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Salbardi–Belkher inland basin: a new site of Lameta sedimentation at the border of districts Amravati, Maharashtra and Betul, Madhya Pradesh, Central India

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The Late Cretaceous infratrappean Lameta sediments in central and western India are known from five inland basins, viz. (i) Nand–Dongargaon, (ii) Jabalpur, (iii) Balasinor–Jhabua, (iv) Ambikapur–Amarkantak and (v) Sagar. Among these, the successions in the first three basins are well studied. The dinosaurian remains from the formations of these inland basins serve as a significant tool for regional reconstructions of palaeogeographic and palaeoenvironmental conditions during Lameta sedimentation. Here, a new inland basin with good outcrops of Lameta sediments having dinosaurian skeletal remains egg nests and eggs is documented. Considering the lithofacies and dinosaurian remains from this new inland basin, it is evident that Lameta sedimentation during the Late Cretaceous was not restricted to only five inland basins documented earlier, but was taking place contemporaneously in an additional inland basin in between Balasinor–Jhabua in the west and Nand–Dongargaon basin in the east. We propose the name of this new site as Salbardi–Belkher inland basin. This newly identified basin lying at the border of Maharashtra and Madhya Pradesh also redefines the existing palaeogeographic limits of Lameta sedimentation, including dinosaur inhabitation.

Keywords: Dinosaurian remains, fluvio-lacustrine succession, infratrappean sediments, inland basins.

THE infratrappean Lameta Formation, disconformably overlying the Gondwana or Precambrian rocks, is mainly exposed in Jablapur district, Madhya Pradesh (MP); Nagpur and Chandrapur districts, Maharashtra and Anjar and Kheda districts, Gujarat, besides the scattered occurrences in Saugor (Sagar) and Amarkantak districts, MP (Figure 1). The Lameta beds are mostly considered to be fluvial-lacustrine in nature. However, there is a debate about the type area succession at Jabalpur regarding its marine[1–4] versus non-marine[5–8] nature. In general, major lithologies of the Formation are represented by variously coloured argillaceous sedimentary rocks, medium to fine-grained sandstones and silicified, brecciated and nodular limestones, which may show variations in stratigraphic position, in the lithocolumns exposed at various localities depending upon the nature of depositional environment than on time of deposition[3,9]. Despite remarkable similarity in lithological sequence, the successions in various areas also show a common characteristic in having dinosaurian remains in the form of bones, egg nests and eggs. Based on lithological succession and fossil remains, Mohabey[9] identified five inland sub-basins in which Lameta sedimentation took place, viz. (i) Nand–Dongargaon, (ii) Jabalpur, (iii) Balasinor–Jhabua, (iv) Ambikapur–Amarkantak and (v) Sagar (Figure 1).

The present study documents a new region in which Lameta sediments are exposed. Good sections exposing Lameta beds in this region occur near Bairam (lat. 21°22′25″N; long. 77°37′23″E), Belkher (lat. 21°21′48″N; long. 77°31′23″E), Pandhri (lat. 21°22′02″N; long. 77°32′54″E) and Salbardi (lat. 21°25′15″N; long. 78°00′00″E), besides 3–4 small, isolated exposures in nearby locations. These exposures are spread over an aerial distance of 10–40 km. In two localities, dinosaur bones and eggs are preserved. Comparing the depositional environment set-up and dinosaurian remains of the studied areas with those of the other five inland basins[9], we propose a new inland basin for Lameta sedimentation called Salbardi–Belkher inland basin, exposed in an area which is presently covered partially by districts Amravati in Maharashtra and Betul in MP.

Small sedimentary inliers consisting of Lameta Formation, overlying the Upper Gondwana sedimentary rocks are exposed in the Deccan Trap region (inset Figure 1). Quartzo-feldspathic gneiss of Archaean age forms the basement for Gondwana sedimentary rocks, which rest on it nonconformably. Broadly, the Lameta Formation is represented by sandstone, clay-marl and limestone litho-units,

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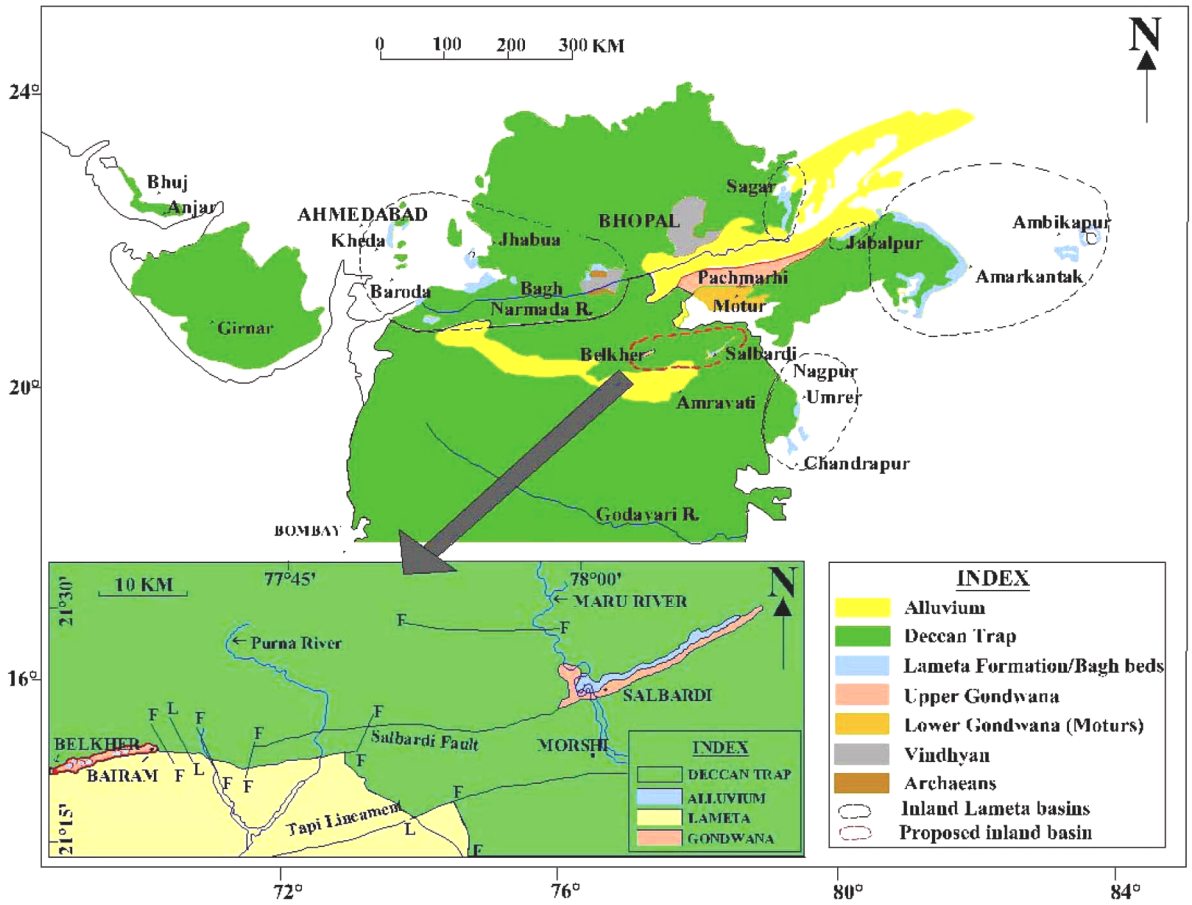

Figure 1. Map showing the proposed inland basin of Lameta sedimentation in central and western India as proposed by Mohabey[18] along with location and extent of newly proposed Salbardi–Belkher inland basin. (Inset) Geological map of the study area having locations and extents of Lameta sediments exposed at Bairam, Belkher and Salbardi areas.

which disconformably overlie arenaceous–argillaceous sediments of the Upper Gondwana Group, with good preservation of current generated structures. Upper Jurassic to Early Cretaceous age of the Upper Gondwana successions exposed at Bairam and Belkher areas has been suggested on the basis of gymnosperm and pteridophyte remains[10]. The lithological similarity between the Gondwana sediments exposed in Salbardi area with the previous two localities, suggests the same age and hence is considered to be a co-eval lithounit[11]. Greyish-black, hard, massive and vesicular to amygdaloidal traps overlie the Lameta Formation.

The succession is studied in three sections in the study area, namely Bairam, Belkher and Salbardi. The successions exposed at these sections are approximately 39, 47 and 35 m thick respectively, and show almost similar lithological set-up. The lithocolumn at Bairam area is represented by clay-marl, arenaceous and calcareous sediments which can be broadly divided into lower, middle and upper litho-units (Figure 2). The lower unit is 12 m thick clay-marl of brownish–yellowish–greenish colour. Occasionally, faint laminations and discontinuous thin beds of siliceous limestone are also observed in them. Overlying 13 m, areno-argillaceous column constitutes the middle unit, of which the lower 2 m is greyish-brown, medium to coarse-grained sandstone. It is succeeded by 9 m thick, light grey clay, having abundant concretions and 5–20 cm thick, discontinuous beds of light-green siliceous limestone. The top 2 m is dark brown, medium to fine-grained sandstone having *Thalassinoides* burrows. The upper unit is 14 m thick calcareous sediment consisting of nodular limestone and chertified limestone. The former is bluish grey, hard and compact rock having nodular tendency and also contains irregular clasts of chert and jasper. The chertified limestone is light grey, hard and compact, having poor tendency of flat bedding. Chert is mostly in the form of horizontal discontinuous beds.

The litho-section at Belkher area is comparatively well exposed attaining a thickness of about 47 m. Broadly, it exhibits sandstone, clay-marl and limestone units (Figure 2). The lower 21 m column is areno-argillaceous, consisting of medium to fine-grained, hard and compact, yellowish-orange and greyish-brown sandstone bed, and dark

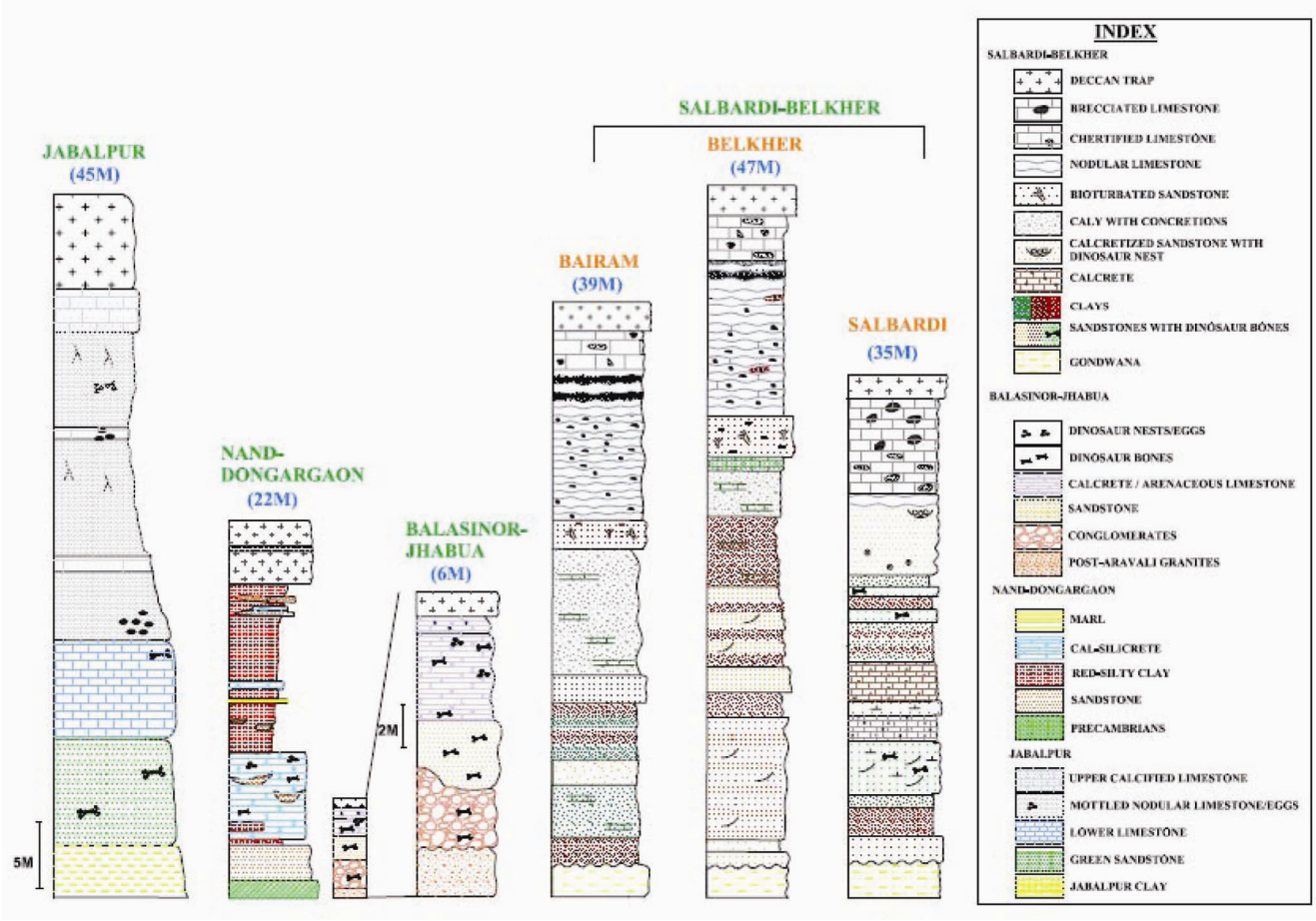

Figure 2. Comparative details of lithological architecture of Lameta successions exposed in various inland basins.

yellowish-orange to dark reddish-brown, massive to faintly laminated clayey beds. The middle 10 m column consists of dark brown to light grey-coloured clay with thin patches of siliceous limestone. Discontinuous beds of greyish-black to medium green-coloured, subangular to subrounded concretions of 3–15 cm diameter are also present. The litho-unit is distinctly overlain by 2 m thick, dark brown, hard and compact sandstone bed showing vertical to inclined burrows of *Thalassinoides*. The upper 14 m thick column consists of nodular and chertified limestone similar to the one observed in Bairam.

The litho-section at Salbardi is about 35 m thick consisting of areno-arglillaceous and calcareous sediments (Figure 2). This locality is significant because of good preservation of dinosaurian fossils. The lowermost 9 m column is areno-argillaceous and consists of dark reddish-brown to medium green, medium to coarse-grained, hard and compact, parallel-bedded to cross-bedded sandstone ranging in thickness from 2 to 4 m, occasionally interbedded with the same coloured clay horizons. Calcrete, clay and calcretized sandstone constitutes the middle 18 m thick column. Calcrete is of two types, i.e. light grey rhizomorphic and light brown nodular, constituting 2 and 4 m columns respectively. Calcrete is overlain by 7 m thick column showing alternations of greenish-grey to dark brown clay in the lower part, whereas the remaining 5 m upper column is green-coloured, medium-grained, hard and compact sandstone having skeletal fragments of dinosaurs. It is succeeded by 5 m thick, greyish-yellow, hard and compact calcretized sandstone showing well-preserved dinosaur egg nest. The uppermost 8 m succession is nodular chertified limestone similar to the ones described earlier from the adjacent localities, except that the topmost 2 m thick intraformational brecciated limestone here is reddish-brown, hard and compact with subangular to subrounded clasts of green sandstone, nodular limestone and certified limestone.

The succession at Salbardi is found to be productive for dinosaurian remains. It contains fragmentary bones preserved in light green-coloured, medium-grained sandstone. Srivastava and Mankar[12] have reported fragmentary remains of right ulna of *Titanosaurus colberti*. Egg nest and eggs belonging to *Megaloolithus* oogenus of Megaloolithidae oofamily have also been reported from the same locality. These are preserved in calcretized sandstone beds overlying green-coloured sandstone having skeletal fragments[13]. Fragmentary bones and

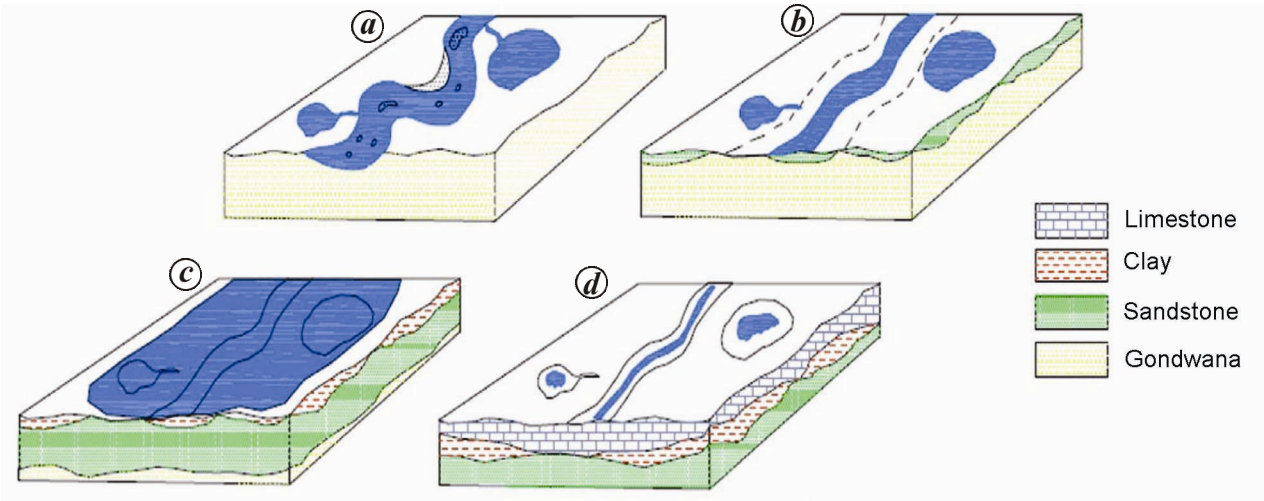

Figure 3. Schematic model of the depositional environment for Lameta sediments. ***a***, Closures of the Gondwana deposition followed by the initiation of Lameta sedimentation as channel floor, point-bar deposits. ***b***, Development of lakes allowing deposition of fine-grained argillaceous sediments and change of river course adding new depositional sites. ***c***, A high stand of water level flooding the entire area, including lakes during which large sheet-like deposits have taken place. ***d***, Low stand of water due to hot and dry climatic conditions causing reduction of sites for fluvial–lacustrine deposition that ultimately terminated due to volcanic activity. Pedogenic activities might have taken place at any stage, but were more pronounced during B stage (Srivastava and Mankar[16]).

occasional coprolite occurrences have also been recorded from the succession of Pandhri area.

Reconstruction of depositional environments in detail for the successions exposed at Bairam, Belkher and Salbardi areas and a model showing the same on the basis of rock types and lithofacies analysis have already been reported[14–16]. Three major lithofacies associations, viz. arenaceous, argillaceous and calcareous have been identified. The arenaceous lithofacies association includes (i) massive sandstone, (ii) green sandstone, (iii) thinly bedded, yellowish-orange and greyish-brown sandstone, (iv) coarse-grained sandstone, and (v) dark brown bioturbated sandstone. The argillaceous association consists of (i) yellowish–brownish–greenish clay–siltstone and (ii) light grey silty clay with concretions. The calcareous association is represented by (i) calcrete, (ii) nodular limestone, (iii) chertified limestone, and (iv) intraformational brecciated limestone[16].

The lithofacies assemblages indicate a fluvial–lacustrine environment of deposition, in which temporal variations in depositional setting and climatic condition have been observed (Figure 3). The lower arenaceous part of the succession mostly represented by thinly bedded, parallel laminated units shows low to moderate energy conditions. Deposition of argillaceous sediments interbedded with cross- and parallel-bedded sandstones shows fluctuation in the energy condition of the depositing medium. Calcrete formation point to seasonal variability of energy condition of the river system during arid climate, and also formation of detached lakes and water bodies during low water condition. The bioturbated sandstone indicates short-span high growth of benthic fauna and complete churning of the sediments by benthonic community during calm; and quiet water conditions.

The predominance of carbonate sedimentation in the upper part of the succession shows a major change in the chemical set-up and prevalence of alkaline environment of deposition. Sheet flood environments of deposition, similar to that reported from Jabalpur area[6], are evident by horizontally bedded units of nodular and cherty limestone.

The Lameta Formation, in the form of discontinuous patches is exposed at several places in central and western India. These deposits are considered to have been formed in five inland basins as determined on the basis of their lithological correlatability and dinosaurian remains[9]. A brief account of each is given below.

Jabalpur: The scattered patches of Lameta sediments exposed in and around Jabalpur area are considered to be deposited in a smaller basin compared to the others. However, Jabalpur Lameta beds are considered to be more significant due to rich preservation of dinosaurian remains and also due to controversy about their environment of deposition as to whether they are marine or non-marine deposits. Dinosaur remains consist of rich assemblage belonging to caudal vertebrae, tooth, coprolites and skull of Sauropoda, Theropoda and Ornithopoda, i.e. *Titanosaurus indicus* and *Antarctosaurus septentrionalis* (sauropods); *Indosuchus raptorius*, *I. matleyi*, *Lametasaurus indicus*, *Composuchus solus*, *Laevisuchus indicus*, *Jubbalppuria tenuis*, *Dryptosauroides (?)grandis*, *Ornithomimoides mobilis*, *O. barasimlensis* (Theropoda) and *Brachypodasaurus gravis* (Ornithopoda)[17–24]. Egg nests and eggs are represented by *Megaloolithus dhoridungriensis* and *M. phensaniensis* of Megaloolithidae oofamily and *Elipsoolithus khedaensis* of Elipsoolithidae oofamily[9,25–27]. Various successions exposed at different places in this inland basin are extensively studied for environment of deposition, trace fossils, palaeo-floral and faunal

Table 1. A generalized idea about the lithological set-up and depositional environments of Lameta sediments in various inland basins

		Jabalpur inland basin		Nand-Dongargaon inland basin	Balasinor-Jhabua inland basin	Salbardi-Belkher inland basin
Major lithounits		(1) Upper sandstone (2) Upper limestone (3) Mottled nodular marl (4) Lower limestone (5) Green sandstone		(1) Red green silly clays associated with sandstone (2) Channel related sandstone with calcretized in upper part (3) Yellow laminated clays and interbedded with limestone, marlite and septarian concretion bands (4) Calcrete (5) Gray nodular marls	(1) Arenaceous limestone (2) Calcareous sandstone (3) Grits (4) Conglomerate	(1) Intraformational brecciated limestone (2) Chertified limestone (3) Nodular limestone (4) Clay-marl with concretions (5) Yellowish-greenish-reddish clay-marl (6) Bioturbated sandstone (7) Greyish-yellowish-brownish sandstone (8) Green sandstone
Depositional environment	Marine	Singh[28]	Saha *et al.*[4]	–	–	–
		(1) Intertidal (2) Intertidal (3) Tidal flat (4) Tidal flat (5) Estuarine	(1) Intertidal-supratidal (2) Intertidal channels on the marshes (3) Marsh (4) Lagoon (5) Estuary			
	Non-marine	Tandon *et al.*,[6]		Mohabey[9]	Mohabey[27]	Srivastava and Mankar[16]
		(1) Sheet flood (2) Sheet wash-pedogenically modified (3) Palustrine flat (4) Braided stream	Fluvial under semi-arid, pedogenically modified and flat-palustrine system	(1) Overbank (2) Channel (3) Overbank (4) Lacustrine (5) Flood plain (6) Back-swamp	(1) Palustrine environment (2) Fluvial or mostly lacustrine environment	(1) Gravity flow (2) Flood plain (3) Flood plain (4) Pedogenic (5) Lacustrine (6) Fluvial (7) Point bar (8) Channel floor
				Alluvial-limnic under semi-arid condition		Fluvial-lacustrine under semi arid condition

assemblage, including dinosaur remains. The overall succession is represented by green sandstone, lower limestone, mottled nodular marl, upper limestone and upper sandstone (Figure 2 and Table 1). The 18 m thick succession at type locality consists of Lower limestone, Mottled nodular marl and Upper limestone[28], which was further redefined by Saha *et al.*[4], with an increase in total thickness up to 21 m. The succession at Chui Hill ranges in thickness from 39 to 45 m, however, the Upper sandstone is not exposed[4,28]. The succession at Bara Shimla Hill exhibits all the five major lithounits constituting a column of about 34 m thickness[28]. Whether Jabalpur basin was marine or nonmarine, has been a matter of debate. Marine environment has been suggested on the basis of green sandstone and trace fossils[28], petrology, algal structures, glauconitic beds, extensive crab burrows, including *Thalassinoides* and lithological architecture[28–30]. Recently, Shukla and Srivastava[3] and Saha *et al.*[4] suggested marine environment of deposition, including intertidal to supratidal channels, marsh, estuary and lagoon sub-environments based on ichnofossils, lithofacies architecture and nesting habit of lizards.

The non-marine fluvial–lacustrine environment is proposed by many workers on the basis of fossil biota, lithological characteristics, occurrence of various types of calcretes and dinosaurian remains[5–7,9].

Nand–Dongargaon: This basin is well studied for its lithological set-up and dinosaurian remains[9,31,32]. The basin occupies an area of about 700 sq. km and shows good exposures at Pisdura, Dongargaon, Nand and Kotabala areas of Chandrapur district, and Rajulwari, Pahami and Shivapur areas of Nagpur district. The basement is mostly of Precambrian rocks; however, in the northern part of Nand area, the Gondwana sedimentary rocks underlie the Lameta beds. In general, the succession is a 20 m thick, calc-argillaceous litho-unit, deposited in alluvial–limnic environment under semi-arid condition[31] (Figure 2 and Table 1). Mohabey[9] broadly classified four different major lithounits, viz. (i) red and green silty clay associated with sandstone, (ii) channel-related sandstone (trough and cross-bedded), which is calcretized in the upper part, (iii) yellow laminated clay and shale interbedded with limestone, marlite and septarian concretion bands, and (iv) grey nodular marls. On the basis of lithology, sedimentary texture and structure and faunal content, four subenvironments of deposition have been proposed, viz. (i) channel, (ii) overbank, (iii) paludal and (iv) limnic[9,31–33]. Dinosaur remains consists of *T. indicus*, *T. blandfordi*, *T. colberti* and *Laplatasurus madagascariensis*[20,34–36]. Egg nests and eggs include *Megaloolithus matleyi* and *M. megadermus*[37,38]. Recently, the southern sector of Nand–Dongargaon basin has been studied in detail by establishing detailed lithofacies architecture in the succession[32]. Six lithofacies were identified, viz. (i) clay–siltstone lithifacies, (ii) limestone–carbonate mud lithofacies, (iii) septerian concretionary lithofacies, (iv) varved clays lithofacies, (v) fibrous radaxial calcite cryptalgal lithofacies and (vi) sandy-gravel lithofacies showing lacustrine environment of deposition.

Balasinor–Jhabua: This inland basin is significant because of rich preservation of skeletal remains, egg nests and eggs of dinosaurs at Balasinor and Rahioli localities of Kheda and Panchmahal districts in Gujarat. The Lameta sediments in these two adjoining districts lie over a strike length of ca. 40 km over a width of 15 km (ref. 39). At Balasinor, 4–12 m thick succession rests unconformably over the Godhra granites/phyllites of the Aravalli Supergroup (Figure 2 and Table 1). The lower 2–6 m litho-column is an indurated, pebbly-conglomeratic unit showing channel and scour-fill structures with pebbles of quartz and cherty quartzite cemented together by calcareous and siliceous material. Bedding is not distinct; however, rare instances of size gradation of the clasts can be noticed. This litho-unit shows rich preservation of reddishbrown dinosaurian skeletal fragments. It grades upwards into 2 m thick, pebbly, poorly sorted sandstone, which also shows rare occurrences of skeletal remains. Bedding is indistinct; fining upward of grain size is prominent. It grades to grey and brown-coloured siliceous limestone with calcareous claystone and brown marl. The limestone is highly variable and may be mottled, nodular and brecciated with ample amounts of lithoclasts, peloids, and subangular to subrounded detrital quartzs[39]. This litho-unit is considered to be a deposit of palustrine environment due to its fine-grained, massive and micritic nature as well as the presence of discontinuous cracks and bioturbation[40]. The other significant exposure lying at Rahioli is sandy calcrete preserving complete eggs and nests of dinosaurs. It is interpreted to be the deposit of sheet wash into a palustrine environment[25,27]. Dinosaur remains consist of *Antarctosaurs septentrionalis* (sauropods) and *Rajasaurus narmadensis* (thereopods)[19,21,41,42]. Nests and eggs include *Megaolithus rahioliensis*, *M. phensaniesis*, *M. khempuensis*, *M. megadermus* and *M. balasinorensis*[19,25,40,43]. Singh and Tondon[6] using oxygen and carbon isotope analysis interpreted fluvial or mostly lacustrine environment of deposition, particularly for the egg-bearing horizons.

Saugor (Sagar) and Amarkantak–Ambikapur: Both these inland basins lack adequate published data, despite occurrence of good exposures of Lameta sediments with dinosaurian remains. As such, these inland basins are less discussed in the original paper by Mohabey[9]. The Sagar basin with small geographical extent, lying northwest of Jabalpur area, consists of small lithocolumns of gritty sandstone, calcareous clay, chert and mottled limestone having pebbles of jasper and chert. At places, it is calcareous having pockets of chert and jasper[44]. The Amarkantak–Ambikapur basin with a large geographical area is still not well studied[9].

As mentioned earlier, fluvio-lacustarine Lameta sediments of central and western India are considered to be

deposited in five inland basins[9]. The successions exposed in these basins are mainly represented by calc–marl–argillaceous and arenaceous lithofacies. These lithofacies are represented in almost all the successions; however, they vary in thickness and abundance of rock formation in stratigraphic column (Figure 2 and Table 1). Apart from lithological similarities, these sediments also have a common character of preservation of skeletal fragments, eggs and nests of dinosaurs.

The present report of Lameta rocks from a region having a few isolated patches of comparatively larger dimensions at Bairam, Belkher–Pandhri and Salbardi areas, in addition to 3–4 minor exposures nearby has added a new dimension to the geographical extent of Lameta sedimentation. The successions at these places are fluvio-lacustrine and show dinosaur inhabitation represented by preservation of skeletal remains, egg nests and eggs. We are of the opinion that this entire region was a separate inland basin of Lameta sedimentation, in addition to the earlier five proposed by Mohabey[9]. This new region is being proposed as Salbardi–Belkher inland basin (Figure 1).

The Lameta sedimentation in Salbardi–Belkher inland basin occurred after Gondwana sedimentation ceased. The inland basin allowing Lameta sedimentation shows shallowing and deepening of the depositional site because of periodical recharge by river water. In general, the lower part of the Lameta succession is dominantly represented by arenaceous and argillaceous sediments that show a change in the energy condition in the depositing medium. During the deposition of the arenaceous sediments, the energy condition was moderate in which sand-sized particles could be transported and structures like cross-bedding and parallel-bedding were formed. The argillaceous sediments show low energy condition in which the deposition took place mainly from suspension load. Succession in the upper part is mostly calcareous in nature, showing shallowing of the basin as well as alkaline nature of the depositing medium. It is interpreted that the basin in the initial phase was shallow in the east compared to west. In the east, near Salbardi, lower part of the succession is arenaceous and contains calcrete horizons revealing shallow nature, whereas dominance of argillaceous sediments at Belkher and further at Pandhri in the extreme west indicates low energy condition of deposition in deeper parts of the basin.

Comparison of the new inland basin with other Lameta basins shows that the proposed basin was nearly similar in size as the Jabalpur basin. Similar to Rahioli, Jabalpur and Nand–Dongargaon basins, the dinosaurian remains, including bones and eggs are indicative of channel to point bar deposition under sub-arid condition. With the addition of this new basin, the earlier proposed palaeogeography of Lameta sedimentation gets modified with larger geographical extent.

In conclusion, a new inland basin has been identified for Lameta sedimentation, i.e. the Salbardi–Belkher inland basin. The fluvio-lacustrine successions of this basin are similar to other Lameta successions exposed at various places in central and western India. The palaeoenvironmental set-up and palaeoclimate of all these basins were found to be similar.

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