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# Paleobiogeographic Implications of Titanosaurian Sauropod and Abelisaurian Therpod Dinosaurs from Pakistan

M. Sadiq Malkani

Paleontology and Stratigraphy Branch,Geological Survey of Pakistan, Sariab Road, Quetta, Pakistan.
E. Mail; Malkanims@yahoo.com

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**Abstract**

Continental vertebrates are restricted in their geographic distribution by marine and oceanic barriers, which affect all forms, except the birds. Occasionally these barriers break totally or partially and the faunas disperse outside the area of original distribution in diverse forms. These bridges, "land bridges" or "corridors", allow the free circulation of faunas in both directions. Isolation between the northern and southern continents produced dramatically different distribution among dinosaurs. In contrast to northern hemisphere, the dominant herbivores in the Late Cretaceous of India and South America were titanosaurids rather than ornithischians, whereas the large predators were abelisaurids instead of tyrannosaurs.

Examination of fossil records indicates that at the end of the Early Cretaceous, the best adapted and potentially adapted family of sauropod was the Titanosauridae. They flourished in the Late Cretaceous and survived after all the other sauropods had become extinct. After the break up of Gondwanaland, the isolation of the titanosaurids in Indo-Pakistan during much of the Late Cretaceous, without competition from other herbivorous dinosaurs, resulted in a diversification into two families with a total of 5 genera.

Thus far, the Late Cretaceous (Maastrichtian) Lameta Formation of India had served as the sole source of information on Cretaceous vertebrates of the Indo-Pakistan subcontinent. But now discoveries by the author include a variety of large vertebrate that indicate the first Late Jurassic Titanosaurs(one species), first Late Cretaceous herbivorous Titanosaurs (five species) and carnivorous Abelisaurs(one species) Dinosaurs and Pabwehshi a *Baurusuchids* (Mesoeucrocoreptilia) fossils, have broadened their distribution. These discoveries of Jurassic and Cretaceous Arhosaurian reptiles from Pakistan provide a vantage point and act as a milestone for assessing paleobiogeography and phylogeny.

The discovery of Saltasaurids, Abelisaurids, and Baurusuchids from Pakistan broadens their distribution and may prove the close affinity with India, Madagascar and South America. Pakistani Titanosauria shows some affinity with the Late Cretaceous fauna of Europe, and North America. But its resemblance of some skull and especially teeth characters with Mongolian-Chinese forms like *Nemegtosaurus* and *Quaesitosaurus* are encouraging to say the titanosauria as a **Global/Pangean distribution**. The findings of *Vitakridrinda*- an Abelisaurids from Pakistan broaden their spatial distribution and matches with the **Gondwanan linkage** theory.

**Keywords:** Pakistani Titanosauria, Global/Pangean distribution; Pakistani Abelisauria, Gondwanan linkage.

## 1. Introduction

Titanosaurian sauropod dinosaurs from all the continents are: *Alamosaurus* from North America; *Titanosaurus, Aelosaurus, Saltasaurus, Neuquensaurus, Microcoelus, Antarctosaurus, Argyrosaurus, Epachthosaurus, Pellegrinisaurus, Clasmodosaurus and Campylodoniscus from South* Nemegtosaurus, and *Quaesitosaurus* from Mongolia. So its distribution to all the continents represents global distribution.

Most recent treatments of the *Titanosaurus* genus have focused on particular geographic areas, such as Europe (Le Loeuff, 1993; Upchurch, 1999), South America (Bonaparte and Gasparini, 1979; Powel, 1986), and India (Jain and Bandyopadhyay 1997). McIntosh (1990), however, considered the genus in its entirety. Together, these studies accept a handful of valid *Titanosaurus* species, including four from India and one or two from South America but now Pakistan have produced at least 5 genera of Titanosauria based on morphology of caudal vertebrae, supported by the assignment of two partial skull, some axial and appendicular elements.

A central question in historical biogeography is the influence of continental fragmentation on the evolution of terrestrial vertebrate faunas. Sauropod dinosaurs are a useful model because they achieved a nearly Pangaean distribution by the middle Jurassic and persisted until the peak of continental isolation at the end of the Cretaceous Smith *et al.*, 1994).

Continental vertebrates are restricted in their geographic distribution by marine and oceanic barriers, which affect all forms, except the birds (Hallam, 1973). Occasionally these barriers break totally or partially and the faunas disperse outside the area of original distribution in diverse forms. These bridges, "land bridges" or "corridors", allow the free circulation of faunas in both directions (Powell, 2003). There also exists "filter bridges" which are similar to those which are mentioned above, with the difference that climatic or other factors exist which filter or permit the passage of some elected forms. The "sweepstake routes" permit *America; Titanosaurus, Lirainosaurus, Aplelosaurus, Hapselosaurus from Europe; Aegyptosaurus, Malawisaurus, Rapetosaurus, and Titanosaurus from Africa; Titanosaurus, Antarctosaurus and Laplatosaurus from India; Marisaurus, Balochisaurus, Pakisaurus, Sulaimanisaurus, and Khetranisaurus* from Pakistan; Opisthocoeliucaudia migration to cross marine barriers, by the medium of "natural raft" (Simpson, 1940). The titanosaurs dinosaurs, with their great bulk, have the most limited possibilities compared to small vertebrate such as turtle, lizards, snakes, amphibians and small mammals, as they could not have dispersed by natural rafts, which means they must have traveled by bridges.

With the advent and acceptance of the theory of continental drift, other mechanisms which would explain the distribution of fauna were supplement with one called "Noah's Ark" (McKenna 1973), which assumes that a displaced continental mass carries with it a fauna "cargo" from the larger landmass it broke away from (Powell, 2003). The titanosaurs found in the Cretaceous of distinct regions, some of these widely separated today, permit the establishment of a series of interesting paleobiogeographic conclusions which confirm those obtained on the basis of other fossil groups, for the interpretation of the areas where the data provided by other taxonomic groups is limited (Powell, 2003). Most of the titanosaurids specimens were preserved in fluvial sediments, which led to the breakup of the skeletons of these great reptiles. This has lead to errors or confusion as in the case of mixing of fossils of saltasaurids and titanosaurids. Finally, imperfections of fossil record mean that the absence of a taxon on a continent does not absolutely prove its former absence as a living animal. Sometimes the paleontological information has not been used with necessary care. So far, titanosaurs have not been documented from Australia.

## 2. History of dinosaur discoveries from Pakistan.

The firstever discovery of dinosaurs from Pakistan was made by the author during early (2000) from the Last

Cretaceous dinosaur beds (Vitakri member) of Pab Formation in Vitakri area, Barkhan district, Balochistan. First time in Pakistan, the author found a fossil of distal femur of Titanosaurian Sauropod dinosaur and first reported by Malkani and Anwar (2000). Professor Philip D. Gingerich, University of Michigan, congratulated the GSP for the first ever dinosaur discovery from Pakistan and requested to DG, GSP for the visit of dinosaur locality. During late (2000), Professor Phillip D. Gingerich visited Pakistan for previously running project of Eocene whale. On his visit to Vitakri dinosaur locality, the author showed him the in-situ fragmentary bones. About 100 bones/spieces of bones of dinosaur Vitakri locality number 1 were sent to Museum of Paleontology, University of Michigan, USA. The author collected further 1500 bones/pieces of bones from 25 localities in Sulaiman Foldbelt, administratively located in the areas of Barkhan, Kohlu, Dera Bugti, and Dera Ghazi Khan districts of Balochistan and Punjab Provinces during early (2001). Dr. Jaffery A. Wilson, Museum of Paleontology, University of Michigan, USA visited the GSP museum during March, (2001) and Dr. David A. Krauss of Bostan College, USA visited the GSP museum and Vitakri locality during mid of (2001). Second time dinosaur fossils were reported by Malkani, Wilson and Gingerich, (2001). The author collected further 1200 bones/ pieces of bones during mid of (2001), from Sulaiman Foldbelt. Third time dinosaur fossils are reported by Malkani, (2003a,b,c). Then the collected fossils of dinosaurs from Pakistan were documented by a continuous series of research papers by Malkani, (2004a,b,c, 2005a,b, 2006 a-h). The research on a braincase of titanosaurian sauropod dinosaur discovered by the author from the Top Kinwa Kali Kakor locality of Vitakri area was also documented (Wilson, Malkani and Gingerich, 2005; Malkani, in review). The research on the findings of trackways of sauropod dinosaurs confronted by a theropod found from the Middle Jurassic Samanasuk Limestone of Pakistan, wide gauge locomotion argued from skeletal morphology of Late Cretaceous Pakistani Titanosauria, localities of dinosaurs from the Late Cretaceous park of Pakistan, and confrontation scenario between two theropod dinosaurs argued from the discovery of a rostrum of *Vitakridrinda* found from the Late Cretaceous Park of Pakistan (Malkani, in review). The research on Paleobiogeography of titanosaurian and abelisaurian dinosaurs from Pakistan is presented here.

## 3. Geological and stratigraphic setting.

The study area of Sulaiman Fold-belt is located in the Central part of Pakistan **(Fig.1).** Latest Cretaceous (Maestrichtian) dinosaurs are hosted by the Pab Formation of Sulaiman Fold belt. So far, about three thousand bones/pieces of bones of dinosaurs from Pakistan have been collected by the author. The author left many hundreds of observed bones in situ for further study and excavation. These localities of archosaurs are easy for excavation due to soft red mud/clay host rocks to find the articulated skeleton of these exceptional animals. As a whole the Vitakri and vicinity areas seem to be graveyard of terrestrial ecosystems of Vitakri Late Cretaceous Park and are enriched by bones. The Latest Cretaceous sediments in the study area underwent considerable tectonic deformation during the collision of Asian and Indo-Pakistan continental plates that commenced in the Late Cenozoic. As a result dinosaur beds along with other formations have been folded. The lateral extension of dinosaur beds of the Pab Formation have been observed in the major four anticlinoria generally trending NNE to SSW, however the western part of Dhaola and Mari Bohri anticlines trend E-W forming globate belts (**Fig.1**).

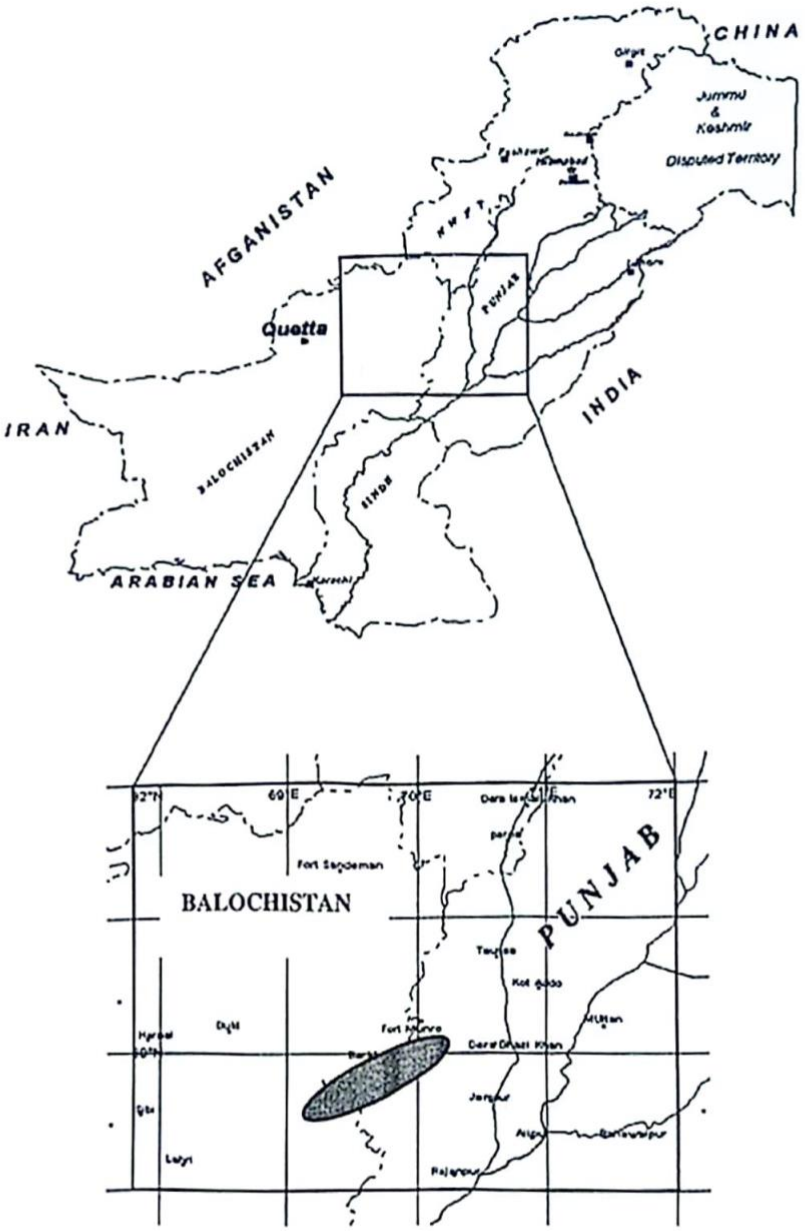



**Figure 1. Grey oval represents the Late Cretaceous Park in Sulaiman Foldbelt, Pakistan from where the dinosaur fossils have been collected.**

The Sulaiman Foldbelt consists of sedimentary rocks ranging in age from Jurassic to Pleistocene (**Fig.2**). The rocks comprising of shale, limestone, sandstone, siltstone, marl and conglomerate in different lithological units in ascending order as; Jurassic Sulaiman group representing Spingwar, Loralai and Chiltan formations; Cretaceous Parh group representing Sembar, Goru and Parh formations; Fort Munro group (type and reference sections are Rakhi Gaj section in toposheet 39 K/1 and Shadani section in toposheet 39 J/4) representing Mughal Kot, Fort Munro andn Pab. Formations; Paleocene Ranikot Group representing Khadro, Rakhi, Gaj and Dungan formations; Eocene Ghazij Group represents Shaheed Ghat, Toi, Drug and Baska formations (newly proposed); Kirthar group represents Habib Rahi, Domanda, Pir Koh and Drazinda formations; Oligocene-Pliocene Vahoa group (type section the Vahoa Rud in toposheet 39 I/4,8) group represents Chitarwata, Vahoa, Litra and Chaudhwan formations, Pleistocene Dada Formation, Subrecent and recent fluvial, eolian and colluvial deposits conceal the bed rock at places (Malkani, 2004c; 2006b) (**Fig.2**).

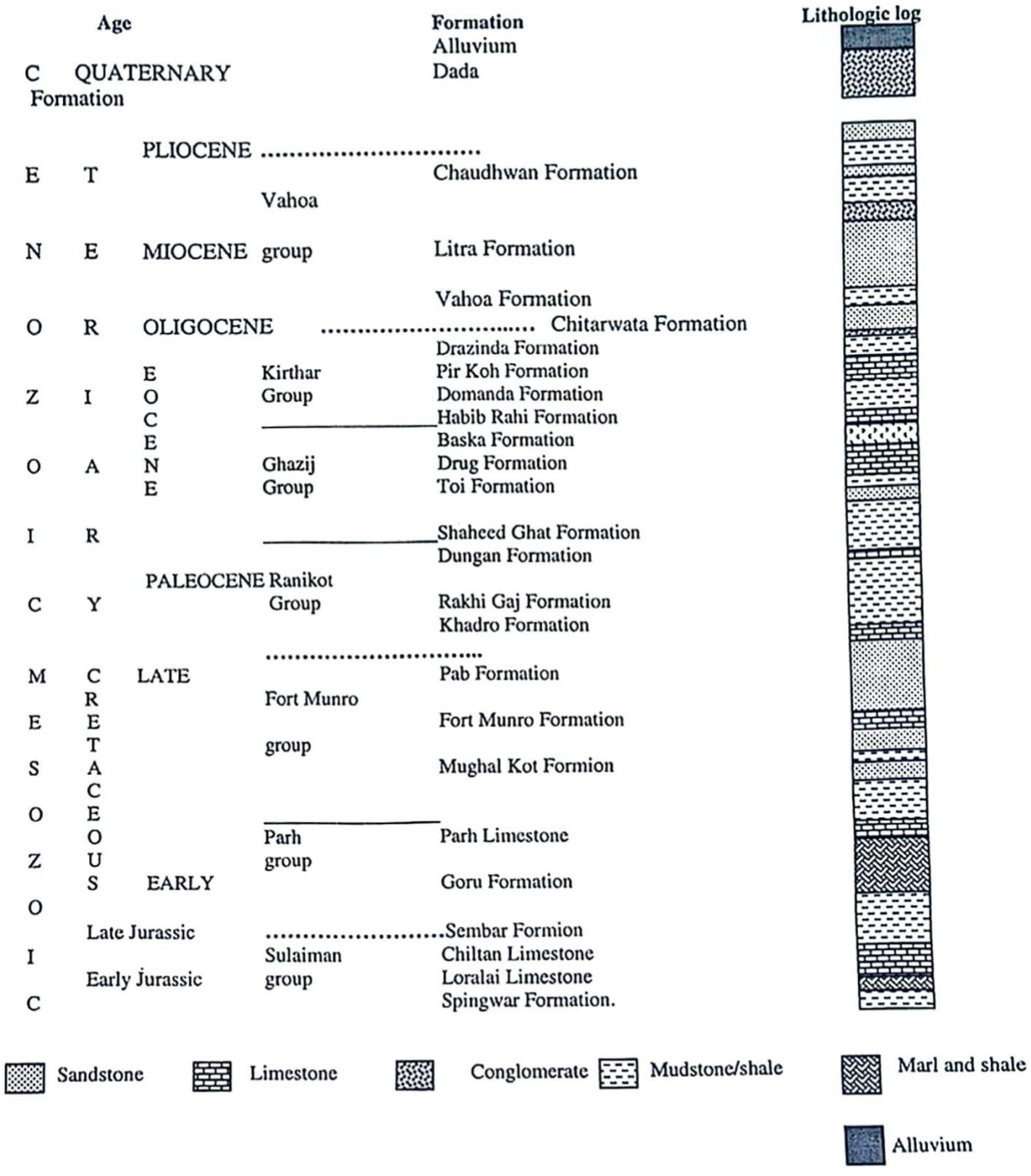



**Fig. 2. Generalized Stratigraphic succession of Sulaiman Foldbelt, Pakistan.**

## 4. Materials and methods.

Sedimentary strata of Pakistan are famous for Cenozoic vertebrate (Gingerich, *et al.*, 2001). Recent dinosaur discoveries by the author from Mesozoic of Pakistan have increased the temporal variation of its vertebrate fauna.

From first discovery until now the author have collected about three thousand bones/ pieces of bone of herbivorous titanosaurian sauropod, and carnivorous abelisaurian theropod dinosaurs and mesoeucrocodilian from the Late Cretaceous strata of Sulaiman Foldbelt, Pakistan. This is the actual materials which provided a base to present this research. The method applied here is the paleontological methods representing description, interpretation, discussion and conclusions.

### Titanosaurian fauna of world

### South American Titanosauria

(Powell, 2003), has reported the following 11 genera from South America; *Titanosaurus* (Lydekker, 1877), *Aelosaurus* (Powell, 2003), *Saltasaurus* (Bonaparte and Powell, 1980), *Neuquensaurus* (Powell, 1992), *Microcoelus*, *Antarctosaurus*, *Argyrosaurus*, *Epachthosaurus* (Powell, 1990), *Pellegrinisaurus* (Salgado, 1996), *Clasmodosaurus* (Ameghino, 1898), and *Campylodoniscus* (Kuhn, 1970).

### North American Titanosauria

Titanosaur has been reported from three localities in the south-west of North America such as the North Horn, Utah, United States; Barrel Springs Arroyo, New Mexico, United States; and Big Bend National Park, Texas, United States.

Gilmore (1946) described and illustrated specimen discovered by George B Peace in (1937) from North Horn, Utah, United States, which included 30 caudal vertebrae with hemapophyses, both iscia, right front limb, scapula, coracoid and sternal plates, assigned to *Alamosaurus sanjuanensis* (Gilmore, 1922). The holotype of *Alamosaurus sanjuanensis* consists of a right scapula and a right ischium. It was found at locality situated 1.5 km south of Ojo Alamo, in San Juan County, Berrel Springs Arroyo, New Mexico. (Lawson, 1972) in Kues *et al.* (1980) cited the presence of titanosaurids in the Beg Bend National Park, Brewer County, in West Texas (Powell, 2003).

### African Titanosauria

**Niger**; Gadofaoua and Beceten are two important localities of Titanosauridae. Taquet (1976) has reported a complete juvenile skeleton with procoelous caudal vertebrae from Gadofaoua locality. It is the oldest among Gondwanan titanosaurs. Curiously they exhibit some derived features in the centra, as in the South American saltasurines, such as the development of cancelous tissue in addition to the notable development of lateral pleurocoels that are only weakly manifested in some Late Senonian South American titanosaurids. Broin (1980) described the general geology and gave brief fauna description from Beceten locality. The study of these old forms would surely contribute to the understanding of the early stages of titanosaurid evolution.

**Egypt**; Baharija is 250km South East of Cairo. It has yielded a profuse number of Early Senonian vertebrate taxa. (Stromer,1932), among which there are crocodiles, chelonians, dinosaurs (coelurosaurs,carnosaurs and two different types of sauropods, one of which corresponds to a lineage related to Dicraeosaurus, and Aegyptosaurus baharijensis, the later related to the titanosaurids family (Powell, 2003).

**Madagascar** Titanosaurus madagascariensis, (Deperet, 1896), is a species founded on scanty material which includes a humerus, two caudal vertebrae, and a large dermal ossification, which probably was the base of a sharp conical spike, as in Saltasurus loricatus. According to (Huene, 1929), this scute does not pertain to this form or to any series of dermal bone. The result of the studies of the specimens of Saltasaurus loricatus and the reinterpretation of similar elements like the dermal ossifications of titanosaurids (Powell, 1980, 2003) shows that the original interpretation of Deperet (1896) was correct and the Titanosaurus madagascariensis is therefore referred here to the subfamily titanosaurinae (Powell, 2003). Reported the *Rapitosaurus.*

**European Titanosauria**

**1. Spain;** Hypselosaurus (Sanz, 1984) Titanosaurus, and Liranosaurus are reported from Spain. Sanz (1986) described osteoderms and a caudal vertebra of titanosaurids from Armuna (Segovia). Documented a diversified vertebrate fauna from a rich fossil locality Lano (north central Spain). The dinosaurs are represented by theropod, ankylosaur, ornithopod, and sauropod remains. Some femoral material seems to be reminiscent of the abelisaurids theropods. Lano site has yielded abundant sauropod titanosaur remains representing one of the better known European titanosaurid taxa described as Lirainosaurus astibiae (Sanz, *et al.*,1999). It is based on the following elements: a small occipital fragment, isolated teeth, dorsal and caudal vertebrae, a scapula, a coracoid, a sternal plate, several humeri, a fragment of illium, a fragment of pubes, several femora, a tibia, a fibula, and several dermal scutes.

**2. France:** *Hypselosaurus priscus* (Matheron, 1869), *Ampelosaurus atacus* (Le Loeuff, 1995), and *Titanosaurus indicus* are reported from France. (Le Loeuff, 1995) described the armoured titanosaurids *Ampelosaurus atacus.* This taxon is based on teeth, dorsal and caudal vertebrae, ribs, hemapophyses, sternal plates,scapula, humerus, ulna, pubis, illium, ischium, femur, tibia, fibula, phalanges and dermal plates.

**3. Rumania:** *Magyarosaurus dacus* (Nopscsa,1915), *M. transylvanicus* (Huene,1932), *M. hungaricus* (Huene, 1932), are documented from Rumania.

**4. England:** Published on a procoelus vertebra from the Wealden Formation, at Brook, Isle of Wight, England, which was interpreted as *Titanosaurus* sp. (Huene, 1929), interpreted this form as a new species which he named *Titanosaurus valdensis.* According to (Le Leouff, 1993), it is now called as Iuticosaurus valdensis. It is a morphological intermediate between *T. indicus* and *T. blanfordi.* Macrurosaurus semnus reported is not titanosauria due to amphiplaton caudal vertebrae and again no anterior incertion of neural arch on caudal. Other related form is *Acanthopholis platypus* probably corresponding to *Macrurosaurus* according to (Huene,1929) and (Steel, 1970).

**Asian Titanosauria**

India-Gondwanan Lands: Jain and Bandyopadhyay (1997) have mentioned the four species of Titanosauria namely *Titanosaurus indicus, Titanosaurus blanfordi, Titanosaurus madagascariensis and Titanosaurus colberti* from the Lameta Formation. There are four major localities in India.

a. Bara Simla, Jubalpur district represents the *Titanosaurus indicus,* and *Antarctosaurus septentrionalis* (Huene and Matley, 1933).

b. Chota Simla, Jubalpur district produced excellent specimens studied.

c. Pisdura hill, Pisdura Basin represents *Titanosaurus blanfordi, titanosaurus Indicus, Titanosaurus madagascariensis* and *Antarctosaurus sp.* (Huene and Matley, 1933).

d. Dongargaon yielded a braincase and vertebrae of Titanosauria. It also produced *Titanosaurus colberti* (Jain and Bandyopadhyay, 1997).

2. China - Mongolia - Laurasian Lands: *Nemegtosaurus* and *Quaesitosaurus* based on skull and teeth characters can be included in the Titanosauria. Opisthocoelicaudia having reverse of procoelous caudal feature.

**Pakistani Titanosauria**

The caudal vertebrae from the Late Cretaceous of Sulaiman Foldbelt, Pakistan tell five tales of Titanosauria like three genus and species (*Pakisaurus balochistani, Sulaimanisaurus gingerichi and Khetranisaurus barkhani)* of herbivorous pakisaurid titanosaurid, and two genus and species (*Marisaurus jeffi and Balochisaurus malkani)* of herbivorous balochisaurids/saltasaurids (Malkani, 2004a, 2005a, 2006a). A genus and species (*Brohisaurus kirthari*) of Late Jurassic/Early Cretaceous Titanosauria (Malkani, 2003c), have been discovered from Kirthar Foldbelt, Pakistan.

### Abelisaurian Fauna of Gondwanlands

Abelisauroids predators have been recorded almost exclusively from South America, India, Niger and Madagascar (Sereno, *et al.*, 2004). Abelisaurian from different fragments of Gondwanalands are: *Rigops primus* from Niger; *Aucasaurus garridoi, Abelisaurus comahuensis, Ilokelesia aguadagrandensis* and *Carnotaurus sastrei* from Argentina; *Magungatholus atopus* from Madagascar; and *Rajasaurus normadensis* from India (**Fig. 4**). But recently Malkani (2006f), have discovered *Vitakridrinda*-an abelisaurian theropod from the Late Cretaceous Park of Pakistan. It has broadened the spatial distribution and match with the Gondwanan association theory.

## 5. Paleobiogeographic Routes of Titanosauria

### South and North America during Late Cretaceous

The presence of *Alamosaurus sanjuanensis,* the only representative of the family Titanosauridae whose presence is known in North America, suggests that this continent and South America were very close at the end of the Late Cretaceous, allowing the passage of the titanoisaurs by a land bridge (Bonaparte, 1984a,b,c) or less likely by a long island arc. (Casamiquela, 1980; Cox, 1980). This hypothesis is consistent with the evidence provided by other groups of vertebrates and even plants, both fossil and living. The Hadrosauridae (ornithischian dinosaurs), and crocodilians of the family Alligatoridae constitute the primary evidence in the favour of the hypothesis of this union. This family dispersed into South America from North America in the Late Cretaceous (Casamiquela 1980; Brett-Surman 1979; Hallam 1981), surely utilizing the same route as the titanosaurs.

### Africa and South America during Late Cretaceous

The list of titanosuraids in Africa is scanty, characterized by isolated specimens, generally caudals and other specimens more complete but little studied. The formations are concentrated in the Central Sahara (Niger and Sudan) and the eastern Sahara (Stromer, 1932; Lapparent 1960; Broin *et al.,* 1974 and Taquet, 1977). The age assigned to the sediments is Aptian and is older than South America and also from Indo-Pakistan. The presence of closely related titanosaurids in South America, Madagascar, Indo-Pakistan indicates in the African late Cretaceous that there were titanosaurs in the African Late cretaceous as in the South America.

The presence of Uruguayan crocodiles of the genus araripesuchas in Brazil and Niger (Buffetant and Taquet, 1979), as well as Pholidosaurid crocodiles of the genus Sarcosuchas inhabiting a lake environment (Gasparini, 1981). Sereno *et al.,* (2004) presented Pan Gondwana model of Gondwana Paleobiogeography.

### Africa and Madagascar during Late Cretaceous

The island of Madagascar has an interesting list of Triassic, Jurassic and Cretaceous tetrapods in spite of its reduced territory if it is compared to the rest of the Gondwana. In the Late Cretaceous of Madagascar the titanosaurs together with other vertebrates, have been recorded from the Mujunga area. The paleontological evidence clearly indicates that Africa and Madagascar had terrestrial connections during the Late Cretaceous, which were probably persisted untill the Companion (Powell, 2003). The presence of *Titanosaurus madagascariensis* (Deperet, 1896) indicated connections with India and South America (via Antarctica). According to (Powell, 2003), it is not certain that Deperet (1896) was correct in assigning a material available to him to the genus titanosaurus. This matter could be decided with the study of additional specimens, such as those collected by Taquet (Russel, *et al.*, 1976). Other evidence provided from the same formation of Mujunga is Trematochanpsa oblita (Buffetaut and Taquet, 1979), a terrestrial crocodile related to *Trematochanpsa taqueti* from the early Senonian in Beceten, Niger.

The ties of Madagascar during the Late Cretaceous are also supported by the presence of Madtsoia madagariensis, a genus listed in the Late Cretaceous of Niger. In the opinion of Rage

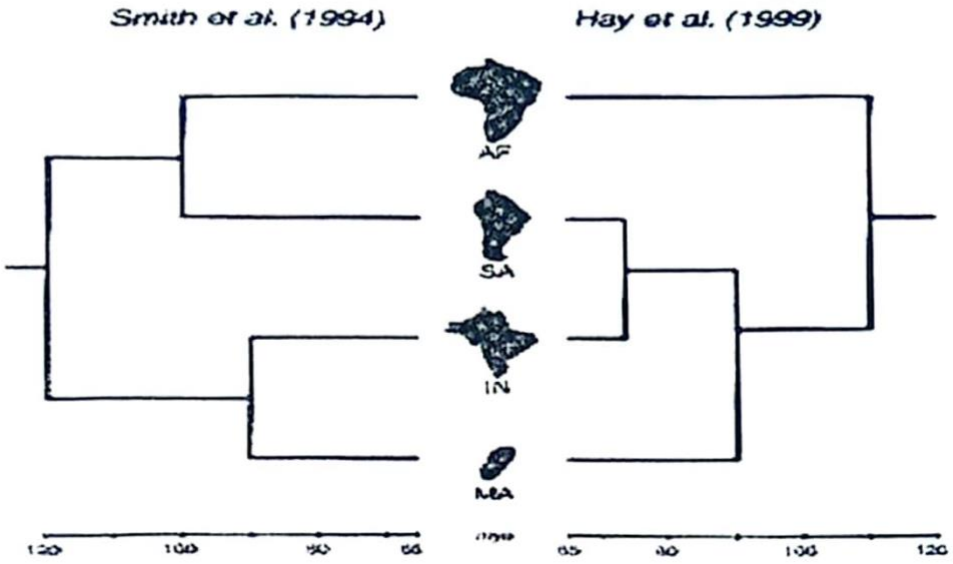



Fig. 3. Two thoughts regarding Paleoland connection of Indo-Pakistan (IN), Madagascar (MA) South America (SA), and Africa (AF) during 65-120 Million year's ago. After Wilson (2001) as implied by the coastline reconstructions of Smith et al. (1994) and Hay, *et al.*, (1999).Close affinity of Pakistani fauna with the South America represent well fit of Hay *et al.*, (1999).

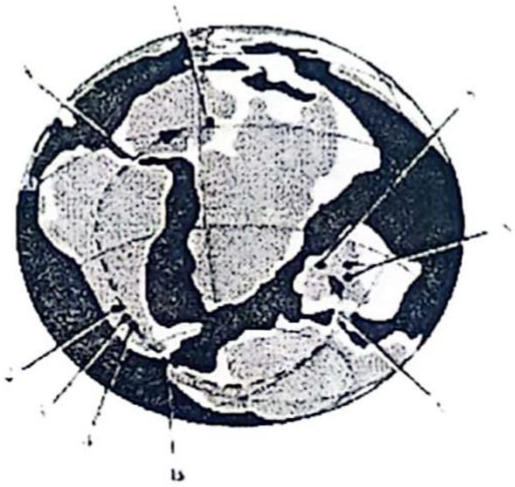



Fig. 4. Early Late Cretaceous Paleogeographic map (Scotese 2001) showing all known Late Cretaceous abelisaurid localities (numbers) and Key land bridges (letters). The arrow shows the southern high altitude dispersal route of the 'Africa-first' and 'Pan-Gondwana' models of Cretaceous biogeography. The Africa first model argues that land bridges A was broken in the Early Cretaceous, 30-50 million years earlier than land bridges B and C; the Pan-Gondwan model argues for final separation at land bridge A at the end of the Early Cretaceous. Land bridges: A, Walvis Ridge, Rio Grand Rise; B, Palmer Land Block, South Geogia Island Terrane; C, Kerguelan Plateau, Gunnerus Ridge. Abelisaurid localities: 1, *Rigops primus* from Niger; 2, *Aucasaurus garridoi,* 3a, *Abelisaurus comahuensis*, 3b, *Ilokelesia aguadagrandensis* and 4, *Carnotaurus sastrei* from Argentina; and 5, *Rajasaurus normadensis* from India; 6, *Magungatholusatopus* from Madagascar (After Sereno *et al.*, 2004). But recently Malkani (2006c) have discovered *Vitakridrinda*-an abelisaurian theropod from the Late Cretaceous Park of Pakistan. It has broadened the spatial distribution and match with the Gondwanan association theory. The finding of Saltasaurids Titanosauria and Baurusuchids crocodile from the Late Cretaceous Park of Pakistan also broaden their distribution and verify this model during Latest Cretaceous.

(1978) it is tentatively of Gondwana origin. The presence of Iguanas a living reptile in Madagascar suggests from Africa or by raft from Antartica because present in South America. Recently, (Taquet, 1982) analyzed new geologic observations consisting of the stratigraphy of the bottom of the Mozambique channel in relation to the paleontological evidence of the Mesozoic and especially of the Late Cretaceous. The conclusion of the new work is that Madagascar was in the same position that is now with respect to Africa from the late Paleozoic, having an intermittent continental connection in the course of the Mesozoic, with a continental phase in the Late Cretaceous (Senonian), across an elevated area. The Davies actually submerged. This follows on the basis of the discovery of continental sediments which underlie a sequence of limestone of Late cretaceous-Pliocene age. In this uplift and this interpretation agrees with the observed endemism of the ammonites (Taquet, 1982). The uplift was brought about by upward movements in this area by the mariner regression which (Taquet, 1982) located between the Cenomanian-Turonian and Maastrichtian transgressions.

## 6, Indo-Pakistan subcontinent and Africa during Late Cretaceous

The resemblance of the Indian fauna with that of Madagascar and South America, shows the presence of atleast one genus of titanosaurs, as indicated by showing the possibility of a connection of the continental faunas of the Late Cretaceous of the Indian Peninsula and the lands of the Southern Hemisphere (Powell, 2003).

Huene (1929), although employing some erroneous identification, developed a hypothesis which explained the disjunct distribution of this family and especially the genus titanosaurus according to which the displacement limited a crossing by a corridor which hypothetically existed between South-east Asia and South America. This corridor was made of bridges.

Recent discoveries from Pakistan show close resemblance with Madagascar and South America, showing corridor connections. Further, the connection with Africa via South America is proposed due to finding of Titanosauria from Niger and Egypt. It is further strengthened by the pan-Gondwanan model **(Fig. 4),** (Sereno *et al.*, 2004), on finding of Abelisauria from Niger.

### Africa and Europe during Late Cretaceous

The presence of titanosaurids which could be included in the subfamily titanosaurinae in the Late Cretaceous (Maastrichtian) in Spain, France, and Rumania, presumes the existence of some type of corridor to cross the emergent areas at the end of Late Cretaceous (Powell, 2003). Other evidence of this connection is the discovery of mammals of the family Palaeoryctidae, of genuine Laurasian stock in the Paleocene of Morocco (Cappetta *et al.*, 1978). The turtle of the family Pelomedusidae, of Gondwana stock, are also listed in the Late Cretaceous and Oligocene of Europe (Broin, 1980) and are commonly found associated with the dinosaurs of the family Titanosauridae in the Late Cretaceous of South America. They are interpreted in this work as following the same migtratory route to Africa and Europe (Powell, 2003).

Other taxa which have migrated along this bridge are the Sebecosuchian crocodiles. Forms assigned to this group are found in Germany (Langston 1975) and Portugal (Antunes, 1975). Their presence has been interpreted as the product of two different routes: the first suggested by (Buffetaut, 1980) and (Rage, 1981) who hypothesize a migration from South America to North America and then to Europe. The Second, proposed much later, and based on the discovery of ziphodont crocodile in the Eocene of Algeria is considered as valid evidence in favor of a migration from South America to Europe going through Africa (Buffetaut, 1982). This route had been independently proposed by (Bonaparte, 1984) who dated it as Early Tertiary (Powel, 2003). Among the ornithischian, is the extinction of the Ophthalmosauria (Ichthopterogia) and Plesiosauridae (Sauropterygia) (Appleby *et al.*, 1967).

## 7. Paleobiogeographic Implications of Titanosaurian Sauropod and belisaurian Therpod Dinosaurs from Pakistan-A Discussion.

Fossil vertebrates of Late Cretaceous age on southern continents are of particular interest because of the dynamic paleogeography (**Fig. 3**) of the period. During the Cretaceous, Gondwana broke apart into separate landmasses, isolating once-contiguous terrestrial faunas. Timing, sequence, and degree of isolation among these landmasses, however remain controversial (Smith *et al.,* 1994; Hay *et al.,* 1999; Maisey, 2000; Cracraft, 2001). This uncertainty is compounded by the relative scarcity of diagnostic Cretaceous vertebrate fossils, whose relationships could offer evidence of prior geographic connections. Among southern landmasses, Cretaceous vertebrates are best documented on South America. This is largely a result of intensive investigations of strata in Argentina over the last 30 years (summarized in Bonaparte, 1978, 1996). But recent discoveries of atleast two families and atleast 5 genera of Pakistani Titanosauria are documented by Malkani (2004a, 2005a, 2006h) **(Fig.3).**

The radiations of the angiosperms in the Cretaceous coincides with the appearance of the hadrosaurs in Laurasia and the titanosaurids in the continents which formed part of Gondwana. Both dinosaur groups were primary consumers. Krssilov (1981) recognized that the replacement of the dinosaur fauna at the end of the Late Cretaceous is clearly tied to the change of vegetation of the whole world, as also inferred by the Bonaparte. In South America, this change was documented although its data is not complete (Archangelsky 1970). Although it is common to discover fossil tree trunks associated with the remains of titanosaurids, there were few studies of these plant specimens. Of the 46 Late Cretaceous plant species known, 6 are pteridophytes, 5 gymnospers, none are monocotyledons and 35 dicotyledons. Of this group, the angiosperms are mostly represented by Magnoliaceae (14 species), Dillenacae (7 species), Rosiacae (6 species) and Hamameliacae (3 species) (Powel, 2003). One fossil of gymnosperm wood have been reported from the Late Cretaceous Park of Pakistan (Malkani, 2006h). As has been shown above, the advent of Late Cretaceous had a different development in Gondwana, and especially South America, and Pakistan, with respect to dinosaurs.

Examination of fossil records indicates that at the end of the Early Cretaceous, the best adapted and potentially adapted family of sauropod was the titanosauridae. They flourished in the Late Cretaceous and survived after all the other sauropods had become extinct (Powell, 2003). After the separation of Indo-Pakistan subcontinent from other Gondwanan landmasses, the isolation of the titanosauria in Pakistan during much of the Late Cretaceous, without competition from other herbivorous dinosaurs, resulted a diversification into two families and 5 genera.

The armour occurs as a diversity of large, morphological diverse dermal plates with spikes, and in the case of Saltasaurus loricatus, as interdermal ossicles. Four types of armoured bones of Titanosauria are found from the Late Cretaceous Sulaiman Foldbelt Park of Pakistan (Malkani, 2003b).

At the end of the Cretaceous, during the Companion-Maastrichtian (Casamiquela 1980; Bonaparte 1984a,b), a land connection was established which permitted the dispersion of the titanosaurids to North America, where until now only *Alamosaurus sanjuanensis* has been discovered (Gilmore 1921; 1946; Mateer 1976; Kues *et al.*, 1980). As a product of this connection, the hadrosaurs and other groups of terrestrial vertebrates penetrated South America, upsetting the equilibrium which had developed during the long isolation of the early Cretaceous (Powell, 2003).

A great similarity with the fauna of the Mesozoic continent, called Lemuria contained both of Indo-Pakistan and Madagascar, however is seen in South America (Patagonia, Uruguay, Brazil ) where though the younger beds (upper Senonian Maastrichtian) all the three Indian auropods genera are distributed. Evidences of close faunistic relations with Africa has not yet been found. At the lower limit of the Cretaceous at Tendaguru, Titanosaurus occur (Gigantosaurus Torneiria) but other sauropods predominate. The

few data yet known from the Upper Cretaceous of Egypt and Sahara indicate that the fauna has a different aspect but it contains a titanosauria (Huene and Matley, 1933).

Smith *et al.,* (1994), represents Indo-Pakistan and Madagascar association, while (Hay *et al.,* 1999), represents Indo-Pakistan and South American association during Late Cretaceous **(Fig. 3).** The Late Cretaceous fauna from Pakistan show close affinity with South America. It represents well interpretation of Hay *et al.,* (1999).

The recorded dinosaurian fauna includes only one genus known from associated elements (Titanosaurus colberti; Jain and Bandyopadhyay, 1997) among the thirteen Indian dinosaurs currently recorded (Loyal *et al.,* 1996). Based on present evidence, it is likely that herbivorous Titanosaurian sauropods and carnivorous abelisaurids theropods predominated in India during the Late Cretaceous (Lydekker,1877,1879; Huene and Matley,1933; Chatterjee and Rudra,1996; Jain and Bandyopadhyay). Titanosaurian had achieved a near global distribution in the Late Cretaceous (Wilson and Sereno, 1998; Curry Rogers and Forster, 2001) and Abelisauroids are known from South America, Madagascar, Europe and Africa (Bonaparte,1991; Sampson *et al.,* 1998; Accarie *et al.,* 1995).

The small vertebrate fauna of India has been more intensely studied, but offers no clearer picture of the biogeographic history of the subcontinent (Wilson, *et al.,* 2001). Localities in Central India have yielded a variety of microvertebrates, including mammals (Prasad and Sahni, 1988; Prasad *et al.,* 1994),sharks (Prasad and Cappetta,1993), frogs (Prasad and Rage,1991,1995), and squamates (Rage and Prasad,1992). Although very few of these remains can be identified to the generic level (Wilson *et al.,* 2001), this fauna has been considered similar to that of Eurasia by several authors (Prasad and Rage, 1991; Sahni and Bajpai, 1991; Chatterjee and Scotese,1999). However Krause *et al.* (1997) argued that the dinosurian and microvertebrate faunas of India are cosmopolitan, bearing affiniuties to both northern and southern faunas. The existing coarse taxonomic identification of these fossils again offer little signal of India's former geographic connectedness and/or isolation (Wilson *et al.,* 2001). But the dinosaur fossils from the Late Cretaceous of Pakistan are well preserved and diagnostic. It will provide a vantage for scientific research.

The disjunct distribution of the titanosaurs-abelisaurs assemblage in South America, India and Europe is interesting in the context of drifting continents in Late Cretaceous time. Paleontological evidence suggest that the Indian/Eurasian collision took place during this time, facilitating the migration of northern fauna of India (Chatterjee,1992; Prasad *et al.,*1994). Isolation between the northern and southern continents produced dramatically different distribution among dinosaurs. In contrast to northern hemisphere, the dominant herbivores in the Late Cretaceous of India and South America were titanosaurids rather than ornithischians, whereas the large predators were abelisaurids instead of tyrannosaurs (Chatterjee and Rudra, 1996).

Theropoda has global occurrences while tyranosaurids have Laurischian affinity and abelisaurids have Gondwanan affinity. Abelisauroid predators have been recorded almost exclusively from South America, India and Madagascar, a distribution thought to document persistent land connections exclusive of Africa. Discovery of horned dinosaur predatory dinosaur *Carnotaurus sastrei* and close relatives (Bonaparte and Novas, 1985; Bonaparte and Powell, 1980) in rocks of Late Cretaceous (Maastrichtian) age in Argentina brought to light a new group of dinosaurs now recognized as abelisauroids. Similar age fossils from India and Madagascar were linked to this group. Huene and Matley (1933) described 4 families of carnosauria from India. Sereno *et al.* (2004) proposed the pan-Gondwana model Scotese, 2001) on the basis of finding of abelisauroids in the Niger, in which three narrow, probably intermittent passages connected major Gondwanan landmasses during

the early Cretaceous and disconnected at the end of early Cretaceous (Fig. 4), while the Africa first model (Sampson *et al.*, 1998; Hay *et al.*, 1999) show separation in early duration of early Cretaceous.

Indo-Pakistan initially interlocked with the Gondwanan landmasses of Africa, South America, Australia, Antarctica and Madagascar early in the Mesozoic, drifted northward during the Cretaceous to collide with Laurasian landmasses during the Cenozoic. Indo-Pakistan thus appears to have experienced a 100-million-year period of isolation during a 9,000 km migration across the equator that can be expected to have influenced the character of its native biota. Fossils from this period of biogeographic isolation were relatively scarce. Thus far, the Late Cretaceous (Maastrichtian) Lameta Formation of India has served as the sole source of information on Cretaceous vertebrates of the Indo-Pakistan sub-continent and their remains are inadequate for assessing generic-level affinities (Wilson *et al.*, 2001). But the recent discoveries of dinosaurs by author include a variety of large vertebrate that indicate the first Late Jurassic titanosaur (one species), first Late Cretaceous herbivorous Titanosaurs (five species) and first carnivorous abelisaurian (one species) dinosaurs (Malkani, 2004a), and first Baurusuchid *Pabwehshi pakistanensis* (Mesoeucrocoreptilia) fossils (Wilson *et al.*, 2001, Malkani, 2004b) from Pakistan. Most of these assemblages show close resemblance to South America and these are best fit to the model **(Fig. 3)** of Hay, (1999). These discoveries of Jurassic and Cretaceous Arhosaurian reptiles from Pakistan provide a vantage point and act as a milestone for assessing paleobiogeography and phylogeny.

The discovery of Saltasaurids, Abelisaurids, and Baurusuchids from Pakistan broadens their distribution and may prove the close affinity with South America. Pakistani Titanosauria shows some affinity with the Late Cretaceous fauna of European, North America, South America and Madagascar. But its resemblance of some skull and especially teeth characters with Mongolian-Chinese forms like *Nemegtosaurus* and *Quaesitosaurus* are encouraging to say the Titanosauria as a **Global/Pangean distribution.** The findings of *Vitakridrinda-* an Abelisaurids from Pakistan broaden their spatial distribution and matches with the **Gondwanan linkage** theory.

## 8. Conclusions

Thus far, the Late Cretaceous (Maastrichtian) Lameta Formation of India has served as the sole source of information on Cretaceous vertebrates of the Indo-Pakistan sub-continent and their remains are inadequate for assessing generic-level affinities (Wilson *et al.*, 2001). But the recent discoveries of dinosaurs by author include a variety of large vertebrate that indicate the first Late Jurassic titanosaur (one species), first Late Cretaceous herbivorous Titanosaurs (five species) and first carnivorous abelisaurian (one species) dinosaurs (Malkani, 2004a), and first Baurusuchid *Pabwehshi pakistanensis* (Mesoeucrocoreptilia) fossils (Wilson *et al.*, 2001, Malkani, 2004b) from Pakistan. These discoveries of Jurassic and Cretaceous Arhosaurian reptiles from Pakistan provide a vantage point and act as a milestone for assessing paleobiogeography and phylogeny.

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