



## NEW *PAKISAURUS* (PAKISAURIDAE, TITANOSAURIA, SAUROPODA) REMAINS, AND CRETACEOUS TERTIARY (K-T) BOUNDARY FROM PAKISTAN

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### Abstract

*Pakisaurus* remains has been found from the latest Cretaceous Vitakri Formation (previous upper member of Pab Formation) in Kinwa, Bor, Top Kinwa, Shalghara, Sangiali, Alam Kali Kakor (north), Zubra, Darwaza, Grut, Dolvahi east, and some other localities of Sulaiman Basin, Pakistan. These fossils provide head to tail and back to foot morphology. Multipurpose tail special with trispinous distalmost caudal centrum of *Pakisaurus* of Pakisauridae and some or all genera of Pakisauridae and Balochisauridae found from Pakistan provide a new look of titanosaurs. The skull discoveries of *Pakisaurus* (*Marisaurus* and *Balochisaurus*) add the skull diversity of titanosaurs from Pakistan. The *Pakisaurus* skull represents widely spaced teeth, and fibrous laminations on external surface of jaw and large open internal cells in the interior jaw rami. Due to dearth of cranial data and lack of common associated elements in titanosaurs has left even the most basic skeletal morphology of the clade controversial and has precluded detailed study of its higher and lower level phylogeny, **but now Pakistan** has this advantage which produced associated cranial, axial and appendicular elements of *Pakisaurus* (*Marisaurus* and *Balochisaurus*). The *Pakisaurus*, *Marisaurus*, *Balochisaurus*, *Rapetosaurus*, some Argentinean and Mongolian forms have great potential to resolve paleobiogeography, lower and higher level phylogeny of titanosaurs.

Cretaceous Tertiary (K-T) boundary is well exposed on the western continental margin of Indo-Pakistan plate like Kirthar and Sulaiman basins, and on the northwestern margin like Kohat and Potwar basins. The K-T boundary sharing formations which are well exposed in the Kirthar and Sulaiman basins are the Late Cretaceous Pab/Vitakri Formation, and Paleocene Sangiali/Khadro Formation, however near to Axial belt the Cretaceous Parh and Mughal Kot formations and Paleocene Dungan Formation. Geological formations below and above the K-T boundary, in the western Salt Range are Chichali and Hangu; in the Surghar Range are Lumshiwai and Hangu; and in the Kohat and Kala Chitta-Hazara areas are Kawagarh and Hangu formations. Cretaceous Chichali/Lumshiwai Formation and Tertiary Siwalik Group represent the Infra Tertiary boundary in the Sheikh Buddin hills and Marawat Range. In Central and Eastern Salt Range, Hazara and Kashmir the boundary is represented between the varying Tertiary rocks with also varying older rocks such as Precambrian, Paleozoic and Mesozoic units. K-T boundary in Pakistan represents wide exposures of marine as well as continental condition. Indus Basin of Pakistan holds a large number of section sites for lateral and vertical rapid environmental/climate change in the Cretaceous greenhouse world. Pakistan has much potential for the study of marine as well as terrestrial Precambrian, Paleozoic, Mesozoic and Cenozoic strata, its boundaries, floras and faunas, paleoclimates, extinctions, phylogeny and paleobiogeography.

**Keywords:** *Pakisaurus*, Pakisauridae Titanosauria, Vitakri Formation, Late Cretaceous, K-T boundary, Pakistan, Malkani.

### 1. Introduction

The end of the Cretaceous represents a wide spread disconformity and verifies the dinosaurs' extinction in Pakistan. The first dinosaur fossils from India were discovered in 1828 (Wilson, 2006) and Falconer reported in 1862 but published as posthumous memoir in 1868 (Powell, 2003). But since 2000 to until about 3000 fossils of cranial, vertebral and

appendicular elements of latest Cretaceous archosaurs were collected by author from the Sulaiman Basin of Pakistan which include *Khetranisaurus*, *Sulaimanisaurus* and *Pakisaurus* of Pakisauridae, *Marisaurus* and *Balochisaurus* of Balochisauridae (Titanosauria, Sauropoda), *Vitakridrinda* (Vitakrisauridae, Theropoda), and *Pabwehshi* sulaimanisuchid mesoeucrocodylid (Malkani and

Anwar, 2000; Malkani *et al.*, 2001; Malkani, 2003a,b; 2004a,b; 2006a,b,c,d,e; Wilson *et al.*, 2001, 2005). A few poorly preserved and poorly recognized specimens of *Brohisaurus kirthari* (Titanosauria) were found from the Jurassic Cretaceous (J-K) boundary of lower Indus (Kirthar Range) Basin (Malkani 2003c). The trackways of wide gauge titanosaurian sauropods (*Malakhelisaurus mianwali* which is renamed from *Malasaurus* due to previously engaged name) confronted by a running narrow gauge abelisaurian theropod (*Samanadrinda surghari*) found from the Middle Jurassic limestone of upper Indus (Kohat and Potwar) Basin (Malkani 2007a; 2008f).

The term Pakisauridae and Balochisauridae were first time introduced by Malkani (2003a,c;2004a) and these were mostly misspelled as titanosaurid and saltosaurid respectively. Pakisauridae represents the *Pakisaurus balochistani*, *Sulaimanisaurus gingerichi*, and *Khetranisaurus barkhani* while Balochisauridae represents *Marisaurus jeffi* and *Balochisaurus malkani*. The term *Pakisaurus*, *Khetranisaurus*, *Sulaimanisaurus* *Balochisaurus* and *Vitakridrinda sulaimani* were first introduced by Malkani (2003b). The term *Marisaurus jeffi* was first introduced by Malkani (2003a). The term *Pakisaurus balochistani*, *Khetranisaurus barkhani*,

*Sulaimanisaurus gingerichi* and *Balochisaurus malkani* were first introduced by Malkani (2004a). *Pakisaurus balochistani* along with four other genera and their two families of latest Cretaceous Titanosauria from Pakistan are based on fragmentary but associated caudal vertebrae due to their most common and most diverse nature, described first time at the occasion of 5<sup>th</sup> Pakistan Geological Congress (Malkani 2004a) and formally published in (Malkani 2006b). Here associated and fragmentary remains of *Pakisaurus* collected from Pakistan and preliminary introduction of K-T boundary in Pakistan are being described.

**2. Materials and Methods**

The materials belong to the collected fossils/bones of *Pakisaurus* from 2000 to date from Pakistan and collected field data for K-T boundary in Pakistan (Table 1-8; Fig.1-5). The methods applied for this scientific research is paleontological and many other discipline of geology which include description, drawing, discussion and conclusions. Further stratigraphic sections were measured for correlation and other related research. Paleogeographic models were prepared for K-T boundary, paleoclimate, paleoenvironments and other related geological studies.

**Table 1. The measurements of caudal centra of *Pakisaurus***

Abbreviations; L1, length without articular cone; L2, length with articular cone; H1, proximal height without chevron ridge; H2, proximal height with chevron ridge; H3, distal height without chevron ridge; H4, distal height with chevron ridge; W1, proximal transverse width; W2, distal transverse width; W3, mid transverse width above; W4, mid transverse width below; W5, mid transverse width between ventral ridges; R, Ratio of mid transverse width above and below.

Specimens No.	L1	L2	H1	H2	H3	H4	W1	W2	W3	W4	W5	R
MSM-207-4	9.0	13.5	13.0	-	11.0	-	14.0	12.0	12.0	9.0	-	1.3
MSM-763.4	-	-	-	-	-	8.3	-	-	-	-	-	1.0
MSM-1005-15	8.0	11.0	8.5	-	7.7	-	7.5	7.5	6.7	6.0	-	1.1
MSM-522-3	6.0	10.0	-	-	6.3	-	-	5.2	4.0	3.8	-	1.1
MSM-154-16	8.0	9.5	6.5	-	6.0	-	4.0	5.0	3.5	3.5	-	1.0
MSM-793-2	7.5	10.5	-	-	6.3	6.4	6.0	6.3	4.2	3.2	-	1.3

**Table 2. Stratigraphic sequence of Sulaiman and Kirthar basins**

Age	Group	Formation	Lithology
Quaternary	Rec and Subrec.	Surficial deposits	Gravel, sand, silt and clay
		-----Angular Unconformity -----	
	Pleistocene	Dada Formation	Conglomerate, sandstone and clays.
		-----Angular Unconformity -----	
T	Pliocene	Vahova/Chaudhwan Formation	Clays, conglomerate (cong) and sandstone
		Manchar Litra/Manchar Formation	Sandstone, clays and conglomerate
E	Miocene	group Vahova/Gaj Formation	Clays, sandstone and conglomerate
	Oligocene	Chittarwata/Nari Fm.	Clays, conglomerate and sandstone
R		-----Disconformity -----	
		Kahan Drazinda Formation	Shale with minor coquina.
T	group	Pir Koh Formation	Limestone, marl and shale.

			Domanda Formation	Shale with minor coquina and gypsum.
I			Habib Rahi/Kirthar Fm.	Limestone, marl and shale.
	Eocene	Chamalang	Baska Formation	Gypsum, shale with minor silty dolomite.
A		group	Drug Formation	Rubbly limestone and mudstone / shale.
			Kingri Formation	Red muds/shale and grey to white sandstone
			Toi Formation	Sandstone, shale, rubbly limestone and coal.
R			Shaheed Ghat/Laki Fm.	Shale with minor marl /lst and siltstone
	Paleocene	Sangiali/	Dungan/Lakhra Fm.	Limestone, marl and shale
Y		Ranikot	Rakhi Gaj/Bara Fm.	Shale, mudstone, siltstone, sst. & limestone
		group	Sangiali/Khadro Fm.	Brown limestone, glauconitic shale and sandst.
C			-----Disconformity (KTB)-----	
R		Fort	Vitakri Formation	Two red mud units alternated with sandstone
		Munro	Pab/Moro Formation	Sandstone (sst) with subordinate shale (sh)
E	Late	group	Fort Munro Formation	Limestone (lst), shale and coquina beds
T			Mughal Kot Formation	Shale, marl, sst and muds
A	Early Parh	Parh Formation		Limestone with minor marl and shale
C		Group	Goru Formation	Shale and marl with minor limestone
EOUS			Sembar Formation	Mainly shale with minor marl and mudstone
	Late		-----Disconformity -----	
JURASSIC	Middle	Sulaiman	Chiltan Formation	Mainly Limestone.
	Early	group	Loralai& Spingwar/ Shirinab Fm.	Limestone, marl & shale

**Table 3. Stratigraphic sequence of Sheikh Buddin hills and Marawat Range**

Age	Formation	Lithology
Quaternary	Rec and Subrec. Surficial deposits	Gravel, sand, silt and clay
T	-----Angular Unconformity -----	
E	Pliocene	Soan Formation
R		Dhok Pathan Formation
T	Miocene	Nagri Formation
I		Chingi Formation
A	-----Disconformity -----	
R		Kamlial Formation
Y	Oligocene	Murree Formation
	-----Disconformity (Infra Tertiary boundary)-----	
		Lumshiwal Formation
CRETACEOUS		Chichali Formation
	-----Disconformity -----	
		Samanasuk Formation
JURASSIC		Shinawari Formation
		Data Formation
	-----Disconformity -----	
		Kingriali Formation

TRIASSIC	Tredian Formation	Mainly sandstone
	Mianwali Formation	Shale, limestone and sandstone
	-----Disconformity -----	
	Chidru Formation	Shale and sandstone.
PERMIAN	Wargal Limestone	Limestone and dolomite
	Amb formation	Sandstone, limestone and shale

**Table 4. Stratigraphic sequence of Khisor Range**

Age	Formation	Lithology
Quaternary	Rec and Subrec. Surficial deposits	Gravel, sand, silt and clay
	-----Angular Unconformity -----	
T	Pliocene	Soan Formation
E		Dhok Pathan Formation
R	Miocene	Nagri Formation
T		Chingi Formation
I	-----Disconformity -----	
A		Kamlial Formation
R	Oligocene	Murree Formation
Y	-----Disconformity (Infra Tertiary Boundary)-----	
JURASSIC	Data Formation	Mainly sandstone with minor shale
	-----Disconformity -----	
	Kingriali Formation	Dolomite and limestone with minor shale
TRIASSIC	Tredian Formation	Mainly sandstone
	Mianwali Formation	Shale, limestone and sandstone
	-----Paraconformity-----	
P	Chidru Formation	Shale and sandstone.
E	Wargal Limestone	Limestone and dolomite
R	Amb Formation	Sandstone, limestone and shale
M	Sardhi Formation	Shale with minor sandstone and siltstone
I	Warcha Sandstone	Mainly sandstone with some shale
A	Dandot Formation	Sandstone and shale
N	Tobra Formation	Conglomerate
	-----Disconformity-----	
	Khisor Formation	Gypsum with shale and dolomite
CAMBRIAN	Jutana Formation	Light green dolomite and shale
	Kussak Formation	Greenish grey and glauconitic sandstone
	Khewra Sandstone	Purple to brown sandstone

**Table 5. Stratigraphic sequence of Surghar Range**

Age	Formation	Lithology
Quaternary	Rec and Subrec. Surficial deposits	Gravel, sand, silt and clay
	-----Angular Unconformity -----	
T	Pliocene	Soan Formation
		Dhok Pathan Formation
E	Miocene	Nagri Formation
		Sandstone with minor sh.and conglomerate

		Chingi Formation	Red Clays, sandstone and conglomerate
R		-----Disconformity -----	
		Kamlial Formation	Shale with subordinate sst and conglomerate
T	Oligocene	Murree Formation	Sandstone, conglomerate and shale
		-----Disconformity -----	
I		Habib Rahi Formation	Mainly limestone with marl and shale
		Kuldana Formation	Shale with minor sandstone and limestone
R		Choregali Formation	Limestone and shale
	Eocene	Skesar Limestone	Limestone with subordinate shale and marl
Y		Nammal Formation	Marl with subordinate shale
		Patala shale	Mainly shale with marl
	Paleocene	Lockhart Limestone	Mainly limestone with minor shale
		Hungu Formation	Sandstone, coal, and shale
		-----Disconformity (KTB)-----	
		Lumshiwai Formation	Sandstone & shale
CRETACEOUS		Chichali Formation	Glauconitic sandstone and shale
		-----Disconformity -----	
		Samanasuk Formation	Mainly limestone with subordinate shale
JURASSIC		Shinawari Formation	Shale, limestone and sandstone.
		Data Formation	Mainly sandstone with minor shale
		-----Disconformity -----	
		Kingriali Formation	Dolomite and limestone with minor shale
TRIASSIC		Tredian Formation	Mainly sandstone
		Mianwali Formation	Shale, limestone and sandstone
		-----Disconformity -----	
		Chidru Formation	Shale and sandstone.
PERMIAN		Wargal Limestone	Limestone and dolomite
		-----Contact not exposed-----	
PRECAMBRIAN		Salt Range Formation	Marl, gypsum, salt and shale

**Table 6. Stratigraphic sequence of Salt Range**

Age	Formation	Lithology	
Quaternary	Rec and Subrec. Surficial deposits	Gravel, sand, silt and clay	
	-----Angular Unconformity -----		
T	Pliocene	Soan Formation	
		Clays, conglomerate and sandstone	
		Dhok Pathan Formation	
		Clays with subordinate sst and conglomerate	
E	Miocene	Nagri Formation	
		Sandstone with minor sh. and conglomerate	
		Chingi Formation	
		Red Clays, sandstone and conglomerate	
R		-----Disconformity -----	
		Kamlial Formation	Shale with subordinate sst and conglomerate
T	Oligocene	Murree Formation	Sandstone, conglomerate and shale
		-----Disconformity -----	
I		Habib Rahi Formation	Mainly limestone with marl and shale

		Kuldana Formation	Shale with minor sandstone and limestone
R		Choregali Formation	Limestone and shale
	Eocene	Skesar Limestone	Limestone with subordinate shale and marl
Y		Nammal Formation	Marl with subordinate shale
		Patala shale	Mainly shale with marl
	Paleocene	Lockhart Limestone	Mainly limestone with minor shale
		Hungu Formation	Sandstone, coal, and shale
		-----Disconformity (KTB)-----	
CRETACEOUS		Chichali Formation	Glauconitic sandstone and shale
		-----Disconformity-----	
		Samanasuk Formation	Mainly limestone with subordinate shale
JURASSIC		Shinawari Formation	Shale, limestone and sandstone.
		Data Formation	Mainly sandstone with minor shale
		-----Disconformity-----	
		Kingriali Formation	Dolomite and limestone with minor shale
TRIASSIC		Tredian Formation	Mainly sandstone
		Mianwali Formation	Shale, limestone and sandstone
		-----Disconformity-----	
		Chidru Formation	Shale and sandstone.
PERMIAN		Wargal Limestone	Limestone and dolomite
		Amb formation	Sandstone, limestone and shale
		-----Contact not exposed-----	
C		Sardhi Formation	Shale with minor sandstone and siltstone
A		Warcha Sandstone	Mainly sandstone with some shale
M		Dandot Formation	Sandstone and shale
B		Tobra Formation	Conglomerate
R		Baghanwal Formation	Red shale alternated with flaggy sandstone
I		Jutana Formation	Light green dolomite and shale
A		Kussak Formation	Greenish grey and glauconitic sandstone
N		Khewra Sandstone	Purple to brown sandstone
PRECAMBRIAN		Salt Range Formation	Marl, gypsum, salt and shale

**Table 7. Stratigraphic sequence of Kohat Region**

Age	Formation	Lithology
Quaternary	Rec and Subrec. Surficial deposits	Gravel, sand, silt and clay
	-----Angular Unconformity-----	
	Pliocene	Soan Formation
		Clays, conglomerate and sandstone
T		Dhok Pathan Formation
		Clays with subordinate sst. and conglomerate
	Miocene	Nagri Formation
		Sandstone with minor sh. and conglomerate
E		Chingi Formation
		Red Clays, sandstone and conglomerate
	-----Disconformity-----	
R		Kamlial Formation
		Shale with subordinate sst. & conglomerate
	Oligocene	Murree Formation
		Sandstone, conglomerate and shale
T	-----Disconformity-----	

		Kohat Formation	Shale with minor sandstone and limestone
I		Kuldana Formation	Shale with minor sandstone and limestone
	Jatta Gypsum	Gypsum with minor marl, dolomite and sh.	
A		Bahadur Khel Salt	Salt, marl, shale and gypsum
	Eocene	Shekhan Formation	Limestone with subordinate shale and marl
R		Panoba Shale	Marl with subordinate shale
		Patala Formation	Mainly shale with marl
Y	Paleocene	Lockhart Limestone	Mainly limestone with minor shale
		Hungu Formation	Sandstone, coal, and shale
		-----KTB-----	Disconformity -----
		Kawagarh Formation	Limestone, marl and shale
		Lumshiwal Formation	Sandstone & shale
CRETACEOUS		Chichali Formation	Glauconitic sandstone and shale
		-----	Disconformity -----
		Samanasuk Formation	Mainly limestone with subordinate shale
JURASSIC		Shinawari Formation	Shale, limestone and sandstone.
		Data Formation	Mainly sandstone with minor shale

**Table 8. Stratigraphic sequence of Kalachitta-Hazara region**

Age		Formation	Lithology
Quaternary	Rec and Subrec.	Surficial deposits	Gravel, sand, silt and clay
		-----	Angular Unconformity -----
T	Pliocene	Soan Formation	Clays, conglomerate and sandstone
		Dhok Pathan Formation	Clays with subordinate sst. & conglomerate
E	Miocene	Nagri Formation	Sandstone with minor sh. and conglomerate
		Chingi Formation	Red Clays, sandstone and conglomerate
R		-----	Disconformity -----
		Kamlial Formation	Shale with subordinate sst. & conglomerate
T	Oligocene	Murree Formation	Sandstone, conglomerate and shale
		-----	Disconformity -----
I		Habib Rahi Formation	Mainly limestone with marl and shale
		Kuldana Formation	Shale with minor sandstone and limestone
A		Choregali Formation	Limestone and shale
	Eocene	Margala Hill Limestone	Limestone with subordinate shale and marl
R		Nammal Formation	Marl with subordinate shale
		Patala shale	Mainly shale with marl
Y	Paleocene	Lockhart Limestone	Mainly limestone with minor shale
		Hungu Formation	Sandstone, coal, and shale
		-----	Disconformity (KTB)-----
		Kawagarh Formation	Limestone, marl and shale
CRETACEOUS		Lumshiwal Formation	Sandstone & shale
		Chichali Formation	Glauconitic sandstone and shale
		-----	Disconformity -----

	Samanasuk Formation	Mainly limestone with subordinate shale
JURASSIC	Shinawari Formation	Shale, limestone and sandstone.
	Data Formation	Mainly sandstone with minor shale
	Contact not exposed, may be faulted or disconformity	
CAMBRIAN	Abbottabad groups	Quartzite, dolomite, schist, phyllite, conglomerate, marble & gypsum.
PRECAMBRIAN	Hazara Formation	Slate, schist, dolomite, phyllite, shale, limestone and graphite layers

### 3. Results and Discussions New remains of *Pakisaurus* (Balochisauridae, Titanosauria) from Pakistan.

#### Systematic Paleontology:

Dinosauria (Owen, 1842)

Order Saurischia (Seeley, 1888)

Infraorder Sauropoda (Marsh, 1878)

Titanosauria (Bonaparte and Coria, 1993)

Family Pakisauridae Malkani, (2003a) 2006b

*Pakisaurus* Malkani, (2004a) 2006b

*Pakisaurus balochistani* Malkani, (2004a) 2006b

**Holotype and locality:** MSM-11-4 to MSM-14-4, four fragmentary but seem associated caudal vertebrae collected from the Kinwa Kali Kakor locality (Malkani, 2006b, fig. 5-8).

**Referred specimens and localities:** The referred caudal vertebrae (MSM-15-15, MSM-16-2, MSM-17-16) collected from Mari Bohri, Bor and Top Kinwa localities were first time described alongwith four holotypic caudal vertebrae by Malkani (2004a) and second time described and figured by Malkani (2006b, fig. 5-8). Third time one cervicodorsal vertebra (MSM-133-4) and a pair of coossified sacral vertebrae (MSM-136-4) were described and figured by Malkani (2006c; fig.2-5) which are being referred here to *Pakisaurus* on the basis of close and cluster forming occurrences. The above-mentioned holotypic and referred vertebrae from Kinwa Locality may be associated with some or most materials of *Pakisaurus* from this locality. Fourth time the following cranial and postcranial elements are being referred here.

#### Kinwa Kali Kakor Locality

(Pakistan dinosaurs locality number 4; PDL 4) yielded presacral vertebrae MSM-340-4, MSM-809-4, MSM-1011-4, MSM-517-4, MSM-810-4, MSM-342-4, MSM-800-4, MSM-341-4, MSM-376-4, and MSM-1011-4 (Fig. 1); mid caudal MSM-1010-4 (Fig. 2);

proximal and distal right femur MSM-595-4, MSM-200-4, MSM-202-4, proximal humerus, mid humerus MSM-268-4, distal humerus MSM-193-4, middle and proximal femur MSM-208-4, proximal humerus MSM-201-4, proximal humerus MSM-195-4, proximal left fibula MSM-349-4; MSM-806-4 ilia/sacricoastal yoke fragment, sternal MSM-355-4, diapophysis MSM-878-4, distal radius MSM-159-4 (Fig. 3); sternal convex MSM-598-4, prox scapulae MSM-318-4, MSM-319-4, prox scapula MSM-317-4, art scapula MSM-335-4, sternal anterolateral near to ridge MSM-353-4, mid scapulae MSM-267-4, MSM-198-4, art scapula MSM-678-4, Ilium MSM-594-4, section scapula MSM-593-4, neural spine MSM-601-4, diapophysis, MSM-878-4 caudal prz and poz MSM-804-4, distal fibula MSM-580-4, scapula section MSM-590-4 distal scapula with glenoid surface MSM-205-4, distal scapula with glenoid MSM-162-4, distal sapula MSM-205-4 and MSM-162-4; proximal metacarpal MSM-280-4, partial metacarpals MSM-350-4, MSM-970-4, left mid scapula MSM-203-4, right mid scapula MSM-198-4, left mid scapula MSM-203-4, right mid scapula MSM-198-4 (Fig.4); and proximal ulnae MSM-603-4, MSM-600-4, proximal fibula MSM-384-4; one ray of proximal ulna M-211-4, distal scapula MSM-678-4, humerus parts MSM-971-4 and MSM-972-4 (Fig. 5).

**Bor Kali Kakor Locality** (PDL 2) produced caudal vertebra MSM-793-2 (Fig.2); jaw ramus MSM-143-2; distal tibia MSM-186-2; mid femur MSM-293-2, distal femur MSM-180-2; proximal and mid femur

MSM-294-2, distal femur MSM-266-2, humerus parts MSM-289-2, MSM-498-2, MSM-288-2, MSM-290-2 and MSM-286-2; proximal and mid femur MSM-69-2 with possible MSM-272-2 and MSM-265-2 distal condyles, and distal ulna MSM-183-2 (Fig. 2).

**Shalghara Locality** (PDL 3) yielded fractured distal caudal vertebrae MSM-523-3, and distal caudal vertebra with horizontal groove on posterior cone MSM-151-3, jaw ramus MSM-139-3 (Fig.2), coracoid with glenoid and fenestra MSM-366-3 (Fig.3.4), pes ungual MSM-152-3 (Fig. 3), and acetabulum MSM-748-3 (Fig.4). **Alam Kali Kakor western Locality**

(northern site; PDL 19) yielded anterior mid caudal vertebrae MSM-758-19n and proximal radius MSM-756-19n (Fig.2), glenoid corocoid MSM-403-19n, and distal ulna MSM-628-19n, (Fig.4); proximal radius MSM-756-19n and distal ulna MSM-628-19n (Fig.5). **Top Kinwa** (PDL 16) yielded caudal vertebrae MSM-510-16 and MSM-154-16 (Fig. 2); distal radius MSM-160-16 (Fig.3); and proximal slender tibia MSM-1032-16, and mid humerus MSM-468-16 (Fig.5). **Mari Bohri** locality (PDL 15) yielded caudal vertebra MSM-1005-15; a partial tibia including proximal slender tibia (MSM-72-2; Malkani 2006b, fig.18a,b) (Fig.2). **Zubra Gambrak** (PDL 7) yielded right mid scapula MSM-746-7 (Fig.4), partial tibia MSM-235-7, proximal fibula MSM-253-7, and proximal metacarpal MSM-296-7 (Fig. 5). **Grut Gambrak** (PDL 9) yielded caudal vertebra MSM- 526-9 (Fig.2), and proximal humerus with head formed from mosaic of MSM-694-9 and MSM-759-9 (Fig. 3). **Sangiali Kali Kakor** (PDL 1) yielded right distal femur (slender) MSM-232-1 and distal humerus MSM-262-1 (Fig.3). **Darwaza Gambrak** (PDL 8) yielded glenoid scapula MSM-742-8 (Fig.4), and **Dolvahi east** (PDL 13) yielded proximal rib MSM-321-13 (Fig.4).

Femur head or nodule MSM-1055-K collected from Karkh area Kirthar Range may belongs to *Pakisaurus*/Titanosauria. The holotypic and referred specimens are housed in the Museum of the Geological Survey of Pakistan, Quetta.

**Horizons, taphonomy and age:** The remains are collected from the latest Cretaceous Vitakri Formation (Fig.1d) of Sulaiman Basin, Pakistan (Fig. 1a). Most of these materials were found as fragmentary clusters or heap forming occurrences, while some materials as isolated and dispersed. The heap or cluster of bones represents associated materials while fragmentary isolated bone represents transportation before deposition. The age of the Vitakri Formation (previous upper member of Pab Formation) is concluded as the latest Cretaceous (latest or uppermost Maastrichtian) which is mostly based on dinosaur extinction and law of superposition.

**Skull elements:** Due to the persistent lack of associated cranial and post cranial material, a clear understanding of even their most basic morphological attributes remains elusive (Curry Roger and Forster, 2001). In contrast with the wealth of data derived from the study of the postcranial skeleton, the information on titanosaurid skull morphology is scarce. A few well-preserved braincases and some fragments constitute all the available skull material attributable to titanosaurids.

Cranial evidence links titanosaurids with other sauropods is poorly understood (Salgado *et al.*, 1997). But here the associated cranial, vertebral and appendicular elements of *Pakisaurus* have been presented. The associated skull specimens MSM-4-3, MSM-5-3, MSM- 139-3 and MSM-140-3 from Shalghara locality represent association with postcrania of this locality. MSM-4-3 represents wide spaced about 6 teeth and jaw symphysis, while MSM-5-3 represents widely spaced 2 or 3 teeth in a jaw ramus. Both of these specimens sent for preparation to Jeffrey A. Wilson, University of Michigan, USA. MSM-140-3 represents jaw symphysis. MSM-139-3 represents 2 teeth in a slightly curved jaw ramus with diastema or opposite teeth fitting impression in between two teeth (Fig.2a). MSM-143-2 collected from Bor locality may be associated with postcrania of *Pakisaurus* from this locality represents jaw ramus with 4 alveolus and partial teeth (Fig.2a). The tooth is circular to subcircular. MSM-143-2 jaw ramus clearly show parallel and alternated fine ridges and grooves, longitudinally trending anteroposteriorly throughout all preserved length (Fig. 2a).

**Vertebral Skeleton:** Four holotypic (MSM-11-4, MSM-12-4, MSM-13-4, MSM-14-4) and three referred (MSM-15-15, MSM-16-2, MSM-17-16) caudal vertebrae were first time described in Milkani, (2004a) and second time described and figured (along with other genera like *Khetranisaurus* and *Sulaimanisaurus* of Pakisauridae, *Marisaurus* and *Balochisaurus* of Balochisauridae, and *Vitakridrinda* of Abelisauridae) in Malkani, (2006b, fig. 5-8). Third time MSM-133-4 one cervicodorsal vertebra and MSM-136-4 a pair of coossified sacral vertebrae were described and figured in Malkani, (2006c; fig.2-5) which are being referred here to *Pakisaurus* on the basis of cluster forming occurrences. Fourth time the following vertebral elements (along with other elements) are being presented here. MSM-1011-4 cervical/anterior dorsal vertebra (Fig.2c); MSM-340-4, MSM-809-4 MSM-1011-4 MSM-517-4, MSM-810-4, MSM-342-4, MSM-800-4, MSM-341-4 and MSM-376-4 presacral vertebrae (Fig.2b);, MSM-1008-4 a sacral pair; MSM-510-16, MSM-154-16 MSM-793-2 caudal vertebrae (Fig.2e); MSM-151-3 distal caudal with horizontal groove on posterior articular cone, MSM-758-19n anterior mid caudal, MSM-1010-4 mid caudal and MSM-523-3 fractured distal caudal (Fig.2e); MSM-207-4 and MSM-763-4 caudal vertebrae (Fig.2d); MSM-1005-15 caudal vertebra and MSM-583-4 a sacral pair. Some measurements of vertebrae are shown in Table 1. The cervical centra are











broad, long and opisthocoelous. The opisthotic dorsal vertebrae represent 3 morphs like short and broad centra, short and circular centra, and tall and relatively long. The vertebrae represent the camellae/spongy/pneumatic texture. The neural spine is undivided. There is no hyposphene-hypantrum articulation. The sacral vertebrae are broad with ventral keel. Diapophysis is shown in Fig. 3e. Malkani (2006c) reported the detail descriptions of sacral and presacral vertebrae. Anterior caudal centra are broad while the mid caudals are strong to moderately tall while posterior caudals are slightly tall. The chevron facets are not found on the anterior most caudals and posterior caudals, while located in the remaining anterior and middle caudals. All the caudal vertebrae are strongly procoelous (except anteriormost and distalmost caudals). Both the height and width of caudal centra reduces much backward with relative to their length, which reduces less. The neural arch is situated on the anterior half of the caudal centra. The prezygapophyses are rod like while post zygapophyses in MSM-758-19n. The middle and posterior caudal spines are laterally compressed and seem to be directed posteriorly. Prominent transverse processes occur which seems like blunted in anterior caudals like MSM-207-4 (Fig. 2). Trispinous distalmost caudal centrum MSM-519-4 (Kinwa Kali Kakor Locality) belongs to *Pakisaurus* show trispinous nature for good defending from its foe like *Vitakridrinda* and *Pabwehshi* etc, balancing body as third support during foraging from tall tree and mating (Malkani, 2008f).

**Appendicular Skeleton:** Appendicular proportion is dominant with reference to cranial and vertebral elements. Here the most representative of limb elements are being briefly described.

**Scapula:** MSM-746-7 right scapula, MSM- 678-4 distal scapula, MSM-205-4, MSM-162-4, MSM-203-4 distal scapulas with glenoid surface, MSM-198-4 right mid scapula, MSM-203-4 mid scapula; MSM-590-4 scapula section, MSM-593-4 section scapula, MSM-267-4 mid scapula, MSM-678-4 distal scapula, MSM-317-4, MSM-318-4, 319-4 prox scapulae MSM-335-4 art scapula, and MSM-742-8 glenoid scapula (Fig.4a,b,c,d). The middle part of scapula is relatively less thick and wide than distal end (and also probably less than proximal part). The dorsal/outer surface represents dominant convexing curvature and ventral/inner surface is concave, forming asymmetric D shape cross section. This convexing curvature is asymmetric and deep convex/crest is located/shifted in the dorsal side (relative to *Marisaurus* or *Balochisaurus* which have also asymmetric shallow crest located close to mid). Distal blade is expanded and represents broadening and thickening at the distal

end forming a deep and spoon shape glenoid for humerus head, and nearby rugosity for the attachment of corocoid and developed into an area for the attachment of the muscles over almost the entire width. Distal scapula is maximum thick at about the center of the glenoid area where it forms ridge on one side and plain on other side. Distal scapula and coracoid are separate. The distal scapula of *Pakisauridae* (*Pakisaurus*) is deflected laterodorsally and expanded in the lateroventral side of mid scapular blade, while the distal scapula of *Marisaurus* (and also *Balochisaurus*) is not deflected laterodorsally i. e., it is straight or slightly deflected medially and also not expanded in the lateroventral side of mid scapular blade.

**Coracoid:** MSM-403-19n glenoid corocoid, MSM-366-3 corocoid (Fig. 4a). The coracoid showing glenoid cavity for humerus and rugose area for attachment of distal scapula and remaining area seems to be smooth plate like. The coracoid plate is maximum thick at the glenoid area and become thin abruptly in the other areas except toward the rugose articular area for the attachment of scapula. The corocoid glenoid area is at the same level as plate on one side but elevated or rose on other side.

**Sternal Plate:** MSM-353-4 sternal anterolateral near to ventral ridge, MSM-598-4 medial sternal with convexing portion (Fig.4a); MSM-355-4 anterolateral sternal (Fig.3d). The anterolateral edge is maximum thick and has anteroventral crest and becoming gradually thin as proceeding posterior and medial directions. The anteroventral crest is diminishing as proceeding posteriorly. There are rugosities on the anterior, anteolateral, anteromedial of anterior of sternal plates. These rugosities show connection with the scapular corocoid region and other fellow. The plate is slightly concave on the ventral and dorsal sides. The anterolateral part is thick and subrounded. From this thick corner the thickness is consistently reduced in the medial side. The anterior end is thickened by an obtuse ridge, which extends over the ventral side for about a decade centimeter.

**Fore limbs:** The humerus, radius, ulna, and metacarpals have been found so far.

**Humerus:** MSM-759-9 mosaic with 694-9 proximal humerus with head, MSM-232-1, MSM-262-1, distal humeral (Fig.3f). MSM-468-16 mid humerus (Fig.5f). MSM-289-2 humerus/femur section, MSM-288-2, MSM-290-2, and MSM-286-2, MSM-498-2 humerus sections (Fig.2f). MSM-202-4 proximal humerus, MSM-268-4 mid humerus, MSM-193-4 distal humerus (Fig.3a), MSM-201-4 proximal humerus, MSM-195-4 mid proximal humerus (Fig.3c). Both the proximal and

distal ends of humerus are expanded. Proximal part is convexing toward posterior side and concaving toward anterior side. Proximal humerus has semi ball like head on posterior view and represents deltopectoral crest (on lateral view) which may be slightly twisted in side. Proximal humerus have a continuous ridge (convexing part) on the posterior view of humerus, starting from head to downward may be running just close to constricted middle part of humerus. The proximal humerus is slightly rugose while distal humerus has intense rugosities. Humeral midshaft cross section shape seems to be elliptical, with long axis oriented transversely. The posterior side has a broad groove for the adjustment of prominent olecranon process. The anterior view of the distal humerus have prominent ridge (may be radioulnar condyle), and posterior part is divided well in to two condyles like radial and ulnar condyles.

**Radius:** MSM-756-19n proximal radius (Fig.1d), MSM-756-19n proximal radius (Fig.2e,5e). MSM-160-16 distal radius, MSM-159-4 distal radius (Fig. 3e). The proximal and distal ends of radius are expanding well. Proximal end is elongated sub oval type, while the distal end is sub rectangle type. The proximal part show slight concavity or depression on proximal view. The proximal end is expanded and has pointed expansion directed medially. The distal end is expanded and is directed downward medially or makes medial inclination on the axis of length of radius bone. It also shows some smooth slight concavity on the distal view. Distal condyle flattened posteriorly and articulating in front of ulna. Radius shaft is nearly circular, only oval in the and when attaching with the medially tilted distal ends. Radius distal breadth is approximately twice the midshaft breadth. Radial distal condyle shape is downwardly inclined and beveled proximolaterally relative long axis of shaft.

**Ulna:** MSM-628-19n distal ulna (Fig.4a,5e), MSM-183-2 distal ulna (Fig.2h); MSM-603-4, MSM-600-4 proximal ulnae, M-211-4 one ray of proximal ulna (Fig.4a); MSM-199-4 proximal ulna. The proximal ulna is rugose with a prominent olecranon process. The proximal ulna is gracile and represents a triradiate structure with three faces. Ulnar proximal condylar processes are unequal. There is a marked concave depression on the proximal lateral side to cradle the head of radius. It has also depression on the medial side also. The posterior side have slight depression and almost smooth. The ulna gradually tapers toward distal end which is subovate in outline and smaller than the proximal end. Distally the shaft has marked depression for the reception of distal radius.

**Metacarpals:** MSM-296-7 proximal metacarpal (Fig.5d); MSM-280-4 proximal metacarpal (Fig.4c). Metacarpal cross section is triangular. Its shaft is long relative to metatarsal. The proximal surface of shaft is rugose. The distal end is undivided and has no rugosities. The proximal and distal ends are expanded.

**Pelvis:** MSM-748-3acetabulum, MSM-594-4 part of ilia (Fig. 4a); MSM-806-4 ilia/sacrocoastal yoke fragment (Fig.3d), mosaic of MSM-971-4 and MSM-972-4 (Fig.5f) possibly preacetabular process of ilium or humerus parts. Ventrally the acetabulum is long and circular and bears parallel ridges indicating calcified tendons. The pubic peduncle is large and subovate or flat and D shape and expanded transversely and anteroposterior thickness is much reduced. In contrast the ischium peduncle is feeble. The acetabulum forms the embayment for the reception and movement of femur heads. The broken part of ilia represents the parallel spongy/pneumatic texture with large open internal cells. The preacetabular process of ilia is thick and platy. The specimen (MSM-971-4 and MSM-972-4; Fig.5f) show no large open internal cells, which show its assignment to limb like humerus. The ilium seems to be low with a long, anteriorly and externally directed preacetabular lamina as occurs in other titanosaurs.

**Hind limb:** The femora, tibia, fibula, metatarsals and ungual have been collected so far.

**Femur:** MSM-71-15 distal femur slender (Malkani 2006b;fig.17a,b); MSM-232-1 distal right femur slender (Fig. 3f); MSM-293-2 section of femur, MSM-180-2 distal femur, MSM-294-2 proximal femur, MSM-266-2 distal femur (Fig. 2f); MSM-69-2 proximal and mid femur with possible distal condyles (Fig. 2g); MSM-208-4 proximal and mid femur (Fig. 3b); MSM-595-4, MSM-200-4 proximal and distal right femur (Fig. 3a); MSM-1055-K femur head or nodule (Fig. 5G). A sub parallel (with reference to medial and lateral sides) ridge has been located on posterior side starting from the greater trochanter to downward. Femoral shaft is elliptical. These slender femora have posterior elongated dominant rugosities starting from distal part to upward constricted part. Distal end is bifurcated in two condyles as tibial and fibular condyles. The tibial condyle is relatively deeper than fibular condyle while the fibular condyle is relatively wider than tibial condyle. The tibial condyle is wheel like. The fibular condyle is posteriorly divided in two sub condyles. The tibiofibular condyle is also present in these femora. The constricted part of femur seems to be relatively high. The femora represent

proximal one third medially deflected, laterally beveled knee condyles and transverse elliptical eccentricity, which may help for wide gauge tracks and trackways.

**Tibia:** MSM-235-7 slender tibia (Fig. 5b), MSM-1032-16 proximal slender tibia (Fig.5f), MSM-72-2, MSM-186-2, partial tibia (Fig. 2f). The possible length of Tibia (MSM-235-7) seems to be about 1m. Tibia represents elongate and thin/narrow proximal surface observed on proximal view and lunate distal surface observed on distal view. Tibia cnemial crest projects anteriorly. Tibial distal posteroventral process is reduced transversely. The proximal part has cnemial crest directed mostly anteriorly which cradle the proximal end of the fibula. The proximal and distal ends are more flattened than robust tibia of *Marisaurus* and *Balochisaurus*.

**Fibula:** MSM-253-7 proximal fibula (Fig.5c), MSM-384-4 proximal fibula (Fig.5a); MSM-498-2 possibly distal fibula (Fig.2e); MSM-349-4 proximal left fibula (Fig.3c). Proximal fibula have medial scar for attachments of tibia. The shape of fibular proximal tibial scar is well marked and deepening anteriorly. There is a ridge in the medial scar, starting from close to center of proximal surface and trending obliquely downward. The distal fibula is oval shape. Fibular distal condyle size is not equal to shaft but expanded transversely more than twice midshaft breadth.

**Metatarsals:** The metatarsals are arranged in semicircular fashion diverging outward and downward in contrast to the vertically oriented metacarpals as reveals by footprints of titanosaurs with pad like heel (Malkani, 2007a, 2008f).

**Ungual:** (MSM-152-3, Fig.3g,4a). The ungual or claw is sickle-shaped, much deeper dorsoventrally than broad transversely.

#### **Osteoderms**

Thick armor oval plate (MSM-85-4, Fig.5) (Malkani 2003b, specimen on right side of fig. 3,4,5) is being assigned to *Pakisaurus* (Malkani, in process).

#### **Wide gauge skeletal morphology of *Pakisaurus* (*Pakisauridae*)**

The Pakistani titanosaurs represent two types of wide gauge movements like less wide gauge and narrow wide gauge movements. The less wide gauge movement is represented by *Balochisaurus* (and *Marisaurus*), based on mid scapula which is almost straight of slightly deflected medially, while more wide gauge movement is represented by *Pakisaurus* (possibly *Khetranisaurus*, *Sulaimanisaurus*), is based on mid scapula which is laterally deflected (Fig. 4a,b,c,d).

#### **Eggs and plant fossils (*Gymnosperm*)**

Two nodules or possibly eggs of dinosaurs like medium size (MSM-125-Kingri, may belong to *Vitakridrinda*, theropod), and large size (MSM-126-Kingri, may belongs to *Pakisaurus* or any member of *Pakisauridae* or *Balochisauridae*) is collected from the Kingri coalmine Chap area from the coeval latest Cretaceous strata. The gymnosperm stem wood fossil (MSM-1038-6) is collected from Pab Formation of Goes Wanga Pass area. These gymnosperms along with other plants were the source of food for *Pakisaurus* and other herbivores. Possibly many eggs (MSM-1058-K egg/nodule with outer spongy surface, MSM-1061 egg/nodule part and MSM-1047 egg/chalcedonic nodule part; lower row MSM-1060-4 egg/nodule part, MSM-316-4n egg/nodule, MSM-1046 egg/nodule and MSM-1045-16 egg/nodule part) may belong to medium size to smaller archosaurs (Fig.5).

#### **K-T boundary in Pakistan**

**Stratigraphy:** Pakistan has a vantage point to include the Gondwanan as well as Laurasian lands. Axial belt is a suture zone of Indus basin (fragment of Gondwana, on the east of Axial belt), and Balochistan basin and Karakoram terrain (part of Laurasia, on the west and north of Axial belt). Balochistan basin (flysch and arc) consists of mostly Cenozoic rocks. The Axial belt in Balochistan Province represents Mesozoic and Cenozoic rocks. Indus Basin is a long (1200 km), and wide (400km; exposed 150 km, alluvium cover 250 km) basin, located in the central axis of Pakistan generally trending north south. Indus basin along with other parts of Indo-Pakistan subcontinent started journey from southern hemisphere during Mesozoic crossed the equator and collided with the northern hemisphere/Asia during middle/Late Cenozoic. In this way, Indus basin experienced about 60 million years of many isolations and connections, rapid variable depositional environments and climate, affecting its sediments, flora and fauna. The Precambrian, Paleozoic, Mesozoic and Cenozoic rocks in the upper Indus basin, while Mesozoic and Cenozoic rocks in the middle and lower Indus basins are well exposed (Fig.1a).

K-T boundary is well exposed on the western continental margin of Indo-Pakistan plate like Kirthar and Sulaiman basins, and on the northwestern margin of subcontinent like Kohat and Potwar basins. The geological formations below the K-T boundary in Sulaiman basin are Late Cretaceous Pab/Vitakri Formation, and above are Early Paleocene Sangiali/Rakhi Gaj Formation. The geological formations sharing the K-T boundary in Kirthar basin are Pab and Khadro formations. Geological formations below and above the KTB, in the western Salt Range are Chichali

and Hangu; in the Surghar Range are Lumshiwai and Hangu; and in the Kohat and Kala Chitta-Hazara areas are Kawagarh and Hangu formations. Cretaceous Chichali/ Lumshiwai Formation and Tertiary Siwalik/ Vahova/Pothwar Group represent the Infra Tertiary boundary in the Sheikh Buddin hills and Marawat Range. In Central and Eastern Salt Range, Hazara and Kashmir the boundary is represented between the varying Tertiary rocks with also varying older rocks such as Precambrian, Paleozoic and Mesozoic units. The brief Stratigraphic sequence of Sulaiman and Kirthar basins is shown in Table 2, Kohat and Potwar basins are shown in Table 3-8.

The Vitakri Formation in the central part of Sulaiman basin is the host of latest Cretaceous dinosaurs from Pakistan. This is the reason the central Sulaiman basin is called latest Cretaceous Park of Pakistan (Malkani, 2006b) and here some detail is also being provided. The Sulaiman basin represents the oldest strata as Jurassic Sulaiman group (Spingwar, Loralai and Chiltan formations; ammonite bearing limestone, marl and shale; marine conditions). Jurassic Cretaceous (J-K) boundary represent red iron beds in the lower Indus Basin, while the yellowish brown coloring on shale, marl and limestone in most part of the middle and possibly upper Indus basins. Early Cretaceous Parh Group represents Sembar, Goru and Parh formations, and Late Cretaceous Fort Munro group (reference section as Fort Munro-Rakhi Gaj section in toposheets 39 G/13 and 39 K/1) represents Mughal Kot, Fort Munro, Pab and Vitakri formations. The Cretaceous (up to 3000m thick) is well exposed with variable lateral and vertical facies in the Kirthar (lower Indus), Sulaiman (middle Indus), and western part of Kohat and Pothwar (upper Indus) basins. The Early Cretaceous belemnite bearing black/grey shale (at places include the quartzose sandstone especially in the Mekhtar and Murgha Kibzai areas) of Sembar Formation (laterally variable from 50 to 1000m) and middle Cretaceous belemnite bearing alternated marl and shale of Goru Formation (100-500m) represent the marine to deltaic condition. The contact of Goru Formation with the overlying Parh Formation is widely marked by a maroon color on limestone/marl. The early Late Cretaceous porcelaneous limestone of Parh Formation (60-300m) represents the fine pelagic condition. During middle Late Cretaceous, a transgression of sea occurred, may be due to uplift in Indo-Pakistan shield, which is the source of Mughal Kot and Pab Formation's clastic material. The shale/mud and sandstone, with minor locally developed marl and limestone of Mughal Kot Formation (100-1200m), and grey to brown limestone of Fort Munro Formation (100m, locally developed) represent the deltaic and shallow marine environments.

The late Late Cretaceous Pab Formation (20-400m) is divided in to two members like lower Dhoala, and upper Kali member. Dhoala member (white quartzose sandstone with minor to moderate black weathering) represents the environments of proximal delta, near the coastline. Kali member (shale and black weathering sandstone with gymnosperm wood log) represent middle and distal deltaic environments. Two members are not consistent every where in the Sulaiman basin. Dhoala member is common in the eastern Sulaiman fold belt while Kali member is common in the western Sulaiman fold belt. The latest Cretaceous Vitakri Formation (15-35m, exposed in central system of middle Indus basin) consist of alternated two units of red mud/clay (2-15m each unit) of over bank flood plain deposits two quartzose sandstone units (2-15m each unit) with black weathering of meandering river system. Its coeval strata (coal, carbonaceous shale and sandstone) represent the lacustrine and deltaic environment, and laterite represent the erosional disconformity. The Vitakri Formation is common only as an ENE trending oval belt starting from Makhmar, crossing Mari Bohri, Vitakri, Gumbrak, Jhabbar, Kachar, Bhal, Mat Khetran, Chitri and Fort Munro areas, and ending at Rakhi Gaj areas (Malkani, 2006d). These areas are cumulatively called latest Cretaceous Park of Pakistan (Malkani, 2006b)

The Paleocene Sangiali group (reference section as Sangiali Kali Kakor locality in Vitakri area, in toposheet 39 G/6) represents Sangiali, Rakhi Gaj and Dungan formations, Early Eocene Chamalang group (reference section as Chamalang in toposheet 39 F/8; renamed instead of Ghazij group because Chamalang locality has best exposure and development of its formations) represents Shaheed Ghat, Toi, Kingri Drug and Baska formations, Late Eocene Kahan group (reference section is Kahan in toposheet 39 C/15 and 39 G/3) represents Habib Rahi, Domanda, Pirkoh and Drazinda formations, Early Oligocene to Late Pliocene Vahova group (reference section as Vahova rud in toposheet 39 I/8) represents Chitarwata, Vahova, Litra and Chaudhwan formations, and Quaternary surficial group represents Pleistocene Dada Formation and Subrecent and Recent deposits in Sulaiman basin. The Dada Formation represents mostly angular contact with the older formations, and it forms continuous resistant belt especially on the eastern foot mountain ranges of Sulaiman basin i.e. on the contact of semi plain area and mountain range (Malkani, 2009f; in process; Malkani, *et al.*, in process).

The K-T boundary models and correlation chart (Fig.1b,c,d) of middle Indus and part of Axial belt represents four depositional systems in the latest

Cretaceous. The northern and southern system represents the deltaic and marine sandstone with minor shale, while the central system in the east represents the alternated fluvial meandering (sandstone, deposited by lateral accretion), and associated flood plain (red mud/clay deposited by vertical accretion), crevasse splays lacustrine (coal may be fusinite? and variegated clays) deposits, and in the west represents the erosional disconformity deposited the Ziarat laterite (represented as Ziarat Paleo Island). At Paleocene the transgression of sea emerged, which deposited the carbonate shallow marine limestone, glauconitic sandstone and shale (fossil bearing like bivalves, nautiloids and gastropods) of Sangiali Formation, which is followed by the deltaic/marine glauconitic and siliciclastic sandstone of Rakhi Gaj Formation, and marine/coral reef limestone of Dungan Formation. Five representatives' lithologic sections through the latest Cretaceous strata in the Sulaiman basin have been correlated (Fig. 1d). A model of meandering paleoriver named as D.G.Khan-Vitakri river flowing generally from east to west, from Indo-Pakistan Shield to Fort Munro, and flowing ENE to WSW from Fort Munro to Mari Bohri via Vitakri. This D.G.Khan-Vitakri paleoriver is surrounded by coeval strata like the lacustrine charged by overbank flood in the near north (Badhi and Kingri), mostly submarine and partly subaerial alluvial deltafan in the farther north (Musa Khel, Mughal Kot and Ragha Sar areas), deltafan and shelf marine in west, deltafan in the south (Kaha-Harrand area), and terrestrial paleoland (and Indo-Pakistan Shield) in the east (Fig. 1b).

**Paleontologic and Economic Significance:** In the case of invertebrate fauna at K-T boundary, the Mesozoic ammonite and belemnite reign finished and Tertiary nautilids, gastropod, bivalve such as oyster etc, and foraminifers like nummulite, assilina and alveolinas' dynasty started. In the case of vertebrate fauna at Permo-Triassic boundary, the Paleozoic amphibian dominancy ceased and Mesozoic age of reptiles started. At the occasion of K-T boundary the reptile age finished along with the extinction of nonavian giant dinosaurs, and the age of mammals along with the birds started.

Coal and iron bearing minerals like laterite, hematite, limonite and glauconite are observed at K-T boundary. **Sulaiman basin** hosts the K-T boundary and its close vicinity minerals like hematite, glauconite and limonite (in Vitakri Formation) and coal from Kingri area (also in Vitakri Formation) in the central and southern part of Sulaiman basin, Balochistan and Punjab provinces; the glauconitic shale and sandstone of Sangiali Formation, the hematitic and green/glauconitic sandstone (in Rakhi Gaj) in the

Sulaiman basin; laterite (between the Cretaceous Parh Limestone and Paleocene Dungan Formation) in the Ziarat, Sanjawi and Harnai areas of Balochistan; and coal and carbonaceous shale (in Pab Formation) in the Ragha Sar and Mughal Kot sections (39 I/2,3); pre K-T boundary minerals like silica sand (in Pab Formation) in eastern and central Sulaiman areas, and barite beds (Sembar Formation) in Mekhtar and Murgha Kibzai areas; and post K-T boundary minerals like gypsum, celestite, uraninite/ tuyumunite/ metatuyumunite, fuller earth, silica sand, iron and coal. The Toi coals have been observed from Khoara Khel locality of Shirani area which is expected to extend further north (39 I/1,2; in the southeastern part of South Waziristan). The coal and carbonaceous shale are also reported in Baska, Domanda and Drazinda formations in the Shirani area (39 I/2,3; northern Sulaiman basin). Coal and carbonaceous shales are also observed in the Drug Formation in the Lunda Sar locality of Baghao area (39 F/12), and Kingri and Baska formations in the Chamalang area (39 F/8). **Kirthar basin** hosts the K-T boundary minerals and rocks like laterite, hematite, limonite and glauconite; pre K-T boundary iron minerals and fluorite deposits; and post K-T boundary minerals coal, celestite and fuller earth. **Kohat and Potwar basin** hosts the K-T boundary related minerals laterite, bauxite, and coal; pre K-T boundary salt/halite; gypsum deposits of Precambrian and Cambrian age; silica sand, fire clay, and iron deposits; and post K-T boundary coal, gypsum, celestite and bentonite. The coal of Paleocene Hangu or Lokhart Formation in the Dara Adam Khel is also significant addition for energy reserves. The laterite and bauxite deposits of K-T or Infra Tertiary boundary are significant. The Hangu Formation coal seams to be time equal of Kingri coal (in Vitakri Formation) of Sulaiman basin. Raza and Iqbal (1977) has explained the basal Paleocene Makerwal coal which is the result of earliest Cainozoic transgression. They also explained the coal has perhaps been transformed from the vegetation which flourished in the area following the Cretaceous regression. But the present author correlates the Hangu, Cherat and Makarwal coal with the Kingri Coal and interprets these coals as lagoon or oxbow lake and crevasse splays lacustrine association.

**Dinosaur Extinction:** There are five major episodes of mass extinctions during the past 600 million years: Late Ordovician (440Ma), Late Devonian (365Ma), Late Permian (245Ma), Late Triassic 210Ma) and Late Cretaceous (65Ma). Of this mass extinction, the one has captured the greatest attention of the earth scientists has been the KT (Cretaceous/Tertiary) extinction when the dinosaurs and two thirds of all marine animal species were wiped out (Chatterjee and Rudra, 1996). New groups of organisms may appear

millions of years before the extinction of old ones and old groups disappear much more rapidly than new ones radiate, leading to empty ecological space for a period of some millions of years (Dodson and Tatarinov, 1990). Extinction can be caused by terrestrial and astronomical/cosmic processes. The terrestrial processes include biological and physical. Biological processes include competition with mammals, egg predation by mammals, origin of angiosperms, poisoning by plants, hyperthermic sterility, alteration of sex ratios, thinning of eggshells, disease/epidemics, and faunal disequilibrium. Physical process includes climatic cooling, cold and darkness, volcanism, continental drift, sea level changes, mountain building and paleomagnetic reversal. Astronomical/ cosmic biological process includes viruses from space "little green men". Cosmic physical processes include supernova, comet/asteroid impact, crossing the galactic plane, poison gases from comet orbital eccentricity (Dodson and Tatarinov, 1990). Maastrichtian extinction was highly selective, as in the case with all mass extinction (Jablonski, 1986). All land vertebrates greater than 25 kg in body weight disappeared. This obviously included dinosaurs, but even small and young dinosaurs below this size limit disappeared (Padian and Clemens, 1985). In contrast, many organisms were little affected by the K-T extinction. Placental mammals diversified and multituberculates suffered little (Padian and Clemens, 1985).

Plant macrofossils show continuity across the K-T boundary (Hickey, 1981, 1984; Tschudy and Tschudy, 1986). The discovery of an iridium anomaly at the K-T boundary (Alvarez *et al.*, 1980) and its confirmation at several scores of sites, both marine and terrestrial, around the world (Alvarez and Alvarez *et al.*, 1984) strongly invite interpretation of extinction caused by asteroid or comet impact. The scenario of months of darkness, stormy weather, freezing temperatures, cessation of photosynthesis, dying off of large animals, and hibernation of small ones (giving rise to the concept of nuclear winter; Turco *et al.*, 1983; Ehrlich *et al.*, 1983) is a compelling one (Dodson and Tatarinov, 1990). Physical evidence for an iridium anomaly is so widespread at the K-T boundary that it cannot be ignored. It is widely accepted that the best source of enrichment for iridium is extra terrestrial, that is to say, a comet or an asteroid (Alvarez *et al.*, 1980; Alvarez and Alvarez *et al.*, 1984). In addition to iridium, shocked quartz grains have been reported from the boundary clay in Montana, New Mexico and Europe (Bohor *et al.*, 1984). Cretaceous was generally warm and frost free (Budyko, 1984). Roughly 85% of marine and 86% of non-marine vertebrates survived around K-T extinctions (Sullivan, 1987).

Upper Indus basin (Kohat and Potwar Province, Hazara and Kashmir) of Pakistan has exposed strata for the study of extinctions at Late Ordovician, Late Devonian, Late Permian, Late Triassic and Late Cretaceous. Middle Indus basin (Sulaiman Province) has best-exposed continental and deltaic marine strata of Cretaceous Tertiary Boundary (KTB). The lower Indus basin like Kirthar Province also has exposed strata for KTB. Infra Tertiary disconformable boundary is well exposed in the Upper Indus basin. KTB along with other boundaries such as Permo-Triassic, Triassic-Jurassic, and Jurassic-Cretaceous are well exposed in Pakistan. Triassic Mianwali and Jurassic Data formations consisting of continental sandstone and red muds, are significant for further dinosaur exploration. Mesozoic limestone and marl are also significant for finding tracks and trackways. The Triassic-Jurassic boundaries can be searched in the Axial belt areas of Sulaiman and Kirthar provinces, and western part of Kohat and Potwar basins, while the Jurassic-Cretaceous boundary are well exposed in the Karkh, Mula-Zahri, Johan-Deghari areas of Kirthar basin, Sor Range-Loralai, and Dhana Sar areas of Sulaiman basin. Continental K-T boundary is well exposed (Malkani, 2006d) in the central Pakistan generally trending east west (Fig.1b,c ). It is represented by the central system of models, consisting the continental part of Sulaiman and at this moment is the host of latest Cretaceous dinosaurs and while the northern and southern system have the deltaic environments.

Besides these localities the eastern Kirthar Province i.e., the Pab in the Khadro and Bara Nai and other areas in the vicinity of Indus River seems to be significant for continental K-T boundary and vertebrate community exploration. Volcanism in the Khadro Formation in the Bara Nai and Rehman Dhoro sections are significant for dinosaurs' extinction and catastrophe. Red and greenish grey clay of K-T boundary in Central Sulaiman basin may reveal the fire or another related enigma, due to its continuous and best exposed strata. Carbonaceous shale and coal of K-T boundary in Upper Indus like Hangu coal (Shah, 2001), Middle Indus like Kingi coal, and Lower Indus basin coal seem to be significant for the study of catastrophic fire (fusinite nature of coal) or other extinction phenomena. The prestrata of K-T boundary show dinosaur occurrences while the poststrata of K-T boundary show none occurrences of dinosaurs in Pakistan. The Late Cretaceous beds in the Sulaiman Province can be worked for dinosaur exploration due to some beds of red clay or continental fluvial muds. The latest Cretaceous dinosaur beds can be studied for fractured quartz, which may also help for catastrophe. The possible glauconitic and hematitic sandstone of

lower Sangiali group (Sangiali and Rakhi Gaj formations) may show some igneous activity, seems to be significant for iron, potash or phosphate mineralizations. Last but not least, the red along with variegated muds of Vitakri Formation are also significant for catastrophic or encroached clays.

#### 4. Discussion

The remains of body fossils from the Mesozoic of Pakistan are assigned to Late Jurassic *Brohisaurus kirthari* (Malkani 2003b), and Late Cretaceous *Khetranisaurus barkhani*, *Sulaimanisaurus gingerichi* and *Pakisaurus balochistani* of *Pakisauridae*, *Marisaurus jeffi* and *Balochisaurus malkani* of *Balochisauridae* titanosaurian sauropods and *Vitakridrinda sulaimani* of abelisaurian theropod dinosaurs (Malkani 2003a,c; 2004a; 2006a,b,c,d,e; 2007b,c,e; 2008a,b,c,d,e,f; 2009a,b,c,d,e,f; Wilson *et al.*, 2005). Further, trackways of wide gauge *Malakhelisaurus* (renamed *Malasaurus* due to previously engaged name) titanosaurian sauropods which is confronted by a running narrow gauge *Samanadrinda* theropod, based on only ichnotypes, have also been found from Middle Jurassic limestone of upper Indus basin (Malkani, 2007a; 2008f). The *Pabwehshi pakistanensis* represented by rostrum and postcranial elements found from Pakistan, which represents the most diagnostic crocodyliform remains from the latest Cretaceous of Indo-Pakistan subcontinent and facilitate comparison with other crocodyliformes especially those from Gondwanan parts such as Africa, South America and Madagascar (Wilson *et al.*, 2001; Malkani, 2004b; Malkani, 2007d). On the basis of trispinous distalmost caudal centrum, the Pakistani titanosaurs show endemic subcontinent fauna.

From the neighboring country like India the dinosaurs are reported from about half and one century ago. Many titanosaurs are named from India like *Titanosaurus indicus*, *Titanosaurus blanfordi*, and *Titanosaurus (Isisaurus) colberti*, *Jainosaurus*, etc however some fossils are also referred to *Titanosaurus madagascariensis*. Wilson and Upchurch (2003) have considered the genus *Titanosaurus* as invalid. Consequently the genus *Titanosaurus* and its species are considered *nomen dubium* and its family *Titanosauridae* was abandoned by them. The material of *Titanosaurus colberti* were diagnosed and also renamed as *Isisaurus* by them. According to Wilson *et al.*, (2009;17) “Early evolution of sauropod diversity in the Cretaceous of India recognized three genera *Titanosaurus*, *Antarctosaurus* = *Jainosaurus* and *Laplotosaurus*, each of which was thought to have closely related species on other southern landmasses. Recent systematic work has challenged the genus

*Titanosaurus*. Likewise *Laplotosaurus* is currently recognized to be restricted South America”. Huene and Matley (1933) established *Antarctosaurus* due to its large size than *Titanosaurus indicus*. The remains from Pakistan are diagnostic and can not be referred to *Titanosaurus* which is invalid, and so these remains have received the new family, subfamily, generic and specific names. The Late Cretaceous Indo-Pakistan fauna represents the following grouping. *Pakisauridae* (more advanced *Titanosauria*) represents three genus and species *Pakisaurus balochistani*, *Sulaimanisaurus gingerichi*, and *Khetranisaurus barkhani* (Malkani 2006b). Their most common ancestor and all descendants are included in this family. *Pakisaurinae* includes the *Pakisaurus balochistani* and its close relative, *Isisaurinae* includes the *Sulaimanisaurus gingerichi/ Isisaurus* and *colberti* and its close relative, and *Khetranisaurinae* includes *Khetranisaurus barkhani* and its close relative. *Balochisauridae* (more advanced *Titanosauria*) represents *Marisaurus jeffi* and *Balochisaurus malkani* (Malkani, 2006b) of *Balochisauridae* (Malkani 2006b). Their most common ancestor and all descendants are included in this family. *Marisaurinae* includes the *Marisaurus jeffi* and its close relative, while *Balochisaurinae* includes the *Balochisaurus Malkani* and its close relative. *Balochisaurinae* (slightly depressed to square mid caudals) is the intermediate subfamily among *Marisaurinae* (slightly tall but dorsal width is slightly more than ventral width) and *Saltasaurinae* (highly depressed caudal). *Sulaimanisaurus* can be differing from *Isisaurus* on having trispinous distalmost caudal centrum. The *Saltasauridae* are clearly differentiated from *Balochisauridae* on the basis of strongly broad anterior, mid and posterior caudal centra. The *Pakisauridae* and *Balochisauridae* are different from other families of *Titanosauria*. As a result *Sulaimanisaurus* or *Isisaurus*, *Pakisaurus*, and *Khetranisaurus* of *Pakisauridae*, and *Balochisaurus* and *Marisaurus* of *Balochisauridae* are distinct titanosaur taxa that coexisted in Indo-Pakistan subcontinent just on or below the Cretaceous Tertiary Boundary. *Rapetosaurus* from Madagascar belong to *Pakisauridae* while the Malagasy Taxon B “with more dorsoventrally compressed caudal centra” belongs to *Balochisauridae*. Wilson *et al.*, (2009) mentioned about 5-9 valid taxa of dinosaurs from India and Pakistan, out of total 30 Late Cretaceous named dinosaurs and also pointed out this is due to few associated skeleton of dinosaurs most holotypes are lost.

Based on diagnostic characters in the holotypic and referred specimens of *Pabwehshi pakistanensis*, and complex characters of *Vitakridrinda sulaimani*, and very far locations from South America, and also along with an endemic character (trispinous

distal most caudal centrum) of its associated Balochisauridae and Pakisauridae (Titanosauria), suggest to assign new family Sulaimanisuchidae (Sulaiman basin is the host of *Pabwehshi*) Mesoeucrocodylia of *Pabwehshi pakistanensis*, and Vitakrisauridae (Vitakri area and Vitakri Formation is the host of *Vitakridrinda*) abelisaur theropod of *Vitakridrinda sulaimani*. Vitakrisaurinae include the slender bodied *Vitakridrinda sulaimani* and cits lose relative, while Rajasaurinae include the stocky bodied *Rajasaurus* and its close relative.

The *Jainosaurus* from India was named on the basis of braincase. The braincase from Pakistan (GSP/MSM-2-16 or GSP-UM-2007) assigned to *Marisaurus*, has many differences from *Jainosaurus*. The braincases from Bara Simla (ISI R 467) and Dongargaon (ISI R 199) in which the occipital condyle is ventrally inclined from skull roof are referable to Balochisauridae (*Marisaurus* and *Balochisaurus*), and from Bara Simla (GSI K27/497) and Rahioli (ISI R 162) in which occipital condyle is parallel to skull roof are referable to Pakisauridae (*Pakisaurus*, *Khetransaurus*, and *Isisaurus* or *Sulaimanisaurus*) (Malkani, 2009f). According to Wilson (2002), the braincases with transversely broad basal tubera resemble with the *Nemegtosaurus*. Further it provides a clue that the Mongolian forms like *Nemegtosaurus* and *Quaesitosaurus*, and Indian form like *Jainosaurus* may belong to a slender limbed family Pakisauridae (Titanosauria). It also strengthens the above-mentioned assignment of braincases with narrow transversely basal tubera to *Marisaurus* (a stocky limbed family Balochisauridae of Titanosauria). In this way these two morphs can be named as Balochisauridae morph and Pakisauridae morph. Balochisauridae morph represent the more vertically deflected basal occipital condyle than Pakisauridae morph. This interpretation also tele with the evolutionary stages like the diplodocids and other most sauropods have braincase closely resemble with the Pakisauridae morph i.e., the basal occipital condyle is nearly parallel to skull roof. In the more derived stage like Balochisauridae morph, there is more vertical deflection than the basal sauropod and early Titanosauria. Wilson *et al.*, 2005 mentioned the braincase from Pakistan belongs to *Isisaurus* which is totally misinterpretation while the braincase from Pakistan is associated to the bones of *Marisaurus* (Balochisauridae) (Malkani, 2008f, 2009e). The interpretation of Wilson *et al.*, 2005 is based on fragmentary fossils while the Pakistani braincase has well association of recognized bones of *Marisaurus* from Top Kinwa Locality are presacral, sacral and caudal vertebrae, and limb elements (Malkani, 2008f). In this way cranial and postcrania associations are well documented by Malkani (2008f).

Falconer described and illustrated the first sauropod bones from India which are formed the basis of *Titanosaurus Indicus* named by Lydekker (1877). Lydekker (1877) diagnosed the six features of *T. indicus*. Wilson and Upchurch (2003) considered the *T. indicus* as invalid due to that some of these features are unique to Titanosauria and others are found in other sauropod lineages. Wilson and Upchurch (2003) mentioned the diplodocids *Barosaurus* and *Diplodocus* have quite well developed chevron ridges that parallel one another and enclose an elongated ventral hollow; chevron ridges of varied length and thickness bounding ventral fossae of different depth are reported in several titanosaurs including *Ampelosaurus*, *Saltasaurus*, *Ampelosaurus*, and *T. Indicus*; further the squared cross section is also reported from *Diplodocus* and Peiropolitis titanosaurs; and elongate cylindrical prezygapophyses on middle caudal neural arches are widely distributed among sauropods. Wilson and Upchurch (2003) mentioned “diplodocoids sauropods (e.g., *Dicraeosaurus*) and non neosauropods (*Mamenchisaurus*) have procoelous caudal in the proximal portion of tail; procoely extends in to the middle part as is preserved in *Titanosaurus indicus*, is restricted to the titanosaurs; and all but basalmost titanosaurs bear this type of caudal centra (*Andesaurus*; *Malawisaurus*). Procoely extending in to middle third of the tail discriminates paraphyletic basal ‘andesaurids’ from derived ‘titanosaurids’ (Bonaparte and Coria 1993; Salgado *et al.*, 1997). Wilson and Upchurch (2003) discussed every feature as autapomorphy and rejected as it is found in another species but they did not considered as the combination of the six characters is autapomorphy. If these six features is found in another species than it becomes junior synonym. If it is not found in another species, than it becomes an autapomorphies. Further they did not mention the affinity of these vertebrae to another single species.

Terrestrial as well as marine K-T boundary is well exposed in Indus basin of Pakistan (Malkani 2006d). At many localities most of the bones are found together representing their association, and deserve excavation for articulated skeletons of these exceptional animals. The *Marisaurus*, *Balochisaurus* and *Pakisaurus* bear the associated cranial, vertebral and limb elements found from Pakistan, because previously no such associations are found except *Rapetosaurus* from Madagascar and a few recent discoveries from Argentina. It also helps to resolve the position of Mongolian genera like *Nemegtosaurus* and *Quaesitosaurus*. It provides new insights in to skull and postcranial morphology. Multipurpose tail special with trispinous distalmost caudal centrum of *Marisaurus* and *Balochisaurus* of Balochisauridae and some or all

genera of *Pakisauridae* found from Pakistan provide a new look of titanosaurs. The skull discoveries of *Pakisaurus*, *Marisaurus* and *Balochisaurus* adds the general morphs of sauropod skulls like moderate inclined, elongate and camellate (with large open internal cells), in the previously reported two morphs like high and short, and low and elongate. Due to dearth of cranial data and lack of common associated elements in titanosaurs has left even the most basic skeletal morphology of the clade controversial and has precluded detailed study of its higher and lower level phylogeny, but now Pakistan has this advantage which produced associated cranial, axial and appendicular elements of *Pakisaurus*, *Marisaurus* and *Balochisaurus*. *Rapetosaurus*, *Marisaurus*, *Balochisaurus*, *Pakisaurus*, some Argentinean and Mongolian forms have great potential to resolve paleobiogeography, lower and higher level phylogeny of titanosaurs.

## 5. Conclusions

Before 2000, India was the only source of Mesozoic fauna but since 2000 Pakistan has produced Middle Jurassic trackway site from Kohat and Potwar basin, Late Jurassic and Late Cretaceous few remains from Kirthar basin, and well preserved latest Cretaceous dinosaurs and crocodylians remains from the Sulaiman basin of Pakistan. Due to dearth of cranial data for titanosaurs, the *Pakisaurus*, *Marisaurus*, and *Balochisaurus*, from Pakistan, *Rapetosaurus* from Madagascar, and some Argentinean and Mongolian forms have great potential to resolve paleobiogeography, lower and higher level phylogeny of titanosaurs. Pakistani titanosaurs provide new insights in to skull and postcranial morphology.

Pakistan has much potential for the study of marine as well as terrestrial Precambrian, Paleozoic, Mesozoic and Cenozoic strata, its boundaries, floras and faunas, paleoclimates, extinctions, phylogeny and paleobiogeography. Indus basin of Pakistan holds a large number of section sites for lateral and vertical rapid environmental/climate change in the K-T boundary and Cretaceous greenhouse world. The central Sulaiman basin which is called latest Cretaceous Park of Pakistan has best exposures of continental environments.

## References

Alvarez, L.W., W. Alvarez, F. Asaro and H.V. Michel (1980) Extraterrestrial cause for the Cretaceous-Tertiary extinction. *Science* (208): 1095-1108.

Alvarez, W., L.W. Alvarez, F. Asaro and H.V. Michel (1984) The end of the Cretaceous: Sharp boundary or gradual transition? *Science* (223): 1183-1186.

Bohor, B.F., E.E. Foord, P.J. Modreski and D.M. Triplehorn (1984) Mineralogic evidence for an impact event at the Cretaceous-Tertiary boundary. *Science* (224): 867-869.

Bonaparte, J.F. and R.A. Coria (1993) Unneuo y gigantesco sauropodo titanosaurio de la formation Rio Limay (Alb.-Cenomanio) de la provincial del Neuquen, Argentina, *Ameghiniana*, (30): 271-282.

Budyko, M.I. (1984) Evolution of the Biosphere. *Gidrometeoizdat*, U.S.S.R., Pp 488 (In Russian)

Chatterjee, S and D.K. Rudra (1996) KT events in India: impact, rifting, volcanism, and dinosaur extinction. In; Novas, F.A and Molnar, R.E. (Eds), *Memoirs of the Queensland Museum*, 489-532.

Curry Rogers, K., and C.A., Forster, (2001) The last of the dinosaur titans: a new sauropod from Madagascar. *Nature* (412): 530-534.

Dodson, P. and L.P. Tatarinov (1990) Dinosaur extinction. In; Weishampel, Dodson, and Osmolska, (eds), *The Dinosauria*, 55-62.

Ehrlich, P.R., (1983) Long term biological consequences of nuclear war. *Science* (222): 1293-1300.

Falconer, H. (1868) Memorandum of two remarkable vertebrae, sent by Dr. Oldham from Jubbalpur-Spilsbury's bed. *Paleontological memoirs and Notes of the late Hugh Falconer* (1): 418-419.

Hickey, L.J. (1981) Land plant evidence compatible with gradual, not catastrophic, change at the end of the Cretaceous. *Nature* (292): 529-531.

Hickey, L.J. (1984) Changes in the angiosperm flora across the Cretaceous Tertiary Boundary. In: Berggren, W.A., and Van Couvering, J.A. *Catastrophes in Earth history*, Princeton, Univ. press, Princeton, 279-314.

Huene, F.V., and C.A. Matley, (1933) Cretaceous Saurischia and Ornithischia of the central provinces of India, *Paleontologia Indica*, (21):1-74.

Jablonski, D. (1986) Causes and consequences of mass extinctions: A comparative approach. In: Elliot, D.K. (ed.). *Dynamics of extinction*. Wiley Interscience, New York, 183-230.

Lydekker, R. (1877) Notes of new and other vertebrata from Indian Tertiary and Secondary rocks. *Record Geological Survey of India* (10): 30-43.

- Malkani, M. S. (2003a) Discovery of Partial Skull and Dentary of Titanosauria (Sauropod dinosaur) from the Late Cretaceous Pab Formation of Vitakri area, Barkhan district, Balochistan, Pakistan. *Geological Bulletin University of Peshawar* **(36)**: 65-71.
- Malkani, M.S. (2003b) Pakistani Titanosauria; are armoured dinosaurs. *Geological Bulletin University of Peshawar* **(36)**: 85-91.
- Malkani, M.S. (2003c) First Jurassic dinosaur fossils found from Kirthar range, Khuzdar District, Balochistan, Pakistan. *Geological Bulletin University of Peshawar* **(36)**: 73-83.
- Malkani, M.S. (2004a) Saurischian dinosaurs from Late Cretaceous of Pakistan. In: Abstract volume of *Fifth Pakistan Geological Congress* (Hussain, S.S., and Akbar, H. D., eds.), National Geological Society of Pakistan, Pakistan Museum of Natural History, Islamabad, 71-73.
- Malkani, M.S. (2004b) First diagnostic fossils of Late Cretaceous Crocodyliform (Mesoeucrocodylia) from Pakistan. In: Abstract volume of *Fifth Pakistan Geological Congress* (Hussain, S.S., and Akbar, H. D., eds.), National Geological Society of Pakistan, Pakistan Museum of Natural History, Islamabad, 68-70.
- Malkani, M.S. (2004c) Stratigraphy and Economic potential of Sulaiman, Kirthar and Makran-Siahan Ranges, Pakistan. In Hussain, S. S., and Akbar, H. D., eds., *Fifth Pakistan Geological Congress*, 14-15 April, Islamabad, Abstracts volume, National Geol. Soc. Pak., Pakistan Museum of Natural History (Pakistan Science Foundation), Islamabad. 63-66.
- Malkani, M.S. (2006a) Diversity of Saurischian dinosaurs from Pakistan. In: *1<sup>st</sup> International Conference on Biotechnology and Informatics*, 10<sup>th</sup>-12<sup>th</sup> April, 2006, Quetta, Pakistan, Additional abstracts volume, Faculty of Biotechnology and Informatics, Balochistan University of Information Technology and Management Sciences, Quetta, Pakistan, Pp 103.
- Malkani, M.S. (2006b) Biodiversity of saurischian dinosaurs from the latest Cretaceous Park of Pakistan. *Journal of Applied and Emerging Sci.* **1(3)**:108-140.
- Malkani, M.S. (2006c) Cervicodorsal, Dorsal and Sacral vertebrae of Titanosauria (Sauropod Dinosaurs) discovered from the Latest Cretaceous Dinosaur beds/Vitakri Member of Pab Formation, Sulaiman Foldbelt, Pakistan. *Journal of Applied and Emerging Sciences*, **1 (3)**:188-196.
- Malkani, M.S. (2006d) Lithofacies and Lateral extension of Latest Cretaceous Dinosaur beds from Sulaiman foldbelt, Pakistan. *Sindh University Research Journal (Sci. Ser.)* **38 (1)**: 1-32.
- Malkani, M.S. (2006e) First Rostrum of Carnivorous *Vitakridrinda* (Abelisaurids Theropod dinosaur) found from the Latest Cretaceous Dinosaur beds (Vitakri) Member of Pab Formation, Alam Kali Kakor Locality of Vitakri area, Barkhan Distt, Bal., Pakistan. *Sindh University Research Journal (Sci. Ser.)* **38 (2)**: 5-24.
- Malkani, M.S. (2007a) Trackways evidence of sauropod dinosaurs confronted by a theropod found from Middle Jurassic Samana Suk Limestone of Pakistan. *Sindh University Research Journal (Sci. Ser.)* **39 (1)**:1-14.
- Malkani, M.S. (2007b) Cretaceous Geology and dinosaurs from terrestrial strata of Pakistan. In: Lee, Y.I., Paik, I.S., Cheong, D.K., Huh, M., Lee, Y.U. (eds.), *Paleoclimates in Asia during the Cretaceous: their variations, causes, and biotic and environmental responses. Proceedings of the 2<sup>nd</sup> International Symposium of the IGCP Project No. 507*, August, 20-21, 2007, Seoul, Korea, 57-63.
- Malkani, M.S. (2007c) Lateral and vertical rapid variable Cretaceous depositional environments and Terrestrial dinosaurs from Pakistan. In; Huang, Y., Wang, P., Gu, J., & Jing, S. eds. Abstracts volume, *Joint Workshop on Rapid Environmental/Climate Change in Cretaceous Greenhouse World: Ocean-Land Interaction and Deep Terrestrial Scientific Drilling Project of the Cretaceous Songliao Basin*, August 28-30, 2007, Daqing, China, Cretaceous World-Publication, 44-47.
- Malkani, M.S., (2007d) First diagnostic fossils of Late Cretaceous Crocodyliform (Mesoeucrocodylia, Reptilia) from Vitakri area, Barkhan District, Balochistan, Pakistan. In; Ashraf, M., Hussain, S. S., and Akbar, H. D. eds. *Contribution to Geology of Pakistan 2007, Proceedings of 5<sup>th</sup> Pakistan Geological Congress 2004, A Publication of National Geological Society of Pakistan, Pakistan Museum of Natural History, Islamabad*, Pakistan, 241-259.
- Malkani, M.S. (2007e) Paleobiogeographic implications of titanosaurian sauropod and abelisaurian theropod dinosaurs from Pakistan. *Sindh University Research Journal (Sci. Ser.)* **39 (2)**: 33-54.
- Malkani, M.S. (2008a) First articulated Atlas-axis complex of Titanosauria (Sauropoda, Dinosauria) uncovered from the latest Cretaceous Vitakri member

(Dinosaur beds) of upper Pab Formation, Kinwa locality of Sulaiman Basin, Pakistan. *Sindh University Research Journal (Sci. Ser.)* 40 (1): 55-70.

Malkani, M.S. (2008b) Mesozoic terrestrial ecosystem from Pakistan. In: Sundquist, B. (Science Programme coordinator), *Abstracts of the 33<sup>rd</sup> International Geological Congress*, Oslo, 2008, Norway 1p. (Abstract: CD-ROM; HPP-14 Major events in the evolution of terrestrial biota, Abstract no. 1137099, 1p.)

Malkani, M.S. (2008c) Mesozoic terrestrial ecosystem from Pakistan. In: Lee, Y.I., Khand, Yo, and Ichinnorov, N. eds., *Paleoclimates in Asia during the Cretaceous: their variations, causes, and biotic and environmental responses. Proceedings of the 3<sup>rd</sup> International Symposium of the IGCP Project No. 507*, August, 16-17, Ulaanbaatar, Mongolia, 51-55.

Malkani, M.S. (2008d) Titanosaur (Dinosauria, Sauropoda) osteoderms from Pakistan. In: Lee, Y.I., Khand, Yo, and Ichinnorov, N. eds., *Paleoclimates in Asia during the Cretaceous: their variations, causes, and biotic and environmental responses. Proceedings of the 3<sup>rd</sup> International Symposium of the IGCP Project No. 507*, August, 16-17, Ulaanbaatar, Mongolia, 56-60.

Malkani, M.S. (2008e) Mesozoic Continental Vertebrate Community from Pakistan-An overview. *Journal of Vertebrate Paleontology* Volume (28), Supplement to Number (3): Pp.111A.

Malkani, M.S. (2008f) *Marisaurus* (Balochisauridae, Titanosauria) remains from the latest Cretaceous of Pakistan. *Sindh University Research Journal (Science Series)*, 40 (2): 55-78.

Malkani, M.S. (2009a) Terrestrial vertebrates from the Mesozoic of Pakistan. In: Hart, M.B. ed., 8<sup>th</sup> International Symposium on the Cretaceous System. Abstract Volume. University of Plymouth, 6<sup>th</sup>-12<sup>th</sup> September, UK, 49-50.

Malkani, M.S. (2009b) Basal (J/K) and upper (K/T) boundaries of Cretaceous System in Pakistan. In: Hart, M.B. ed., 8<sup>th</sup> International Symposium on the Cretaceous System. Abstract Volume. University of Plymouth, 6<sup>th</sup>-12<sup>th</sup> September, UK, 58-59.

Malkani, M.S. (2009c) Cretaceous marine and continental fluvial deposits from Pakistan. In: Hart, M.B. ed., 8<sup>th</sup> International Symposium on the Cretaceous System. Abstract Volume. University of Plymouth, 6<sup>th</sup>-12<sup>th</sup> September, UK, Pp 59.

Malkani, M.S. (2009d) Dinosaur biota of the continental Mesozoic of Pakistan. In: Proceedings of

the 4<sup>th</sup> Symposium of the International Geoscience Programme (IGCP) Project No. 507, Paleoclimates of the Cretaceous in Asia and their global correlation, December, 1-6, 2009, Kumamoto University and Mifune Dinosaur Museum, Japan, 66-67.

Malkani, M.S. (2009e) Basal (J/K) and Upper (K/T) boundaries of the Cretaceous System in Pakistan. In: Proceedings of the 4<sup>th</sup> Symposium of the International Geoscience Programme (IGCP) Project No. 507, Paleoclimates of the Cretaceous in Asia and their global correlation, December, 1-6, 2009, Kumamoto University and Mifune Dinosaur Museum, Japan, 109-110.

Malkani, M.S. (2009f) New *Balochisaurus* (Balochisauridae, Titanosauria, Sauropoda) and *Vitakridrinda* (Theropoda) remains from Pakistan. *Sindh University Research Journal (Sci. Ser.)* 41 (2): 65-92.

Malkani, M. S. (in process) Updated stratigraphy and economic mineral potential of Sulaiman (middle Indus) basin, Makran and Siahan ranges, Pakistan.

Malkani, M.S., M. R. Shah, Z. Hussain and M.S.I. Dhanotr (in process) Coal resources of Pakistan and their depositional environments.

Malkani, M.S., and C.M. Anwar. (2000) Discovery of first dinosaur fossil in Pakistan, Barkhan District, Balochistan. *Geological Survey of Pak. Information Release*, 732, 1-16.

Malkani, M.S., J.A. Wilson and P.D. Gingerich (2001) First Dinosaurs from Pakistan. *Journal of Vertebrate Paleontology* Volume 21, Supplement to Number (3): Pp.77A.

Marsh, O.C. (1878) Principal Characters of American Jurassic dinosaurs. *Part I. Am. Jour. (Sci.)* (16): 411-416.

Owen, R. (1842) Report on British fossil reptiles, pt.II. Reptiles. *Rep. Brit. Assoc. Advancement of Sci.* (1841): 60-204.

Padian, K. and W.A.Clemens (1985) Terrestrial vertebrate diversity: Episodes and insights. In: Valentine, J.W. (ed.). *Phanerozoic diversity patterns*. Princeton University press, Princeton, 41-96.

Powell, J.E. (2003) Revision of South American titanosaurid dinosaurs: paleobiological, paleobiogeographical and phylogenetic aspects. *Records of the Queen Victoria Museum* (3): 1-94.

- Raza, H.A. and M.W.A. Iqbal (1977) Mineral deposits. In: Stratigraphy of Pakistan, (Shah, S.M.I., ed.), GSP, Memoir, (120): 98-120.
- Salgado, L, R.A. Coria and J.O. Calvo (1997) Evolution of titanosaurid sauropods. II; Phylogenetic analysis based on the cranial evidence. *Ameghiniana* (34):33-48.
- Seeley, H.G. (1888) The classification of the Dinosauria. *Brit. Assoc. for advancement of Sci. Report*,(1887): 698-699.
- Shah, M. R. (2001) Paleoenvironments, sedimentology and economic aspects of the Paleocene Hangu Formation in Kohat-Potwar and Hazara area. Ph.D thesis, Notional Centre of Excellence in Geology, University of Peshawar, Peshawar, 208 Pp.
- Sullivan, V.B. (1987) A reassessment of reptilian diversity across the Cretaceous/Tertiary boundary. *Nat. Hist. Mus. Los. Andles County Contrib. Sci.* (391): 01-26.
- Tschudy, R.H. and B.D. Tschudy (1986) Extinction and survival of plant life following the Cretaceous/Tertiary boundary event. Western Interior, North America. *Geology* (14): 667-670.
- Turco, R.P., O.B. Toon, T.P. Ackerman, J.B. Pollack and C. Sagan (1983) Nuclear winter: Global consequences of multiple nuclear explosions. *Science* (222): 1283-1292.
- Wilson, J.A. (2002) Sauropod phylogeny, a critique and cladistic analysis. *Zoological Journal of the Linnean Society*, (136): 217-276.
- Wilson, J.A. (2006) An overview of titanosaur evolution and phylogeny. En (Colectivo Arqueologico-Paleontologico Salense, Ed.), Actas de las III Jorn.sobre Dinos. Entorno 169-190. Sala de los Infrant. Burgos Espana.
- Wilson, J.A., M.D.D'emic, K.A. Curry Rogers, D.M. Mohabey and S. Sen. (2009) Reassessment of the sauropod dinosaur *Jainosaurus* (=“*Antractosaurus*”) septentrionalis from the Upper Cretaceous of India. Contributions from the Museum of Paleontology, The University of Michigan, vol. 32 (2): 17-40.
- Wilson, J.A, M.S. Malkani and P.D. Gingerich (2001) New Crocodyliform (Reptilia, Mesoeucrocodylia) from the upper Cretaceous Pab Formation of Vitakri, Balochistan (Pakistan), *Contributions from the Museum of Paleontology, The University of Michigan*, 30 (12): 321-336.
- Wilson, J.A, M.S. Malkani and P.D. Gingerich (2005) A sauropod braincase from the Pab Formation (Upper Cretaceous, Maastrichtian) of Balochistan, Pakistan. *Gondwana Geol. Mag., Spec. Vol.*, (8) 101-109.
- Wilson, J.A. and P. Upchurch, (2003) A revision of *Titanosaurus* Lydekker (Dinosauria-Sauropoda), the first dinosaur genus with a ‘Gondwanan’ distribution. *Journal of Systematic Paleontology* (1): 125-160.