, University of Michigan*, **31**(1): 1-42.

Wilson J.A., D'emic, Michael, D., Curry Rogers, K.A., Mohabey, D.M. and Sen, S. 2009. Reassessment of the sauropod dinosaur Jainosaurus (=Antarctosaurus) septentrionalis from the Upper Cretaceous of India. *Contributions from the Museum of Palaeontology, University of Michigan*, **32**(2): 17-40.

Wilson, J.A., Mohabey, D.M., Peters, S.E. and Head, J.J. 2010. Predation upon hatchling dinosaur by a new snake from the Late Cretaceous of India. *PLoS Biology,* **8**(3): 1-10

Wilson, J.A., Barrett, P.M. and Carranos, M.T. An associated partial skeleton of *Jainosaurus septentrionalis* (Dinosauria: Sauropoda) from the Late Cretaceous of Chhota Simla, Central India. *Palaeontology (in press)*.

Yadagiri, P. 1986. Lower Jurassic vertebrates from Kota Formation, Pranhita-Godavari valley, India. *Journal of the Palaeontological Society of India*, **31**, 89-96.

Yadagiri, P. 1988. A new sauropod *Kotasurus yamenpalliensis* from Late Jurassic Kota Formation, India. *Records Geological Survey India*, **11**, 3-8: 102-107.

Yadagiri, P. 2001. The osteology of Kotasaurus yamanpalliensis a sauropod dinosaur from the early Jurassic Kota Formation. *Journal Vertebrate Palaeo*ntology, **21**(2): 242-252.

Yadagiri, P. and Rao, B.R.J. 1987. Contribution to the stratigraphy of vertebrate fauna of Lower Jurassic Kota Formation, Pranhita-Godavari valley, India. *Palaeobotanist*, **36**: 230-244.

Yadagiri, P. and Ayyasami, K. 1987.A carnosaurian dinosaur from the kallamedu Formation (Maastrichtian Horizon), Tamil Nadu. *Geological Survey of India, Special Publication,* **11**(I): 523-528.

Yadagiri, P., Prasad, K. N. and Satsangi, P.P. 1979. The sauropod dinosaur from Kota Formation of Pranhita-Godavari valley, India. p. 190-203. In: *Fourth International Gondwana Symposium* (Eds. Laskar, B and Raja Rao, C.S.), *Geological Survey of India.*

Manuscript Accepted July 2011