Review of dinosaur egg fossils from Gujarat State, India

A real life size model of Sauropod Dinosaurs *Rajasorus narmadensis* at the Fossils Park, Indroda, GEER Foundation, Gandhinagar, Gujarat. This dinosaur's fossils were excavated at Narmada River Valley area. (Photo: Raju Vyas)

Abstract:

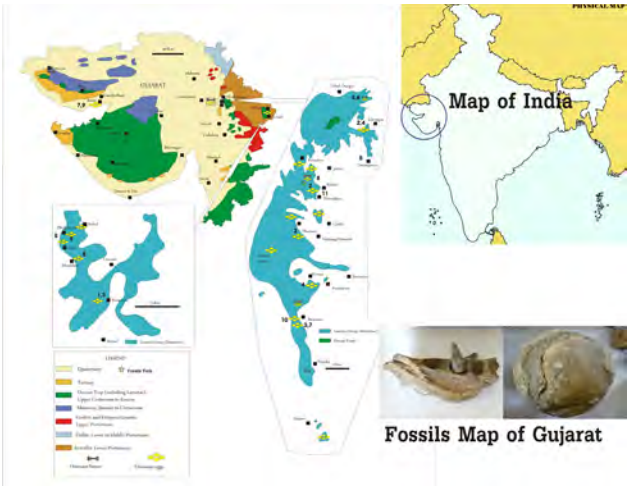
Literature surveys show nine oospecies, excluding three (uncertain) identified dinosaur eggs, recorded from various localities across India. Global research on the subject indicates the presence of some of these or similar oospecies in Europe (France), South America (Argentina), and Africa (Morocco). Such affinities and similarities in egg taxa suggest close phylogenetic relationships as well as the probable existence of a terrestrial connection for dinosaur fauna between erstwhile landmasses of present-day India, Europe (France), South America (Argentina), and Africa (Morocco) during the Late Cretaceous in between Gondwanaland and India.

Dinosaurs and their egg fossils

A reptilian egg is one of the most significant evidence of evolutionary history tracing the origins of life. Reptiles were the first tetrapod vertebrates that vacated the waters to begin terrestrial life on earth, thus evolving advanced reproductive mechanisms through the process of laying calcareous eggs. The study of fossilized reptilian eggs, especially those of dinosaurs, is most essential

and warranted for scientists to know the evolutionary histories of life in terms of the rise and fall of the dinosaurian era on Earth. By studying dinosaur eggs, we can infer upon not only the reproductive system and behaviour of dinosaurs but also the palaeo-environment, palaeo-climate, and palaeo-ecology in which they once lived. Moreover, dinosaur eggs are useful for stratigraphic division and correlation as well as paleo-biogeographic interpretations.

Dinosaurs and other dinosaur-remnant animals evolved on our planet about 200 million years ago, during the early Permian period and later diversified/ flourished during the Jurassic period of the Mesozoic era. There were a number of theories about their mass extinction, with the most popular theories explaining an extra-terrestrial impact, such as an asteroid or comet, or a massive bout of volcanism. Either scenario would have choked the skies with debris that starved the Earth of the sun's energy, throwing a wrench in photosynthesis and sending destruction up and down the food chain. Once the dust settled, the greenhouse gases locked in the atmosphere would have caused the temperature to soar, a swift climate swing that toppled much of the life that survived the prolonged darkness. Most of the dinosaur fossils, however, occur with sediment rocks. These sediments are Triassic, Jurassic, and Cretaceous sediments indicating that at least these systems must be post-flood (Garner 1996).



Gujarat State with various excavation sites of dinosaur fossils and egg fossils. Numbers from 1 to 12 correspond with Table 1 showing locations of each oospecies (map revised and compiled after Mariela et al. 2014)

Extinction of dinosaurs

Across the globe, the last batch of dinosaurs could not survive the climatic catastrophic event known as the Cretaceous-Tertiary boundary (KTB) mass extinction event, which is dated to have occurred 65 million years ago. In the Indian context, this age has a special implication as it not only corresponds with one of the peak activities of the Deccan volcanic eruptions but is also coincidental with the Chicxulub Impact crater in the Central Americas (Adatte et al. 2014). Both these events, though did not occur simultaneously, must have added to the deterioration of climatic and environmental factors leading to the destruction of nearly 65–70 % of all life on Earth.

Fossils of dinosaur eggs

Eggs are the reproductive byproducts of an environmental adaptation within a distinct phase of vertebrate evolutionary history. The evolutionary trend, i.e., concluding mode, was obtained from the lowest grade to the highest. There were six basic types of amniote vertebrate eggshells, namely Geckoid, Crocodiloid, Testudoid, Dinosauroid-spherulithic, Dinosuroid-prismatic, and Ornithoid. Among these, the last three types are considered dinosaur eggs (Hirsch 1994). On the basis of para-taxonomy of eggshell structure, the work done at present helps to divulge and place the observed dinosaur eggs in their proper systematic position and to correlate evolutionary history. The mould of dinosaur eggs possesses sediments, which helps to know the Cretaceous mode and trends of climatic fluctuations. Applying microscopy, new research has been done in recent years on the fossil dinosaur eggs. The results come out with the discovery of extreme diversity in microscopic structures of eggshells. If a comparison of the cross-sectional study is being done to establish the taxonomic position, potentially consistent evolutionary direction and ancestral relationship could be erected. Chinese palaeontologist Zhao (1975, 1979) made a para-taxonomic classification for classifying dinosaur eggs and the material of eggshells. He classified them into seven distinct families. The para-taxonomic classification was combined with the structural classification of fossil eggs and their shells. Taxonomically valuable features of the eggshell, ultra-structure, and histo-structure are its base. Three hierarchical categories—oofamily, oogenus, and oospecies—were taken into account in classifying fossil egg para-taxa. The usual morphological features like sculpture, shape, size, and colour of the egg and ranges of shell thickness and its detailed micro-structures can be used as keys of central importance for preliminary specimen identification (Mikhailov 1987, 1991; Mikhailov et al. 1996).

The highest number of dinosaur egg fossils were found from a scrubland of Rahioli Village, Mahi Sagar District, Gujarat, India. This site is now called Fossil Park and is one of the best sites for the study of dinosaur fossils (Photo: Raju Vyas).

Dinosaur fossils in Gujarat

Classification of the Indian dinosaur eggs and eggshell material was established in an entirely new manner by Khosla & Sahni (1995) and Mohabey (1998). They proposed a new para-taxonomic scheme for the classification

of dinosaur eggs and eggshell material. This para-taxonomic scheme is on the basis of the description of the new oospecies and is in contrast with their previous acquainted forms. Several oospecies were reported from India and were consigned to the oofamily Megaloolithidae of Sauropod (lizard-hipped) and Theropod (beast-footed) group to the oofamily Subtiliolithidae of avian group.

Palaeontology study demonstrates that five dinosaur fossils occur (*Titanosaurus indicus* Lydekker, 1877; *T. rahioliensis* Mathur & Srivastava, 1987; *Rajasorus narmadensis* Wilson et al., 2003; *Rahiolisaurus gujaratensis* Novas et al., 2010; and *Indosuchus* sp. Huene & Matley, 1933, along with dinosaurs eating the snake *Sanajeh indicus* Wilson et al., 2010) where from most oospecies fossils are excavated in the state. It is, however, most difficult to further demonstrate oospecies and its prenatal connection (their parent producers) or the origins from any specific species of dinosaurs.

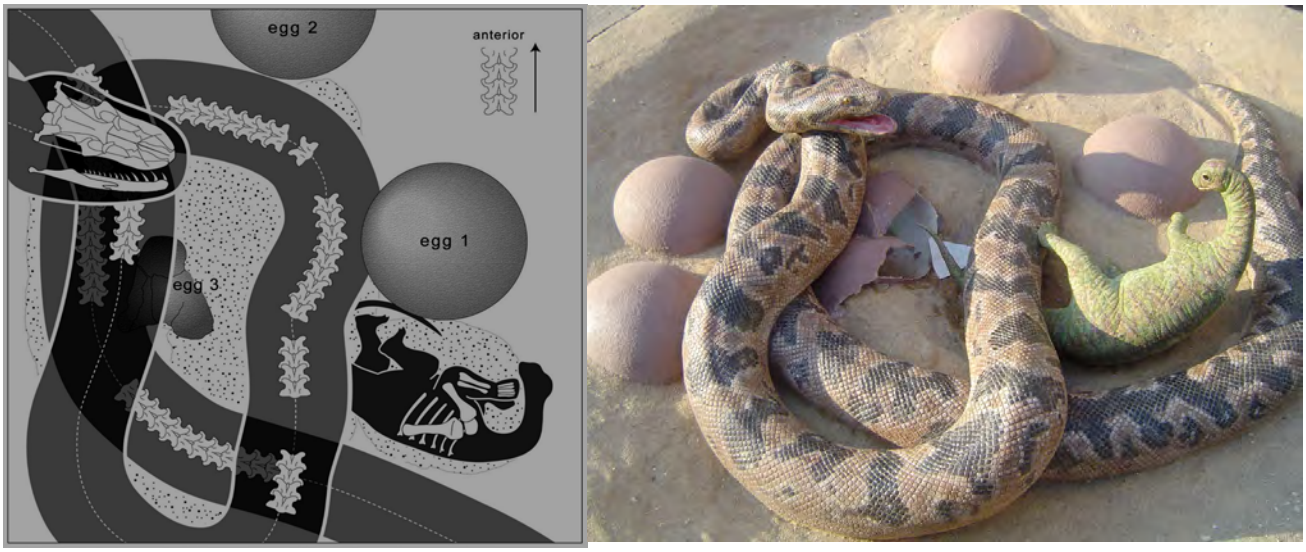
Egg fossils of the Sauropod dinosaur Megaloolithus dhoridungriensis along with its baby hatchling and fossils of few vertebrae of the snake Sanajeh indicus, which probably predated on dinosaur babies. 'Scale bar = 5cm' (Image: Wilson et al. 2010).

Diversity of oospecies

High and rich diversified fossil eggs of various species of dinosaurs were found at different locations of Gujarat, including Kutch, Kheda, Mahi Sagar, Panchmahal, and Dohad districts. All these locations are formations from Jurassic and Upper Cretaceous periods of Lameta group (limestone) and inter-trappean beds, broadly during the Mesozoic era. The literature surveys indicate nine eggshell oopsecies, excluding two indeterminable forms, Problematica? *Megaloolithus* (Waniawao, Dohad District) and *Trachoolithus* sp. (Lavariya Muwada, Dohad District), and an Incertae sedis (Dolidungri, Mahi Sagar District) recognized from Gujarat (Table 1).

Records of Oospecies from Gujarat

1. ***Megaloolithus jabalpurensis:*** (Synonym: *Megaloolithus matleyi* Mohabey, 1996; type locality: Pavna, Chandrapur District, Maharashtra). The species was described on the basis of 250 fossils of broken eggshells found under Lameta formation sites in Bara Simal Hills, Jabalpur. Similar egg fossils were also found from Dholiya, Bagh Cave, and Padiyal, Dhar District, Madhya Pradesh, along with very similar megascopic characteristics of the spherical-



The imaginary graphical representation of predation of a dinosaur hatchling by a snake in the Late Cretaceous period, after fossils of Sauropod dinosaur eggs were found from Dholi Dungari, Mahi Sagar District, Gujarat, India (Image credit: Wilson et al. 2010).

shaped dinosaur eggs having a diameter of 140–160 mm as recorded earlier from Waniawao, Dohad District, Gujarat. The name '*jabalpurensis*' is derived from the name of the closest excavation locality site town, Jabalpur.

2. ***Megaloolithus cylindricus:*** (Synonym: *Megaloolithus rahioliensis* Mohabey, 1998; type locality: Rahioli, India). The species was described on the basis of fossils of broken eggshells found under Lameta formation sites of Chui Hill and Pat Baba Mandir, Jabalpur District, and Dholiya, Dhar District, Madhya Pradesh. Similar egg fossils were also found from Khempur Village on the edge of Aravalli Hills in Mahi Sagar District, Gujarat. This fossil site (Khempur) is at a distance of 8km from the present Fossil Park at Rahioli, Gujarat. The name '*cylindricus*' is derived from the cylindrical shape of the spheroliths.

3. ***Megaloolithus mohabeyi:*** (Synonym: *Megaloolithus phensaniensis* Mohabey, 1998; type locality: Phenasani Lake, Gujarat). The species was described on the basis of three eggshell fragments/ fossils of broken eggshells found under a sandy carbonate bed of Late Cretaceous Lameta formation site of Dholiya, Dhar, Madhya Pradesh. Also, similar eggshell fossils were found from Lameta formation of Phensani, near Balasinor, Sonipur, Maha Sagar District and Waniawao, Dohad District. The name '*mohabeyi*' is in honour of Dr. D.M. Mohabey, Nagpur, Geological Survey of India.

4. ***Megaloolithus khempurensis:*** The species was described on the basis of a

Table 1. Dinosaur egg fossils (oospecies) and its records from different locations in Gujarat State, India.

*	Oospecies & type locality	Fossils location site in Gujarat	Source/ reference
1	*Megaloolithus jabalpurensis* Khosla & Sahni, 1995 Bara Simla Hill, Jabalpur, Madhya Pradesh	• Waniawao, Dohad	Mohabey & Mathur 1989 Ferna´ndez & Khosla 2014
		• Dhoridungi (23^0 7'55.32"N & 73^{0}23'5.93"E), Mahi Sagar	Mohabey 1998
2	*M. cylindricus* Khosla & Sahni, 1995 Chui Hill, Jabalpur, Madhya Pradesh	• Khempur (23^0 6'14.92"N & 73^{0}23'12.79"E), Lunawa-da, Mahi Sagar	Khosla & Sahni 1995
		• Rahioli (23^0 2'52.10"N & 73^{0}20'20.46"E), Mahi Sagar	Mohabey 1998
3	*M. mohabeyi* Khosla & Sahni, 1995 Dholiya, Dhar, Madhya Pradesh	• Balasinor (22^{0}57'0.88"N & 73^{0}19'50.92"E), Mahi Sagar • Waniawao, Dohad	Khosla & Sahni 1995
		• Phensani (23^{0}1'31.50"N & 73^{0}19'20.15"E = Felsani), Mahi Sagar	Mohabey 1998
4	*M. khempurensis* Mohabey, 1998 Khempur, Mahi Sagar, Gujarat	• Khempur (23^0 6'13.79"N & 73^{0}23'14.12"E) • Werasa (22^{0}59'25.25"N & 73^{0}19'54.30"E), Mahi Sagar	Mohabey 1998
5	*M. megadermus* Mohabey, 1998 Dholidhanti, Dohad, Gujarat	• Dholidhanti, Dohad • Paori, Dohad	Mohabey 1998
		• Daulatporia (23^0 5'31.92"N & 73^{0}23'33.04"E = Dolatpoyda), Mahi Sagar	Mohabey 1998
6	*M. dhoridungriensis* Mohabey, 1998 Dholi Dungri, Mahi Sagar, Gujarat	• Dholidungri (23^{0}7'55.29"N & 73^{0}23'5.93"E), Mahi Sagar	Wilson et al. 2010
7	*Fusioolithus baghensis* (Khosla & Sahni, 1995) Bagh Caves, Jabalpur, Madhya Pradesh	• ---	Khosla & Sahni 1995
		• Anjar (23^0 7'7.57"N & 70^0 0'50.36"E), Kutch	Khosla & Sahni 1995
		• Balasinor (22^{0}57'0.88"N & 73^{0}19'50.92"E), Mahi Sagar • Jetholi (23^0 4'18.10"N & 73^{0}21'3.10"E), Mahi Sagar • Dhuvadiya (23^0 1'52.40"N & 73^{0}20'58.35"E), Mahi Sagar	Mohabey 1998
8	*Ellipsoolithus khedaensis* Loyal et al., 1998 Lavaria Muwada, Mahi Sagar, Gujarat	• Kevadiya (23^0 4'11.74"N & 73^{0}19'7.04"E), Mahi Sagar • Rahioli (23^0 2'52.10"N & 73^{0}20'20.46"E), Mahi Sagar	Mohabey 1998 Loyal et al. 1998
9	*Subtiliolithus kachchhensis* Khosla & Sahni, 1995 Viri Village, Anjar, Kutch, Gujarat	• Anjar (23^0 7'7.57"N &70^0 0'50.36"E), Kutch	Khosla & Sahni 1995
10	? *Megaloolithidae problematica*	• Balasinor (22^{0}57'0.88"N & 73^{0}19'50.92"E), Mahi Sagar • Phensani (23^0 1'31.50"N & 73^{0}19'20.15"), Mahi Sagar • Sonipur (22^{0}50'38.77"N & 73^{0}21'31.57"E), Mahi Sagar	Mohabey 1998
11	*cf. Trachoolithus*	• Rahioli (23^0 2'52.10"N & 73^{0}20'20.46"E), Mahi Sagar	Mohabey 1998
12	Incertae sedis (of uncertain placement)	• Dhoridungi (23^0 7'55.29"N & 73^{0}23'5.93"E), Mahi Sagar	Mohabey 1998

* **Numbers correspond with map**

Dinosaur egg fossils of *Megaloolithus balasinorensis* (now synonymous with *Fusioolithus baghensis*) found from the quarry of Balasinor, Mahi Sagar District, Gujarat, India (Photo: Raju Vyas).

complete but fragmented egg and eggshell debris found from Lameda formation site of Khempur, Mahi Sagar District, Gujarat. Similar eggshell fossils were found in Werasa, Mahi Sagar. The Type-4 eggshells from Aix-en-basin, France (William et al. 1984) and *M. siruguei* are closely similar. *Megaloolithus khempurensis*, however, differs in having shell units that are moderately long and a broad and shallow-arched roof that is faintly tuberculate. The shell units tend to be cylindrical, taper into broad basal cups, and are mostly consistent in shape and size. The name '*khempurensis*' is derived from the excavation locality site village, 'Khempur', previously a tehsil of Kheda District but now part of Mahi Sagar District.

5. ***Megaloolithus megadermus:*** This species was described on the basis of numerous fossils of fragmented eggshells found under Lameta Formation of Dholidhanti and Paori, Dohad Panchmahal District, and Daulatporia, Mahi Sagar District, Gujarat (Mohabey1998). These share a fairly close resemblance with the eggshells described from the Dansle Basin, France (Kerourio 1987), thus assigning eggshells to the titanosaurid *Hypselosaurus*.

6. ***Megaloolithus dhoridungriensis:*** This oospecies was described on the basis of a complete egg, broken eggs, and egg debris fossils found from Dhori Dungri along with a fossilized snake skeleton of *Sanajeh indicus*. These egg fossils were excavated from Lameta Formation exposed near Dholi Dungri, Kheda, Gujarat. The skeleton of *Sanajeh* was preserved in close association with three Sauropod eggs of the oospecies *Megaloolithus dhoridungriensis* and a partial sauropod hatchling.

7. ***Fusioolithus baghensis:*** (Synonym: *Megaloolithus balasinorensis* Mohabey, 1998; type locality: Balasinor, India). This species was described on the basis of numerous fossilized broken eggshells found under Lameta formation sites of Bagh Cave, Dhar District, Madhya Pradesh, Pisdura, Chandrapur, Maharashtra, and Ottakovil, Kallamedu, Ariyalur District, Cauvery basin in Tamil Nadu southern India. Also, similar egg fossils were found from a quarry in Balasinor, Mahi Sagar and Anjar, Kutch District, Gujarat. The name '*baghensis*' is derived from the excavation site name Bagh Cave, Bagh Town, MP. The oospecies of these eggs have been related to Sauropod dinosaurs.

8. ***Ellipsoolithus khedaensis:*** The species was described on the basis of numerous fossils of broken eggshells found under Lameta formation sites of Lavaria Muwada and Kevadiya Village. The fossil site is at a distance of 1.5km from the limestone quarries of Rahioli Village, Mahi Sagar District. The name '*khedaensisis*' is derived from the excavation locality site district name though the locality is part of Mahi Sagar District. The oospecies of these eggs have been related to Theropod dinosaurs.

9. ***Subtiliolithus kachchhensis:*** The species is described on the basis of numerous fossils of broken fragmented eggshells found under Deccan inter-trappean beds site at Viri Village, Anjar, Kutch District. The name '*kachchhensis*' is derived from the excavation locality site name.

Indian oospecies and its affinities

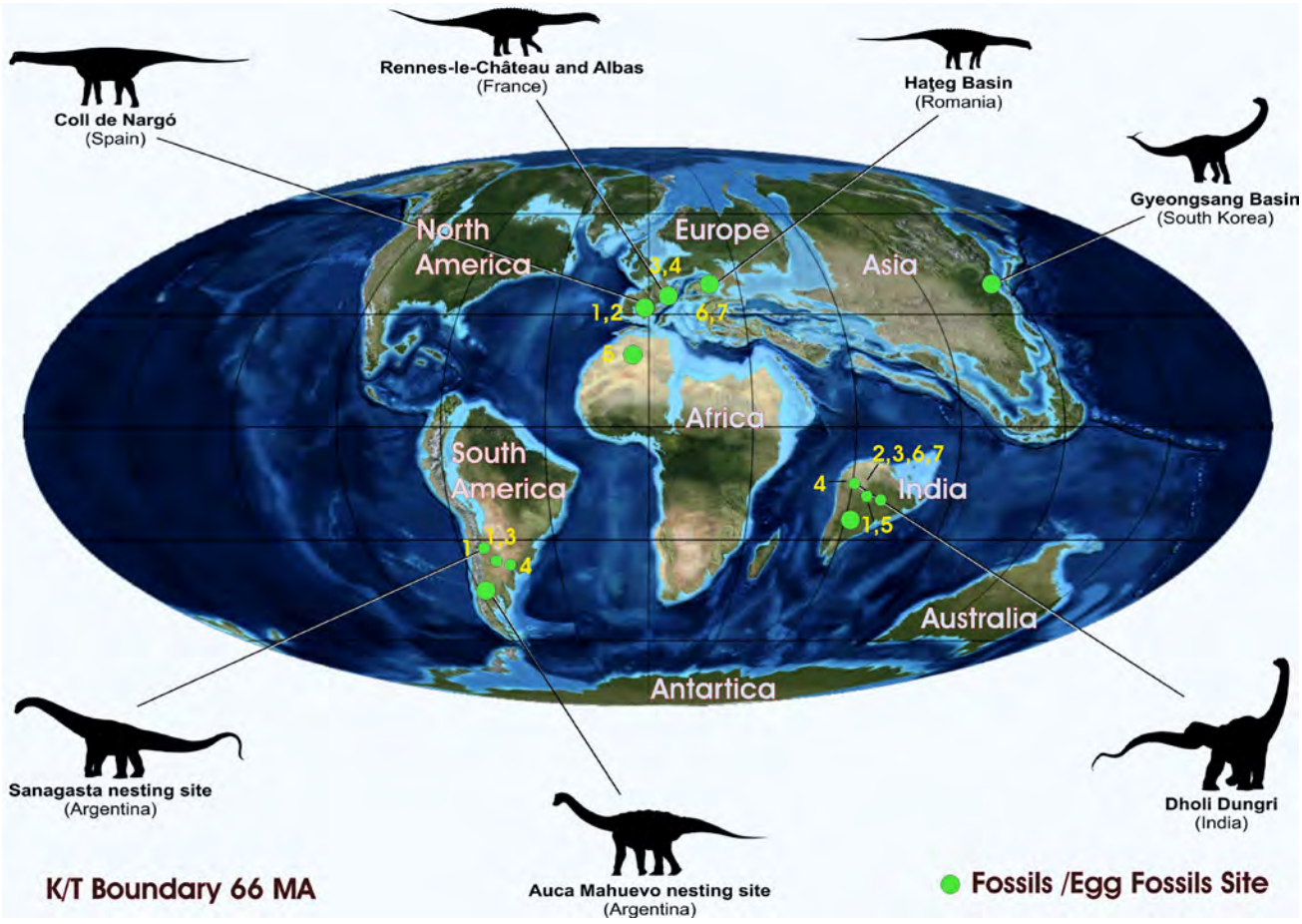
Many of the palaeontology studies describing oospecies from other countries depict the possibility of shared geographical connections between the

Table 2. Oospecies taxa and their global distribution

*	Oospecies taxa	Global distribution			
		State in India	Europe	South America (Location)	Africa
1	*Fusioolithus baghensis*	MP & G	Les Bre´guie`res	Argentina (Salitral Moreno)	
2	*Megaloolithus jabalpurensis*	MP & G		Argentina (Patagonia)	
3	*M. cylindricus*	MP & G	France	Argentina (Bajos de Santa Rosa, Rı´o Negro)	
4	*M. megadermus*	MP & G		Argentina (Rı´o Negro)	
5	*M. mohabeyi*	MP & G			Morocco (Achlouj)
6	*M. padiyalensis*	MP	France		
7	*M. dholiyensis*	MP	France (La Cairanne)		

* **Numbers correspond with map; MP - Madhya Pradesh, G - Gujarat**

Indian subcontinent and other continents in the past. The palaeo-biogeographic and site maps of fossils oospecies depict a picture of a consolidated landmass from Late Cretaceous periods. A few oospecies recorded from India and other countries were similar or same, suggestive of those oospecies being much widely distributed across the globe. The comparisons between *Megaloolithus* oospecies described by Khosla & Sahni (1995), Mohabey (1998), and Dhiman et al. (2018) with those described by Vianey-Liaud et al. (1994, 1997), Garcia & Vianey-Liaud (2001), and Garcia et al. (2003) well demonstrate close similarities between specimens from different parts of the world (Table 2). Such close affinities and similarities in egg taxa, however, suggest close phylogenetic relationships as well as the probable existence of a terrestrial connection for dinosaur fauna between India, Europe (France), South America (Argentina), and Africa (Morocco) during the Late Cretaceous as between Gondwanaland and India.



Late Cretaceous paleobiogeographic continents showing the distribution of *Tetrapoda dinosaur* oospecies from India with similarities with oospecies from other parts of the world (denoted numbers correspond with oospecies mentioned in Table 2; compiled and revised after Dhiman et al. 2018).

A fossil study of the Surapoda genus *Titanosaurus* supports that this genus was very widely distributed and found across Argentina, Europe, Madagascar, India, and Laos and throughout 60 million years of the Cretaceous (Wilson & Upchurch 2003); the same hypothesis is well-presented by Hechenleitner et al. (2015).

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Citation: Vyas, R.V. (2019). Review of dinosaur egg fossils from Gujarat State, India. Highlight, In: *Zoo's Print* 34(5): 8–17