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MARISAURUS (BALOCHISAURIDAE, TITANOSAURIA) REMAINS FROM THE LATEST CRETACEOUS OF PAKISTAN

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Abstract

Marisaurus associated remains has been found from the latest Cretaceous Vitakri member of Pab Formation in Mari Bohri, Darwaza, Bor, Kinwa, Top Kinwa, Alam Kali Kakor and some other localitie of Sulaiman Basin, Pakistan. *Marisaurus* from Alam Kali Kakor locality provides the opportunity to view the most complete (more than one third) skeleton of titanosaur yet discovered. It is also hoped other remaining preserved assemblages can be found on further excavations at many sites. 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 *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 *Marisaurus* (and also *Balochisaurus* and *Pakisaurus*). The *Rapetosaurus, Marisaurus, Balochisaurus, Pakisaurus*, some Argentinean and Mongolian forms have great potential to resolve paleobiogeography, lower and higher level phylogeny of titanosaurs.

Keywords: *Marisaurus*, Balochisauridae, Titanosauria, Vitakri member, Pab Formation, Late Cretaceous, Pakistan, Malkani.

1. Introduction

From 1864 to 1999, India was the only source of Mesozoic vertebrates (Hislop 1864, Falconer 1868, Lydekker 1877, 79; Huene and Matley, 1933, Jain and Bandyopadhyay, 1997). Since 2000, about 3000 fossils collected by author from latest Cretaceous strata of Sulaiman Basin, Pakistan **(Fig. 1A),** which are the basis of *Khetranisaurus*, *Sulaimanisaurus* and *Pakisaurus* of Pakisauridae, and *Marisaurus* and *Balochisaurus* of Balochisauridae (Titanosauria, Sauropoda), *Vitakridrinda* abelisaurid theropod, and *Pabwehshi* baurusuchid mesoeucrocodile (Malkani & Anwar, 2000; Malkani et al., 2001; Malkani, 2003a,b,c; 2004a,b; 2006a,b,c,d,e; 2007a,b,c,d,e; 2008a,b,c,d,e; Wilson et al., 2001, 2005). Most of these materials were found as fragmentary but seems to be associated due to clusters or heap forming occurrences. The *Brohisaurus kirthari* (Titanosauria) from the J/K boundary of lower Indus (Kirthar Range) Basin has also established (Malkani 2003c). The trackways of wide gauge titanosaurian sauropods (*Malakhelisaurus mianwali*) confronted by a running narrow gauge abelisaurian theropod (*Samanadrinda surghari*) found from the Middle Jurassic limestone of upper Indus (Kohat and Pothwar) Basin (Malkani 2007a).

Marisaurus jeffi was reported first time on the basis of articulated partial skull (Malkani 2003a). The five genera and its two family of latest Cretaceous Titanosauria from Pakistan, which are based on associated caudal vertebrae (especially mid-caudal) due to their most common and most diverse nature, presented at the occasion of 5th Pakistan Geological Congress (Malkani 2004a) and this classification is formally published in (Malkani 2006b). Here associated and fragmentary remains of *Marisaurus* collected from Pakistan are being figured and described.

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2. Systematic Paleontology
Dinosauria (Owen, 1842)
Order Saurischia (Seeley, 1888)
Infraorder Sauropoda (Marsh, 1878)
Titanosauria (Bonaparte & Coria, 1993)
Family Balochisauridae (Malkani, 2004a, 2006b)
Marisaurus (Malkani, 2003a, 2004a, 2006b)

Holotypic specimens and locality: The holotypic specimen of *Marisaurus* MSM-7-15 biconvex first caudal, MSM-29-15, MSM-30-15, MSM-31-15, MSM-32-15 and MSM-33-15 five fragmentary but associated caudal vertebrae were collected from Mari Bohri locality (Malkani, 2006b: fig 9-12). These remains seem to be associated with referred material of this locality. These specimens are housed at the Museum of Geological Survey of Pakistan, Quetta.

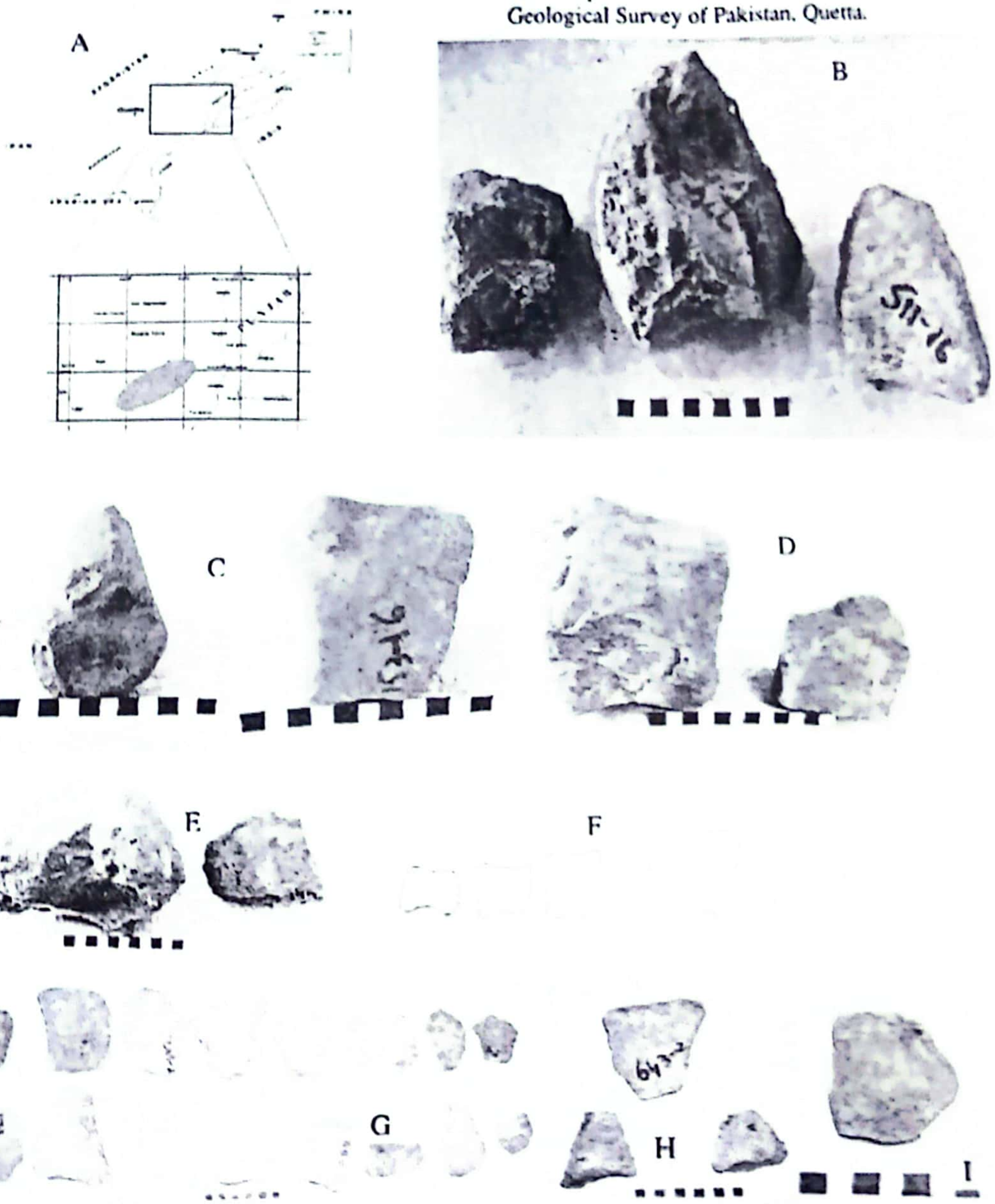


Fig. 1. A, Grey oval represents the study area in Pakistan. B, MSM-256-16 cervical/anterior dorsal vertebra, MSM-774-16, MSM-511-16 ventral ridge forming tall dorsal vertebrae. C, MSM-153-16 caudal with prezygapophyses and postzygapophyses ? and neural spine. D, MSM-815-15, MSM-506-15 caudal vertebrae. E, MSM-359-2 cervical vertebra, MSM-441-2 dorsal vertebra. F, Generalized 5 types of caudals from Pakistan. G, Upper row, MSM-295-2, MSM-279-2, MSM-685-2, MSM-566-2, MSM-278-2, MSM-686-2, MSM-1029-2, MSM-688-2 proximal metacarpals; Lower row, MSM-277-2,MSM-1028-2, MSM-285-2, MSM-370-2, MSM-684-2, MSM-687-2, MSM-361-2, MSM-683-2 distal metacarpals. H, upper MSM-643-2, and lower MSM-1031-2, MSM-1030-2 metatarsals. I, MSM-1036-16 distal metacarpal. Scale, Each black digit is 1 cm.

Referred specimens and localities: The referred specimen were collected from Mari Bohri (PDL-15), Darwaza Gumbrak (PDL-8), Kinwa (PDL-4), Top Kinwa (PDL-16), Bor (PDL-2), Alam Kali Kakor (PDL-19) and other localities. The partial skull (MSM-79-19, MSM-80-19) of *Marisaurus* was described Malkani (2003a; **Figs. 2,3,4,5**; here reconstructed **Fig. 2A**). The braincase (GSP/MSM-2-16 or GSP-UM 7000) was collected by the present author and described by Wilson *et al.*, (2005; **Figs. 2,3,4**) and here referred to *Marisaurus* due to associated axial and appendicular remains of *Marisaurus*. The presacral vertebrae MSM-120-2 cervicodorsal, MSM-121-2, MSM-122-2, MSM-123-2, MSM-124-2, MSM-125-2 and a pair of sacral MSM-135-2 found from the south-central site just on the base of resistant elongated ridge of Bor locality, and precaudal vertebrae MSM-131-16, MSM-132-16cervicodorsal, MSM-131-16, and MSM-137-16 sacral pair, found from the Top Kinwa locality, and one presacral vertebra MSM-134-8 from Darwaz Gumbrak locality were described by Malkani (2006c; **figs.2-5**) and here being referred to *Marisaurus* due to associated caudal vertebrae and other elements. The association is mostly interpreted on the basis of heap or cluster occurrences of specimens. Five fragmentary but seems to be associated caudal vertebrae MSM-36-4, MSM-37-4, MSM-38-4, MSM- 39a-4 and MSM-39-4 from Kinwa locality and two fragmentary but associated MSM-34-16 and MSM-35-16 were described by Malkani (2006b:figs. 9-12). An articulated atlas-axis complex (GSP/MSM-82-4) of *Marisaurus* was described by Malkani (2008a; **figs. 2-6**). Two fragmentary but seems to be associated caudal vertebrae MSM-34-16 and MSM-35-16 from Mari Bohri locality, one fragmentary caudal vertebra MSM-40-8 from Darwaza Gumbrak, and two fragmentary but associated caudal vertebrae MSM-41-2 and MSM-42-2 from Bor locality were described by Malkani (2006b:figs 9-12).

The following remains of *Marisaurus* are being referred and described here. The Alam Kali Kakor locality has yielded associated remains of *Marisaurus* (adult animal) including the partial skull (articulated) (Malkani, 2003a), vertebral and limb elements. Cervical vertebrae (MSM-107-19, MSM-108-19, MSM-109-19; Fig. 2B,C), (MSM-437-19, MSM-220-19, MSM-502-19; Fig. 4B); dorsal vertebrae (MSM-110-19, MSM-111-19, MSM-112-19; Fig. 2B,C), (MSM-617-19; Fig. 4B); caudal vertebrae (MSM-113-19, MSM-114-19, MSM-115-19, MSM-116-19, MSM-117; Fig. 2B,C), (MSM-219-19, MSM-218-19, MSM-696-19, MSM-777-19, MSM-221-19; Fig. 3B,C), left femur (MSM-213-19, MSM-118-19; Fig. 4A), proximal radius (MSM-215-19; Fig. 4A), Left proximal tibia (MSM-119-19; Fig. 4A), a pair of left and right distal tibiae (MSM-710-19, MSM-569-19; Fig. 4A); a pair of left and right distal scapulae (MSM-1100-19, MSM-217-19; **Fig. 3C**), sternal plate partial ilia (MSM-216-19; **Fig. 4B**) and diapophysis (MSM-638-19c; **Fig. 7A**). A large number of fossils/pieces, which are covered by brown muddy matrix, are also collected from this site. The whole picture of this animal can be clear after cleaning of matrix from collected materials, and the possible further exploration and excavation at this site.

Bor Kali Kakor locality yielded cervical (MSM-359-2; **Fig. 1E**), and dorsal (MSM-441-2; **Fig. 1E**) vertebrae, metacarpals (MSM-295-2, MSM-279-2, MSM-685-2, MSM-566-2, MSM-278-2, MSM-686-2, MSM-1029-2, MSM-688-2, MSM-277-2, MSM- 1028-2, MSM-285-2, MSM-370-2, MSM-684-2, MSM-687-2, MSM-361-2, MSM-683-2; **Fig. 1G**), metatarsals (MSM-643-2, MSM-1031-2, MSM-1030-2; **Fig. 1H**), proximal and distal femur (MSM-178-2, MSM-182-2; **Fig. 5A**), distal scapula (MSM-573-2; **Fig. 5A**), **proximal ulna (MSM-271-2; Fig. 5A)**, proximal ischium (MSM-184-2; **Fig. 5A**), humerus parts (MSM-850-2, MSM-559-2, MSM-287-2, MSM-852-2, MSM-181-2, MSM-362-2, MSM-362-2,MSM-343-2; **Fig. 5A**), sternal (MSM-565-2; **Fig. 7A**), (MSM-1004-2; **Fig. 7A**), coracoids (MSM-560-2; **Fig. 7A**), distal portion of dorsal rib (MSM-187-2; **Fig. 7A**), neural spines (MSM-301-2, MSM-792-2, MSM-784-2; **Fig. 7A**) and trispinous distalmost caudal centrum (MSM- 302-2; **Fig. 6A,B,C**).

Kinwa locality yielded mid-scapula with ventral ridge (MSM-838-4; **Fig. 7A**). Top Kinwa yielded cervical or anterior dorsal (MSM-256-16; Fig. 1B), dorsal vertebrae (MSM-774-16, MSM-511-16; Fig. 1B), caudal with prezygapophyses and neural spine (MSM-153-16; **Fig. 1C**), distal metacarpal (MSM-1036-16; **Fig. 1,i**), proximal ulna (MSM-175-16, MSM-240-16; **Fig. 5E**), distal ulna (MSM-74-16; **Fig. 5E**), a pair of distal scapulae (MSM-250-16, MSM-176-16; **Fig. 5G**), part of ilia (MSM-557-16; Fig. 5H), (MSM-150-16; **Fig. 7A**), acetabulum (MSM-147-16, 148-16; **Fig. 7A**), sternal (MSM-1014-16, MSM-604-16; Fig. 7A), metatarsal/phalanges (MSM-149-16; Fig. 7A), cervical rib (MSM-328-16, MSM-767-16, MSM-329-16; Fig. 7A), sacral (MSM-776-16; Fig. 7A), chevron (MSM-330-16; Fig. 7A), prezygapophyses (MSM-327-16; Fig. 7A) and armour plate (MSM-1035-16; Fig. 7A). Mari Bohri locality yielded caudals vertebrae (MSM-815-15, MSM-506-15; **Fig. 1D**), a femur (MSM-169-15, MSM-70-15; **Fig. 5B**), a distal scapula (MSM-163-15; **Fig. 5D**), proximal and distal pubis (MSM-165-15, MSM-164-15; **Fig. 5C**). These specimens are housed at the Museum of Geological Survey of Pakistan, Quetta.

Horizons; These remains are collected from the latest Pab Formation of Sulaiman Basin, Pakistan. The Pab Formation (20-400m) is divided in to Dhoala, Kali and

Vitakri members. Dhaola member (white quartzose sandstone with minor to moderate black weathering; Fort Munro and Dhaola are best reference sections) represents the environments of proximal delta, near the coastline and consistent in the central and eastern Sulaiman Basin. Kali member (shale and black weathering sandstone; Dhaola and Tor Thana are reference sections) represent middle and distal deltaic environments and exposed in the western part of Sulaiman Basin. Vitakri member (15-35m, exposed in central system of middle Indus Basin; Dhaola and vitakri are best reference sections) consist of alternated two units of red mud/clay (2-15m each unit) of over bank flood plain deposits and two quartzose sandstone units (2-15meach unit) with black weathering of meandering river system. Lower red mud horizon is based on Kali member or Dhaola member and capped by middle sandstone horizon of Vitakri member. The upper red mud horizon is based on middle sandstone horizon and capped by a resistant sandstone horizon. Its coeval strata (coal, carbonaceous shale and sandstone) represent the lacustrine and deltaic environment, and laterite represent the erosional disconformity. Topography is semiplain to rugged. The relief of dinosaur host area varies from 800 to 2000m. Low hills capped by Vitakri Member with gentle dips produced many associated bones. The lateral extensions of dinosaur beds (30km Northwestnorth direction and 100km eastnortheast direction; gray oval in **Fig. 1A**) have been observed in the Vitakri-Mari Bohri, Dhaola, Phulali (Pikal-Siah Koh), and Fort Munro anticlinoriums (Malkani, 2006d). The sauropods from the Vitakri member demonstrate extreme morphological variation in caudal vertebrae.

Age; The age of the dinosaur beds (Vitakri) Member of upper Pab Formation is considered as the latest Cretaceous (Maastrichtian) (Malkani 2006d).

3. Partial skull of *Marisaurus* (Balochisauridae) from Pakistan

Titanosaurian sauropods have one of the most extensive geographic and temporal ranges of any dinosaurian clade. However 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 & Forster, 1999; 2001). Traditionally, titanosaurids were considered as bearing a Diplodocus-type skull (Salgado *et al.*, 1997). In contrast with the wealth of data derived from the study of the postcranial skeleton, the information on titanosaurid skull morphology is scarce (Salgado *et al.*, 1997). No complete titanosaurid skull has been found to date. A few well-preserved braincases and some fragments constitute all the available material attributable to titanosaurids (Salgado *et al.*, 1997). Cranial evidence links titanosaurids with other sauropods is poorly understood. In this regards, an important question should be answered: do titanosaurids have diplodocus type skull, as previously stated? (Salgado *et al.*, 1997). But here the associated materials such as partial skull (articulated), and post crania of *Marisaurus* have a vantage point to solve most of the questions and problems.

The partial skull is reconstructed (**Fig. 2A**) by the specimens MSM-79-19 and MSM-80-19 (Malkani, 2003a). These specimen were collected 50 meters apart towards east from its postcranial material, which may belongs to same animal. It may be dragons away by the *Vitakridrinda* theropod abelisaurs because the skull of *Vitakridrinda* abelisaurian theropod (Malkani, 2006e) is found near the skull of *Marisaurus*. The braincase (GSP/MSM-2-16; Wilson *et al*, 2005) of Kinwa Top locality, which is found about half km toward north from *Marisaurus* skull locality. An atlas-axis complex (Malkani, 2008a), which is found 1 km apart towards west from *Marisaurus* skull locality. On the basis of the matrix, horizon/age, and shape, this partial skull, braincase and atlas-axis complex may belong to *Marisaurus*. The size of skull matches with the appendicular and axial fossils from Alam locality but matrix is slightly different. These skull specimens represent large internal open cells like Kinwa atlas-axis complex and *Marisaurus* cervical of Alam locality, which is also a basis of its assignment to *Marisaurus*.

4. Vertebral materials of *Marisaurus* (Balochisauridae) from Pakistan

Marisaurus jeffi based on first biconvex caudal centrum; moderate short, heavy and slightly tall with broad ventral groove (u shape) on posterior parts of anterior caudal centra (except some anteriormost caudals) due to well developed posterior chevron facets; moderate short, heavy and slightly tall with broad ventral groove (u shape) of mid-caudals due to well developed posterior and faint anterior chevron facets; the ratio of dorsal view width to mid-ventral width of anterior caudal centra (except some anteriormost caudal centra), and mid-caudal centra is around 1.5; lateral surfaces on ventral view are clearly observed in the anterior and mid caudals due to mid-dorsal width greater than ventral width; robust femora; thick transversely proximal tibiae; narrow lateral width (mediolaterally elongated oval shape) of distal tibiae; and mid-mediolateral width is greater than mid-anteroposterior width of distal tibiae (Malkani, 2006b).

First time, the caudal vertebrae of 3 genera of Pakisauridae and 2 genera of Balochisauridae Titanosauria from Pakistan were described and figured by Malkani, (2006b). Second time, the sacral and presacral vertebrae of Pakistani Titanosauria are reported and figured by Malkani, (2006c). Third time, an articulated atlas-axis complex of *Marisaurus* are figured and described (Malkani, 2008a). Fourth time it

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is being descried here. The precaudal vertebrae are recovered from Alam, Bor, Top Kinwa and Darwaza localities. The caudal vertebrae are recovered from Mari Bohri, Kinwa, Alam, Bor, Top Kinwa, Darwaza, and some other localities. The Alam locality has produced the associated materials of *Marisaurus* including about 6 cervical, 4 dorsal, and 10 caudal vertebrae along with partial left femur, partial left and right tibiae, and partial radius, a pair of partial distal scapulae, partial sternal plate/ilia, etc. Although fragmentary and disarticulated but it is associated because all of these material is found within one site of same locality. The field study show that these materials are associated due to following reason. Some vertebrae are found aligned according to strike direction in about 10 m length and appendicular elements were some 3 m down slope. However, some vertebrae were little transported down slope. There is no any duplication from this site. The field evidence indicate all these materials are found in situ host formation and excavation can reveals remaining preserved assemblages. The nature of matrix, relative size and collection from one locality represents association and belongs to same adult animal. However a partial articulated skull (Malkani, 2003a) is found 50 meter apart from the axial and appendicular elements and relative size show one animal but their matrix is slightly different. Top Kinwa and Bor localities have produced associated vertebral and appendicular elements. Mari Bohri locality has also yielded holotypic and some referred caudal vertebrae, a femur, a pubis and a distal scapula, which may belong to one animal.

Cervical vertebrae; Axis parapophysis is robust and rectangular (posteriormost part is subrounded) in shape. Axis parapophyses are located in the central and posterior half of the ventral surface of centrum. The parapophysis is rectangular, and positioned on the ventral surface of axis centrum. In remaining cervicals parapophysis is becoming anteroposteriorly elliptical, and position is shifting to the mid and then anterior of centra as the centra proceeding posterior. The parapophyses seems to directed outward and downward. It begins to travel anteriorly as the series going backward (toward posterior). The rectangular nature of parapophysis is becoming oval as the series going backward of cervical series. The centra have almost flat and slightly concave ventral surface because anterior cone and posterior articular surfaces are trending to lower level than central surface of centra. Centra are broad, long and opisthocoelous. Pleurocoel is small and elongated. The centra are constricted in the middle and successively increase in length. The posterior concavity seems to be larger than anterior convexity. The broadness and length is increasing much backward in all discontinuous series. The transverse processes are directed laterally. The well developed diapophysis have small diameter in the anterior most cervical but become some what relatively with larger diameter and stouter, projecting outward and little upwards as proceeding backward in the series. The prezygapophyses are becoming wide divergent backward depending on the broadness of centrum. The neural canal is uniformly rounded to sub rounded in all the cervicals. The fragmentary neural spine is single and seems to be low. The postzygapophyses are high and divergent and may change position according to prezygapophyses. The cervical vertebrae have camellae/pneumatic texture. The fragmentary pieces of cervical ribs are collected having boat shape. These ribs are pneumatic (large open internal cells). Measurements of some cervical centra are shown in **(Table 1).**

Table 1. Measurement of cervical centra in centimeters.

Sample no	Length	Width	Height
MSM-107-19	18	18	13
MSM-108-19	28	18	13
MSM-109-19	30	-	-

Dorsal vertebrae; There are three opisthotic morphs. First morph is short and broad centra with smooth ventral surface, open wide pleurocoel and small ventrolateral surface below the pleurocoel, as characterised by the first cervicodorsal vertebrae and may be found in other anterior dorsals. Second morph is short and circular centra, which may be in the transition between the anterior and posterior dorsals as hemisperical to cylinderical centra. Third morph is tall and relatively long and has sagital ventral ridge/keel, and narrow and long pleurocoels may found in posterior dorsals. Posterior concavity seems to be larger than anterior convexity. From morphology I can guess that the transeversely hemisphericity decreases up to mid dorsal. In posterior dorsal the transeversely hemisperity shifted to the ventrodorsally hemisperity. The broadness is going to be less i.e., transeverse ellipticity is going to be low as going backward. Early middle centra may be circular. The remaining middle and all posterior centra seems to be tall and relatively long and having ventral saggital ridge and long pleurocoel. Keel/ridge may be transition from dorsal to sacral. The broken dorsal vertebrae represent the camellae/spongy/ pneumatic texture. The neural canal is subrounded. Parapophyses come close to diapophyses in mid dorsals. There are interprezygapophyses lamina, centro diapophyseal laminae, post zygapophyses and spine laminae. The postzygapophseal lamina is directed backward to the postzygapophysis and the supradiapophseal lamina is directed upward to the spine. There are two-separated prespinal laminas.

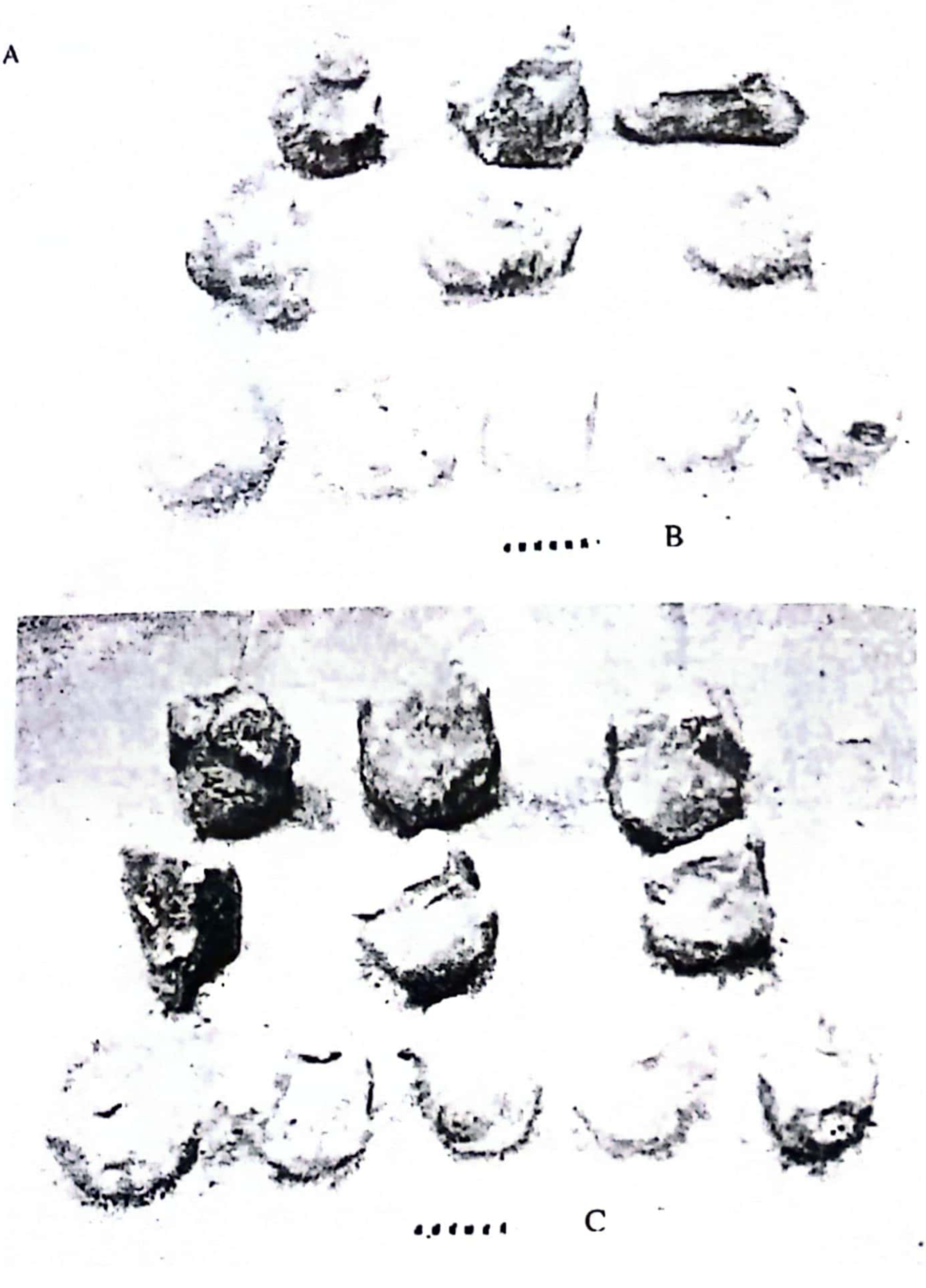


Fig. 2. A, reconstructed partial skull. B, Upper (top) row, MSM-107-19 cervical vertebra, left posterolateral view, MSM-108-19, MSM-109-19 cervical vertebrae, left lateral view; Middle row, MSM-110-19, MSM-111-19, MSM-112-19 dorsal vertebrae, left lateral view; Lower row, MSM-113-19, MSM-114-19, MSM-115-19, MSM-116-19, MSM-117-19 caudal vertebrae, right lateral view; C, Upper row, MSM-107-19, MSM-108-19, MSM-109-19 cervical vertebrae, anterior view; Middle row, MSM-110-19, MSM-111-19, MSM-112-19 dorsal vertebrae, anterior view; Lower row, MSM-113-19, MSM-114-19, MSM-115-19, MSM-116-19, MSM-117-19 caudal vertebrae, posterior view. Scale, Each black digit is 1 cm.Most of the specimens in this research are partial. Specimen numbers started in each row from left to right. The specimen number like GSP/MSM-107-19 represents GSP Geological Survey of Pakistan; MSM collector name (M. Sadiq Malkani); 107 represents sample number; 19 represents Pakistani Dinosaurs locality number or PDL-19.

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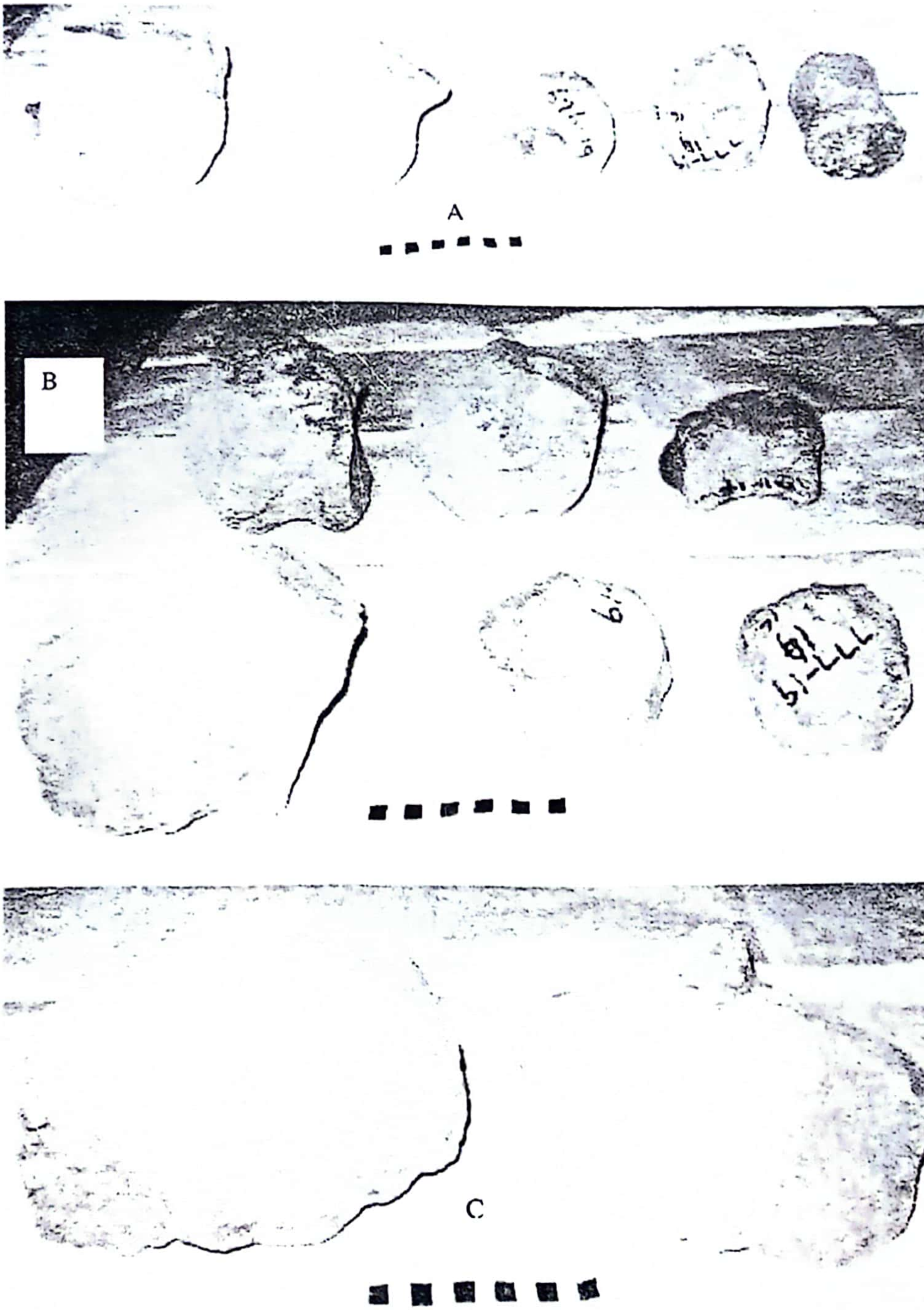
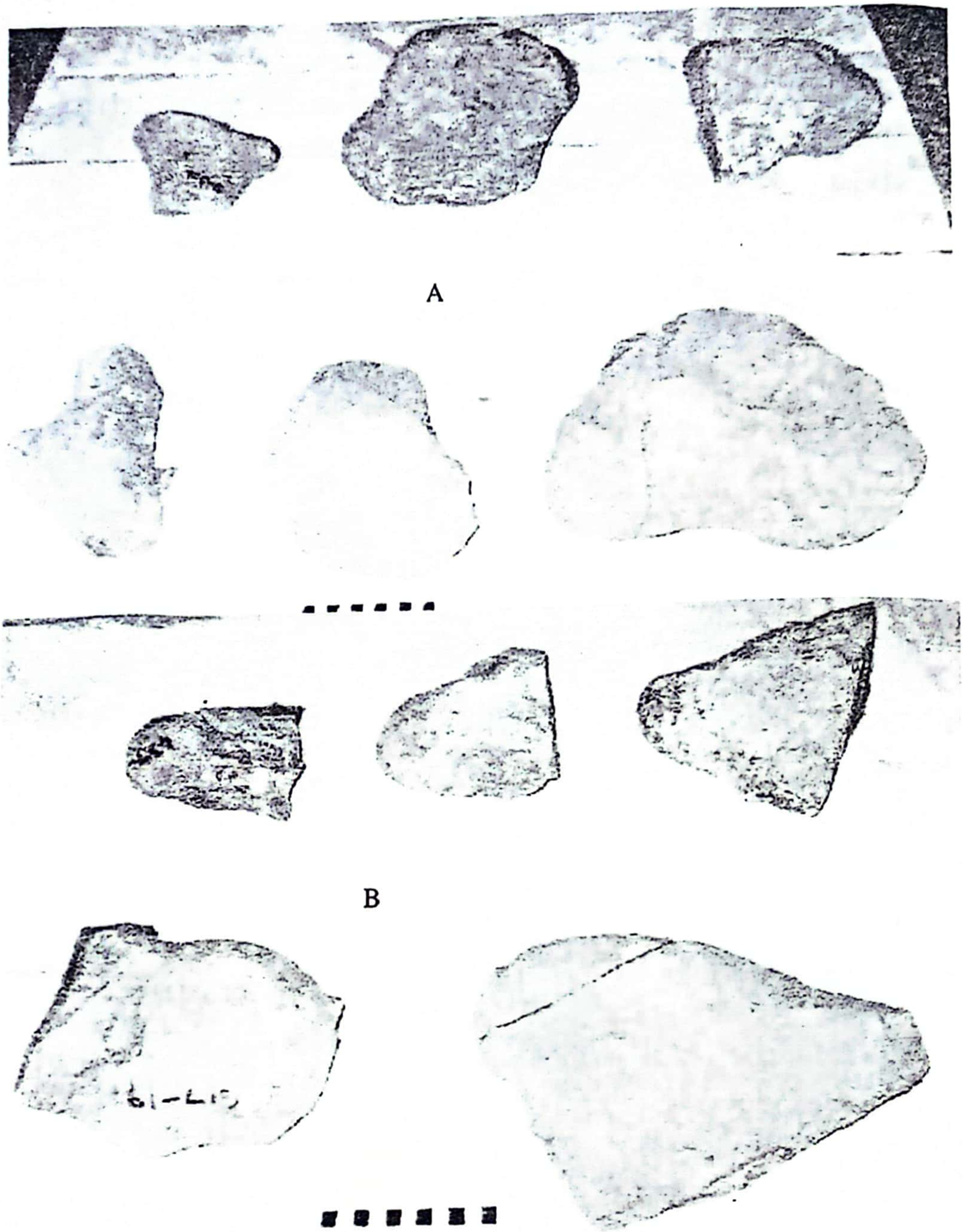


Fig. 3. A, MSM-219-19, MSM-218-19, MSM-696-19, MSM-777-19, MSM-221-19 caudal vertebrae, posterior view. B, Upper row, MSM-219-19, MSM-218-19, MSM-221-19 caudal vertebrae, right lateral view. Lower row, MSM-217-19 partial distal right scapula; MSM-696-19, MSM-777-19 caudal vertebrae, posteroventral view. C, MSM-1100-19, MSM-217-19 a pair of left and right partial distal scapula. Scale, Each black digit is 1 cı



A

B

Fig. 4. A. Upper row, MSM-215-19 proximal radius, posterior view; MSM-119-19 proximal left tibia, lateral view; MSM-213-19 proximal left femur, ventroposterior view; Lower row, MSM-569-19 distal right tibia, ventral view; MSM-710-19 left distal tibia, ventral view; MSM-118-19 left distal femur, posteroventral view. B, Upper row, MSM-437-19, MSM-220-19, MSM-502-19 cervical vertebrae left lateral view; lower row, MSM-617-19 dorsal vertebra, right lateroventral view, MSM-216-19 sternal plate/ partial ilia. Scale, Each black digit is 1 cm.

undivided. The spine is directed perpendicular to the neural canal and may slightly inclined backward. Some rib pieces are also collected. The tuberculum and capitulum are in sub equal size. Capitulum is subrounded while tuberculum is oval to suboval. Both are marked with a notch in between. There is a marked ridge running along the length of the rib shaft bifurcating just before the proximal notch and terminating toward the end of the capitulum and tuberculum. Medially there is a marked depression running anteriorly. The proximal part of the rib is spongy and concavo-convex in cross section and distally massive and plano-convex. Measurements of dorsal centra are shown in **Table 2.**

Table 2. Measurement of dorsal centra in centimeters.

Sample no	Length	Width	Height
MSM-110-19	20	16	15
MSM-111-19	23	17	15
MSM-112-19	18	16	14

Caudal Vertebrae; 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. Anterior caudals are broad while the mid caudals are slightly tall and posterior caudals are long and cylindrical with anterior circular articular and posterior squarish to circular posterior articular region. The chevron facets are not found on the anterior most caudals and posterior caudals, while located in the remaining anterior and middle caudals. The neural arch is situated on the anterior half of the caudal centra. The prezygapophyses are rod like while post zygapophyses also have lateral small surface for attachment. The middle and posterior caudal spines are laterally compressed and seems to be directed posteriorly. Prominent ridge facets occur which seems like blunted in anterior caudals. Measurements of some caudal centra are shown in **(Table) 3.**

Table 3. Measurements of caudal centra in centimeters.

Sample no	Length	Width	Height
MSM-113-19	17	15	14
MSM-114-19	16	13	12
MSM-115-19	14	13	13
MSM-116-19	13	12	11
MSM-117-19	13	11	10

5.A new look of titanosaurs: multipurpose tail special with trispinous distalmost caudal centrum found from Pakistan.

The first and new tail special with trispinous caudal centrum which provide a new look of Titanosauria, has been found from the latest Cretaceous Vitakri member of Upper Pab Formation, Sulaiman Basin of Pakistan. Tail of titanosaurs from Pakistan is unique among World. It seems to be robust and relatively short which may act for multipurpose like good defending tool for its foe, balancing body as third support during foraging from tall tree, and mating. This tail resemble with *Shunosaurus* of China (Laurasia). This discovery has an advantage for evolutionary history from Middle Jurassic *Shunosaurus* to latest Cretaceous Pakisauridae and Balochisauridae (Titanosauria) from Pakistan (Gondwana).

Five terminal caudal centra **(Fig.6 A,B,C)** of different genera are found from Barkhan District of Balochistan Province, Pakistan. These caudals show anterior surface with concave ring **(Fig.1 A),** like other caudal centra (except anteriormost caudal centrum in some genera) but their posterior, ventral and dorsal surfaces are specialized trispinous **(Fig.6 B,C)** forming unique character. Distalmost caudal centrum represents three enlarged and thick triradial spines **(Fig. 6 B,C).** Two spines are found in the ventroposterior region of posterior centrum which are diverging with low angle, while one spine is found on the mid of dorsal surface of centrum. The bases of spines are only preserved and remaining portions damaged. It may be broken in defending with its foe or taking support during foraging from tall tree or by erosion and weathering. The cross section of these spines at the base shows oval nature with maximum width varies from 3.5 to 6.5 cm and depth varies from 1.5 to 3.5 cm. The oval axis of dorsal spine shows two different directions **(Fig.6 C).** Three distalmost caudal centra show its oval axis trend posterolateral towards right ventral spine, while the other two trend posterolateral towards left ventral spine. It shows sexual dimorphism (male and female) or two genera or two rows of centra at terminal tail. The right and left ventral spines are symmetrical and directed lateroposteroventrally **(Fig.6 C).** The dorsal spine directed upward. Tail of titanosaurs from Pakistan seems to be robust (and relatively

short), due to robust distalmost caudal centrum. These tails may act for multipurpose like good defending tool for its foe like *Vitakridrinda* and *Pabwehshi* etc, balancing body as third support during foraging from tall tree, and mating.

Since 2000 (first discovery to until) about 3000 (cranial and posteranial) fossils have been collected by present author from the latest Cretaceous Vitakri member (Dinosaur beds) of Pab Formation which are the basis for *Pakisaurus, Khetranisaurus and Sulaimanisaurus* of Pakisauridae, and *Marisaurus* and *Balochisaurus* of Balochisauridae Titanosauria, and *Vitakridrinda* of abelisaurian theropod dinosaurs, and *Pabwehshi* of baurusuchid mesoeucrocodylian fauna (Malkani, 2006b).

A short tail of about 35 stout caudal vertebrae characterizes titanosaurs while primitive sauropods have about 50 caudal vertebrae and diplodocids have about 80 caudal vertebrae (Wilson, 2002). This shortened tail might have function as a third support when derived titanosaurs reared during feeding or mating (Borsuk-Bialynicka, 1977, Wilson, 2006). This idea is also strengthened by the present discovery. Sauropod is characterized by various tail specializations, including the fusion of the distalmost three or four caudal vertebrae in to a bony tail club in *Shunosaurus* (Dong, *et al.*, 1989), and the short series of mobile, biconvex caudals in unnamed titanosaurs (neosauropod) from Argentina, which is modified in to a 'whiplash' tail in diplodocids[6]. Terminal tail with trispines of Titanosauria from Pakistan is a unique record among world.

The tail club of *Shunosaurus*, which appears to fuse late in growth, composed of atleast three enlarged, coossified caudal vertebrae with atleast two dermal spine (Dong *et al.*, 1989; Zhang, 1988), while Pakistani Titanosauria has three spines on a single centrum. Present discovery shows clues of resemblance with Chinese form of Laurasia. Its temporal and spatial variation from Middle Jurassic (China; *Shunosaurus lii*) to latest Cretaceous (Pakistan; Balochisauridae and Pakisauridae) has an advantage for the hypothesis of evolutionary history and paleobiogeography.

6. Appendicular elements of *Marisaurus* (Balochisauridae) from Pakistan.

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

Sternal Plate; Partial fragments of sternal plates are collected. One piece which is expanded and represents the anteroventral crest.

Pectoral girdle; Pectoral girdle is represented by fragmentary partial mid scapula and distal scapula, and coracoids. The thickness and width of middle part (and also probably proximal part) is remarkably less than distal ends. The outer surface represents slight convexing curvature and internal surface is concave, forming D shape cross section. One section of right scapula having ventral crest. 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 and coracoid are separate. The acromian size seems to be narrow (and acromial edge is not expanded). 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, while the scapula of Pakisaurridae (*Pakisaurus*) is deflected laterodorsally and expanded in the lateroventral side of mid scapular blade. The coracoid showing glenoid for humerus and rugose area for attachment of distal scapula. The remaining area seems to be plate like. The corocoid glenoid area is at the same level as plate but elevated or raised in other side of plate

Humerus; The anterior view of the distal humerus have prominent ridge, and posterior part is divided well in to two condyles. Humerus having a continuous ridge (convexing part) on the posterior view of humerus starting from head to downward may be running up to constricted middle part of humerus. Proximal humerus has head and represents deltopectoral crest which may be slightly twisted. The proximal humerus is slightly rugose while distal humerus has intense

[illegible] Humeral trochlear crest section shape seems to be elliptical, with long axis oriented transversely. The supracondylar ridges are prominent forming well developed depressions for the adjustments of pronation supination process.

Ulna: The proximal ulna is rugose and bears a prominent olecranon process. The proximal ulna represents a triradiate structure. The ulna is gracile. There is a marked depression on the proximal lateral side for the adjustment 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 subcircular in outline and smaller than the proximal end. Usually the shaft has marked depressions for the reception of distal radius. Ulna has well developed olecranon process. Relative length of Ulnar proximal condylar processes are unequal.

Radius: Both the ends of radius are expanding with. 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 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 articulated in front of ulna. Radius distal breadth is approximately twice the midshaft breadth. Radial distal condyle shape is beveled approximately 20-degree proximodistally relative to long axis of shaft.

Metacarpals: Metacarpals are elongated and triangular and have rugose articular proximal surfaces. Distal condyle shape is undivided and has no articular rugosities. A proximal and distal end is expanded with triangle shape.

Pelvic girdle: Pelvic girdle is represented by partial ilium, pubis and ischium.

Ilium: Partial ilium represented by acetabulum along with large pubic peduncle condyle (broken) and short and laminar ischium peduncle. Ventrally the acetabulum is long and oval and bears parallel ridges indicating calcified tendons. Up of the pubis peduncle a robust subrounded tubercle bone is located which may join to the preacetabular process. The pubic peduncle is large and subovate or flat and D shape. In contrast the ischium peduncle is fanlike. 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 semicircular on one side and nearly straight in other side.

Pubis: The proximal pubis bears a large glenoid surface for femur head. The anterior side of pubis is broad, cylindrical to sub oval, and posterior side is platy and possibly sigmoid. Proximal pubis has a ventral ridge. The distalmost end of pubis is slightly expanded and has rugose junction to its follow.

Ischium: Partial ischium is also found. The proximal part is platy having iliac condyle and long, thin acetabular glenoid and then articular surface for pubis. The proximal surface is thin as comparable to proximal pubis.

Femur: *Mariamarus* (and *Balochisaurus*) has stocky femur. The slender femur is assigned to Pakisauridae (*Pakisaurus*) (Malkani, 2006b, 17a, 17b). The slender type has posterior elongated dominant rugosities starting from proximal part to downward constricted part, while the stocky type has no dominant rugosities. Proximal femora are beveled one third medially. Distal end is bifurcated in two condyles as tibial and fibular condyles. The tibial condyle is relatively more deep than fibular condyle while the fibular condyle is relatively more wide than tibial condyle. The tibial condyle is wheel like. The fibular condyle is posteriorly divided in two sub condyles. The distal femora may be divided atleast into two types like robust and slender. The cross section of shaft is elliptical eccentric and have constricted portion in the lower part. The constricted part of slender type seems to be relatively high. The parallel ridge on side seems to be running from proximal part/greater trochanter to downward. Femoral shaft is elliptical. It may become subcircular to circular in the minimum transverse diameter, relatively close to distal condyle than proximal condyle. In one type, the articular face shape is expanded onto anterior portion of femoral shaft. Femora show a posterior ridge on proximal shaft. 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; Two types of tibia are collected (Malkani, 2006b; fig, 18a,b, 19a). First type is elongate and thin/narrow proximal surface observed on proximal view and lunate distal surface observing on distal view, while the other has a broad and thick proximal surface and oval shape distal surfaces. Tibia cnemial crest orientation represent also two type of orientation, one is projecting laterally and others projecting anteriorly. Tibial distal posteroventral process is also two types, the size of first type is broad transversely and size of second type is reduced. The stocky tibia is assigned to *Marisaurus* and *Balochisaurus*.

Fibula; A pair (left and right) of proximal fibula has been collected (Malkani, 2006b; fig. 19b). Proximal fibula have medial scar for attachments of tibia. The shape of fibular proximal tibial scar is well marked and deepening anteriorly. The distal fibula is oval shape. Fibular distal condyle size is not equal to shaft but expanded transeversely more than twice midshaft breadth. . Fibular distal condyle is broad transversely like also *Barapasaurus*.

Metatarsals; Metatarsals represent irregular concave proximal and distal expanded surfaces.

Unguals; The ungulas are sickle-shaped, much deeper dorsoventrally than broad transversely. Their assignments are in process.

7. Osteoderms of *Marisaurus* (and other genera) from Pakistan.

Four types of dermal armour bones, which are lacking distinct pit patterns as in crocodilians, are referred to different genera from Titanosauria found from Pakistan. The armour plate found from Top Kinwa locality 16 is about 9 cm in diameter are made up of polygon like ossicles of irregularly shaped varying diameter ranging from half centimeter to 4 centimeters, separated by internal ducts of 1-3mm wide. This plate is 1-1.5 centimeters thick and partially preserved (Malkani, 2003b). This armour plate may belong to *Marisaurus*-a member of Balochisauridae due to bone association in the field. Now another armour plate found from the same site **(Fig. 7A)** has above mentioned characters is also referred to *Marisaurus*. An oval plate (MSM-84-7) is sub circular plate which has slight concavity and rugosities on smooth ventral surface, and rugosities on lateral and dorsal surfaces. Dorsal surface has an asymmetrical low ridge/cone. The ossicles on the ridge area are tightly packed and fibrous like directing toward the tip of ridge making radial pattern, having centre at tip; and remaining dorsal and lateral area has irregularly shaped ossicles and internal ducts. The ridge seems to be directed dorsoposterior. The maximum length and width of ventral sub circular surface are 19 and 16 cm respectively; and dorsoventral depth of dorsal ridge from ventral surface to preserved apex is 12 cm. Apex/tip of cone/ridge is not preserved. This armour plate is being likely attributed to *Balochisaurus* due to field association with its caudal vertebrae. Another different oval plate (MSM-85-4) is also found. Its ventral surface is semi plain slightly convexing downward, with irregularly rugose ossicles and internal ducts pattern. The dorsal surface has well developed asymmetrical, low and sharp cone/ridge having possibly dorsoposterior directed tip/apex. The ossicles on the ridge area are tightly packed and course fibrous like directing toward the tip of ridge making radial pattern, having centre at tip. In the centre of dorsal surface of plate has a transverse median concavity belt just in front of ridge. The remaining dorsal and lateral surfaces have irregular rugosities of ossicles and internal ducts. The length and width of ventral oval surface are about 21 and 13 cm respectively, and dorsoventral depth of dorsal ridge/cone is 13 cm i.e., from ventral surface to apex or tip of ridge/cone. The third and fourth varieties have resemblance in shape but differ in nature of smooth, concave, convex, circular and oval ventral surfaces, and transverse median concavity belt on dorsal surface. The ventral surface of third type is slightly concave and smooth having corroded rugosities on circular ventral surface. The fourth type shows slight convexity and well developed, irregular rugosities on oval ventral surface, and it bears a transverse median concave belt on dorsal surface. This locality has produced diverse fauna of Pakisauridae and Balochisauridae. This type of armour plate probably belongs to *Pakisaurus* (Pakisauridae)

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because of resemblance to armour bone of basal *Malawisaurus*. The discovery of larger and smaller osteoderms from Pakistan provides a further opportunity for evolutionary history and correlation with the armor bones already discovered from Madagascar, Argentina, Brazil, France, Malawi, Romania and Spain.

8. Wide gauge skeletal morphology of Titanosauria found from Pakistan.

Wide-gauge trackways have been defined as those in which manus and pes impressions are well away from the trackway midline, whereas those of narrow gauge tracks are close to or even intersect the trackway midline (Farlow 1992). Sauropod trackways are notable in that they document distinct gauges. Variation in track and trackway morphology of other dinosaur clades appears to be circumstantial rather than systematic, serving to differentiate speeds, sizes, or individual ichnotaxa. (Wilson and Carrano, 1999). Pakistani Titanosaurian Sauropod dinosaurs represent also the obligatory quadrupedal posture. The forelimb proximal segment like humerus, middle segment like the tibia and fibula, and the distal segment like metacarpals seems to be vertical or subvertical orientations. So the forelimb of Pakistani titanosauria represents columnar digitigrade posture. The hindlimb proximal segment like the femur (proximal part deflected medially), middle segment like tibia and fibula seems to be vertical or subvertical orientation, while the last segment (metapodials and unguals) may be semi plantigrade or plantigrade.

But it is also known from morphology of appendicular elements that the Pakistani form is wide gauge quadrupedal. The theropod belongs to bipedal movements while Sauropod belongs to quadrupedal movements. Further among sauropod it is narrow gauge and wide gauge. The Pakistani titanosauria is a wide gauge, which is confirmed by the collected fossils of dinosaurs from Pakistan. The distal scapula in some Pakistani taxa is deflected laterodorsally creating more wide gauge movements while in some other Pakistani taxa the distal scapula is straight or inclined medially with less wide gauge movements. Further acetabulum orientation and horizontal preacetabular process can help for wide gauge. The femur of titanosaurian Pakistani forms have proximal part medially deflected, the shaft have eccentricity represented by transversely greater width than anteroposterior width and the distal condyles are more inclined outward. These features like femur proximal deflected medially, femoral eccentricity, laterally beveled fibular condyle of femur, broad sacrum and ilia, laterodorsally deflected distal scapula and large sternal plates are basic theme going to wide gauge trackways.

9. Trackways; interaction among a theropod and a group of wide gauge titanosaurian sauropod from Middle Jurassic limestone of Pakistan.

The trackways of wide gauge titanosaurian sauropods (*Malakhelisaurus mianwali*, renamed here due to previously engaged name *Malasaurus*) confronted by a running narrow gauge abelisaurian theropod (*Samanadrinda surghari*) found from the Middle Jurassic Samanasuk Limestone of upper Indus (Kohat and Pothwar) Basin. I report here the reanalysis of trackways representing interaction among a theropod and a group of wide gauge titanosaurian sauropod which were interpreted narrow gauge movements of sauropods along with overlaps of manus by large pes print (Malkani, 2007a.). The host limestone dip 52^0 west and strike north 5^0 east. These trackways were formed on coastal plain. These ichnofossils are deep footprints probably due to good granolometric sorting and the high plasticity of the limy substrate. In the vicinity, some footprints and tracks of possibly avian or nonavian small bodied theropods are also found. The footprint bearing strata are found in the upper successions of Samanasuk marine limestone, which show the slight regression of sea and area, was exposed as beach. This ichnocoenosis consists of exposed more than 15 footprints, and 4 short trackways. These trackways of titanosaurian sauropods trend in a southeast direction and are parallel to each other, which are confronted at about 117^0 angle by a theropod trackway with north-northeast trend (Fig. 7 B). These are indicative of a wide gauge titanosaurian sauropods herd composed of 3 or more individuals defending the attack of a solitary predatory theropod. The footprints are well preserved and only show overprinting some in the back area. The exposed area is small like $60m^2$. The excavation along dipward can clear

further these trackways and interaction among herbivores and carnivores.

The large prints belong to titanosaurs are diagnosed on the basis of the D shape manus impression represents that metacarpals were arranged in D shape, and there is no indication of manus claw on digit I (Fig. 7 B). The pollex claw and all manual phalanges appear to absent in titanosaurs, and distal end of the metacarpals have reduced or lost the well developed articular surface present in most basal sauropods (Salgado, *et al.*, 1997), thus the absence of the pollex claw impressions and wide gauge category (external trackway width, 340cm; internal trackway width, 60cm) in this site are the indication of titanosaur affinities. This site characterized the largest known pes trackmakers (pes length 150cm, width 140cm: manus length 60cm, width 70cm). The manus/pes heteropody area ratio is about 1/5 as compared with ratios ½ of middle Jurassic sauropods (Galinha, Portugal), 1/3 of Cretaceous *Brontopodus birdi* (Texas), and ¼ to 1/5 of Late Jurassic sauropods (Colorado) tracks (Santos *et al.*, 1994). Manus without claw and pes with toes impressions are well preserved. The apparent absence of pes prints from many known sauropods trackways may be due to overlapping (Day, *et al.*, 2004) but here the pes along with toes are best preserved (Fig. 7 B).The sagittal axis of the manus (passing through digit III) and pes prints show no rotation. However the right manus print of right side titanosaur is rotated inwards which may be due to danger of interaction.

Theropod trackway is represented by large tridactyl prints with median symmetry. The pes print consists of three large weight bearing toes (digit II-IV) that are moderately divergent (Fig. 1). The other toed are not marked on footprints. The pes prints having maximum length about 60cm and width about 45cm are diagnosed only for a running large bodied probably abelisaurian theropod. Its assignment to lower level is difficult, because until now, no theropod fossils from these strata are collected. The common vertebrate fossils belong to titanosaurian sauropods (*Pakisaurus*, *Khetranisaurus and Sulaimanisaurus* of Pakisauridae; *Marisaurus* and *Balochisaurus* of Balochisauridae) and abelisaurian theropod (*Vitakridrinda*) dinosaurs, and mesoeucrocodylian (*Pabwehshi*) fauna from the latest Cretaceous of Pakistan (Malkani, 2006b).

Sauropod trackways are by far the most abundant and are representative of taxa that exhibit both narrow and wide gauge styles of locomotion (Day, *et al.*, 2004). Narrow gauge limb posture, acquired early in sauropod evolution, was retained by all basal sauropods, diplodocoids, and basal macronarians (Day, *et al.*, 2002). "The Titanosauria, in contrast, developed a number of derived skeletal features indicating that their limbs were held further from the midline of the animal, suggesting that this advanced clade of largely Cretaceous sauropods was responsible for wide gauge trackways (Wilson and Carrano, 1999). Both the narrow gauge sauropod tracks and those belonging to the theropods (Day, *et al.*, 2004) include claw impressions. The large manus claw on digit I is found in diplodocoids and basal macronarians. In brachiosaurs [the sister group to titanosaurs (Upchurch, 1998)], the claw is somewhat reduced, and in titanosaurs, it is believed to have been entirely lost (Upchurch, 1998). The loss of manus claw is a derived state that supports the view that wide gauge trackways were made by titanosaurs" (Day, *et al.*, 2002). "Several Middle Jurassic localities are reported as putative wide gauge tracks (Ishigaki, 1989, Santos *et al.*, 1994); however, there is no evidence that these trackways were formed by titanosaurs, because they are associated with manus claw marks and in some cases are not truly wide gauge. Therefore the previous earliest substantiated "titanosaur" tracks are from the Late Jurassic (Wilson, and Carrano, 1999)" (Day *et al*, 2002). The oldest known remains of titanosaurs belong to *Janenschia* (Wild, 1991) and *Brohisaurus* (Malkani, 2003c) from the Late Jurassic of Tanzania and Pakistan respectively. Thus after the wide gauge sauropod tracks from Ardley (U.K), the Baroch site (Pakistan) is the second locality which provide the direct evidence that titanosaurs had diverged from other sauropods by the Bathonian.

Baroch site is very significant due to following reasons. Middle Jurassic tracks and the vertebrate record in general are very sparse globally, therefore, any new information is valuable. These tracks of wide gauge Titanosauria and a running Abelisauria help for its early evolution. The manus impressions of Titanosauria are well preserved (even the manus has no claw)

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that help resolve a long standing discussion about the character of claw impressions associated with digit first (Beaumont and Dematheu, 1980, Farlow, *et al.*, 1989). Heteropody ratios are hard to determine for many trackways due to absence of pes impressions (Day *et al.*, 2004), while the present site has heteropody ratio 1/5 of titanosaur. Baroch site has much potential for picnic and academic point of view. It is the largest known pes trackmakers. It is among the largest known sauropod and theropod footprints. It is the first oldest locality which reveals the interaction among a titanosaurian sauropod herd and an abelisaurian theropod. It is another example of marine platform carbonates and fall in to *Brontopodus* ichnofacies. It adds considerably to the taxonomic composition of Middle Jurassic ecosystem. Many dinosaur groups radiated during the Middle Jurassic, replacing Late Triassic and Early Jurassic faunas (Weishampel, *et al.*, 1990; Sereno, 1997). It represents the titanosaurian locomotion as herds while the theropod attacking solitary confirming the idea that the nonavian theropods were likely more solitary in nature, engaging in agonistic, ora like feeding aggregations (Roachand Brinkman 2007). It is the first oldest locality, which has highest depth of theropod footprint more than 10cm, and sauropod about 7 cm or more. Deeper footprints are formed due to increasing water content in the substrate. This tracksite of wide gauge titanosaurians from middle Jurassic limestone may be the second locality (after the Ardley site of UK) in the world and first locality in Asia. Morphological details such as digital pads or skin textures have not yet been recorded from any footprint (Day, *et al.*, 2004), but this site has preserved pes digits especially ungual pads. As with extant mammals, titanosaurs may have formed a herd as part of defense against predation. The Baroch site adds significantly to our understanding of locomotor styles, potential trackmaker, evolutionary history, faunal diversity, echnology, behavior and social interaction of saurischian dinosaurs.

10. Discussions and conclusions

Before 2000, India was the only source of Mesozoic vertebrates but since 2000 to so far about 3000 fossils are collected by author which include the *Khetranisaurus barkhani* (slightly broad midcaudals), *Sulaimanisaurus gingerichi* (squarish long midcaudals), and *Pakisaurus balochistani* (tall midcaudals) of Pakisauridae, and *Marisaurus jeffi* (heavy, slightly tall midcaudals), and *Balochisaurus malkani* (heavy, short, slightly to moderate broad midcaudals) of Balochisauridae established, with the ratio of mid transverse width above and below of midcaudal centra which are less than 1, about 1, 1, 1.5 and 2 respectively (Fig. 1F). Further the stocky limbs (especially stocky tibia) and straight or slight medial deflection deflection of distal scapula is attributed to **Balochisauridae,** while slender limbs (especially slender tibia) and laterodorsal deflection of distal scapula may belong to one or more genera of **Pakisauridae.** The **Saltasauridae** (Titanosauria) may be considered for the extreme broad or dorsoventral compression of caudal centra. The **Andesauridae** include basal characters of titanosaurs like hyposphene-hapantrum articulation and some caudals with mild procoelic nature.

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 remains from Pakistan are diagnostic and can not be referred to *Titanosaurus* which is invalid, and so these remains have received the new family, generic and specific names like *Khetranisaurus*, *Sulaimanisaurus and Pakisaurus*, of Pakisauridae, and *Balochisaurus* and *Marisaurus* of Balochisauridae. 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 distict titanosaur taxa that coexisted in Indo-Pakistan subcontinent just on or below the Cretaceous Tertiary Boundary. *Sulaimanisaurus* is different from *Isisaurus* on having trispinous distalmost caudal centrum.

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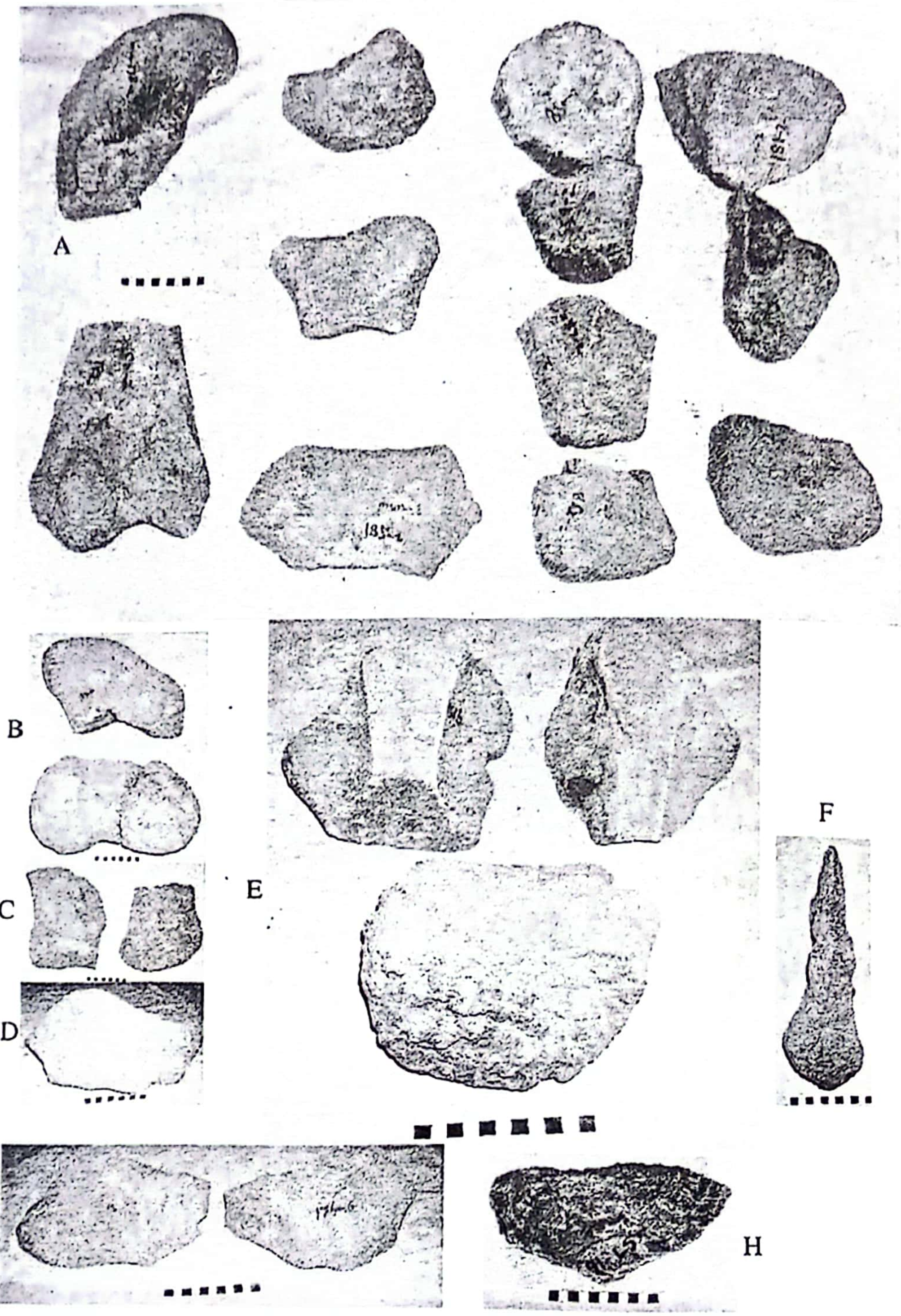


Fig. 5. A, First column, MSM-178-2, MSM-182-2 proximal and distal femur; Second column, MSM-573-2 distal scapula, MSM-271-2 proximal ulna, MSM-184-2 proximal ischium; Third column, MSM-850-2, MSM-559-2, MSM-287-2, MSM-852-2 humerus parts; Fourth Column, MSM-181-2, MSM-362-2, MSM-343-2 humeus parts. B, MSM-169-15, MSM-70-15 proximal and distal femur. C, MSM-165-15 proximal pubis, MSM-164-15 distal pubis/ischium; D, MSM-163-15 distal right scapula; E, MSM-175-16, MSM-240-16 Proximal ulnae MSM-74-16 distal ulna. F, MSM-164-15 distal pubis/ischium; G, MSM-250-16, MSM-176-16 a pair of left and right distal scapulae. H, MSM-557-16 spongy may be part of ilia. Scale, Each black digit is 1 cm.

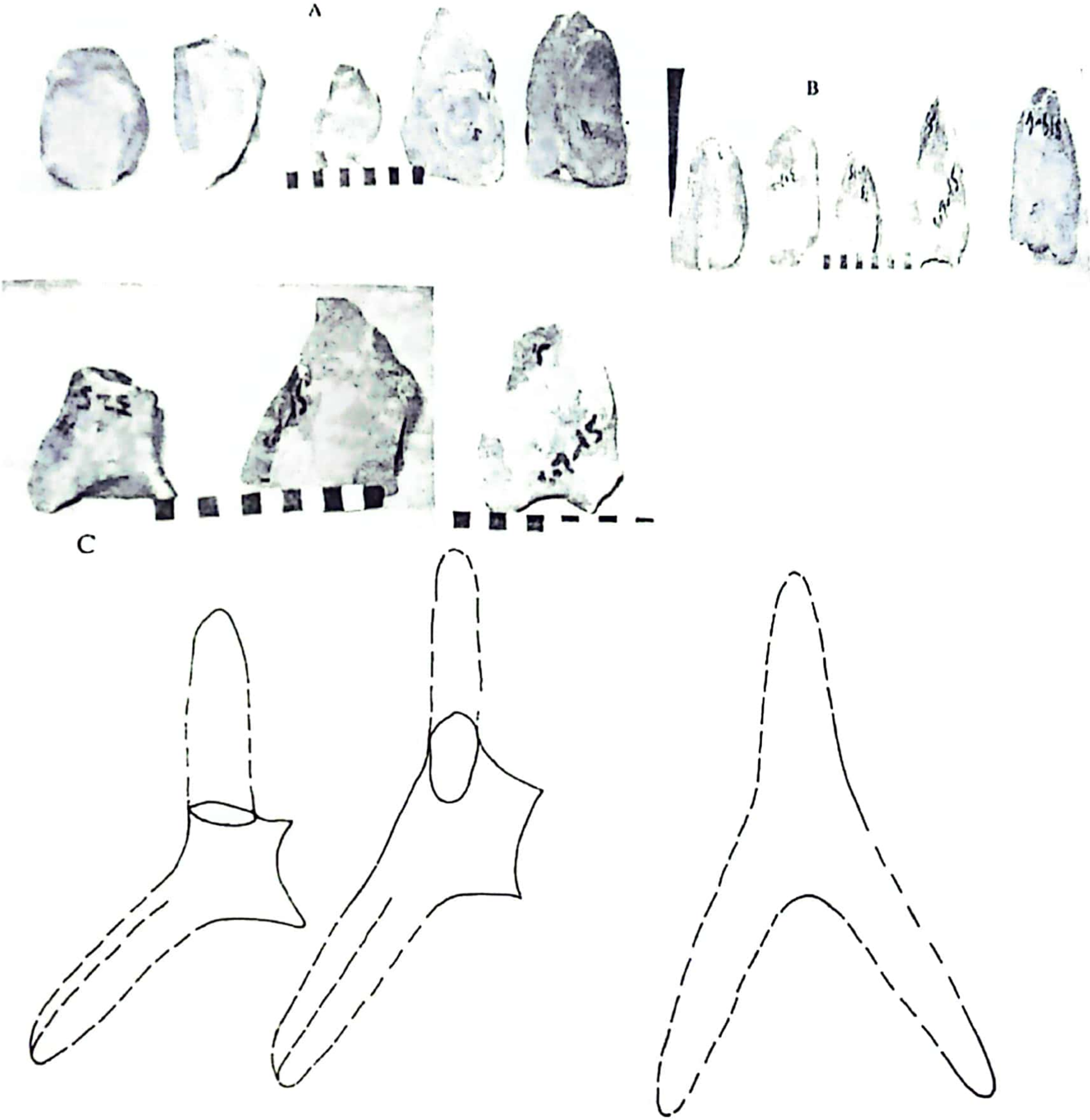
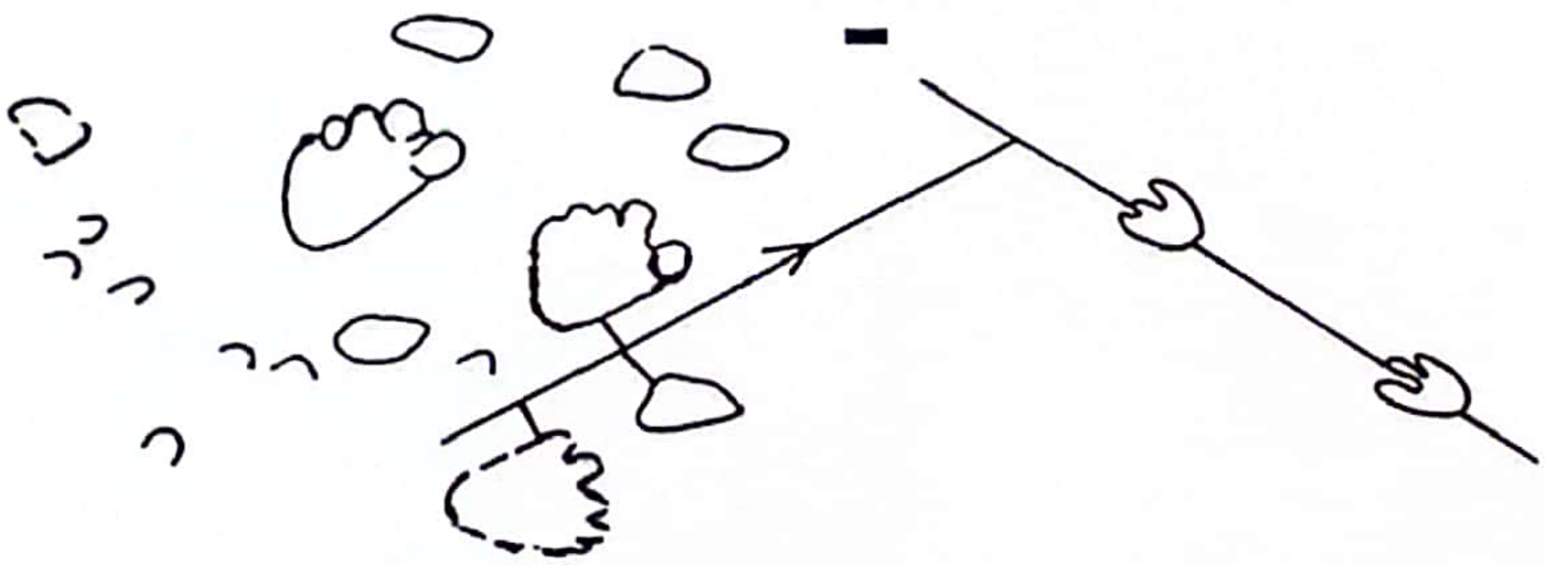


Fig. 6. Distalmost caudal centra with trispinous structure found from Sulaiman Basin of Pakistan. A, MSM-521-3 (Shallghara Locality; *Sulaimanisaurus*), MSM-302-2 (Bor Kali Kakor Locality; *Marisaurus*), MSM-325-15 (Mari Bohri Locality; *Balochisaurus*), MSM-507-15 (Mari Bohri Locality; *Marisaurus*), and MSM-519-4 (Kinwa Kali Kakor Locality; *Pakisaurus*), anterior view. B, posterior view. C. MSM-325-15, MSM-507-15, right lateral view, MSM-507-15, posterior view. Scale, Each black digit is 1 cm.





Fig. 7. A, First row, MSM-565-2 anterolateral part of sternal, MSM-1004-2 sternal part?, MSM-147-16, 148-16 acetabulum part, MSM-150-16 part of ilia. Second row, MSM-1014-16 convex part of sternal, MSM-604-16 sternal part, MSM-560-2 corocoid, MSM-149-16 metatarsal/phalange, MSM-838-4 mid scapula with ridge. Third row, MSM-328-16 cervical rib, MSM-767-16 cervical rib, MSM-329-16 cervical rib, MSM-187-2 distal part of dorsal rib, MSM-638-19c diapophysis, MSM-776-16 sacral. Fourth row, MSM-301-2 neural spine, MSM-792-2 neural spine, MSM-330-16 chevron, MSM-327-16 prezygapophyses, MSM-784-2 neural spine, MSM-391-16 neural spine, MSM-1035-16 osteoderm. Scale, Each black digit is 1 cm. B. Trackways; Interaction among a running narrow gauge abelisaurid theropod, and a group of wide gauge titanosaurian sauropods, found from Middle Jurassic Limestone of Pakistan. Longer arrow shows the advancing movement of an abelisaur, while the smaller arrow shows the advancing movements of titanosaurian herd. Scale, hammer in photo or black digit which is 30 cm.



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, Khetranisaurus,* and *Isisaurus* or *Sulaimanisaurus*) (Malkani, in process). 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* 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).

With the few exceptions of new discoveries in Argentina, Madagascar, and

Mongolia, most titanosaurs are known only from fragmentary postcranial skeletons and rare isolated skull elements. Titanosaurian postcrania are found worldwide, but their skulls are exceptionally rare. This nagging lack of association has left even the most basic skeletal morphology of the clade controversial and has precluded detailed study of the higher and lowers level phylogeny of the group (Curry Rogers and Forster, 2004). Titanosaurs with cranial materials are *Ampelosaurus* (teeth, dentary, 3 braincases), *Antarctosaurus* (braincase, dentary), Baja Santa Rosa (2 partial skulls), *Jainosaurus* (3 partial braincase, maxilla, squamosal), Jabalpur indet. (1 partial braincase), *Limaysaurus* (partial braincase, teeth), *Magyarosaurus* (partial braincase), *Malawisaurus* (partial skull, 2 dentary, teeth), *Nemegtosaurus* (partial skull, dentaries), *Quaesitosaurus* (partial skull, dentaries), *Rapetosaurus* (partial juvenile and adult skulls), *Saltasaurus* (1 juvenile braincase), and *Titanosaurus indet.* (Partial skull) (Curry Rogers and Forster, 2004). Recently *Marisaurus* (Partial skull) and *Balochisaurus* (Partial skull, in review) are also included.

In fact, no titanosaur skull found in association with postcrania have ever been fully described or illustrated, and very instances of direct association of skull and postcrania have been documented. This nagging lack of association has left even the most basic skeletal morphology of the clade controversial and has precluded detailed study of the higher and lower level phylogeny of the group (e.g., Salgado et al., 1997; Upchurch, 1998; Wilson and Sereno, 2006; Curry Rogers and Forster, 2004). Titanosaurs comprised nearly half of all known sauropod genera, and were the only sauropod lineage to survive to the end of the Cretaceous. Their post crania are found worldwide, but their skulls are exceptionally rare. Cranial material is known only from ten titanosaurs and is limited to isolated elements and fragmentary braincases (Curry Rogers and Forster, 2004). The *Marisaurus* (and *Balochisaurus*, in review, and *Pakisaurus*, in review) bear the associated cranial, vertebral and limb elements, because previously no such associations are found in most derived titanosaurs except *Rapetosaurus* from Madagascar (Curry Rogers & Forster, 2004). It provides new insights in to skull and postcranial morphology. Due to dearth of cranial data for titanosaurs, the *Rapetosaurus*, *Marisaurus*, *Balochisaurus*, some Argentinean and Mongolian forms have great potential to solve paleobiogeography, lower and higher level phylogeny of titanosaurs. *Marisaurus* provides the opportunity to view the most complete (associated cranial, axial and limb elements) titanosaurs yet discovered. The skull of *Marisaurus* is articulated while the *Rapetosaurus* is disarticulated. The skull of *Marisaurus* is associated with vertebral and limb elements while *Nemegtosaurus* and *Quaesitosaurus* lack the postcranial articulation and association.

Nemegtosaurus and *Quaesitosaurus* are known from skulls, and have been alternately placed within the Titanosauria or the Diplodocoidea. With regards to these Mongolian genera, *Rapetosaurus* is particularly illuminating because its elongated skull with retracted nares exhibits a general similarity to diplodocoids, whereas it's skeleton striking commonalities with brachiosaurids and other titanosaurs (Curry Rogers and Forster, 2004). *Marisaurus* offers an opportunity to test the monophyly of Titanosauriformes with abundant associated skull, axial and limb elements. It also offers the best opportunity yet to resolve the phylogenetic positions of two controversial Mongolian sauropods, *Nemegtosaurus* and *Quaesitosaurus*.

Malawisaurus has short and high macronarian skull and amphicoelous caudals (except some anteriormost) vertebrae, which is differentiated from *Marisaurus* with moderate inclined and elongated Balochisaurids skulls and procoelous caudal (except biconvex anteriormost caudal) vertebrae. *Karongasaurus* has low and elongate macronarian skull, which is differentiated from *Marisaurus* with moderate, inclined and elongated Balochisaurids skulls. *Marisaurus* differs from the broad centra of *Adamantisaurus*, heart shape caudals and first procoelous caudal of *Gondwanatitan*, squared caudals of *Isisaurus*, squared caudals and first biconvex caudal of *Baurutitan* (Series C), slightly procoelous mid caudals of basal titanosaur *Mendozasaurus*. The ventral view of *Trigonosaurus pricei* (series B) from Peiropolis are not described and not figured (Campos *et al.* 2005). *Marisaurus* differs from the *Austrosaurus* which is more derived than *Malawisaurus*.

Marisaurus differs from the broad caudal centra of *Saltasaurus* and *Neuquensaurus*, squared jaws and perpendicular dentary symphyses of *Bonitasaura*, perpendicular dentary symphyses of Mongolian taxa *Nemegtosaurus* and *Quaesitosaurus*, ventral crest of caudal centra of *Bonatitan*, and very long cervical vertebrae of *Futalognkosauria*. *Marisaurus* is most derived titanosaurs and differs from the basal titanosaurs like *Haplocanthosaurus*, *Chubutisaurus*, *Amargatitanis*, and *Gobititan*. *Marisaurus* also differs from the limb elements of *Argyrosaurus*. *Marisaurus* show a procoelous caudal vertebrae differentiated from basal forms like *Andesaurus* and *Malawisaurus*. *Marisaurus* also lack hyposphene-hypantrum articulation observed in basal titanosaurids like Andesauridae (*Argentinosaurus*, *Andesaurus*, *Epachthosaurus*).

In general there are two types of skull among sauropods like *Camarasaurus*-type and *Diplodocus*-type. *Camarasaurus*-type skull can be characterized as a short, high skull with broad nares separated from each other by an arch formed by the premaxillae and nasals, quaderates nearly vertical oriented, basioccipital condyle posteroventrally directed, basipterygoid processes ventrally projecting and broad spoon shaped teeth inserted on the entire margins of the maxilla and dentary. On the other hand, the *Diplodocus* type is a long skull with confluent external nares located posterodorsally between the orbits, quaderate anteriorly inclined, basioccipital condyle ventrally directed, basipterygoid processes anteroventrally oriented and slender peg like teeth confined to the anterior part of the snout (Salgado *et al.*, 1997). Traditionally, titanosaurids were considered as bearing a Diplodocus-type skull (Salgado *et al.*, 1997). Calvo (1994a, 1994b) recognized the existence of at least four different tooth shapes: peg like teeth (in diplodocids), spoon like teeth (in camarasaurids), compressed cone chisel like teeth (in Brachiosaurus and Astrodon) and Chisel like teeth (in titanosaurids, Nemegtosaurus Nowinski and Quaesitosaurus Kurzanov and Banikov) (Salgado and Calvo, 1997). The wear facets are useful in investigating mechanisms of mandibular occlusion and feeding habits (Calvo, 1994a, 1994b). Prosauropods are characterized by the absence of tooth-to-tooth contact. In *Camarasaurus* each tooth contacts two teeth of the opposite jaw. *Brachiosaurus* and titanosaurids are similar in that one upper tooth can meet either one or two lower ones and vice versa (Calvo, 1994a, 1994b). *Diplodocus* is characterized by precise tooth to tooth contact (Calvo, 1994a, 1994b). Calvo (1994a, 1994b) pointed out titanosaurids resemble diplodocids by the slenderness of their crowns but they differ in the pattern of wear facets and tooth to tooth contact.

However there are some indications of the probable *Camarasaurus* like skull. Powell, (2003) mentioned a premaxilla bearing slender peg teeth from Argentina is too high to correspond to a Diplodocus type skull. Further Huene and Matley (1933) mentioned a premaxilla which is also high. In this way, Jacobs et al. (1993) mentioned the complete premaxilla of the basal titanosaurids *Malawisaurus dixeyii* with doubled external nares which are placed anteriorly. Seeing the above mentioned discussion, the skulls of *Balochisaurus* (Malkani, in process), and *Marisaurus* (Malkani, 2003a, in process) can solve many cranial problems among world. The skull of *Marisaurus* is more incline than diplodocoids. However tooth distribution throughout the upper and lower jaws is more similar to those of macronarians like *Camarasaurus* and *Brachiosaurus* but skull inclination is less than these genera. The skull discoveries of *Marisaurus* and *Balochisaurus* adds the general morphs of sauropod skulls like moderate inclined, elongate and spongy (with large open internal cell) in the previously reported two morphs like high and short, and low and elongate.

All analyses of titanosaur interrelationships have lacked a full body view for a diverse taxonomic sample due to the sheer lack of skeletal data for almost all titanosaur genera. *Rapetosaurus* is a keystone taxon that is most significant because it preserves cranial and postcranial materials (Curry Rogers 2005). Recently Pakistan has produced two articulated partial skulls and associated postcrania of Titanosauria which will also clear the morphology of titanosaurs. Pakisauridae (*Pakisaurus*) teeth on jaws are widely spaced than *Marisaurus* which are again more widely spaced than more derived *Balochisaurus* (Balochisauridae). This character adds help for evolution.

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