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Vertebrate fauna from the Late Triassic Tiki Formation of India: new finds and their biostratigraphic implications

SANGHAMITRA RAY[1*], MOHD. SHAFI BHAT[1], DEBARATI MUKHERJEE[2] AND P.M. DATTA[3]

[1]*Department of Geology and Geophysics, Indian Institute of Technology, Kharagpur 721302, India.*
[2]*Geological Studies Unit, Indian Statistical Institute, 203 B.T. Road, Kolkata 700108, India.*
[3]*Greenwood Housing Cooperative Society Ltd., 315B Upen Banerjee Road, Kolkata 700060, India.*
**Corresponding author: sray@gg.iitkgp.ernet.in*

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ABSTRACT

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Recent work on the Tiki Formation has resulted in the collection of new and varied vertebrate micro–and megafossils, including a new bonebed containing low diversity, mono–dominant, multitaxic vertebrate accumulation where the rhynchosaur, *Hyperodapedon tikiensis* constitute the dominant component. This bonebed has also yielded a large traversodontid cynodont *Ruberodon roychowdhurii*. In addition, there are several diagnostic postcrania such as vertebrae and incomplete limb bones belonging to a basal saurischian dinosaur. Systematic exploration and collection has yielded numerous isolated teeth and postcrania of small vertebrates such as different types of freshwater sharks, bony fishes, archosauriforms, lepidosauromorphs, cynodonts and other reptiles. Based on its fossil flora and fauna, the Tiki Formation is globally correlated with other coeval horizons such as the lower member of the Maleri Formation of the Pranhita–Godavari basin, the upper part of the Santa Maria Formation of Brazil, the Camp Springs and lower Tecovas formations of the Chinle Group, USA. A Carnian (Otischalkian to early Adamanian) age is proposed for the Tiki Formation.

Key–words—Biostratigraphy, Carnian, Late Triassic, Tiki Formation, Vertebrate.

भारत के विलंबित ट्राइएसिक टीकी शैलसमूह से प्राप्त कशेरूकी प्राणिजात : नूतन प्राप्तियॉ एवं उनके जैवस्तरिक निहितार्थ

संगमित्र राय, मो. शफी भट, देबारती मुखर्जी एवं पी.एम.दत्ता

सारांश

सारांश

टीकी शैलसमूह पर अभिनव शोध कार्य अल्प विविधता, एकल प्रभावी, मल्टीटेक्सिक कशेरूकी संचयन सन्निहित नूतन अस्थि–संस्तर सहित नवीन एवं परिवर्तित सूक्ष्म एवं स्थूलजीवाश्मों के संग्रहण का परिणामी है जहॉं रिन्कोसौर *हायपरओडापेंडॉन टीकीएन्सिस* प्रधान घटक गठित करता है। इस अस्थि–संस्तर से एक विशाल ट्रेवर्सोडॉटिड साइनोडॉट *रूबेरोडॉन रॉयचौधरीयाई* भी मिली है। इसके अलावा, आधारी सॉरिस्कियन डायनोसॉर की कशेरूकी एवं अधूरी अंग अस्थियॉं जैसी बहुत–सी नैदानिक पश्चकपालीय हैं। क्रमबद्ध अन्वेषण एवं संग्रहण से अलवणजल शाक्र, अस्थिल मछली, एर्कोसारॉफार्म, लेपिडोसॉरोमॉर्फ सायनोडॉट एवं अन्य सरीसृपों के विविध प्रकार जैसे छोटी कशेरूकीयों के कई एकाकी दंत एवं पश्चकपालीय प्राप्त हुए हैं। इसके जीवाश्म एवं प्राणिजात पर आधारित, प्राणहित–गोदावरी द्रोणी में मलेरी शैलसमूह के अधो सदस्य, ब्राज़ील में सांता मारिया शैलसमूह का ऊपरी भाग, चिन्ले समूह, संयुक्त राज्य अमेरिका के कैंप स्प्रिंग्स एवं अधो टेकोवस शैलसमूह जैसे अन्य समकालीन क्षितिजों से भू–मंडलीय रूप से सहसंबंधित है। टीकी शैलसमूह हेतु कार्नियन (ओटिसचाकियन से प्रारंभिक अडमेनियन) काल प्रस्तावित है।

सूचक शब्द—जैवस्तरक्रमविज्ञान, कार्नियन, विलंबित ट्राइएसिक, टीकी शैलसमूह, कशेरूकी।

INTRODUCTION

THE Gondwana deposits of India mostly outcrop in four isolated basins in the peninsular India such as the Pranhita–Godavari (PG), Damodar, Satpura and Son–Mahanadi (Fig. 1). These basins are rich storehouses of vertebrate fossils and at least twelve vertebrate fossil bearing horizons (Table 1) are known, which have contributed significantly to the understanding of the Palaeozoic–Mesozoic ecosystems and were instrumental for biostratigraphic correlation in global context. Two of these horizons are Permian in age, and seven are Triassic. Of these, the Late Triassic horizons are the Maleri Formation of PG Basin and the Tiki Formation of the Rewa Gondwana Basin, a sub–basin of the Son–Mahanadi Basin. Another horizon, the Dharmaram Formation of PG basin is time transgressive as it ranges from Late Triassic to Early Jurassic, and the remaining horizons pertain to the Jurassic itself (Bandyopadhyay, 1999, 2011).

In recent years, systematic exploration and excavation has yielded a series of new vertebrate fossil finds from the Late Triassic Tiki Formation of the Rewa Gondwana Basin, which is the focus of the current work. Here we give an overview of the Tiki Formation, document the new vertebrate fossil finds and discuss their biostratigraphic implications.

GEOLOGICAL BACKGROUND

Geological setting

The Son–Mahanadi Basin, a centrally–positioned Gondwana Basin in peninsular India is a composite basin, and comprises three sub–basins namely the Rewa Basin in the north, the Hasdo–Arand Basin in the centre and the Mahanadi Basin in the south (Fig. 2A). The Rewa Basin is relatively long in the ENE–WSW direction and the overall attitude of the basin–fill strata is low, dipping towards the north. The lower part of the Gondwana succession of the Rewa Basin shows uniformity in lithological features with that of other Indian Gondwana basins (Table 1) whereas the upper part comprises a basal Pali Formation overlain by the Karki and Tiki formations. These sediments are unconformably overlain by the Jurassic Parsora Formation (Mukherjee *et al*., 2012).

The new vertebrate fossils under discussion in the current work were collected from the study area (Fig. 2B), which encompasses the type locality of the Tiki Formation and covers an area of about 1000 sq. km (Mukherjee *et al*., 2012). The vertebrate fossil–bearing Tiki Formation (400 m thick) is composed of thick, essentially red–coloured, floodplain mud units and a subordinate amount of channel–fill sandstones (Fig. 2C). The Tiki floodplain mudstones show well developed palaeosol horizons and pedogenic features such as coarse, irregular, subspherical to platy glaebules, tubular, tapering and branching calcareous root moulds, irregular pedogenic cracks and slickensides, and colour mottling. Laterally connected channel–fill sand bodies and presence of thick mudstone units suggest channel and overbank facies, respectively where the river channel was confined within the extensive floodplain deposits of the Tiki Formation (Mukherjee *et al*. 2012). The exposed areas of the Tiki floodplain were subjected to soil forming processes resulting in the formation of caliche profiles of varying thicknesses suggesting cessation of deposition on the floodplains for some time. The red colouration of the floodplain fines and the calcareous palaeosol profiles indicate a semi–arid climate with seasonal rainfall during the deposition of the Tiki sediments (Ahmed & Ray, 2010).

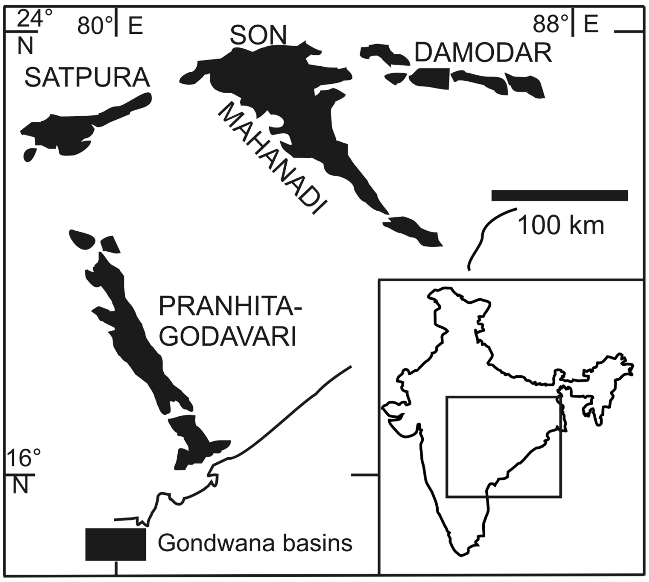

Fig. 1—Four major Gondwana basins of peninsular India (after Ray, 2015).

Tiki vertebrate assemblages

Previous works on the Tiki Formation show that it had yielded well–preserved and highly varied fossil vertebrates such as different types of fishes, amphibians, several reptilian and mammalian amniotes (Mukherjee & Ray, 2012). These include the dipnoan *Ceratodus*, the metoposaurid *Metoposaurus maleriensis* (Sengupta, 2002), the phytosaur *Parasuchus hislopi* (Chatterjee, 1978), rauisuchid *Tikisuchus romeri* (Chatterjee & Majumdar, 1987), the cynodont *Rewaconodon tikiensis* (Datta *et al*., 2004) along with a morganucodontid mammal *Gondwanodon tapani* (Datta & Das, 1996). Moreover, one of the earliest 'nontherian' mammals with a transversely expanded upper molar *Tikitherium* (Datta, 2005) and the earliest acrodont *Tikiguania estesi* (Datta & Ray, 2006) are reported from this formation. In addition, Prasad *et al*. (2008) reported several hybodont taxa based on isolated but well–preserved teeth from the formation.

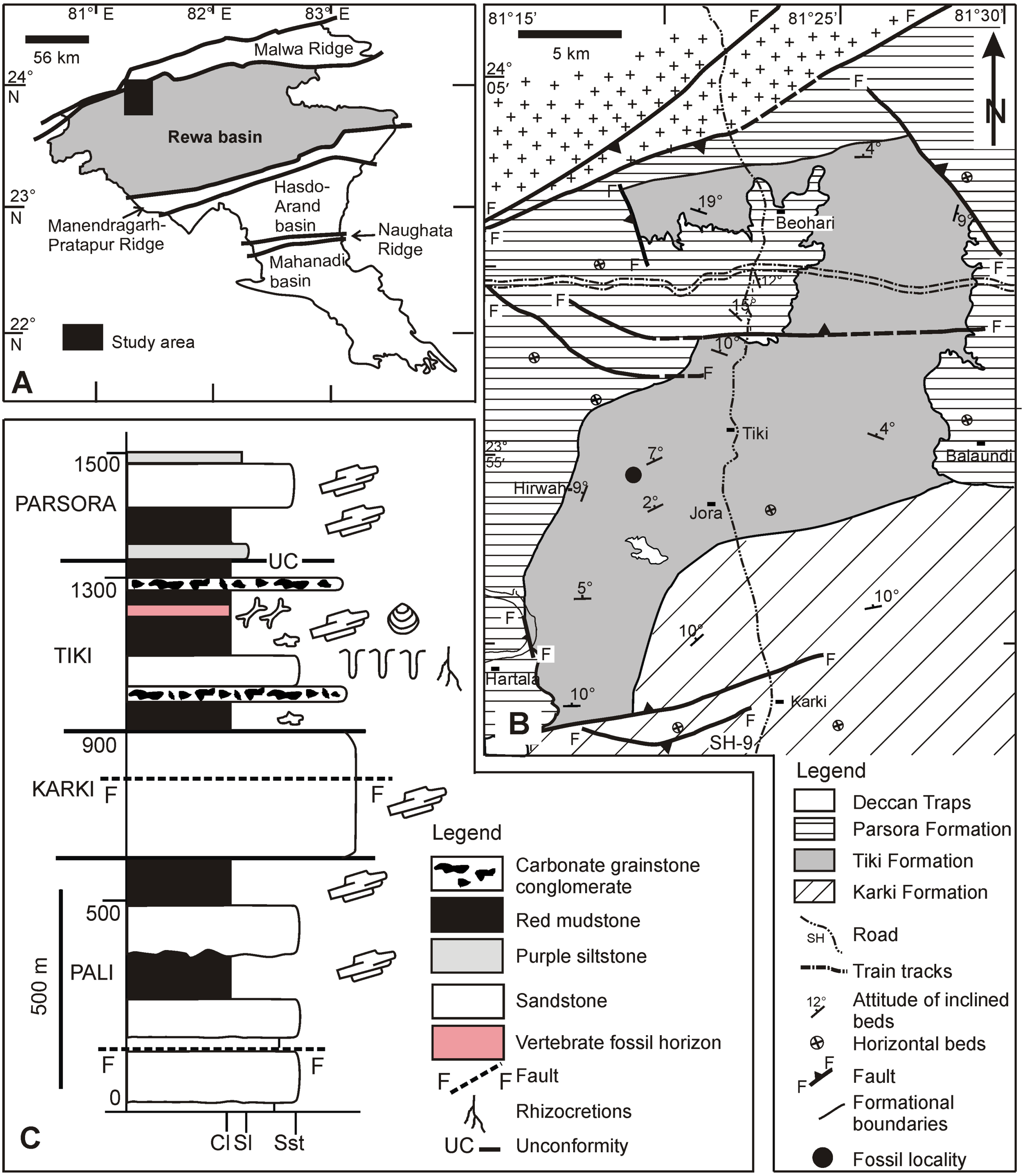

Fig. 2—Geological map of the A, composite Son–Mahanadi Basin showing the study area; B, study area showing the locality of the rhynchosaur bonebed (after Mukherjee & Ray, 2012); C, a composite litholog of the Tiki formation showing the vertebrate fossil–bearing horizon.

Age			Pranhita-Godavari	Satpura	Son-Mahanadi	Damodar
Jurassic		Upper		Bagra	Parsora	
		Middle	Kota			
		Lower	Dharmaram			
Triassic	Upper	Rhaetian				
		Norian	Maleri – Upper			
		Carnian	Maleri – Lower		Tiki	
	Middle	Ladinian	Bhimaram		Karki	
		Anisian	Yerrapalli	Denwa		
	Lower	Olenekian	Kamthi	Pachmarhi	Pali	Panchet
		Induan				
Permian	Upper		Kundaram	Bijori	← Raniganj →	
				Motur	← Barren Measures →	
	Lower		← Barakar →			
			← Talchir →			

Table 1—Stratigraphic correlation of the major Gondwana basins (after Mukherjee *et al*., 2012; Mukherjee & Ray, 2012).

NEW VERTEBRATE FOSSIL FINDS

Vertebrate macrofossils

A bonebed, about 1 m thick and encompassing an area of 250 x 217 m^2 , containing abundant rhynchosaur fossils was described by Mukherjee and Ray (2012) from the upper part of about 18 m thick Tiki mudstone that occurs between a basal sandstone unit and overlying units of caliche–derived calcarenites/calcirudites. Petrified wood and unionid *Tikhia* (Sahni, 1955) are found in the vicinity of the bone specimens. The sandstone unit that underlies this fossil–bearing mudstone unit contains small tubular burrows similar to the ichnogenus *Skolithos*. The bonebed is a low–diversity, multitaxic vertebrate accumulation and has been attributed to biological aggregation with a hydraulic overprint resulting in a mixed origin concentration (Mukherjee & Ray, 2012). It is hypothesized that the animals were concentrated in the vicinity of the water sources during a period of aridity and possibly died during high seasonal rainfall that resulted in a major flood event. Subsequently, the soft tissues decomposed, and the skeletons suffered subaerial exposure when the water receded, leading to disarticulation, fragmentation, and minor dispersion by low–velocity water currents. This resulted in segregation of skeletal specimens, which were gradually covered by mud deposited during later flooding events.

Given below is a brief description of the recovered vertebrate macrofossil assemblages.

Rhynchosaurs—A total of 617 identified specimens of rhynchosaurs (Fig. 3A–B) were collected from the bonebed (Mukherjee & Ray, 2012), where minimum number of individuals (MNI) ranges between 13 and 20 and belong to different ontogenetic stages as suggested by their relative size, degree of ossification and osteohistology (Mukherjee 2015). These specimens pertain to a recently described new species of the genus *Hyperodapedon*, namely *H. tikiensis* (Mukherjee & Ray, 2014). *Hyperodapedon tikiensis* is diagnosed on the basis of several cranial and postcranial features including longer than wide basipterygoid process, crest–shaped maxillary cross–section lateral to the main longitudinal groove, deeply excavated neural arches of mid–dorsal vertebrae, long scapular blade, a pronounced deltopectoral crest, proximal humeral end much broader than distal end, iliac length greater than iliac height, equal pre–and postacetabular iliac lengths and circular femoral cross–section. Mukherjee & Ray (2014) showed that there are two morphotypes (I and II) of *H. tikiensis* based on maxillary tooth plates. The morphotype I is abundant in the bonebed and is characterized by a single longitudinal groove, subdividing the dentigerous space into lateral and medial, where four and at least two rows of teeth are present, respectively (Fig. 3C–D). These show distinct diagonal rows of tooth replacement (Fig. 3C). On the other hand, morphotype II is distinctly different from morphotype I as being larger in size, relatively rare in the bonebed, and characterized by double longitudinal grooves with a much wider lateral dentigerous space (LDS, Fig. 3E–F). Mukherjee & Ray (2014) considered morphotype II to represent late ontogeny.

Cynodonts—From the same bonebed, a new and large traversodontid cynodont was recovered from a single site with an area of about 2 m^2. The cynodont, *Ruberodon roychowdhurii* (Fig. 4A–B) is based on an ontogenetic series of five partial lower jaws, of which three symphyseal regions are shown in Figure 4C–E. These range from 78–260 mm in total length of the dentary (Ray, 2015). The taxon is a gomphodontosuchine traversodontid diagnosed on the basis of a procumbent and hypertrophied lower first incisor, a robust and posteriorly sloping, deep lower jaw symphysis, a long diastema between lower canine and first postcanine, splenial forming medioventral margin of lower jaw, and a high coronoid process at an angle of about 60º with horizontal axis. Autapomorphic characters of *Ruberodon* in relation to Gomphodontosuchinae include a large lower canine and a strong coronoid process anterior to the masseteric fossa (Ray, 2015).

Dinosaurs—In addition, numerous small partial and complete vertebrae and partial limb bones have been discovered from a single locality, about 500 m away from the cynodont locality. The study of these skeletal specimens is in progress but several diagnostic features such as sigmoidal femur with rectangular 4^{th} trochanter, quadrangular distal tibial articular surface and a prominent posteroventral process of the tibia suggest the presence of a basal saurischian dinosaur.

Vertebrate microfossils

Vertebrate microfossils incorporate both complete skeletal elements and fragments of teeth, bones and scales, which are less than 12.5 mm in diameter, though the organism could be larger in size (Heckert, 2004). Several microsites *(sensu* Sankey, 2008) were prospected for microfossils which included bulk sampling of nearly 5 tonnes of sediments and screen washing. From microscopic examination of the screen–washed material, different groups of vertebrate microfossils, mostly in the form of numerous isolated teeth (80%) and skeletal elements such as skull and mandibular fragments, vertebrae and complete or partial limb bones (20%) were collected. Since isolated teeth are resistant to weathering in comparison to body fossils, these are found in abundance and help in the identification of taxonomic groups. Major Tiki vertebrate groups as based on distinct dental morphology include different types of freshwater sharks, bony fishes, varied archosauriforms, lepidosauromorphs, other indeterminate reptiles and cynodonts (Fig. 5).

Fishes—The freshwater sharks incorporate the hybodonts and xenacanths. The former is characterized by lateral teeth having mesiodistal elongation, low coronal profile, a principal cusp, lingual face depressed near lingual peg, and a distinct

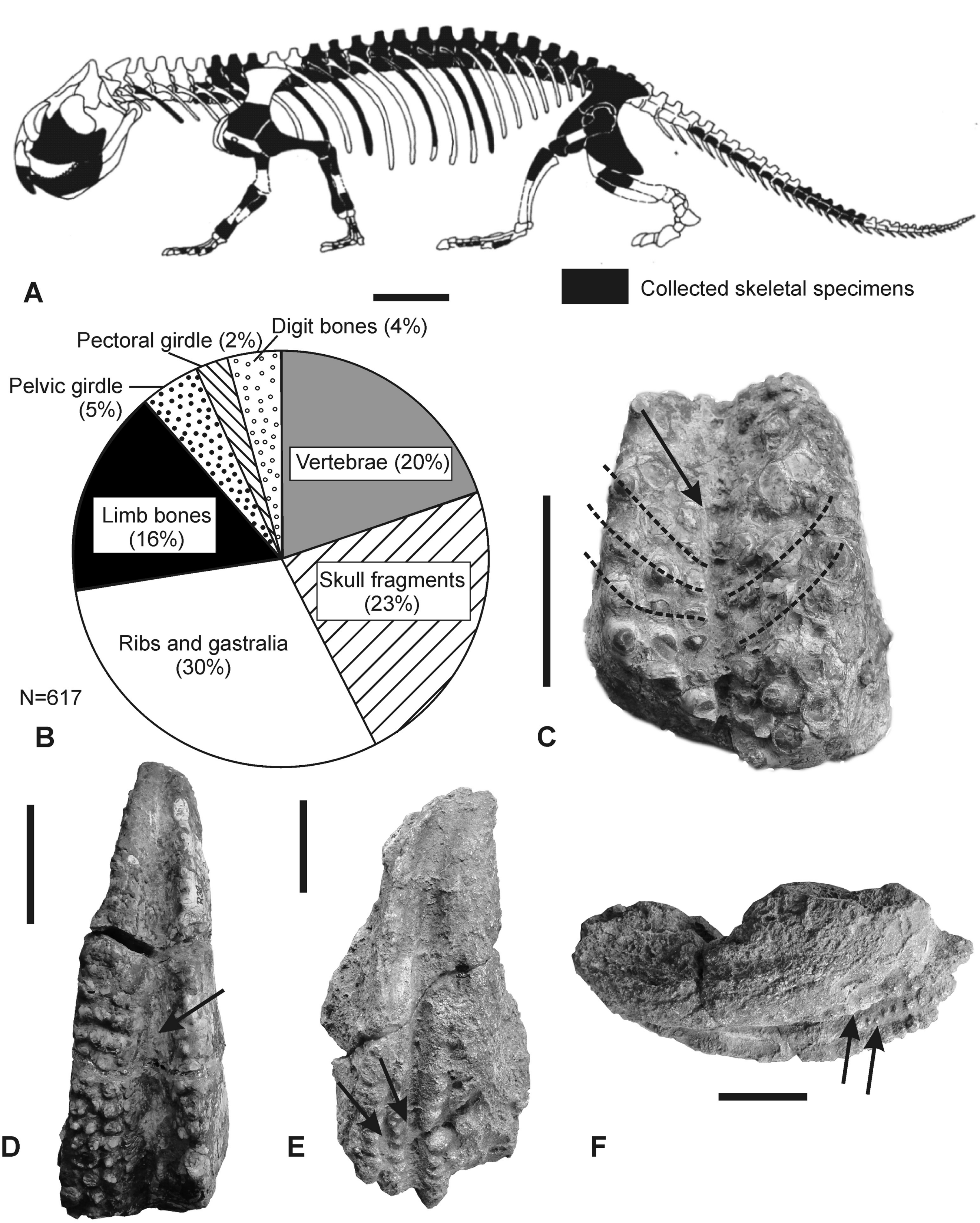

Fig. 3—*Hyperodapedon tikiensis* Mukherjee & Ray (2014). A, reconstructed skeleton showing the different types of bones collected (in black); B, pie diagram showing relative abundance of the collected specimens; C, IITKGPR50, a partial maxillary tooth plate showing diagonal rows of tooth replacement (dashed lines); D–F, complete maxillary tooth plates, D, IITKGPR38, right maxilla (morphotype I) in occlusal view; E–F, IITKGPR42, left maxilla (morphotype II) in E, occlusal and F, lingual views. Arrows indicate longitudinal grooves. Scale bars represent 100 mm (A), 30 mm (C–F).

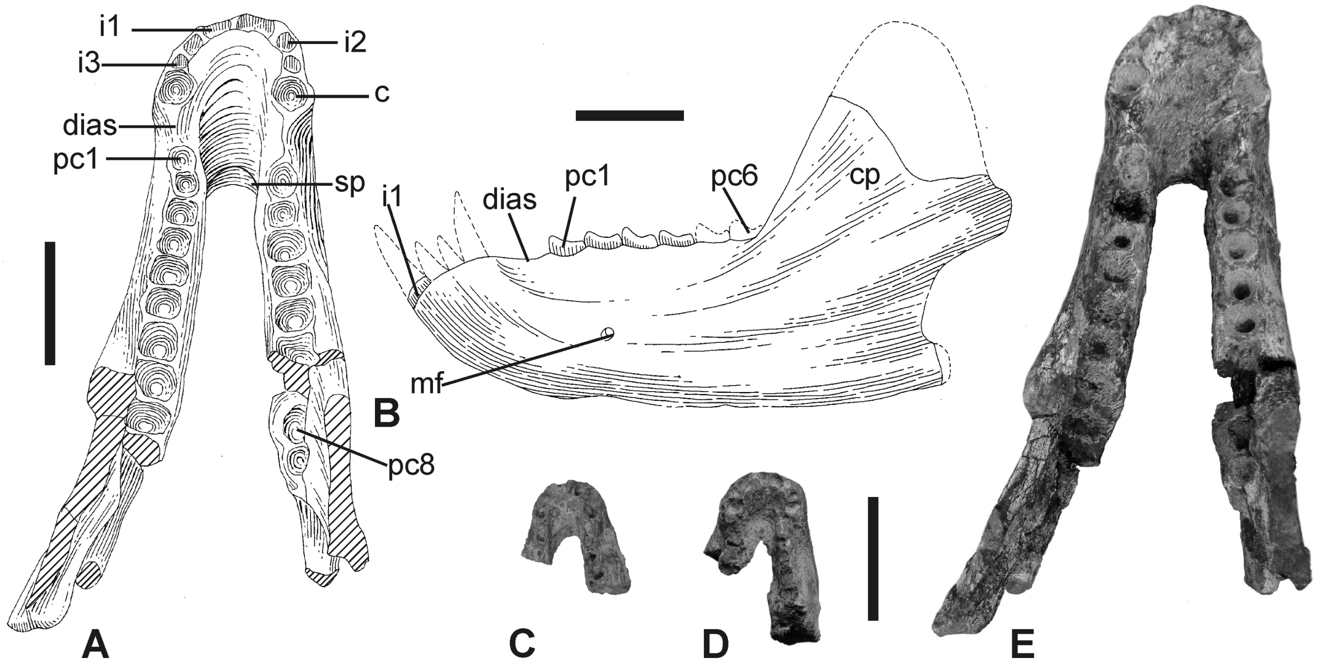

Fig. 4—*Ruberodon roychowdhurii* Ray (2015). A, IITKGPR381, a nearly complete lower jaw in occlusal view; B, restored left mandible in lateral view [modified after Ray (2015)] ; C-E, three partial lower jaws showing a growth series, C, IITKGPR376; D, IITKGPR375; E, IITKGPR381. **Abbreviations used**: **c**, canine (alveolus); **cp**, coronoid process; **d**, dentary; **dias**, diastema; **i1–i3**, alveoli of the incisors; **mf**, mental foramen; **pc1–pc8**, teeth/alveoli of the postcanines; **sp**, splenial. Scale bars represent 50 mm.

linear depression along the crown base near crown–root junction (Fig. 6A–C), whereas the latter is characterized by a tricuspid crown, high lateral cusps and a triangular tooth base (Fig. 6D–G). In addition, there are more than 200 upright, actinopterygian teeth, which have semi–transparent acrodin cap and circular base (Fig. 6H–I). They may be subdivided into several morphotypes based on their distinct morphological features such as stoutness, curvature and extent of the acrodin caps. In addition, there are tooth plates (Fig. 6J), which are characterized by five or six moderately robust ridges separated by angular clefts suggesting that these belonged to the lung–fish or the dipnoan family Ceratodontidae.

Reptiles (Archosauriformes)—There are about 700 reptilian teeth preserved, of which nearly 300 teeth have slightly recurved, subtriangular crowns with expanded bases, asymmetrical in basal view and distinct denticles both on the posterior or anterior carinae (Fig. 7A–E). In most of these teeth, only crowns are preserved, suggesting that these represent shedded teeth, though several specimens have their roots attached. The morphology of these teeth suggests that these belong to the archosauriforms and are similar to that of *Tecovasaurus*, *Revueltosaurus* and others (Godefroit & Cuny, 1997; Heckert, 2004; Irmi*s, et al*., 2007). There are several long, cylindrical teeth with asymmetric crown base and show similarity with that of the saurischians, especially the theropod dinosaurs (Fig. 7D–E). However, since the teeth were found isolated, without being associated with any other skeletal elements, it is not possible to ascertain their taxonomic position up to the generic and specific level.

In addition, there are multiple partial rhynchocephalian maxillary and dentary regions which show either fully acrodont or pleurodont dentition. Each of these maxillary regions bear two or three mature teeth, which are acrodont, rounded, conical with broad base and longitudinally striated (Fig. 7F–G). A small partial and slender mandibular ramus where the dentary is essentially preserved show a long tooth row with pleurodont implantation in which the teeth are ankylosed to the medial wall of the dentary and rest on a basal

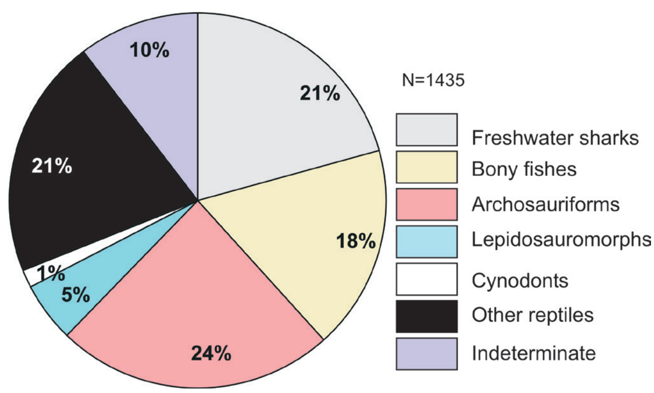

Fig. 5—Pie diagram showing relative abundances of the major groups of vertebrate microfossils, where total number of collected specimens is represented by N.

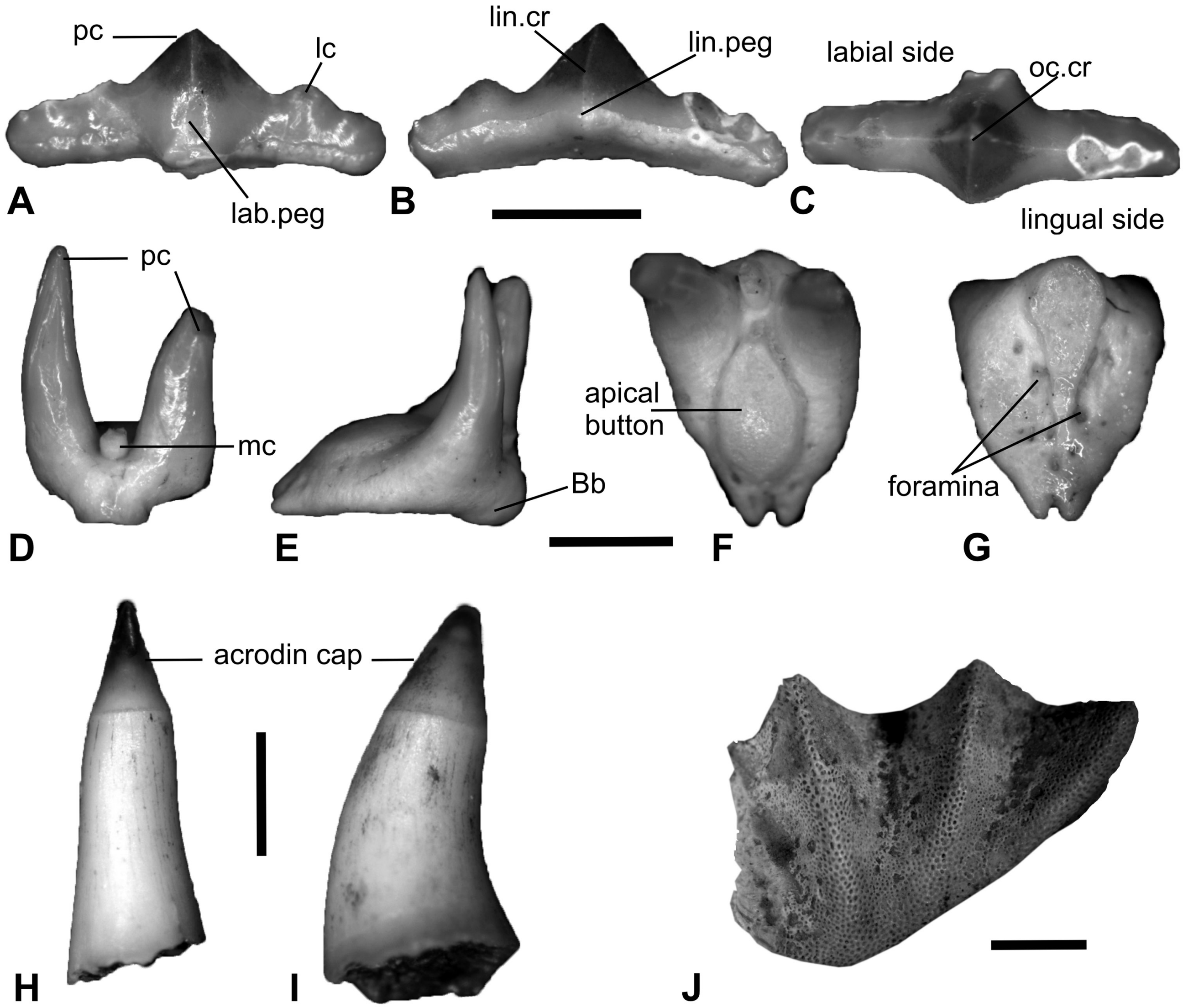

Fig. 6—Representative isolated teeth of the A–C, IITKGPP12, hybodont in A, labial, B, lingual and C, occlusal views; D–G, IITKGPP40, xenacanthid, in D, labial, E, distal, F, occlusal and G, basal views; H–J, bony fishes, H, IITKGPP70, I, IITKGPP88 in side views; J, IITKGPPT10, *Ceratodus* sp. in dorsal view. **Abbreviations used**: **Bb**, basal boss; **lc**, lateral cusp; **lin.cr**, lingual crest; **lin. peg**, lingual peg; **mc**, medial cusp; **oc.cr**, occlusal crest; **pc**, principal cusp. Scale bars represent 1 mm (A–C), 0.5 mm (D–I), 2 mm (J).

shelf (Fig. 7I). There are no tooth sockets. Each tooth is held in position by a layer of ankylosing bone or cementum around its base (Edmund, 1960; Zaher & Rieppel, 1999). Anterior teeth are slender, long and slightly recurved whereas the posterior ones are relatively small and broad. The study on this specimen is in progress and it possibly belongs to a new rhynchocephalian taxon.

BIOSTRATIGRAPHIC IMPLICATIONS

Although there are difficulties in correlating tetrapod–bearing continental rocks with well–dated marine sequences and with standard palynological zonation (Lucas & Heckert, 2000; Langer, 2005), recent advances have made it possible to correlate continental deposits based on tetrapod fossils globally (e.g., Lucas, 1998; Lucas & Heckert, 2002; Langer, 2005; Lucas *et al.*, 2007). At present, eight temporally

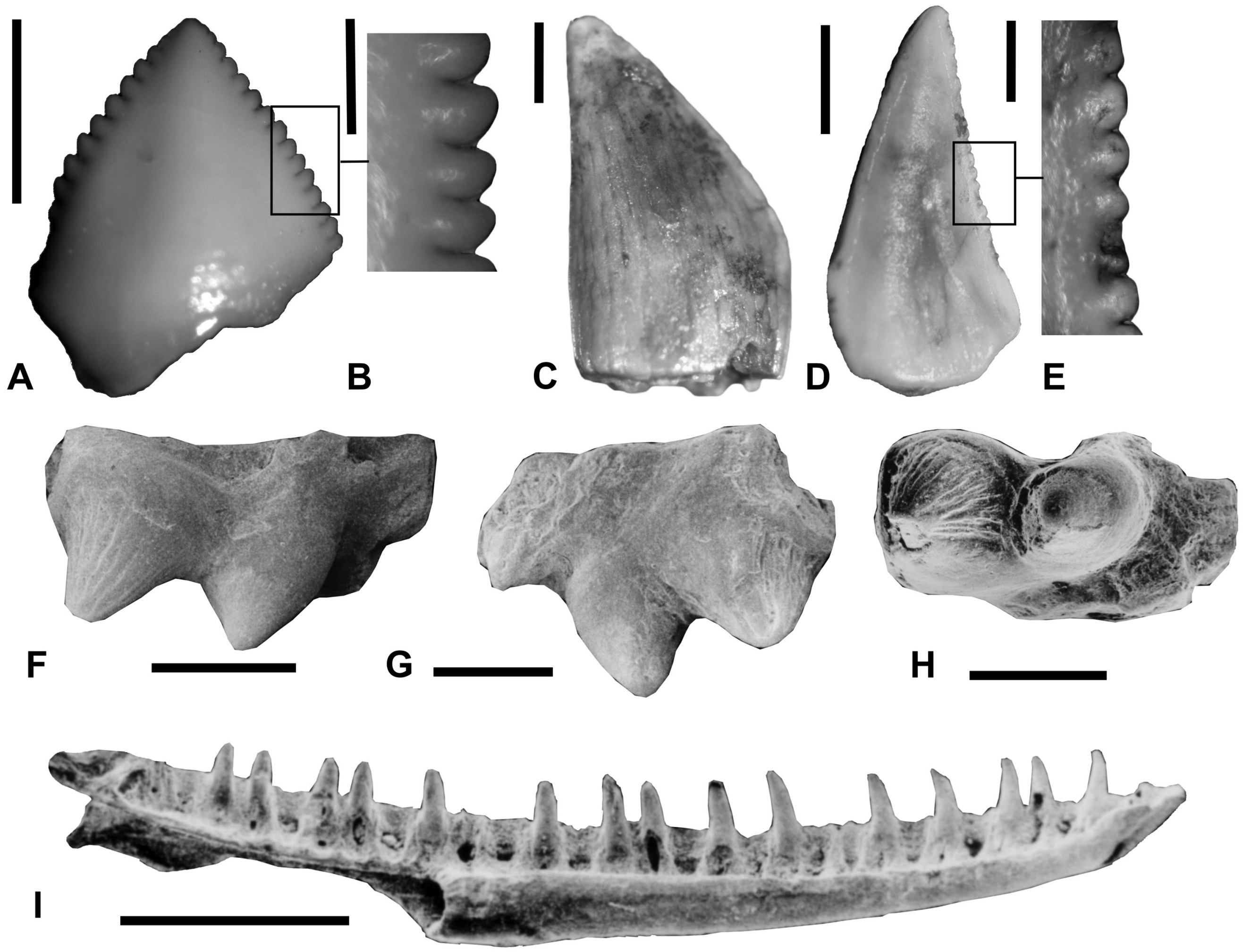

Fig. 7—A–E, Representative isolated teeth of an A–C, indeterminate archosauriform, A–B, IITKGPR417D in A, labial view; B, inset at higher magnification showing distinct denticles oblique to the longitudinal axis of the tooth; C, IITKGPR404A in lingual view; D–E, IITKGPR435B, indeterminate theropod in D, labial view; E, inset at higher magnification showing distinct denticles perpendicular to the crown–margin; F–I indeterminate rhynchocephalian showing F–H, right maxillary region with acrodont implantation in F, labial, G, lingual and H, occlusal views; I, a partial mandibular ramus showing long tooth row with pleurodont implantation in lateral view. Scale bars represent 1 mm (A, D, I), 0.5 mm (C), 0.2 mm (B, E), 600 µm (F–H).

successive land vertebrate faunachrons (LVF) are recognized (Table 3), which compare to the seven Triassic Stages/Ages of the standard global chronostratigraphic scale (Lucas, 1998; Gradstein *et al*., 2012). Of these eight LVFs, four pertains to the Late Triassic encompassing Carnian, Norian and Rhaetian Stages/Ages. In the Late Triassic, a *Hyperodapedon* biochron (Lucas & Heckert, 2002; Lucas *et al*., 2002) was established, which belongs to the Carnian substage. This biochron can be traced globally in countries such as North America, Scotland, India, Tanzania, Zimbabwe, Madagascar, Argentina, and Brazil.

In India, the Late Triassic is represented by three different stratigraphic horizons, the Maleri and the lower part of the overlying Dharmaram formations of the PG Basin and the Tiki Formation of the Rewa Basin (Table 1). Two distinct vertebrate assemblages are recognized from the Maleri Formation (Kutty & Sengupta, 1989), where the lower fauna includes the rhynchosaur *Hyperodapedon huxleyi*, a basal phytosaur *Parasuchus hislopi*, a prolacertiform *Malerisaurus*, fragmentary remains of an aetosaur that may be assigned to *Typothorax*, a basal saurischian *Alwalkeria*, a large undescribed dicynodont, and the traversodontid *Exeraetodon statisticae* (Chatterjee, 1987; Kutty & Sengupta, 1989; Langer, 2005; Bandyopadhyay, 2011). Because of the abundance of *Hyperodapedon* in the Lower Maleri fauna (about 60% of the total diversity, Benton, 1983), Langer (2005) equated the lower Maleri fauna with the lower fauna–bearing zone of the Ischigualasto Formation, lower part of the Cacheuta and the upper part of lower Makay, Pebbly Arkose, and Molteno formations, and suggested an early Ischigualstian (Carnian) age for the lower Maleri Formation. Bandyopadhyay & Sengupta (2006) corroborated this finding. On the other hand, the Upper Maleri fauna includes two chigutisaurs (*Compsocerops* and *Kuttycephalus*), two phytosaurs (*Rutiodon* and *Leptosuchus*), an aetosaur, and a dicynodont (Kutty & Sengupta, 1989; Hungerbühler *et al*., 2002; Bandyopadhyay & Sengupta, 2006). This fauna occurs in a stratigraphically younger horizon, and has not yielded any *Hyperodapedon*, *Exeraetodon* and *Parasuchus*. The upper Maleri faunal zone has been correlated with that of the Lower Elliot, lower part of the upper Makay, and lower parts of the Rio Blanco and Los Colorados formations and an early Norian age has been proposed (Bandyopadhyay & Sengupta, 2006; Bandyopadhyay, 2011).

Stratigraphically important palynomorph assemblage of the Tiki Formation includes *Aulisporites artigomosus, Camnosporites secatus, Duplicisporites granulatus, Granuloparculatipoliis sp., Enzonalasporites densus, E. ignacii and E. vigenus* (Maheshwari & Kumaran, 1979). This assemblage appears to be closely similar to the upper part of the *Samaropollenites* Zone of the Onslow palynoflora of Northwestern Australia (Datta, 2004; Mukherjee *et al*., 2012). Based on its floral and faunal content, the Tiki Formation was correlated with the lower member of the Maleri Formation of the Pranhita–Godavari Basin (Lucas, 1998; Datta, 2004; Ray, 2015) and the Camp Springs Member of the Dockum Formation, USA (Datta *et al*., 2004). A Carnian age was suggested for the Tiki Formation (Datta, 2005; Mukherjee *et al*., 2012).

Although it is evident that the Late Triassic horizons of India record highly diverse tetrapod assemblages, reports on fossil fish fauna are rare. Pleuracanth sharks and actinopterygians, including the xenacanthid *Xenacanthus indicus* having diplodus teeth with well–developed prongs (Jain *et al*., 1964; Jain, 1980) and the hybodontid *Polyacrodus contrariusi* (Prasad *et al*., 2008) were reported from the Maleri Formation, whereas the Tiki Formation has yielded several hybodontid sharks such as *Lonchidion estesi, Lonchidion incumbens, Lissodus duffini,* and *Parvodus tikiensis* (Prasad *et al*., 2008).

Ongoing research work has yielded numerous isolated teeth of hybodontid and xenacanthid freshwater sharks from the Tiki Formation. Previous work on these forms (e.g., Murry,1981; Heckert, 2004; Cappetta, 2012) show that these are mostly recovered from Laurasian countries such as USA, France, Spain, Germany, England, Russia and China, with only a few genera are known from the Gondwanan countries such as Brazil, South Africa, Australia and India. Many of these fish taxa have long stratigraphic ranges showing that they are not suitable as index fossils (Heckert & Lucas, 2006). However, examination of archosauriform teeth reveals presence of *Tecovasaurus*–and *Revueltosaurus*–like teeth in

Class	**Family**	**Specific name**
Pisces	Ceratodontidae	*Ceratodus sp.*
	Hybodontidae	*Lonchidion estesi*
		Lonchidion incumbens
		Lissodus duffini
		Parvodus tikiensis
		New Undescribed forms
	Xenacanthidae	New undescribed forms
Amphibia	Metoposauridae	*Metoposaurus maleriensis*
Reptilia	Rhynchosauridae	*Hyperodapedon tikiensis*
	Phytosauridae	*Parasuchus hislopi*
	Rauisuchidae	*Tikisuchus romeri*
	Rhynchocephalia	Undescribed
	Acrodonta	*Tikiguania estesi*
	Basal Saurischia	Undescribed
	Dromatheriidae	*Rewaconodon tikiensis*
	Traversodontidae	*Ruberodon roychowdhurii*
Mammalia	Mammaliaformes	*Tikitherium copei*
	Mammaliaformes	*Gondwanodon tapani*

Table 2—Vertebrate fossil assemblage of the Tiki Formation, India. Sources of information: Chatterjee (1978), Chatterjee & Mazumdar (1987), Datta & Das (1996), Sengupta (2002), Datta *et al.* (2004), Datta (2005), Prasad *et al.* (2008), Mukherjee & Ray (2014), Kammerer *et al.* (2015), Ray (2015).

	Epoch	Age	LVF	Brazil: Paraná	Argentina: Isch.-Villa Unión	Madagascar: Morondava	India: PG	India: Rewa	USA: Arizona New Mex.	USA: Texas
TRIASSIC	U	Rhaetian	Apac.	Ictidosaur AZ	Los Colorados		Dharmaram		Chinle: Rk.Pt; Owl Rock	Chinle: Redonda
	U	Norian	Rev.				Maleri U		Chinle: Pet. Fm.	Chinle: Bull Can; Trujillo
	U	Norian	Adam.	Cat.Fm.	? Ischigualasto Fm.	Isalo II beds	Maleri L	? Tiki Fm.	Chinle: Blue Creek	Chinle: Tec.Fm
	U	Carnian	Otis.	Santa Maria Formation U: *Hyp.* AZ	Ischigualasto Fm.	Isalo II beds	Maleri L	Tiki Fm.	Chinle: Shinarump	Chinle: CC.Fm; CS.Fm
	M	Ladinian	Berd.	Santa Maria Formation L: Trav. BZ; *Dino.* BZ	Chañares	Isalo II beds	Bhimaram			
	M	Anisian	Per.	?Santa Maria Formation			Yerrapalli		Moenkopi	
	E	Olenekian	Non.	Sanga do Cabral			Kamthi		Moenkopi	
	E	Induan	Loot.	Sanga do Cabral			Kamthi			

Table 3—Correlation of the Tiki Formation with other major verte brate–bearing horizons (shaded in grey). Question marks (?) indicate uncertainty in the extent of the lower or upper boundaries. Sources of information: Bandyopadhyay & Sengupta (2006), Flynn *et al*. (2000), Langer (2005), Gradstein *et al*. (2012), Tanner *et al*. (2013), Ray (2015), Kammerer *et al*. (2015) and current study. **Abbreviations**: **Apac**, Apachean; **Adam**, Adamanian; **AZ**, Assemblage Zone; **Berd**, Berdyankian; **Bull Can**, Bull Canyon Formation; **CC.Fm**, Colorado City Formation; **Cat. Fm**, Caturrita Formation; **CS.Fm**, Camp Spring Formation; **Cynog. AZ**, *Cynognathus* Assemblage Zone; **Dam**., Damodar Basin; **E**, Early; **Fm**., Formation; **L**, Late; **Loot**., Lootsbergian; **Lystro. AZ**, *Lystrosaurus* Assemblage Zone; **LVF**, Land Vertebrate Faunachron; **M**, Middle; **Non**, Nonesian; **Otis**, Otischalkian; **Per**, Perovkan; **Pet.For**, Petrified Forest Formation; **Rev**, Revueltian; **RK.Pt**, Rock Point Formation; **Sat,** Satpura Basin; **Tec.Fm**, Tecovas Formation.

the Tiki Formation, whereas the dromatheriid *Rewaconodon* is found in the lower part of the Tecovas Formation of USA. Hence, the Tiki Formation shows an overlapping of vertebrate fauna with the lower Tecovas Formation of the Chinle Group, USA and may be correlated with the latter (Table 3), which belongs to early Adamanian (Tanner *et al*., 2013) in age.

On the other hand, the dominant components of the Tiki vertebrate fauna are the temnospondyl *Metoposaurus maleriensis* (Sengupta, 2002), the rhynchosaur *Hyperodapedon tikiensis* (Mukherjee & Ray, 2014) and the phytosaur *Parasuchus hislopi* (Chatterjee, 1978). In addition, the formation has yielded a traversodontid *Ruberodon roychowdhurii* (Ray, 2015) and fragmentary remains of a basal saurischian (Table 2). The association of *Metoposaurus–Hyperodapedon–Parasuchus* suggests that the Tiki fauna pertains to the Otischalkian LVF (*sensu* Lucas, 1998), *Hyperodapedon* biochron (*sensu* Lucas & Heckert, 2002) and the Ischigualastian LVF (*sensu* Langer, 2005). Most traversodontid genera diversified during Ladinian–Carnian, and are essentially known from the Santa Maria Formation of the Paraná Basin of Brazil and the Chañares Formation of Argentina. Based on tetrapod assemblage, Ray (2015) correlated the Tiki Formation with the upper part of the Santa Maria Formation of Brazil (Table 3) and proposed an early Carnian age for the Tiki Formation. However, the new recovery of a rich microvertebrate assemblage shows possible correlation with the lower Tecovas Formation of the Chinle Group, USA suggesting a narrower range where the Tiki Formation is Otischalkian to early Adamanian in age.

CONCLUSIONS

The current work gives an overview of the recent discovery of vertebrate fossils from the Tiki Formation of India, which includes a new rhynchosaur, a new traversodontid cynodont, an undescribed basal saurischian and numerous varied vertebrate microfossils. Based on the flora and fauna, the Tiki Formation is globally correlated with different stratigraphic horizons such as the lower Maleri Formation of the Pranhita–Godavari Basin, India, the upper part of the Santa Maria Formation of Brazil, the Camp Springs and lower Tecovas formations of the Chinle Group, USA. Hence, an Otischalkian to early Adamanian age is proposed for the formation.

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