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Contribution to the stratigraphy and vertebrate fauna of Lower Jurassic Kota Formation, Pranhita-Godavari Valley, India

P. Yadagiri[1] & B. R. J. Rao[2]

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Gondwana Sequence of the Pranhita-Godavari Valley represents a thick succession of sediments ranging in age from Early Permian to Early Cretaceous. The Mesozoic Gondwana sediments contain a number of vertebrate bearing zones which are important for correlation and for assigning age to different units. New data on the vertebrate fossils of Kota formation help trace the evolutionary history of Early Jurassic mammals and dinosaurs and palaeogeographic configuration. The status of Gangapur Formation, as a unit, overlying Kota Formation and underlying Chikiala Formation is elaborated. Its lithological identity is established in the Yamanpalli area. Measured lithostratigraphic column of the limestone zone of Kota Formation is described with the lithological variations and fossil contents. The data is useful for correlation of limestone members in delineating Kota Formation along its strike. Analysis of the geochemical data and vertebrate fossil community of Mesozoic sediments with particular emphasis on the Kota Formation, provide overwhelming evidences for fresh water environment of deposition of the Kota Formation. The evolutionary status of vertebrate fauna consisting of early mammals, dinosaurs and pholidophorid fishes is described which supports Liassic age of the Kota Formation.

Key-words—Stratigraphy, Vertebrate fauna, Palaeoecology, Palaeobiogeography, Pranhita-Godavari Valley, (India).

[1]*P. Yadagiri, Geological Survey of India, Training Institute, Hyderabad 500 029, India.*
[2]*B. R. J. Rao, Geological Survey of India, Marine Geology, P.K.V. Bhandarkar's Complex, Mannagudda, Mangalore 575 003, India.*

सारॉंश

प्रणहिता-गोदावरी घाटी (भारत) में अधरि जूराई कोटा शैल-समूह के रीढ़धारी जीवजात तथा स्तरविन्यास पर योगदान

पी० यादागिरी एवं बी० आर० जे० राव

गोदावरी घाटी के गोंडवाना अनुक्रम में प्रारम्भिक परमी से प्रारम्भिक क्रीटेशी तक विस्तृत अवसादों का एक वहुत मोटा अनुक्रम विद्यमान है। मध्यजीवी गोंडवाना अवसादों में अनेक रीढ़धारी जन्तुधारक संस्तर विद्यमान हैं जो कि विभिन्न इकाइयों के सहसम्बन्धन तथा आयुनिर्धारण में महत्वपूर्ण भूमिका निभाते हैं। कोटा शैल-समूह के रीढ़धारी अश्मित जन्तुओं के नये आँकड़े प्रारम्भिक जूराई कालीन स्तनधारीयों एवं डाइनोसोरों के वैकासिक इतिहास तथा पुराभौगोलिक आकृति के अन्वेषण में सहायक सिद्ध हुए हैं। कोटा शैल-समूह के ऊपर तथा चिकियाला शैल-समूह के नीचे एक इकाई के रूप में विद्यमान गंगापुर शैल-समूह की स्थिति की विवेचना की गई है। यमनपल्ली क्षेत्र में इसकी शैलिकीय स्थिति भी स्थापित की गई है। कोटा शैल-समूह के चूनापत्थर मंडल के अनुमापित शैलस्तरिकीय कॉलम में प्रेक्षित शैलिकीय विभिन्नताओं तथा उपलब्ध जीवाश्मों का वर्णन किया गया है। उपलब्ध आँकड़े चूनापत्थर सदस्यों के सहसम्बन्धन में महत्वपूर्ण सिद्ध हुए हैं। मध्यजीवी अवसादों विशेषत: कोटा शैल-समूह के रीढ़धारी अश्मित समुदाय तथा भूरासायनिक आँकड़ों के विश्लेषण से कोटा शैल-समूह के निक्षेपणीय वातावरण के प्रमाण मिलते हैं जो कि अलवणी जल-परिस्थितियों में हुआ था। प्रारम्भिक स्तनधारीयों, डाइनोसोरों एवं फॉलिडोफोरिड मछलियों से युक्त रीढ़धारी जीवजात की वैकासिक स्थिति विवेचित की गई है जिससे कोटा शैल-समूह की लिऑसिक आयु की पुष्टी होती है।

Concepts, limits and extension of the Indian Gondwana
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THE Gondwana Sequence in the Pranhita-Godavari Valley contains rich vertebrate fossil horizons. The Upper Gondwana sediments were considered as consisting of three units namely Maleri, Kota and Chikiala in the order of succession (King, 1881). Recent remapping of the northern part of the Pranhita-Godavari Valley, especially by Jain *et al.* (1964), Chatterjee (1967), Kutty (1969), Sengupta (1970) and Rudra (1982), has led to substantial revision and modification to the Upper Gondwana stratigraphy as proposed by King (1881). However, the lateral equivalency of the Gangapur Formation and King's Chikiala still remains undecided and needs to be analysed (Rudra, 1982). On the basis of detailed mapping of lithounits around Yamanpalli covering an area of about 600 sq km and collection of *in situ* fossils from different horizons it is found that the Gangapur Formation overlies the Kota Formation with an unconformity and the former is overlain by the Chikiala Formation.

The paper presents the revisions to the stratigraphy of the area around Yamanpalli and the detailed account of faunal content of Kota Formation, and their bearing on palaeoecology and palaeobiogeography.

STRATIGRAPHY

The Maleri according to King (1881), consists of predominant red clays which contain Upper Triassic vertebrate fossils and few interbedded calcareous sandstones. The Kota consists of sandstones dominantly, which are either calcareous or non-calcareous and some intercalated red clays and three strongly developed fossiliferous bedded limestones yielding Lower Jurassic Vertebrate fossils.

The mapping carried out along with collection of fossils between Yamanpalli and Sironcha has helped in establishing the following stratigraphy of the area (Table 1, Text-fig. 1). In the area investigated, the Gangapur unit is recognised overlying the Kota Formation from Radharam to Garkapet. It is also observed that the Gangapur Formation is overlain by Chikiala Formation (Text-figs 2, 3).

King (1881) placed the sandstones found near Annaram and Arjungutta as basal beds of Kota 'Stage' and considered them to be equivalent of Gangapur beds occurring in Jangaon Valley. Kutty (1969) placed Gangapur as a separate unit overlying the Kota Formation with an angular unconformity. Rudra (1986) included the Annaram beds as part of Dharmaram formation. Annaram beds have yielded typical floral elements, viz., *Pagiophyllum, Elatocladus, Araucarites cutchensis*, etc. (Tripathi, 1975), the assemblage being similar to that of the Gangapur Formation. The lithounits comprising coarse sandstones are also comparable to the outcrops occurring near Radharam and Kalamalpet. These are classified under Gangapur Formation.

UPPER GONDWANA LITHOUNITS

Maleri

Good outcrops of Maleri are seen near Nakalapalli, Isnai, Pinnaram and Parpalli. There are three main lithologies in the Maleri Formation namely, clays, lime pellet rocks and sandstones; various intermediate types such as siltstones and silty clays are also common. The clays, in general, are soft and red in colour. The lime pellet rocks are mainly composed of rounded pellets of lime varying in size from a millimeter to about a centimeter in diameter. The pellets have an interstitial matrix of clay and are sometimes cemented together with lime to form a tolerably hard rock. The sandstone is light coloured, fine or medium-grained, and contain green and red clay galls, lime pellets and siltstone fragments. In geomorphic expression, the clays normally form the low ground, whereas the sandstone bodies form fairly long ridges trending parallel to the regional strike.

The Maleri fauna is essentially a vertebrate fauna. Only one invertebrate, a unionid *Tihkia* is known. The vertebrates represent the dipnoan *Ceratodus*, the pleuracanth *Xenacanthus*, the labyrinthodont *Metoposaurus*, the rhynchosaur *Paradapedon* and a coelurosaur and a prosauropod dinosaur.

Dharmaram

The Dharmaram Formation comprises a succession of alternating sandstone and clay bands (Pl. 1, fig. 1), the clays forming the low ground and the sandstones standing out as ridge features. The sandstones are generally pale coloured but occasionally dark. The clays are dominantly red in colour. The sandstones are usually current bedded, rarely fine grained. The occurrence of gypsum flakes in the red clays of Dharmaram near Kureampalli is interesting. The gypsum flakes are 3 to 8 mm in thickness. A number of mud crack nodules are also found. The sandstone exposed north of Nilwai is yellow in colour, coarse and sometimes gritty and poorly sorted. The strike of the beds is N35°W and dip at 9° towards NE direction. The red and green clays overlie them. The Dharmaram Formation is observed to thin down in the south-eastern part.

The Dharmaram Formation can be distinguished from the underlying Maleri Formation by the

Table 1—Lithological sequence in Yamanpalli area

Formation	*Lithology*	*Thickness in metres*	*Characteristic fossils*	*Age*
Chikiala	Ferruginous sandstones with conglomerates	400	Plant fossils	Early Cretaceous
Gangapur	Highly calcareous sandstones; fine grained sandstones with interbedded clays; basal part conglomeratic with pebbles of quartz, quartzite and chert; mudstones, etc.	500	Fossil wood, plant fossils, etc.	Early Cretaceous
Kota	Red clays with interbedded siltstones and thin layers of ferruginous clay	100		
	Argillaceous, bedded limestones, beds locally laminated and with desiccation cracks	30	Fishes, flying reptiles and bivalved crustaceans	Early Jurassic
	Red and green clays with interbedded sandstones	50	Dinosaurs, early mammals	
	Current bedded grey calcareous sandstones grading to conglomerate in places with pebbles of quartzite, quartz and chert	250		
Dharmaram	Sandstones with interbedded red clays at places indurated mudstones	500	Prosauropods	Upper Triassic
Maleri	Red clays with interbedded sandstones and lime concretions	300	Metoposaurs, Rhnchosaurs, Phytosaurs	Upper Triassic

absence of lime pellet rock and white fine-grained sandstones. The contact of Dharmaram Formation with the Kota Formation is demarcated by the presence of pebbly sandstone and conglomeratic horizon.

The fauna from Dharmaram Formation includes at least two dinosaurs, a plateosaurid and a prosauropod.

Kota

The Kota Formation comprises mainly light brown sandstones and grits, red clays and a prominent limestone zone. The basal unit consists of coarse, poorly sorted, pebbly sandstone. The pebbles are of banded chert, quartz, and quartzite. In the upper unit, the pebbles become fewer and smaller and the pebbly sandstone passes into fine-grained white sandstones. These sandstones appear to grade laterally and vertically into red clays. The clays are overlain by the calcareous zone which consists of beds of limestone intercalated with marly clays. Limestones are usually pale grey, creamy or reddish in colour. The limestone is overlain by a highly ferruginous mudstone. The sandstone grades upward into siltstone and fine-grained sandstone.

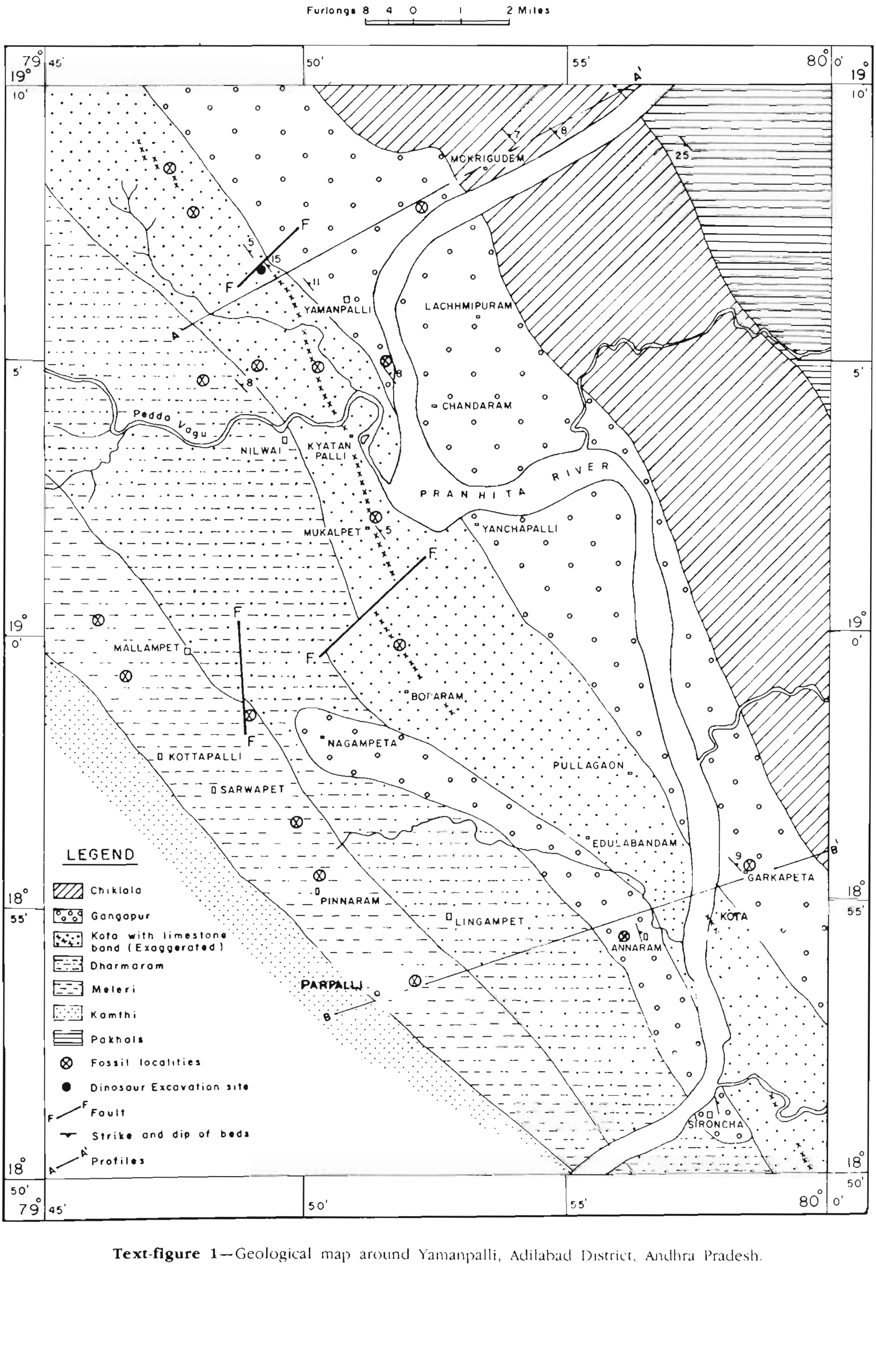
The important marker horizon of the Kota Formation is the limestone horizon (Pl. 1, fig. 3). This is traceable from kadamba in the north to Varidium in the south. In the area investigated, good outcrop of limestone horizon is traceable from Manganpalli to Mukalpet villages. Smaller outcrops are found near Boparam, Kota, Chitur and Varidium.

The basal limestone bed contains abundant ostracod shells (Text-fig. 4) cemented with lime mud. The marly bed immediately underlying this bed has yielded dinosaurian fossils. The succeeding limestone bed is massive, cream-coloured and with a few chert veins. It is stromatolitic at places; a 20-25 cm thick stromatolite-bearing limestone is seen 2 km east of Nagaram. The stromatolites are hemispherical and laterally linked (Pl. 2, fig. 3). Similar structures are also found near Manganpalli and Gorlapalli villages. The third bed is very massive, grey in colour and contains a number of desiccation cracks. The next limestone bed is of laminated variety. Abundant fish fossils are found in this horizon. The topmost limestone bed is nodular. A number of limestone pebbles, varying in size from 1 to 7 cm, are found embedded in the lime mud.

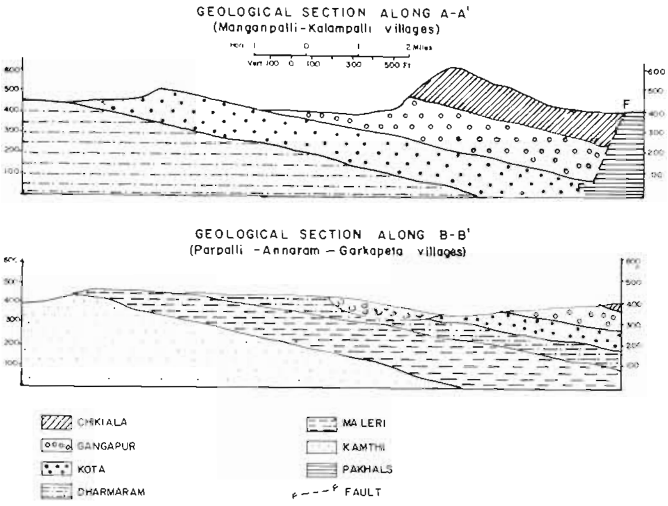
Overlying the limestone bed, the red clays intercalated with fine grained sandstones are found. The red clays are distinctly different from Maleri and Dharmaram clay is being devoid of ferruginous lumps and mudcrack nodules.

Gangapur

In the area investigated, the Gangapur Formation extends from Radharam mound to Garkapeta in the southeast. The basal beds consist of



Text-figure 1—Geological map around Yamanpalli, Adilabad District, Andhra Pradesh.



Text-figure 2—Geological section along A-A (Manganpalli-Kalampalli villages).

pebbly sandstones and mudstones which are locally conglomeratic. The conglomerate consists of pebbles of quartz, quartzite embedded in calcareous matrix (Pl. 1, fig. 2). The quartz pebbles vary in size from 0.5 to 2 cm. Above this horizon, clay clasts are found embedded in a ferruginous matrix. The conglomeratic bed becomes extensively ferruginous in the Pranhita River Section near Yamanpalli. The clay clasts measuring 5 to 50 cm are found sometimes within the conglomeratic bed. They are of pink, lilac, white and yellow colours. The conglomeratic bed is overlain by yellow to brown and lilac coloured sandstones which are soft and friable. This zone extends from Sumtam to Yamanpalli villages. It has yielded large fossil wood trunks. The topmost beds become calcareous and locally nodular limestone in which large fossil wood trunks are found embedded.

The sandstones near Annaram Village are reddish brown to yellowish and are indurated; frequent seams of quartz pebbles and lumps of pink and lilac clay are common. The same horizon extends to Kandampeta and Arjungutta. The strike of the beds is N25° W and the dip is 9° towards NE direction.

The Gangapur Formation has yielded flora representing *Taeniopteris* sp., *Ptilophyllum acutifolium, Cycadites* sp. and *Araucarites cutchensis*, etc.

Chikiala

Chikiala Formation represents the youngest unit of Gondwana sequence of the Pranhita-Godavari Basin and outcrops along the eastern fringes of the area. It consists of conglomerates, sandstones and clays. The lower beds consist of predominantly ferruginous conglomeratic sandstone. The conglomerate is composed of rounded to sub-rounded pebbles of quartz, quartzite, chert, hard porcellan clays and jasper in an arenaceous matrix. A good outcrop can be seen north of Makrigudem. The iron content is appreciably high. The conglomerate unit is succeeded by red clays, cross bedded calcareous sandstone which is occasionally conglomeratic towards top. This unit is overlain by brown-coloured loosely packed sandstone, which is ferruginous and rarely conglomeratic. The topmost beds consist of conglomerates with phyllite pebbles and ferruginous sandstone. The sandstones are generally coarse to medium grained (Pl. 2, fig. 2) and ferruginous; those are red, brown or white in colour. The most common of the clays interbedded in current bedded sandstones is red and purple clay. According to King (1881) sandstones of Chikiala are similar in appearance to that of Tirupathi sandstones.

Rao and Shah (1959) have reported a number of plant fossils from Chikiala Formation. The floral assemblage is characterised by the dominance of conifers which resembles the assemblage of Nipania Bed of Rajmahal, East Coast Gondwana and Bhuj Formation of Kutch.

VERTEBRATE FAUNA

The Kota fauna comprises the following taxa:

FISHES

SEMIONOTIDATE:

Lepidotes deccanensis Egerton, 1851
Paradapedium egertoni Jain, 1973
Tetragonolepis oldhami Egerton, 1851

PHOLIDOPHORIDAE:

Pholidophorus kingii Yadagiri & Prasad, 1977
Pholidophorus indicus Yadagiri & Prasad, 1977

COELACANTHIDAE:

Indocoelacanthus robustus Jain, 1974

REPTILES

DIMORPHODONTIDAE:

Campylognathoides indicus Jain, 1974

SAUROPOD DINOSAUR:

Barapasaurus tagoreii Jain *et al.*, 1975
Kotasaurus yamanapalliensis Yadagiri *et al.*, 1979; Yadagiri, 1988

MAMMALS

SYMMETRODONTA:

Kuehneotheriidae—*Kotatherium haldanei* Datta, 1981

Incertae sedis—*Trishulotherium kotaensis* Yadagiri, 1984
Indotherium pranhitai Yadagiri, 1984
Amphidontidae—*Nakunodon paikasiensis* Yadagiri, 1985

The Kota fauna encompasses aquatic, terrestrial, and aerial vertebrates, most of them excellently preserved.

Fishes

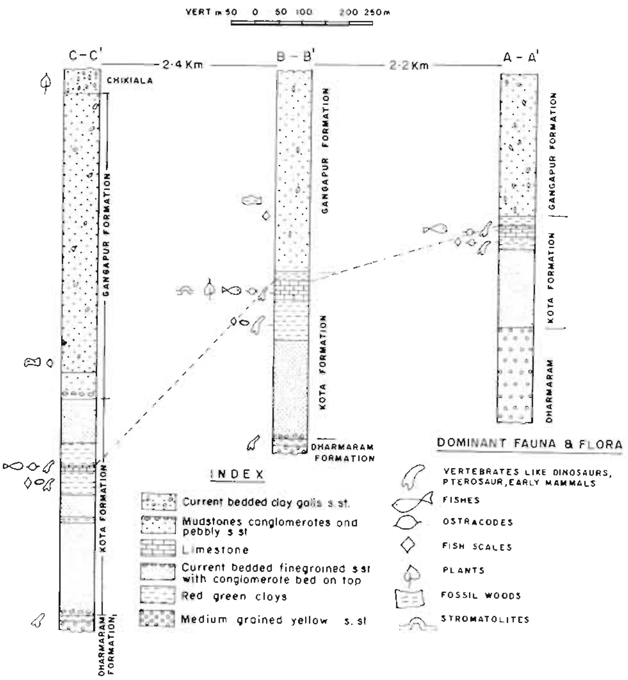
Lepidotes is the most commonly occurring member of the entire Piscine fauna; five species were designated by Egerton (1851). A detailed study of Kota specimens of *Lepidotes* (Yadagiri *et al.*, 1980; Jain, 1983) and an examination of the validity of characters used to distinguish species within the limits of genus, suggest that all Kota specimens should be placed in a single species, viz., *Lepidotes deccanensis*.

The semionotid *Dapedium*, recognized in the nineteenth century, were found morphologically different and a new genus *Paradapedium* was erected (Jain, 1973).

Tetragonolepis, another semionotid, was redescribed by Jain (1973) under the species *Tetragonolepis oldhami*. Two other species of the genus were considered by him as not valid species.

The coelacanth *Indocoelacanthus robustus* Jain, 1974 is estimated to be slightly larger than *Holephaqus*. In the Kota form, the skull bones are heavily tuberculated, except the frontals which are slightly ornamented. Of the species of pholidophorid fishes, namely, *Pholidophorus kingii* and *Pholidophorus indicus, P. kingii* was of smaller size, about 110 mm in length with fusiform body. The length of the head is almost equal to the depth of the body. The ratio of the length of head to the length of the body is 1 : 4. The preoperculum has a very characteristic shape. The posterior margin of the preoperculum is deeply notched with straight sides and convex base, and the anterior margin is inclined; on the body, there are four longitudinal rows of enlarged scales, the deepest being about twice as deep as broad. All scales have even posterior margin. The dorsal fin is directly opposed to the pelvic fin.

The comparison and a critical evaluation of morphological characters of these different pholidophorids known from Early Jurassic sediments have revealed that *Pholidophorus kingii* from India was primitive in pholidophoriform condition than *Oreochima* from Antarctica and Archaeomaenids from Australia.



Text-figure 3—Correlation of measured stratigraphic sections.

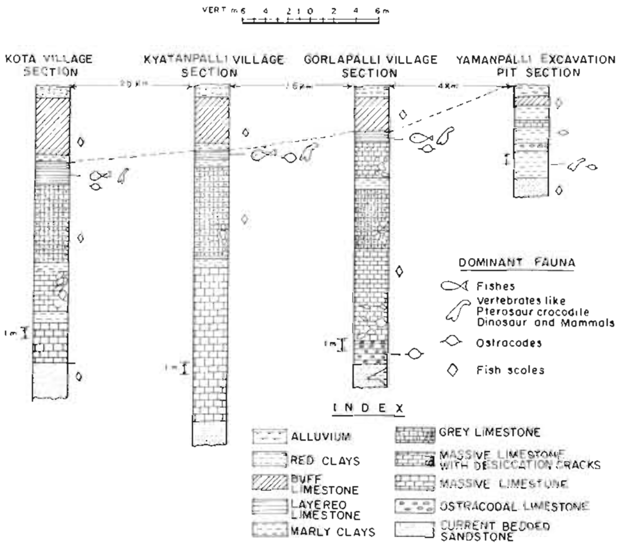
Dinosaurs

A major gap in the understanding of the evolution of sauropod dinosaurs has been due to lack of good fossil material from Lower Jurassic rocks, except fragmentary material *Ohmdenosaurus* described by Wild (1978) from Europe. The discovery of dinosaurian fauna from Kota Formation (Jain *et al.*, 1962) has been a major break through in the knowledge of Mesozoic terrestrial vertebrates from India. A sauropod dinosaur namely *Barapasaurus tagorei* was described from Posampalli area in Maharashtra (Jain *et al.*, 1980). The excavation carried out near Yamanpalli Village, Andhra Pradesh has yielded a number of skeletal parts belonging to different dinosaurs (Yadagiri *et al.*, 1979). In the collection, a new Sauropod dinosaur *Kotasaurus yamanapalliensis* was recognized (Yadagiri, 1988).

The *Kotasaurus* has many sauropodian characters. Its level of development is intermediate between sauropods and prosauropods. It seems to possess a mossaic of prosauropod and sauropod features. The important character of *Kotasaurus* is its elongated and straight pelvis. The ilium of a sauropod is in general rounded in margin with extended pubis process. The ilium of *Kotasaurus* is entirely different. The dorsal margin of the ilium is straight and the anterior and posterior processes are enlarged and tapered. The ilium, in general, is comparable to prosauropodian pelvis.

Table 2—Major and Trace element analysis of clays

Formation	Sp. No. and locality	CaO	MgO	SiO_2	Fe_2O_3	Cu	Cr	Zn	V	Ni	Ba	B	Rb	Ca	Li
		(in percentage)									(in ppm)				
Gangapur	91 Sumtam	1.57	2.66	50.3	11.90	25	20	100	10	50	5	20	200	4	—
	331 Arjungutta	1.57	1.33	56.74	6.40	25	100	80	50	70	500	—	—	—	—
	313 Arjungutta	7.24	3.36	54.06	7.80	40	20	100	20	100	5	—	—	—	—
Kota	355 Gorlapalli	1.93	2.58	64.50	5.95	40	100	90	50	80	100	—	—	—	—
												40	400	5	—
	360 Excavation site	18.30	4.03	37.78	5.80	40	10	90	5	110	50	—	—	—	—
	90 Site											5	200	5	—
	403 Gorlapalli											30	500	5	—
	405 —do—											40	500	5	—
	525 Posampalli											20	500	5	—
Dharmaram	32 Nagaram	1.4	0.93	72.31	4.63	25	20	50	10	50	5	20	500	5	—
	152 Kandampet	19.82	2.16	37.40	5.90	40	10	80	20	100	1000	—	—	—	—
Maleri	169 Pinnaram	3.53	2.62	48.96	11.90	60	5	110	5	130	5	—	—	—	—
	173	3.03	2.30	52.12	'1.60	40	10	80	10	110	200	—	—	—	—



Text-figure 4—Correlation of measured sections of Kota limestones.

The femur is very much slender, the slenderness index being 12.0. The slenderness is least compared to other Jurassic sauropods including the *Barapasaurus* which has 13.1. The fourth trochanter in the femur of *Kotasaurus* has an acuminate and slightly declined tip, a feature apparently not seen in later sauropods, but almost universal among the prosauropods. The character of astragalus in *Kotasaurus*, which is ovoidal in shape with low mound in the centre and two depressions on either side, suggests to be prosauropodian.

Some features of *Kotasaurus* strongly indicate relationship with the family Melanorosauridae among the prosauropods, on the other hand, several characteristics indicate, if not close relationship, atleast convergence between *Kotasaurus* and the Sauropod family. It differs from *Barapasaurus* in slenderness of femur, straight ilium, slender scapula, and low mound astragalus. Thus *Kotasaurus* is an intermediate form possessing the characters of prosauropods and sauropods.

Early Mammals

The mammalian history of the Jurassic Period is poorly documented. Any new occurrence, however scanty, from Early Jurassic may help in understanding the early evolutionary history of this important class.

A preliminary report of the Indian Jurassic mammals was published by Datta, Yadagiri and Rao (1978). Three new genera of symmetrodonts, viz., *Kotatherium haldanei* (Datta, 1981), *Trishulotherium kotaensis* and *Indotherium pranhitai* (Yadagiri, 1984) have been described. Recently, an amphidontid symmetrodont *Nakunodon paikasiensis* was also reported (Yadagiri, 1985).

Earlier, *Kotatherium haldanei* was assigned to the *Kuehneotheriid* family but both *Trishulotherium* and *Indotherium* were grouped under *incertae sedis* because of their distinctly different characters from that of *Kuehneotheriids*. The above fossil forms unequivocally indicate complicated and diversified nature of symmetrodont stock represented in the Kota vertebrate fauna.

The discovery of an early mammalian fauna in the Kota Formation has greatly expanded the biogeographic evaluation of the Mesozoic mammals. Earlier reports were confined to Laurasia but the Kota mammals were the first record from Gondwanaland.

PALAEOECOLOGY AND DEPOSITIONAL ENVIRONMENT

An attempt is made to relate the faunal evidences with geochemical and sedimentological data accruing from the Kota Formation.

Geochemistry of clay minerals—The clay samples from Dharmaram, Kota and Gangapur formations and limestone samples from Kota Formation were subjected to geochemical analysis. Nine clay samples were processed for determination of major and trace element distribution (Table 2). In addition, nineteen limestone samples collected from the Kota Formation were also processed for the determination of major and trace elements.

In Maleri clays (in ppm) Cu ranges from 40-60, Cr 5-10, Ni 100-130, Ba 5-1000, Zn 80-110 and V 5-20. The trace elements values in Dharamaram Formation are (in ppm) Cu 25, Cr 20, Ni 50, Ba 50, Zn 50, B 20, Rb 500, Li 70, Ga 5 and V 10-50.

Kota clays have the trace element concentrations as (in ppm) Cu 25, Cr 30, 110, Cr 10-100, Ni 45-110, Ba 5-100, Zn 55-110, B 5-40, Rb 200-500, Li 40-50, Ga 5-5 and V 10-50.

The Gangapur clays have yielded the trace element concentration in the values (in ppm) ranging Cu 25-110, Cr 10-100, Ni 50-100, Ba 5-500, Zn 80-100, B 20, Rb 100, Li 100, Ga 5 and V 10-50.

From these values it can be seen that:

i) Cu values are comparable in Kota and Gangapur clays.

ii) The Maleri clays have lesser quantity of Cu and Dharmaram clays even less.

iii) The V values are comparable in three formations, ranging 10-50 ppm, except Maleri clays where it ranges from 5-20 ppm.

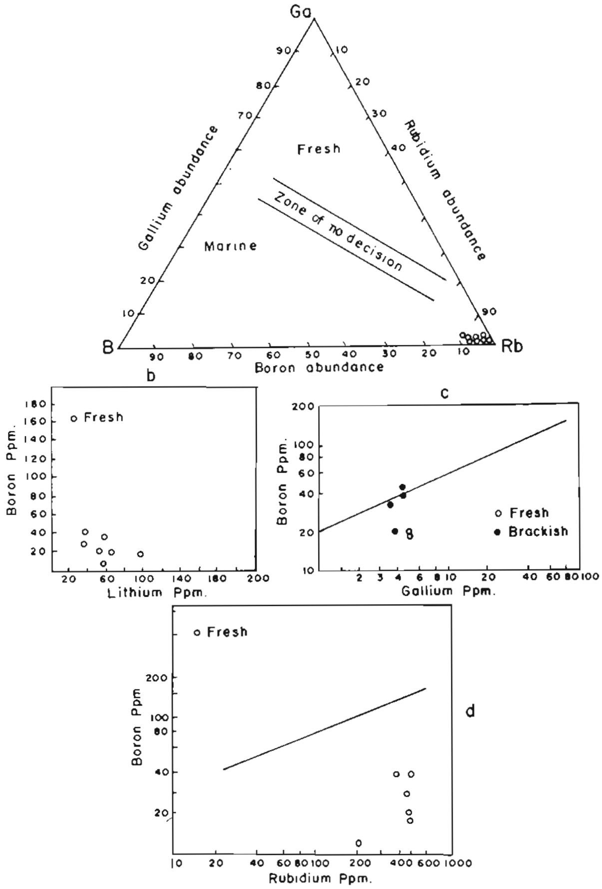
iv) The Cr values are comparable in Kota and Gangapur clays ranging from 10-100 ppm, whereas in Maleri and Dharmaram clays, the values are 5-10 ppm.

v) The Ba values are comparable with a range from 5-40 ppm, in all the four formations.

vi) The Rb values are slightly high ranging from 100-500 ppm in all of them.

The relative abundance of boron, gallium and rubidium of Kota, Gangapur and Dharmaram clays, are plotted on a triangular diagram (Text-fig. 5). All the points have fallen closely near the apex of rubidium and when compared to the diagram standardized by Degens *et al.* (1959), they are in marine zone.

A graph was prepared showing gallium in ppm, on X-axis and boron in ppm, on Y-axis, (Text-fig. 5c). The points are scattered out, all of them falling in fresh water zone except three points (Kota clays) are near brackish line. If we consider the ratio of abundance of two elements of B and Ga as reliable, the clays are deposited in fresh water environment. Some of the Kota clays appear to have been deposited under higher conditions of salinity. Another graph (Text-fig. 5b) was prepared showing the values of Li and B and it was compared with the graph produced by Keith and Degens (1959). The points fall in the zone of fresh water deposition.



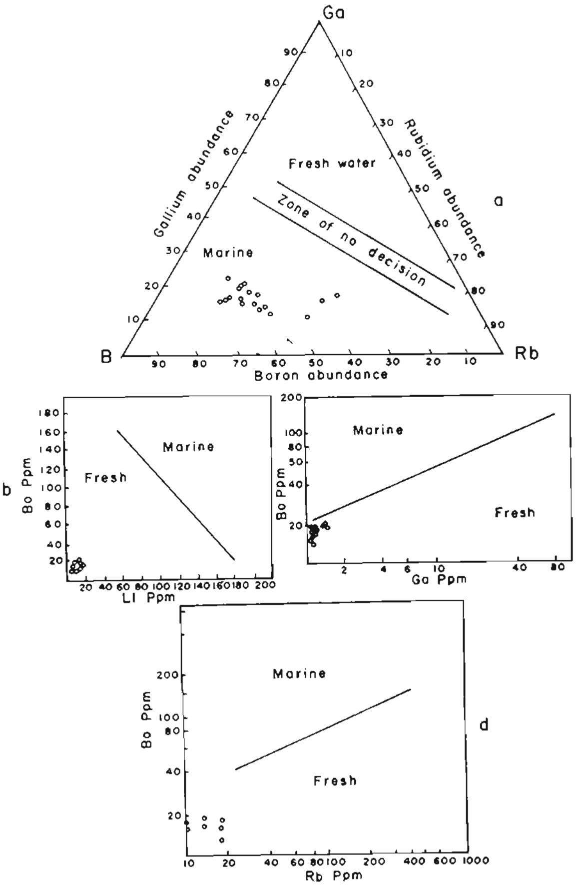
Text-figure 5—Scatter diagrams of trace elements in clays.

The critical evaluation of the trace elements shows that in Upper Gondwana clays, the boron is less in quantity, the gallium is also less but unusually the rubidium is high. Degens *et al.* (1959) stated that the rubidium ion is only slightly larger than potassium and can substitute for potassium in inter layer position of rubidium and illite. Kaolinite ratio in fresh water shales was mainly due to the rubidium being combined in detrital illite and mica.

From X-ray analysis (Table 3), it is observed that the kaolinite, illite and mica are present in lesser quantity, whereas montomorillonite mineral is abundant. It may be stated that the rubidium ions might have largely substituted the layers of illite and mica minerals resulting in high percentage of rubidium.

Table 3—Clay minerals determined by x-ray analysis

Formation	*Sp. No.*	*Locality*	*Major*	*Considerable amount*	*Small amount*	*Very small amount*	*Trace*
Chikiala	246	Jagalpet	montmorillonite	quartz	—	feldspar	kaolinite
Gangapur	310	Paikasigudem	kaolinite	quartz	—	—	—
	319	Naogaon	kaolinite	—	quartz montomorillonite	—	—
Kota	223	Manganpalli	montmorillonite	kaolinite	quartz	—	—
	226	Manganpalli after limestone	—do—	—	—do—	—	feldspar
	227	Manganpalli after limestone	montmorillonite	quartz	kaolinite	—	feldspar
	357	Gorlapalli	—do—	—do—	Illite, kaolinite, feldspar	—	—
	360	Excavation site	—do—	calcite and mica	quartz	dolomite	—
Dharmaram	260	Mamdalapalle	—do—	quartz	calcite	—	kaolinite
Maleri	309	Kottapalli	—do—	—do—	—	calcite	mica



Text-figure 6—Scatter diagrams of trace elements in Kota limestones.

In the circumstances, the triangular diagram as suggested by Degen *et al.* (1959) cannot be used as criteria for determining the environment of deposition of Upper Gondwana clays of Yamanpalli area. It is necessary to demarcate more plausible basis of fresh water, marine water interphase on more clay mineral and abundance of trace elements data. Based on critical elements like B, Ga, Cr, Cu and V it can be stated that clays of Maleri, Dharmaram, Kota and Chikiala were deposited in flood basins and lakes and some of the lakes being enriched in salinity.

Kota limestones—The Kota limestones were analysed for major elements and from the same material the trace elements were determined. Nineteen limestones from Kota Formation are analysed (Table 4). The CaO percentage ranges from 41 to 53 whereas the MgO ranges from 0.8 to 10.40. The high of Cu is 5-10, Cr 5, Ni 5, Ba 5-150, and V 5-20 ppm. There is no direct relation between the increase of CaO or MgO to trace elements. B ranges from 15-20, Ga 5-8, Li 4-7 and Rb 5-20 ppm.

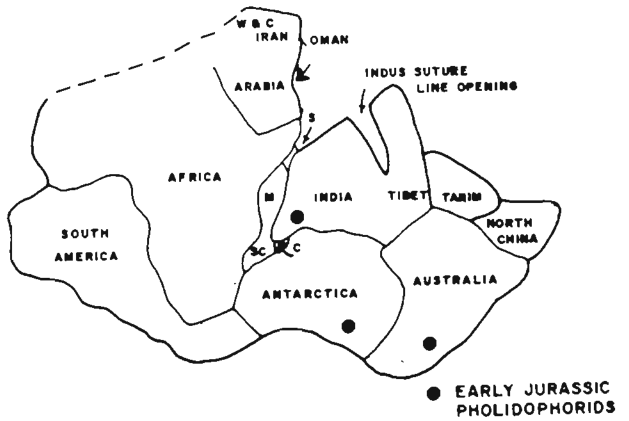
A triangular diagramme (Text-fig. 6a) was prepared with the abundance of the elements of B, Rb and Ga. It can be seen that the points fall closely towards the apex of boron. As per the diagram of Degens *et al.* (1959) they fall in marine zone. As stated earlier, it is necessary to re-evaluate the trace element distribution based on more samples with some samples from closely related marine horizons.

The graph (Text-fig. 6b) between lithium and boron shows the points in fresh water zone. The graph between gallium and boron also show the points in fresh water zone. Another graph between rubidium and boron also shows the points in fresh water zone. All the above graphs point towards a fresh water environment of deposition for the limestones.

Bhattacharya (1980) has recently discussed the depositional patterns in limestones of the Kota Formation. The clay bands associated with limestones are mostly montmorillonite but also include kaolinite and minor quantities of degraded illite. Distribution of clay minerals in insoluble residues of the limestones is similar to that of the clays. Most of the samples have 200-400 ppm of boron and 10-15 ppm of gallium, the points fall in the brackish to non-marine zone. Coccoliths were found almost in all specimens from the region, but they are abundant in marls than in hard limestones. The common forms have a central hole or depression with or without repeated layering and are conical (Bhattacharya, 1980).

Bhattacharya further stated that the well bedded limestones of significant thickness containing chert, dolomite, montmorillonite, microcrystalline ooze and coccoliths with high boron distribution suggest that the carbonates were of marine origin. He assumed that broken ostracodes and microvertebrates were probably transported before burial. It is possible that plankton could live under such conditions and become abundant in estuaries as a result of tidal movements. It is postulated by him that the limestones of the Kota Formation were deposited when the sea penetrated far inside into the subcontinent along a river estuary.

The present investigation does not support the above conclusions. The X-ray analysis shows that montmorillonite is present in Kota as well as in Maleri, Dharmaram and Chikiala clays. The presence of montmorillonite may be explained due to aridity and deposition in flood plain basins (Keller, 1956). The distribution of boron in different clay samples is 20-40 ppm, and of gallium is 4-5 ppm. But rubidium content is slightly high, ranging from 200-500 ppm. The high content of rubidium may be due to the replacement of K molecules in Kaolinite and illite with rubidium molecules, which are of approximately of same size (Keller, 1956). The view expressed about the ostracodes and early mammals that they were transported is not consistent with their nature of preservation. In the marly clays presence of complete carapaces of ostracodes and unworn surfaces of early mammals indicate *in situ* deposition and not transportation and redeposition. The abundance of fossils of land vertebrates also



Text-figure 7—Gondwanaland at its maximum extent after Crawford (1974). The reconstruction with Antarctica and Australia in close proximity to India satisfies the condition for dispersal of pholidophorids in them.

points that the Kota Formation was essentially deposited under fresh water environment with increased salinity possibly resulting from arid climate.

With the foregoing discussion, it is concluded that the sandstones were deposited in braided channels and clays were deposited in flood plain basins, partly isolated and the limestones were deposited in lakes with increased salinity.

Vertebrate fauna

The Kota vertebrate remains represent aquatic, semi-aquatic, terrestrial and arboreal habitats. The community structure of the fauna can be discussed in the existing physical and biologic conditions of the formation. Four communities have been distinguished on the basis of the ecological niches of their members. The stream and stream bank community is proximal and is represented by nearly 50 per cent of the members constituting the fauna. This community comprises organisms of stream habitat like fishes, or partially stream bank community like Teleosaurid. The distal elements comprise dinosaurs, early mammals and pterosaurs.

The total number of skeletal elements recovered are analysed for their abundance relations. The most abundant community in the fauna are dinosaurs representing about 45 per cent. The fishes are next to dinosaurs in abundance representing 25 per cent of the total skeletal parts. The remaining percentage includes early mammals and pterosaurs.

There is a regular abundance order in the occurrence of fishes. The semionotid fishes dominate in number over all the fish remains known from the Kota. *Lepidotes* is abundant (17.5% of the total fauna), *Tetragonolepis* is rare (0.47%). The pholidophorids account for 1.4 per cent of the total

Table 4—Major and trace element analysis of Kota limestones

Section	Sp. No.	CaO (in percentage)	MgO	Cu	Cr	Ni	Ba (in ppm)	V	B	Ga	Rb	Li
Yamanpalli	17	47.88	0.8	5	5	5	5	10	20	5	20	5
Excavation site	361	49.0	2.4	5	5	5	50	20	20	7	7	6
	98	51.52	1.0	5	5	5	50	20	18	8	5	7
Manganpalli	117	51.8	1.0	5	5	5	5	10	18	4	10	7
Kota type section	268	53.76	0.8	10	5	5	5	10	18	6	6	6
	262	44.80	6.6	5	5	5	5	10	20	5	8	5
N.E. of Sironcha	290	47.32	2.40	5	5	5	5	5	20	7	10	7
	288	43.40	0.80	5	5	5	100	10	20	5	10	5
Gorlapalli section	349	52.64	1.60	5	5	5	100	10	16	4	6	5
	347	50.68	1.20	5	5	5	5	10	18	5	8	5
	346	41.16	10.40	5	5	5	5	5	20	7	5	6
	345	48.44	3.00	5	5	5	20	10	15	8	20	5
	344	51.80	1.80	5	5	5	150	10	19	5	10	4
Sumtam (concretionary bed in Gangapur Formation)	59	45.36	1.00	5	5	5	100	5	19	8	20	6

elements whereas the *Coelacanthus* represents 0.7 per cent. The juvenile specimens of actinopterygian fishes are extremely rare, in comparison to medium and large fishes.

Lepidotes is a long ranging genus which has habitat of colonizing in marine and fresh waters. Species of *Lepidotes* occur in the brackish to fresh water Rhaetic; marine Upper Liassic, Oxfordian and Kimmeridgian; brackish to fresh water Purbeckian; fresh water Wealden and Brazilian. The genus may be regarded as euryhaline, so *Lepidotes deccanensis* was probably adaptable and could withstand at least moderate salinity of lake water. It had slender, cylindrical, acutely pointed conical teeth in the dentary and premaxilla; and suited for preying upon fast moving invertebrates including estherids and ostracodes, in addition to worms.

Paradapedium and *Tetragonolepis* had relatively poor development of paired and unpaired fins. *Paradapedium* had acutely pointed conical teeth whereas *Tetragonolepis* had fine pointed teeth. As such, they are presumed to be predators of fast moving prey. *Tetragonolepis* in Europe is known from marine sediments and so also *Dapedium*. It is therefore, likely that they were euryhaline forms which existed in Kota lakes.

The Kota coelacanths were large, with weak dentition, bottom living in shallow lake. The coelacanths in general appear to have been rather sedentary animals lying in wait for their prey. A number of *Lepidotes* scales were found associated in cranial part of *Coelacanthus*. Probably they were preying on juveniles of *Lepidotes*. The extant genus *Latimeria* exhibits a poor dentition and among its gut contents have been found small intact fishes in addition to other food stuff. The Kota pholidophorids have well-developed strong paired and unpaired fins, but poor dentition. They may have been active fishes like *Lepidotes*, but may have depended less on fast moving prey for food rather eating the soft annelids and nibbling aquatic plants.

It is believed that Pterodactyles and Pterosaurs lived near the sea coast because all the fossil material comes from marine sediments, except the Kota Pterosaurs. Kota Pterosaurs can be visualised as inhabiting the trees close by the Kota lake and occasionally sweeping down to prey upon small actinopterygian fishes. The Solnhofen Pterodactyles were also fish eaters.

The Kota dinosaurs, *Barapasaurus* and *Kotasaurus* were herbivorous and were probably similar to better known saurischian Jurassic dinosaurs like *Diplodocus* and *Camarasaurus* in their habits and habitat. Coombs (1975) has recently summed up the habitat of Sauropods. The data on sauropod narial morphology indicates either aquatic or terrestrial habits. The axial and appendicular modifications point primarily to terrestrial behaviour. The deep thorax is an adaptation to problems of terrestrial weight bearing. They definitely entered streams at least sometimes, but sedimentologic evidence does not support immersion in deep lakes as sauropods are frequently pictured. Charig (1979) has suggested that the

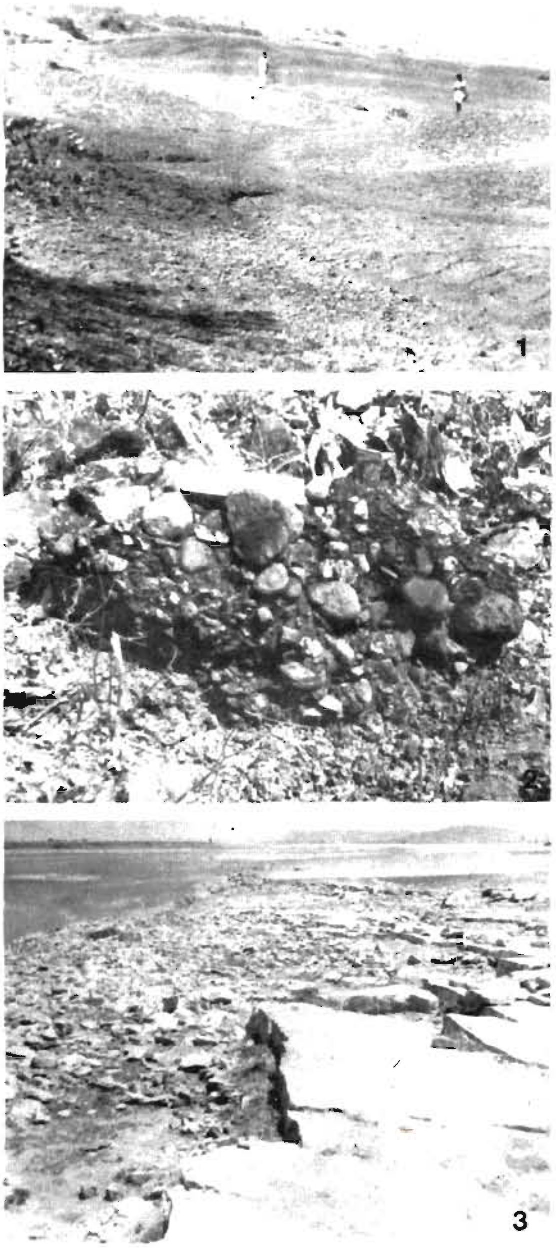


PLATE 1

1. Red clays and sandstones of Dharmaram Formation with prosauropod remains.
2. Conglomerate of Gangapur Formation showing pebbles of quartz, quartzite and chert.
3. Limestone bed near Kota Village showing large blocks.

sauropods were proper land dwellers. It can be assumed that *Barapasaurus* and *Kotasaurus* were inhabiting land close to Kota lake and largely feeding upon nearby vegetation

The early mammals belonging to symmetrodonts and morganucodonts possess sharp conulids for tearing the prey. All of them were considered to be insectivorus in their habitat. Crompton *et al.* (1978) have suggested that the early mammals were probably similar to modern day hedgehogs in maintaining a low body temperature and possessing a reptilian metabolic rate which is three to four times lower than most living mammals. Like the African forms, the Kota mammals appear to be small insectivors, with dentition designed for puncturing and shearing. The view is justified by the abundance of insect occurrence in the Kota Formation.

The Kota Formation contains rather two different kinds of sediments; fluviatile sandstones and clays and thin limestones representing evaporite deposits in inland lake. Robinson (1970) on the basis of geology, Tasch *et al.* (1973) on the basis of conchostracans, and Govindan (1975) on the basis of ostracods support fresh-water deposition of Kota sediments, including the limestone. Bhattacharya (1980) on the basis of petrographic, mineralogic and geochemical analysis of the carbonates, suggested deposition in marine inter-tidal flats where abundant terrigenous material was brought in by a river estuary.

During the present investigation, the results obtained on Kota limestones from the geochemical analysis and other evidences weigh heavily in favour of a fresh-water origin. The vertebrate faunal assemblage with their habitat also suggest a fluviatile environment with flood channels and lacustrine deposit, for Kota Formation.

PALAEOBIOGEOGRAPHIC SIGNIFICANCE OF KOTA FAUNA

The significance of Kota fauna as evidence of Lower Jurassic geographic configuration can be discussed on three different counts: (a) early mammals, (b) *Pholidophorus* fishes, and (c) dinosaurs.

A major evidence in understanding the evolutionary transition from synapsids to mammals is being facilitated by increased refinement of determination of the ages and correlations of local faunas that until recently were considered of Late Triassic (Rhaetian) or Early Jurassic age (Clemens *et al.*, 1979). Current research shows that so-called "Rhaetic fissure fillings" of England and Wales, which have produced a wealth of specimens of early mammals and advanced synapsids, were deposited at various times during this interval. Most of the fillings yielding *Morganocodon* and *Kuehneotherium* are now thought to be of Liassic, probably Sinemurian age (Kermack, Mussett & Rigney, 1981). In the light of the new findings, the Kayenta Formation of North

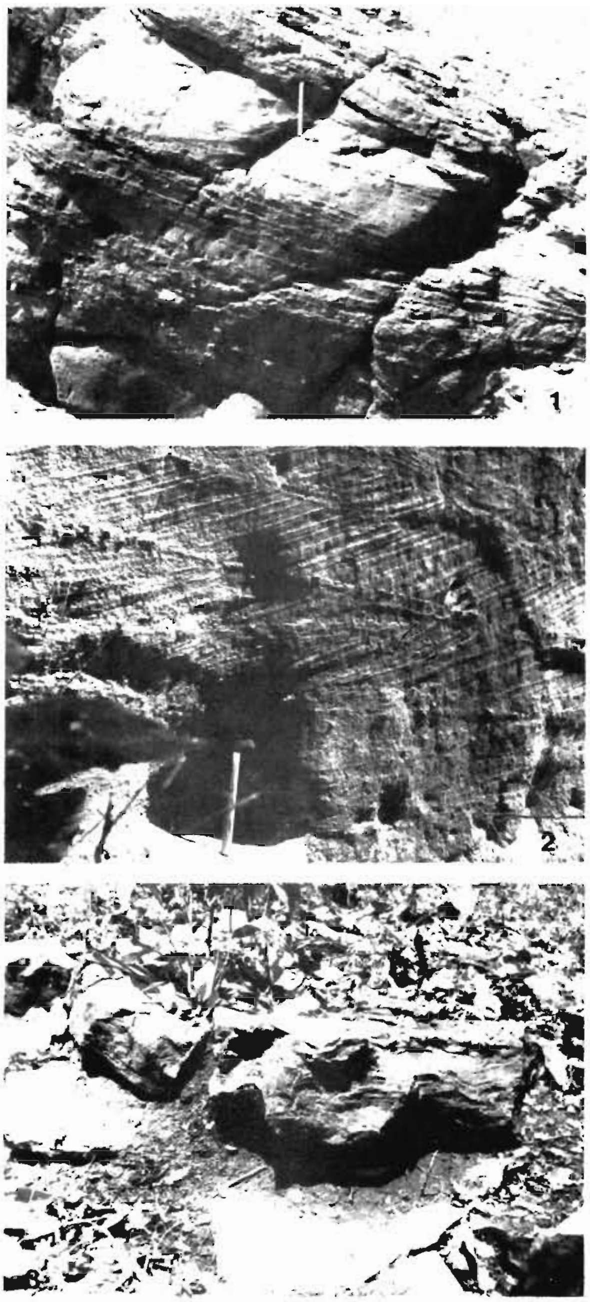


PLATE 2

1. Cross bedding in Gangapur sandstones seen in the Pranhita River Section near Kalmalpet.
2. Current bedding seen in Chikiala sandstones near Makrigudem.
3. Stromatolitic structures seen in massive limestone near Nagaram Village.

America, the upper part of the Stormberg Group of South Africa, the Kota Formation of India, and the Lufeng beds of China are now thought to be broadly correlative units and of Early Jurassic age. The aforesaid occurrences suggest that early mammals were widely dispersed through Laurasia and Gondwana before fragmentation of the supercontinents.

The find of pholidophorid fishes in India has great palaeogeographic significance in the sense that it adds a new evidence to evaluate the position of India vis-a-vis the position of other continents of the Gondwanaland before its fragmentation. Tasch *et al.* (1973) brought out the significance of estherids for continental fit. Jurassic beetles and palaeolimnadids from Antarctica and India and Triassic palaeolimnadids and estherinids in India and Australia required nonmarine dispersal routes which suggest the proximity of the three continents. They pointed out that the configurations of Smith and Hallam (1969) and Veevers *et al.* (1971) are not adequate to explain the dispersal of the fauna in three continents.

Schaeffer (1972) mentioned that the presence of fresh-water Archaeomaenidae both in Australia and Antarctica during the Jurassic was not surprising as these two continents were in contact throughout the Mesozoic. However, the position of India relative to Antarctica and Australia remained uncertain. All the pholidophorid fishes from three continents, viz., Australia, Antarctica and India *were fresh-water forms* and were restricted to Early Jurassic horizons. Thus, the occurrence of pholidophorids supports the view of Australia, Antarctica and India to be in close proximity. The fossil evidence is in conformity to the configuration (Text-fig. 7) as suggested by Crawford (1974). The pholidophorids might have dispersed from India to Australia through Antarctica.

The presence of sauropod dinosaurs namely *Barapasaurus* and *Kotasaurus* in the Kota Formation suggests its close proximity to the South African region, as dinosaurs of Late Triassic and Middle Jurassic period are found in the latter continent. The occurrence of *Rhoteosaurus* in the Middle Jurassic sediments also supports the view that during Early Jurassic to Middle Jurassic peninsular India was a land-locked part of Gondwanaland.

CONCLUSIONS

From a study of the Upper Gondwana sequence in the Yamanpalli area of Adilabad District, Andhra Pradesh, the following points emerge which are significant for Gondwana stratigraphy:

1. Kota Formation is underlain by Dharmaram Formation and overlain by Gangapur Formation.
2. The Gangapur Formation is overlain by Chikiala Formation.
3. Kota limestone horizon consists of three beds of limestone separated by marly beds; considerable difference is recognisable in the distribution of vertebrate fauna in these beds.

4. The geochemical and clay mineral studies of Upper Gondwana sediments have revealed that no diagnostic change is recognisable from Dharmaram, Kota and Gangapur formations and a more indepth study of elemental distribution in sediments is required for palaeoenvironmental characterisation of Kota for marine depositional environment.
5. The evidences favouring marine depositional environment are wanting; rather, evidences of fauna weigh heavily in favour of lacustrine accumulation for Kota Limestone with salinity of water being more than in normal lacustrine environment.
6. Early mammals and dinosaurs recorded from Kota Formation have distinct Liassic affinity in their evolutionary level.
7. The palaeogeographic implication of early mammalian vertebrates and pholidophorid fishes from the Kota Formation suggests a landlocked set up for peninsular India.

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