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A Middle Miocene (~14 Ma) vertebrate assemblage from Palasava, Rapar Taluka, Kutch (Kachchh) District, Gujarat State, western India

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ABSTRACT

The present article aims to record a recently discovered middle Miocene vertebrate assemblage (including marine and terrestrial mammals) from Palasava, Kutch (Kachchh) District, Gujarat State, western India. The faunal assemblage comprising fishes, chelonians, crocodiles, snakes, birds and mammals is significant in terms of palaeoecology, palaeoenvironment and biostratigraphy of the region and yields evidence concerning its biogeographic affinities linked to Neogene Eustatic history. Palasava fauna together with previously known Neogene (particularly Miocene) vertebrate assemblages from the Kutch region indicates the presence of a riverine-estuarine system(s) linked to the sea, i.e. the depositional centres were quite close to the sea. Furthermore, the Palasava vertebrate assemblage (recorded herein) points towards a prevalence of warm, humid/wet, tropical to sub-tropical environmental conditions. The terrestrial mammalian assemblage from Palasava represents at least seven families with six of the terrestrial mammalian taxa identified herein to the genus level, namely: *Sanitherium*, *Sivameryx*, *Brachypotherium*, *Zygodon*, *Gomphotherium*, and *Deinotherium*. The overall assemblage (including *Zygodon* and *Deinotherium*) is indicative of a Middle Miocene, 14 ± 2 Ma (Langhian to Serravallian) age for the sedimentary succession at Palasava. Furthermore, a ~ 14 Ma age for the Palasava fauna indicates a correlation to regression cycle R5 in the Tagus Valley succession of Portugal.

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Introduction

The Kutch region of western India (Figure 1) has been known to yield Neogene vertebrates since the late nineteenth century (Wynne 1872; Lydekker 1876, 1880). However, during much of the following century, the Neogene terrestrial fauna of Kutch remained neglected except for occasional notices of fossil mammals (Prasad 1962, 1964, 1967; Sahni and Mishra 1975). Simultaneously, Mehrotra et al. (1973) and Sahni and Mishra (1975) also recorded fish (Osteichthyes and Chondrichthyes) remains from the Neogene (Miocene) sedimentary sequences of Kutch, western India. During the past decade, renewed efforts in the peninsula have resulted in several important discoveries of Neogene vertebrates, including both terrestrial and marine mammals (Bajpai et al. 2010; Thewissen and Bajpai 2009; Bhandari et al. 2010, 2015, 2018; Patnaik et al. 2014). Considering the Middle Miocene mammals, the central Kutch region (Tapar-Pasuda area; see Figure 1(a)) has previously yielded fragmentary remains (mainly dental elements) that have been assigned to rodents, chiropterans, proboscideans (*Gomphotherium* and *Deinotherium*), perissodactyls (*Hipparion* and *Brachypotherium*), the artiodactyls (*Sivameryx*, *Tetraconodon*, *Sanitherium*, *Dorcatherium*, *Giraffokeryx*, *Giraffa*, *Protragoceras* and *Gazella*), and the Hominoid genus *Sivapithecus* (Bhandari et al. 2010, 2015, 2018). The discovery of Neogene land mammals at two sites (Pasuda and Tapar) in central Kutch reveal the previously unappreciated potential for the presence of vertebrate faunas

in the Neogene (particularly Miocene) of Kutch, while hinting at the presence of geologically younger ossiferous deposits than hitherto thought possible (Head et al. 2007). Patnaik et al. (2014) recorded fragmentary dental remains of a perissodactyl (*Brachypotherium*) and proboscidean (*Deinotherium*) from the Miocene sediments of western Kutch region (i.e., the Jangadia-Samda area; see Figure 1(a)). Apart from mammals, vertebrates reported from the Miocene interval of Kutch include sharks, rays, snakes, chelonians, crocodylians and birds (Head et al. 2007; Patnaik et al. 2014; this paper). Very recently, Kapur et al. (2019) recorded India's first evidence on microcoprolites (a total of three morphotypes that were linked to fishes) recovered from the Miocene sediments belonging to the Khari Nadi Formation of Kutch Basin, western India.

The biostratigraphy of the Kutch Basin was based largely on marine organisms which abound in the Palaeogene strata (Grant 1840; Biswas and Raju 1973; Biswas 1992; Raju 2014). However, the accuracy of the proposed correlations of the Neogene horizons to the global time scale proved largely illusory because of the paucity of fossils from various time intervals within the Miocene Epoch. As currently understood, the various Neogene fossiliferous levels appear to span the Early Miocene (Burdigalian), Middle Miocene (Langhian, Serravallian) and basal Late Miocene (Early Tortonian) periods, much as in the Manchar succession in Sindh, Pakistan (Lydekker 1876). If inclusion of the faunal assemblage previously known from Piram (= Perim) Island (located within

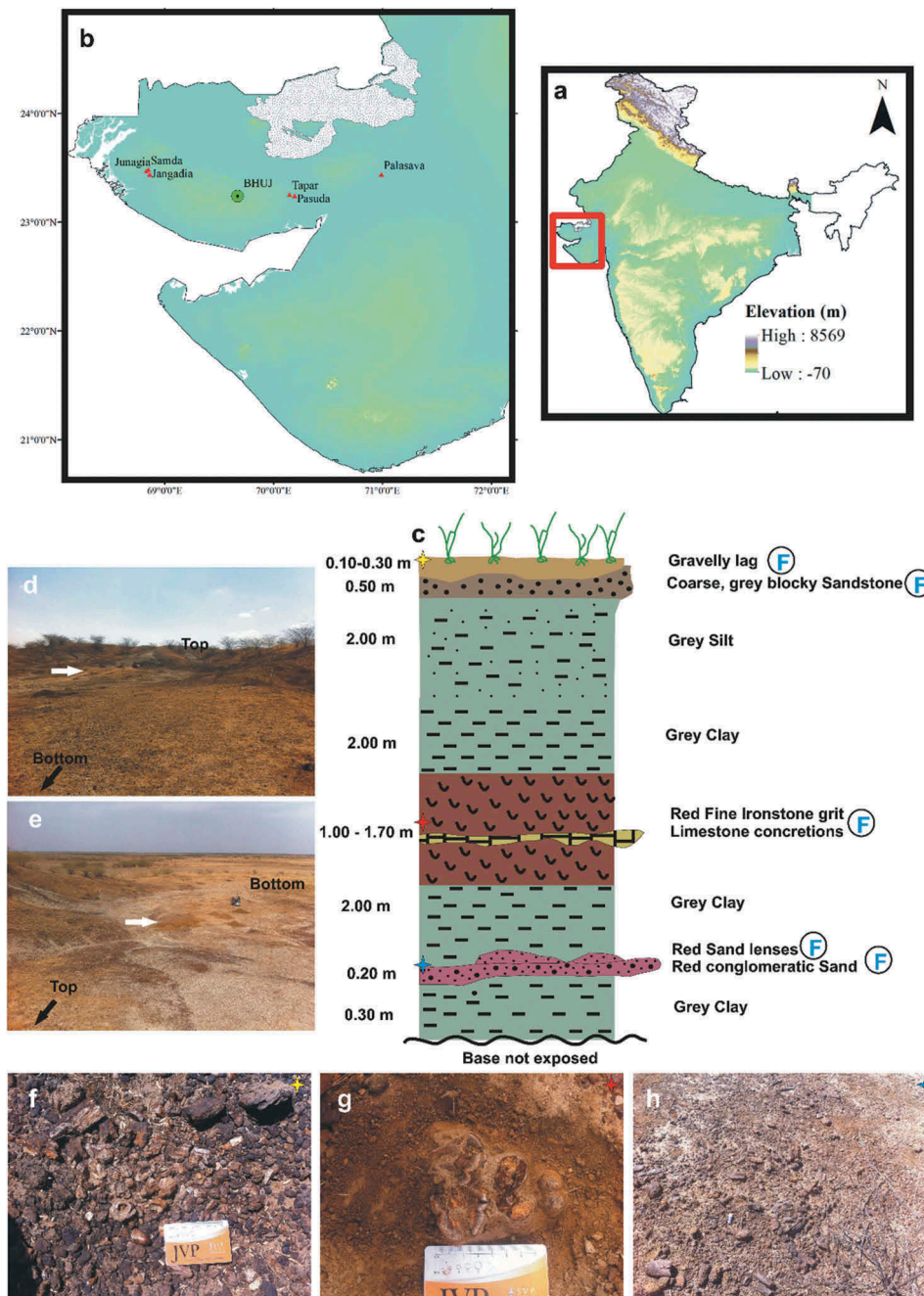


Figure 1. Location and lithology of Palasava. **a)** Digital Elevation Model (DEM) map of India with Kutch (Kachchh) region marked in red box, **b)** DEM map of the Kutch region (western India) showing the Miocene ossiferous localities including the present study area i.e. Palasava, **c)** lithological section measured at Palasava with fossiliferous horizons marked by a 'F' in blue text within a black circle, **d & e)** Panoramic views of the studied succession at Palasava, **f)** fragmentary crocodilian rostrum with teeth observed within the gravelly lag at the top of the section, **g)** gomphothere molar observed within the Ironstone grit, and **h)** scattered fragments of mammalian bones observed within the red conglomeratic sands at the bottom of the Palasava section.

Note: Positions of fossils illustrated in figures **f**, **g** & **h** have been marked by a yellow, red and blue star, respectively within the Palasava lithological section.

the Gulf of Cambay; Fulljames 1836; ; Duckworth 1858; Lydekker 1887; Prasad 1974) is included then the stratigraphic representation of the fossiliferous levels in Western India extends into the upper part of the Late Miocene (Late Tortonian).

The geological field relations of the fossil-bearing sites and the presence of an admixture of marine and terrestrial vertebrates in the Neogene sites of Kutch suggest that deposition occurred quite close to the sea. It is a scenario quite similar to

the one observed for the Neogene successions of the Faluns (France), the Tagus Basin (Portugal), the Paratethys (Austria and Germany) (Steininger et al. 1976) and the coastal zones of Namibia in Africa (Pickford 1998).

Herein, we describe a recently discovered, middle Miocene vertebrate assemblage from Palasava village (Rapar Taluka, Kutch District, Gujarat State; for details on the locality information refer to the section 'Location, geology, and age') dominated by terrestrial taxa, including mammals. It should be

noted that the Palasava ossiferous site is located near the eastern extremity of the Kutch Basin, ca. 100 km east of the central Kutch localities of Tapar and Pasuda (see [Figure 1](#)). Detailed investigations by the authors since 2007, particularly in the year 2015 (for details refer to the section ‘*A historical perspective on Palasava vertebrate explorations*’) resulted in the recovery of several hundred vertebrate fossil specimens belonging to fishes, reptiles, mammals (marine and terrestrial) and birds. Previous palaeobotanical investigations of the Palasava deposits have yielded palynomorphs (Verma et al. 2013), and permineralized wood remains (Shukla et al. 2014). The present article describes the vertebrate assemblage from Palasava with a focus on mammalian taxa. In addition, we interpret the palaeoecological and palaeoenvironmental conditions based on the vertebrate assemblage recorded herein while taking into consideration the previously known palaeobotanical evidence from Palasava. Further, we discuss the biostratigraphic significance of the Palasava mammalian assemblage in terms of the geological distribution of the records of the terrestrial genera (particularly *Deinotherium*, *Sanitherium*, *Hipparion* and *Sivapithecus*) in the Indo-Pakistan, African and European regions. Lastly, we attempt a correlation of the Miocene mammalian assemblages from Kutch (particularly the ones reported herein from Palasava) with the recorded sea-level changes (linked to Eustasy) during the Neogene within the Mediterranean and Paratethyan megabasins.

A historical perspective on Palasava vertebrate explorations

The initial discovery of vertebrate fossils at Palasava was made more than a decade ago (i.e. in 2007) and thus, we believe that it is imperative to provide readers with a brief historical background of the Palasava fossil explorations and collections prior to dealing with their significance for palaeontological and allied aspects. Early in 2007, an office assistant (Mr Ladak) in one of the authors’ (MGT) office came with a small fossilised rib, that Mr Ladak had found while wandering in the vicinity of his village ‘Palasava’. Taking heed to Mr Ladak’s curiosity, MGT organised a field visit to the fossil locality ‘Palasava’ with an amateur fossil collector Mr Mohansingh Sodha. To their great astonishment, MGT and his team found several vertebrate fossils embedded in grey blocky sandstone (belonging to the Miocene Epoch) exposed in the vicinity of the village ‘Palasava’. Later in 2007, MGT invited Professor GVR Prasad (presently at Department of Geology, University of Delhi) to conduct palaeontological research on a few selected specimens from Palasava. However, unfortunately for almost four years, no progress in the matter could be made largely because Professor GVR Prasad was obliged to move office frequently within the country and was mostly concentrating on working on the Mesozoic vertebrates from India. Subsequently, MGT invited Professor S Bajpai (Department of Earth Sciences, Indian Institute of Technology Roorkee, Uttarakhand) to study the Palasava vertebrate specimens in a palaeontological and allied context. In the meantime, MGT moved from RR Lallan College into the newly established Department of Earth and

Environmental Science at KSKV Kachchh University (Bhuj, Gujarat State, India) and shifted the entire Palasava fossil collection to his new office. On the 8th of April, 2013, Professor S Bajpai along with Professor JGM Thewissen (Northeastern Universities College of Medicine, Ohio, USA) and a few of Professor Thewissen’s students visited MGT’s office for a preliminary examination of the Palasava fossil material. Subsequently, the entire team (including MGT) spent a few hours on site at Palasava for surface collections. A part of the fossil collection housed at KSKV Kachchh University (including a crocodile jaw, rhino and giraffe skulls, and a few other important identifiable fossils) was loaned to Professor S Bajpai (SB) for palaeontological studies. Although, the Palasava fossil finds did receive a mention in Mandal et al. (2012); unfortunately, no research progress was made on the Palasava fossil collection, and for a second time, the fate of the Miocene mega fauna appeared to be in jeopardy. After numerous discussions on the matter, Prof. M Pickford (Sorbonne Université, Paris, France) was eventually invited for collaborative work. Subsequently, in March 2015, the authors (VVK, MP, MGT, and GC) carried out a detailed palaeontological excursion and stratigraphic surveys at the Palasava fossil site (refer to section ‘*Material and Methods*’). However, due to other commitments SB could not join the excursion team (i.e. onsite) until the last stage of the field excursion. In the meantime, the team members had already made 163 entries in the field catalogue of the fossil material from Palasava that they collected, comprising plants, molluscs, fish, reptiles, birds and a diversity of small to huge mammals that are presently housed at BSIP. Subsequently, in September 2015, MP completed the first draft of the report on Palasava excursion with help from VVK and MGT that was circulated to the field excursion team members for corrections, comments, and amendments. Since then, progress has been slow (partly due to the fact that the fossil collection required laboratory preparation); however, the present article provides (in detail) a record of the Middle Miocene (~ 14 Ma) vertebrate faunal assemblage from Palasava village, Rapar Taluka, Kutch (Kachchh) District, Gujarat State, western India.

Location, geology, and age

The vertebrate remains described herein were recovered from a sedimentary succession exposed along a ridge about 6 km east of the village of Palasava (Latitude: 23°26’18.1”N; Longitude: 70°59’25.2”E), Taluka Rapar, District Kutch, Gujarat State, western India ([Figure 1](#)). We identified five ossiferous levels/horizons in the sedimentary sequence at Palasava that belong to the Chhasra Formation and consist predominantly of grey silts/clays with sand lenses with the top 0.50 m of the succession comprised of gravelly lag and coarse sandstone ([Figure 1](#)). According to Biswas (1992), the ‘Chhasra Formation’ [originally described as ‘Vinjhan Shale’ by Biswas and Raju (1973)] occurs extensively but as patchy outcrops in the low plains in the southern and eastern Kutch region. Furthermore, the Chhasra Formation overlies older Palaeogene-Neogene sedimentary sequences that occur as crescentic exposures in the Kutch region ([Figure 1](#) in Biswas

1992). Biswas (1992) suggested an Early Miocene (Burdigalian) age for the Chhasra Formation based on miogypsinid foraminifers; however, he emphasized the lithostratigraphic correlations rather than chronostratigraphy (pers. comm. to VVK). Based on the mammalian assemblage we estimate a Middle Miocene (Langhian-Serravallian; $\sim 14 \pm 2$ Ma) age for the ossiferous sedimentary succession at Palasava (refer to the section 'Biostratigraphy').

Materials and methods

The Palasava vertebrate specimens were recovered as surface collection and by excavating and sieving (both dry and wet screening) tons of sediment onsite as well as in the Vertebrate Palaeontology and Preparation Laboratory (VPPL) at Birbal Sahni Institute of Palaeosciences (BSIP). In addition, the mega-vertebrate specimens were prepared with the help of pneumatic air scribes at VPPL, BSIP. The micro-vertebrate specimens were recovered from the dried and well-sorted sediment samples, photographed, and examined with the help of a stereoscopic microscope (Model: Leica S8APO) attached to a digital camera (Model: Leica MC170 HD). The micro-vertebrate remains were measured using Leica Application Suite (LAS V4.8) software while the macroscopic vertebrate elements were measured using a Dial Vernier Caliper. Scale bars have been provided with the illustrations of the fossils. The specimens studied as part of the present investigation are housed in the Birbal Sahni Institute of Palaeosciences, Lucknow, India [BSIP museum locality reference number: 9916; field catalogue acronym: PSV; museum specimen acronym: BSIP; the museum specimen series of the 54 specimens illustrated herein is 41754–41807].

Vertebrate faunal assemblage recovered from Palasava, Rapar Taluka, Kutch District, Gujarat State, western India

A diverse vertebrate fauna has been recovered from Palasava (Kutch District, Gujarat State, western India). It includes fishes, reptiles, birds and marine and terrestrial mammals. We here discuss the individual groups recovered from Palasava; however, we focus on the terrestrial mammals owing to their stratigraphic and biogeographic significance for understanding the Eustatic changes during the Neogene.

Pisces (fishes)

Numerous fish remains (spines, vertebrae and isolated dental elements) were recovered from Palasava by employing dry and wet sieving techniques onsite as well as in the laboratory. The isolated dental remains utilized for the taxonomic identifications of fish taxa are illustrated in Figure 2. The fish elements from Palasava indicate the presence of Selachimorphs (sharks) (*Carcharinus* sp.; Figure 2(a–h)), Cyprinids (Figure 2(i–k)); Myliobatiformes (rays) (*Myliobatis* sp.; Figure 2(l)), and (sawfish *Pristis* sp.; Figure 2(m–u)).

Reptilia (reptiles)

Abundant reptilian remains were recovered by surface prospecting and by wet and dry sieving techniques onsite and in the laboratory. Reptilian fossils are abundant at Palasava and are represented by three orders, namely: Chelonia (turtles), Crocodylia (crocodiles) and Serpentes (snakes).

At Palasava, the commonest chelonian fossil elements are scutes. Interestingly, we observe three differently ornamented types of scutes that highlight the taxonomic diversity of Palasava chelonians represented by cyclanorbids, trionychids, and pelomedusids (Figure 3(a–d)).

Crocodylian remains (isolated teeth, scutes, vertebrae, and limb bones) are common at Palasava and vary in size (Figure 4(a–g)) indicating the presence of both large (adults) and small (juvenile) crocodiles. For instance, a large vertebra (specimen: BSIP41785; centrum 11.5 cm long; Figure 4(g)) attests to the presence of huge crocodiles at Palasava during the Langhian-Serravallian (Middle Miocene) age (also refer to section 'biostratigraphy'). Apart from size variation in the recovered crocodylian teeth, we observe that the dental remains include at least two different morphotypes that can be assigned to either *Crocodylus* sp. (most common in the Palasava assemblage) or to the longirostral genus *Tomistoma* sp.

The expedition collected several large snake vertebrae at Palasava. A snake vertebra specimen (BSIP41786) assigned herein to the genus *Acrochordus* is illustrated in Figure 5. It should be noted that the snake genus *Acrochordus* is known by vertebrae specimens from a few other localities in Kachchh (see Head et al. 2007).

Aves (birds)

A few bird fossils (two phalanges) were recovered from Palasava (Figure 6(a,b)) that possibly represent the family Phoenicopteridae (flamingoes) (Mourer-Chauviré, pers. comm. to MP) or Ciconiidae (storks).

Mammalia (mammals)

Palasava has yielded a diverse assemblage of mammals (both marine and terrestrial). The mammalian elements from Palasava include isolated teeth, numerous mandibles and maxillae fragments with dentitions and post-cranial remains. Marine mammals are represented by a few edentulous mandible fragments of cetaceans assigned to the Eurhinodelphinid genus *Schizodelphis* and a few pachyostotic rib fragments of sirenians (sea cows). However, field observations suggest that the sirenian ribs at Palasava are confined to the red conglomerates at the base of the Palasava sedimentary succession, with the entire sample being rolled and polished, suggesting that the sirenian specimens quite likely have been reworked from a pre-existing deposit. It should be noted that the Sirenian skeletal material (particularly ribs) are quite commonly found within the older Miocene (Aquitania) sedimentary successions (Khari Nadi Formation) of Kutch (Bajpai et al. 2006; Thewissen and Bajpai 2009).

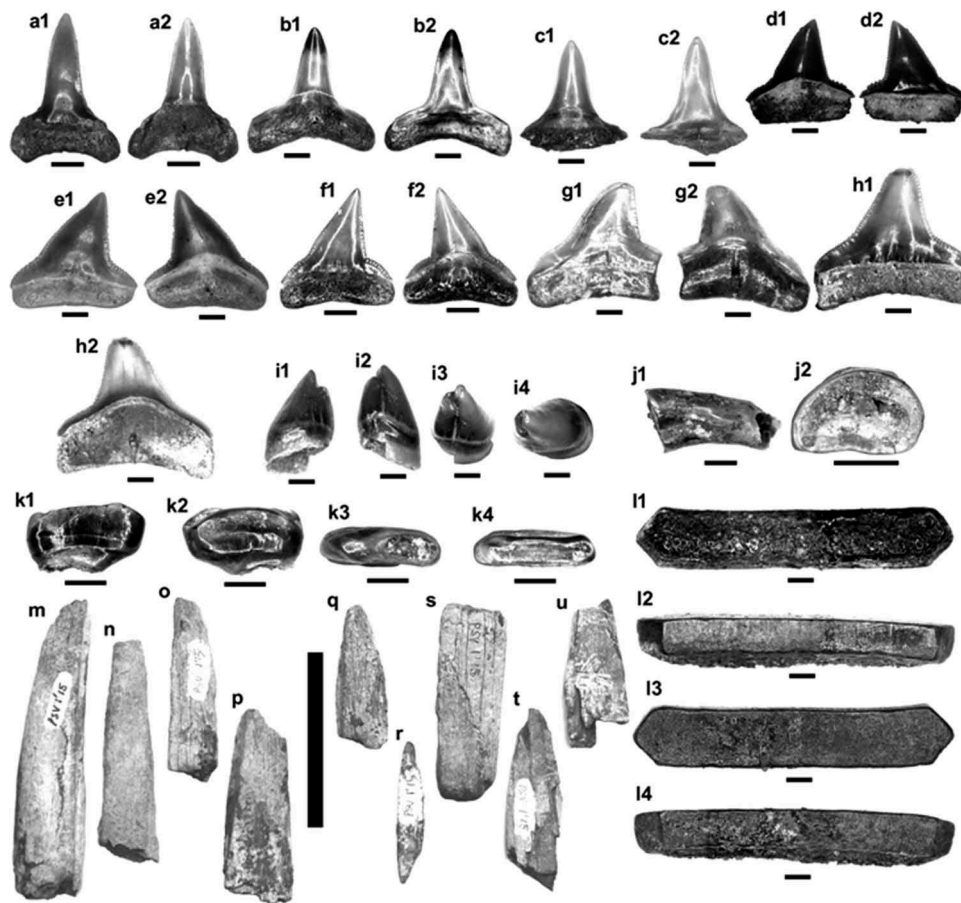


Figure 2. Fish remains from Palasava, Kutch (Kachchh) District, Gujarat State, western India. **a-h:** isolated teeth belonging to Selachimorpha family indet. [**a1-a2:** BSIP41754 (PSV165a'15); **b1-b2:** BSIP41755 (PSV165b'15); **c1-c2:** BSIP41756 (PSV165c'15); **d1-d2:** BSIP41757 (PSV165d'15); **e1-e2:** BSIP41758 (PSV96a'15); **f1-f2:** BSIP41759 (PSV165e'15); **g1-g2:** BSIP41760 (PSV165f'15); **h1-h2:** BSIP41761 (PSV165g'15)], **i:** isolated teeth belonging to Teleost gen. et sp. indet. [**i1-i4:** BSIP41762 (PSV166a'15)]; **j1-j2:** BSIP41763 (PSV166b'15); **k1-k4:** BSIP41764 (PSV166c'15)], **l:** Isolated tooth belonging to Myliobatidae gen. et sp. indet. [**l1-l4:** BSIP41765 (PSV164a'15)], **m-u:** isolated teeth of Pristidae *Pristis* sp. [**m:** BSIP41766 (PSV1a'15); **n:** BSIP41767 (PSV1b'15); **o:** BSIP41768 (PSV1c'15); **p:** BSIP41769 (PSV1d'15); **q:** BSIP41770 (PSV1e'15); **r:** BSIP41771 (PSV1f'15); **s:** BSIP41772 (PSV1g'15); **t:** BSIP41773 (PSV1h'15); **u:** BSIP41774 (PSV1i'15)]. Scale bar equals 2mm for **a-l**; 5cm for **m-u**.

The terrestrial mammalian assemblage from Palasava is represented by three orders viz. Artiodactyla, Perissodactyla, and Proboscidea, representing at least seven families. Six of the taxa can be identified to the genus level, namely: *Sanitherium*, *Sivameryx*, *Brachypotherium*, *Zygodon*, *Gomphotherium* and *Deinotherium* (Table 1). Further, a long-limbed rhinocerotid, unidentified species of Suidae, Bovidae, and Giraffidae were also recovered in the present investigation but would be dealt with (in detail) as a separate study.

Family Eurhinodelphinidae Abel 1901

Genus *Schizodelphis* Gervais 1861

Type species *Schizodelphis sulcatus* Gervais 1853

Schizodelphis sp.

Two mandible fragments from Palasava (BSIP41789, BSIP41790) represent the cetacean family Eurhinodelphinidae. In occlusal view, the dental roots or their empty alveoli are well separated from each other, and they lie within a longitudinal groove that runs the length of

the preserved part of the jaw (Figure 7). The tooth roots are simple, suggesting a homodont dentition. In lingual view, there is an elongated lingual fossa occupying the middle third of the jaw. Buccally the jaw preserves a longitudinal groove. The great separation of the dental alveoli from each other and their position along the alveolar groove indicate affinities with the longirostral cetacean genus *Schizodelphi* and possibly comparable to *Schizodelphis sulcatus* (Gervais 1853).

Order Artiodactyla Owen 1848

Family Suidae Gray 1821

Suidae gen. et sp. indet.

A single 2nd phalanx is attributed to the family Suidae. The specimen (BSIP41791) is too large to represent family Sanitheriidae and too tall to represent an anthracothere but is compatible in dimensions (Table 2) with the taxon *Libycochoerus fategadensis* (Prasad 1967).

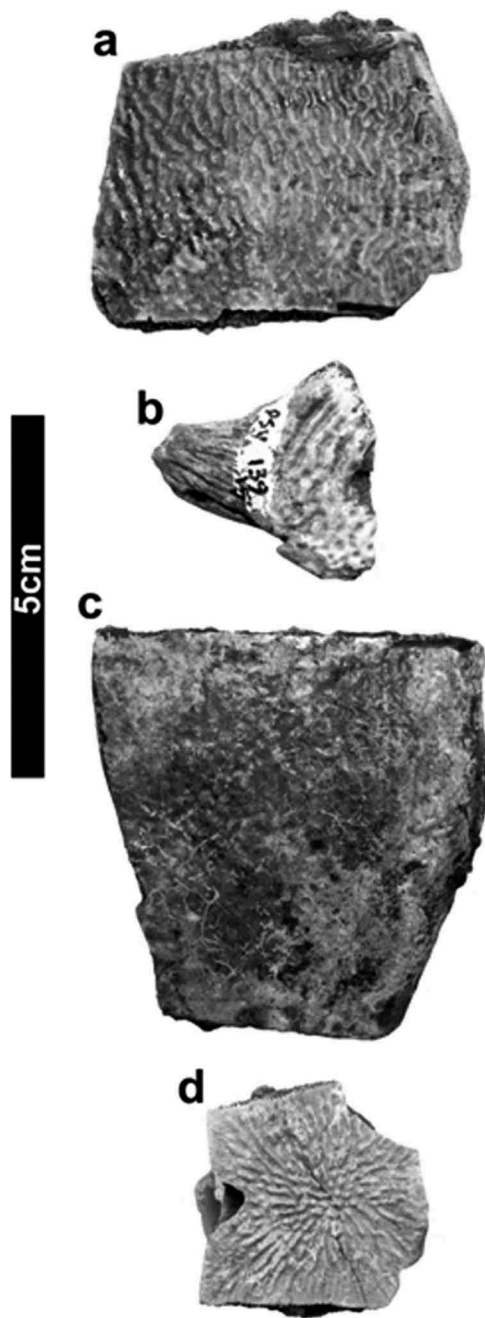


Figure 3. Chelonian scutes from Palasava, District Kachchh (Kutch), Gujarat State, western India. **a:** BSIP41775 (PSV140'15), **b:** BSIP41776 (PSV139'15), **c:** BSIP41777 (PSV141'15), **d:** BSIP41778 (PSV152'15) (note the three different types of ornamentation). Scale bar equals 5 cm for all.

Family Sanitheriidae Simpson 1945

Genus *Sanitherium* Von Meyer 1866

Type species *Sanitherium schlagintweiti* Von Meyer 1866

Sanitherium schlagintweiti Von Meyer 1866

A left mandible with p4-m3 (BSIP41792) and a left calcaneum (BSIP41793) are attributed to *Sanitherium schlagintweiti*. Table 3 provides measurements of the teeth and compares them with other specimens from the Indo-Pakistan region. Table 4 provides measurements of the

calcaneum (BSIP41793). The mandible (BSIP41792) is slender with a clear buccinator ridge just beneath the alveolar process on the buccal side. The ventral border is strongly curved (convex from front to rear) while the occlusal surface of the cheek teeth is concave longitudinally. The mental foramen lies beneath the p4 in the lower third of the mandible. The p4 is somewhat molarised, with strong paracoid and a well-developed hypoconid. The metaconid is prominent and placed lingually and slightly behind the protoconid. The first and second molars are quadricuspidate with a strong buccal cingulum. The lingual cusps are narrower and positioned bucco-lingually in comparison to the buccal cusps. There is a cusplet (metastylid) positioned slightly posterior to the summit of the metaconid. The anterior two lophids of the m3 are constructed along with the same plan as the m2; however, a prominent talonid which is as long as the second lophid is observed posteriorly. The cheek tooth enamel is coarsely wrinkled. The specimen was found in situ in indurated red sand with the mandibular chamber filled with the same sediment. This indicates that the sand is of the same age as the fossil specimen, i.e. Middle Miocene.

The second molar in the mandible from Palasava is similar to the type material of *Sanitherium schlagintweiti* from Kushalghar, Pakistan (Von Meyer 1866). It should be noted that Van der Made and Hussein (1992) described some poorly preserved sanithere teeth from the Manchar Formation of Sind and attributed them to *Sanitherium schlagintweiti*. Van der Made and Hussein (1992) concluded that *Sanitherium schlagintweiti* from Kushalghar and Manchar differed sufficiently from the Bugti (Pakistan) species which possesses simpler and smaller premolars, that the Bugti material should be classified in a separate species which they called *Sanitherium jeffreysi*. We agree with the morphological distinctions between *S. schlagintweiti* and *S. jeffreysi* noted by Van der Made and Hussein (1992), but we consider that the differences between the dental morphology of these two taxa are not only of specific value but indicate a difference at the genus level and for this reason we classify the Bugti taxon as *Diamantohyus jeffreysi*. We attribute the Palasava fossil material to *Sanitherium schlagintweiti*. It should be noted that prior to the discovery of the Palasava mandible the premolars of this species (particularly p4) were poorly preserved (see Van der Made and Hussein 1992) and thus were variously attributed to *Diamantohyus jeffreysi*, *Diamantohyus africanus* or *Sanitherium leobense*. The lower premolar (p4) of the Palasava specimen (BSIP41792) is larger and has a more complicated crown morphology compared to the p4 in the genus *Diamantohyus*, and supports our attribution of the premolars from Manchar described by Van der Made and Hussein (1992) to *Sanitherium* rather than to *Diamantohyus* (Pickford 1984, 1997, 2004, 2008; Pickford and Tsujikawa 2005).

It is pertinent to mention here that, in light of the global distribution of *Sanitherium* (Figure 10), the record of this genus

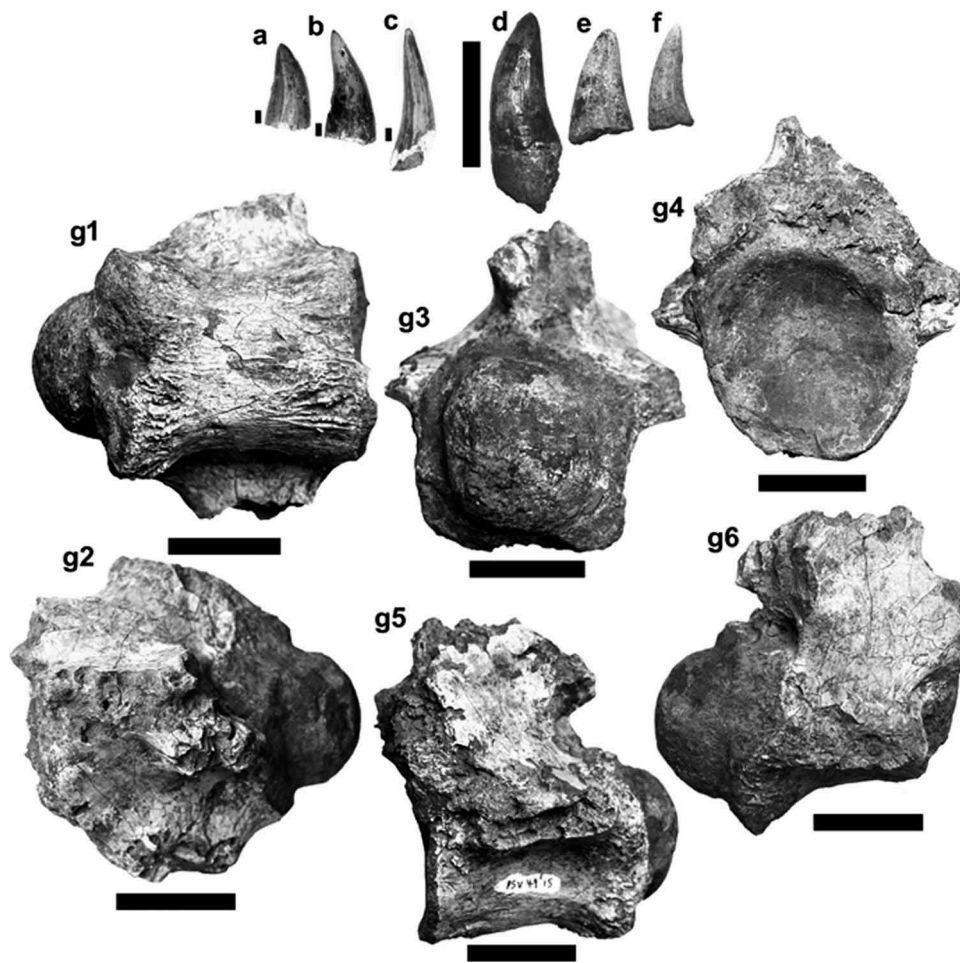


Figure 4. Crocodylian remains from Palasava, District Kutch (Kachchh), Gujarat State, western India. **a-f:** teeth [**a:** BSIP41779 (PSV1001'15); **b:** BSIP41780 (PSV1002'15); **c:** BSIP41781 (PSV1003'15); **d:** BSIP41782 (PSV1004'15); **e:** BSIP41783 (PSV1005'15); **f:** BSIP41784 (PSV1006'15)], **g:** vertebra [**g1-g6:** BSIP41785 (PSV49'15)]. Scale bar equals 2mm for **a-c**; 5 cm for **d-g**.

from India (present study) is quite rare, but certainly the oldest from the region.

Family Anthracotheriidae Gill 1872

Genus *Sivameryx* Lydekker 1878

Type species *Rhagatherium sindiense* Lydekker 1877

Sivameryx palaeindicus Lydekker 1877

Two poorly preserved anthracothere upper molars, an upper M1 or M2 (BSIP41794) and an M3 (BSIP41795) were collected from Palasava. Based on their general morphology and size, the two specimens are attributed to the genus *Sivameryx palaeindicus*. Measurements of the two specimens (BSIP41794 and BSIP41795) are provided in Table 5.

Family Tragulidae Milne-Edwards 1864

Gen. et sp. indet.

A few post-cranial bones from Palasava belong to a medium-sized Tragulidae. The most diagnostic

specimen is a left talus (BSIP41796) and its dimensions are provided in Table 6. The dimensions correspond to those of *Dorcabune sindiense* from the Sind region (Pakistan) and *Dorcatherium* form 2 and form 4 from the Siwaliks of the Potwar Plateau, Pakistan (Barry 2014). Other fossils, including a calcaneum, PSV114'15 (tuber length 26.7 mm) and a scapula fragment, PSV 87'15, of which the glenoid cavity measures 15.7 mm broad by 13.5 mm tall, are compatible in dimensions with the talus, suggesting the presence of a single species of tragulid in the deposits.

Order Perissodactyla Owen 1848

Family Rhinocerotidae Gray 1821

Genus *Brachypotherium* Roger 1904

Type species *Rhinoceros brachypus* Lartet 1837

Brachypotherium perimense Falconer and Cautley 1847

The most significant rhinocerotid specimen (BSIP41797) recovered from Palasava (District Kachchh (Kutch), Gujarat State, western India) is a left maxillary fragment with M1-M3. The antero-lingual portion of M1

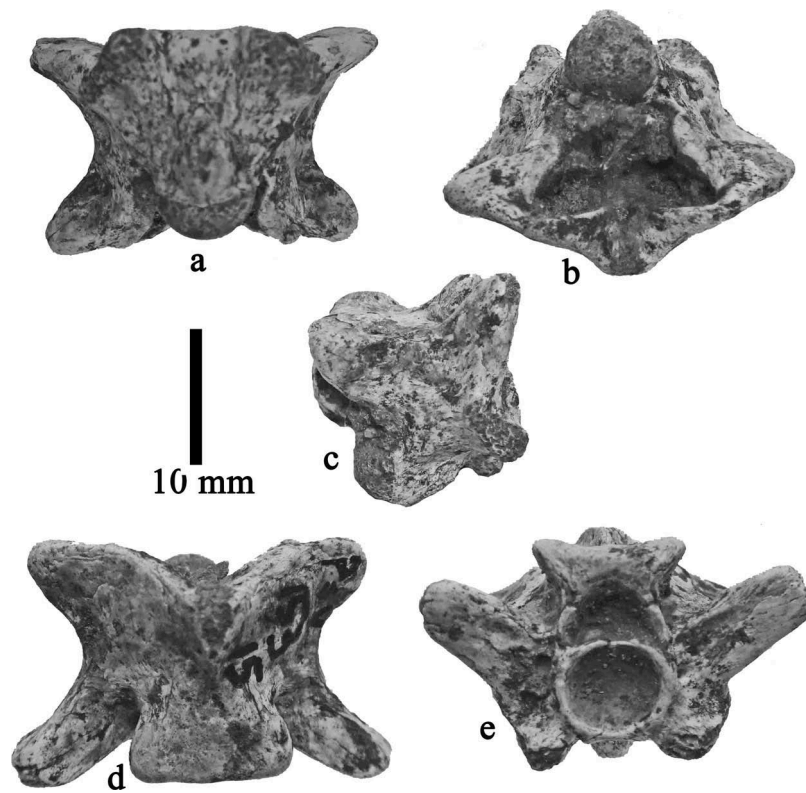


Figure 5. Isolated snake vertebra from Palasava [BSIP41786 (PSV 153'15)] attributed to *Acrochordus* sp. (a: ventral, b: caudal, c: lateral, d: dorsal, e: cranial views). Scale bar equals 10mm.

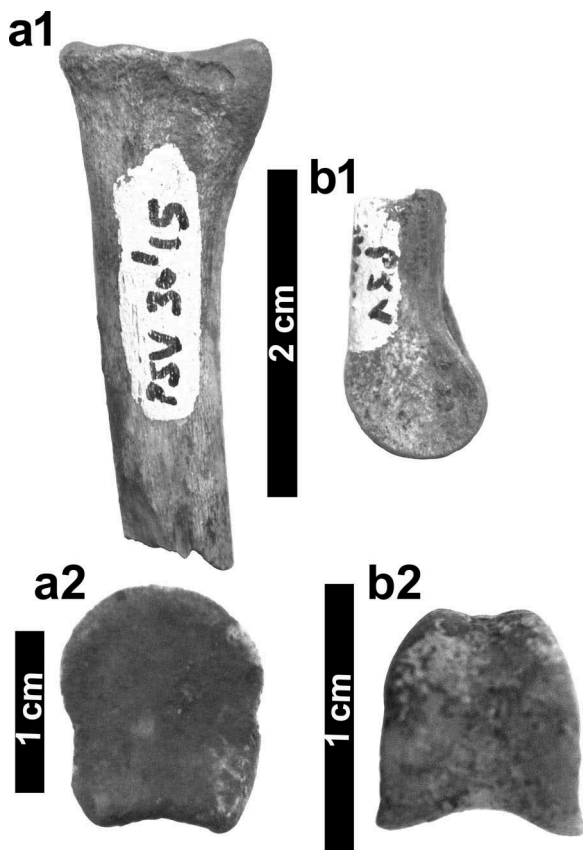


Figure 6. Remains of Aves possibly belonging to 'Flamingos' (Phoenicopteridae gen. et sp. indet) or 'Storks' (Ciconiidae gen. et sp. indet.) from Palasava, District Kutch (Kachchh), Gujarat State, western India. a1-a2: first pedal phalange; BSIP41787 (PSV 30'15) (a1: side view; a2: proximal view), b1-b2: first pedal phalange; BSIP41788 (PSV 144'15) (b1: side view; b2: distal view). Scale bar equals 2 cm for a1, b1; 1 cm for a2, b2.

and the lingual side of the M2 are broken; however, M3 is better preserved than the M1 and M2. The hypsodont molars lack a lingual cingulum (as observed in M3), have a weak protocone constriction, and moderately developed crochet and antecrochet which indicate that it belongs to *Brachypotherium perimense*. Furthermore, the dimensions of the molars in BSIP41797 (Table 7) are in agreement with the large size of *B. perimense* that has been previously recorded from the Siwaliks of the Indo-Pakistan region (Rafeh et al. 2018).

Rhinocerotidae gen. et sp. indet

At Palasava, the second taxon belonging to the family Rhinocerotidae is indeed a large rhinocerotoid that is represented by several huge post-cranial elements. The most complete specimen is a third metacarpal (BSIP41798) which is 240 mm long (Figure 14) with a flattened oval diaphyseal cross-section. The proximal articulation is 75 mm broad medio-laterally, and the dorso-volar height is 63.8 mm. At midshaft, the diaphysis measures 61 mm medio-laterally by 31.5 mm in dorso-volar dimensions, and the distal end is about 72 mm broad (damaged) by 50 mm in dorso-volar diameter. This bone indicates the presence of a running rhino at the site with major locomotor differences from the short-footed genus *Brachypotherium*. The metacarpal is probably too small to represent an indricothere, so we tentatively attribute it to a rhinocerotid.

Table 1. List of terrestrial mammals from Palasava, Rapar Taluka, Kutch (Kachchh) District, Gujarat State, western India.

Order	Superfamily/Family	Taxon	Representation (present study)
Artiodactyla	Suidae	-	Post-cranial remains (Figure 8; Table 2)
Artiodactyla	Sanitheriidae	<i>Sanitherium schlagintweiti</i>	Jaw, post-cranial remains (Figure 9; Tables 3 & 4)
Artiodactyla	Anthrotheriidae	<i>Sivameryx palaeindicus</i>	Teeth, post-cranial remains (Figure 11; Table 5)
Artiodactyla	Tragulidae	-	Post-cranial remains (Figure 12; Table 6)
Artiodactyla	Giraffoidea	-	Post-cranial remains (not illustrated)
Artiodactyla	Bovidae	-	Post-cranial remains (not illustrated)
Perissodactyla	Rhinocerotidae	<i>Brachypotherium perimense</i>	Teeth (Figure 13; Table 7)
Perissodactyla	Rhinocerotidae	-	Post-cranial remains (Figure 14)
Proboscidea	Mammutidae	<i>Zygodon sp.</i>	Teeth (Figure 15; Table 8)
Proboscidea	Gomphotheriidae	<i>Gomphotherium sp.</i>	Teeth, post-cranial remains (Figure 16; Table 9)
Proboscidea	Deinotheriidae	<i>Deinotherium sindiense</i>	Teeth, post-cranial remains (Figure 17; Table 10)

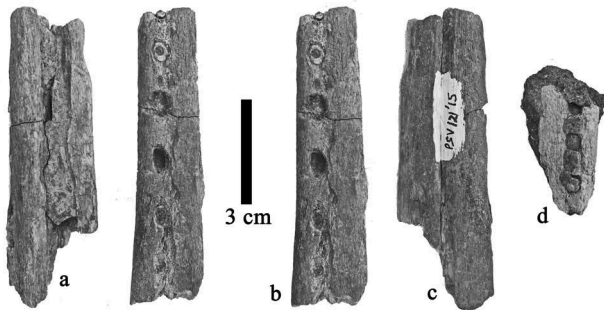


Figure 7. Cetacean (Eurhinodelphinidae gen. et sp. indet.) remains from Palasava, District Kutch (Kachchh), Gujarat State, western India. **a-c:** left mandible fragment with tooth sockets; BSIP41789 (PSV 121'15) (**a:** lingual, **b:** stereo occlusal, **c:** buccal view), **d:** right mandible fragment with tooth sockets; BSIP41790 (PSV 79'15); occlusal view. Scale bar equals 3 cm.

Order Proboscidea Illiger 1811

Family Mammutidae Hay 1922

Genus *Zygodon* Vacek 1877

Type species *Mastodonte tapiroide* Cuvier 1824

(= *Zygodon tapiroides*)

Zygodon sp.

Specimen BSIP41799, a left D2, is attributed to *Zygodon sp.* (for measurements refer to Table 8). The specimen has four low cusplets; however, the buccal cusplets are somewhat larger than the lingual cusplets. The two buccal cusplets are separated from the smaller, lower lingual cusplets by a well-developed, somewhat sinuous longitudinal valley. The transverse valley is V-shaped and unobstructed from buccal to lingual. In front of the anterior or 1st loph, there is a centrally positioned cusplet at the end of the preprotocrista. Distally there is a cingulum that descends from the lingual to the buccal side of the crown.

Family Gomphotheriidae Hay 1922

Type species of *Gomphotherium* – *Mastodon angustidens* Cuvier 1817

Gomphotherium sp.

The family Gomphotheriidae is represented at Palasava by an isolated upper third molar (M3) (BSIP41800) and an isolated lower second molar (m2) (BSIP41801) that we assign to *Gomphotherium sp.* (for measurements refer to Table 9). The tooth (BSIP41801) is heavily worn, showing large pre-trite cusps with prominent centroconids which give the enamel outline

Table 2. Dimensions (in mm) of the suid second phalanx [BSIP41791 (PSV 113'15)] from Palasava, Rapar Taluka, Kutch (Kachchh) District, Gujarat State, western India.

2nd phalanx (Specimen no. BSIP41791)	Measurement (mm)
Length	24.8
Proximal breadth	15.0
Proximal height	13.5
Distal breadth	13.2
Distal height	12.0

a trefoil shape. The post-trite cusps are mesio-distally narrower compared to pre-trite cusps and are devoid of centroconids.

It is pertinent to mention here that bunodont proboscidean molars are notoriously variable in the genera *Progomphotherium*, *Gomphotherium*, *Archaeobelodon*, *Platybelodon*, *Afrochoerodon* and *Protanancus* and thus, it is often difficult to determine the taxonomic affinities of isolated teeth. The gomphother teeth recovered from Palasava are similar in their diminutive dimensions and some aspects of their morphology to the *Gomphotherium annectens* group (Sanders et al. 2010); however, we refrain from providing a species level identification for the gomphother specimens recovered from Palasava (Figure 16).

Family Deinotheriidae Bonaparte 1845

Genus *Deinotherium* Kaup 1829

Type species *Deinotherium giganteum* Kaup 1829

Deinotherium sindiense Lydekker 1880

Our field investigation of the Palasava sedimentary succession yielded numerous well-preserved, isolated (but associated) teeth of a medium-sized species of *Deinotherium* herein attributed to *Deinotherium sindiense*. The *D. sindiense* specimens were found *in situ* in the basal red sand at the southern end of the Palasava Ridge, in close association with a well-preserved mandibular specimen of *Sanitherium schlagintweiti*. Measurements of these *D. sindiense* specimens are provided in Table 10. The upper premolars (P3) possess a strongly developed mesial loph with a distal groove, a strong postparacrista and a small, low hypocone. The mesial cingulum is present but weak. The upper premolar (P4) has two lophs separated by a deep, transverse valley. The postparacrista and premetacrista in the P4 (BSIP41804) descend towards the median transverse valley but do not cross the valley. The postprotocrista is oriented obliquely towards the middle of the transverse valley. Furthermore, the left P4 exhibits a strong lingual cingulum

Table 3. Measurements (in mm) of the teeth of *Sanitherium schlagintweiti* [BSIP41792 (PSV 32'15)] from Palasava (Rapar Taluka, Kutch (Kachchh) District, Gujarat State, western India) compared with specimens from the Indo-Pakistan region.

Tooth	Meiso-distal length (mm)	Bucco-lingual breadth (mm)	Locality/Region	Reference
p4	9.0	4.6	Palasava (India)	<i>Present study (Figure 9)</i>
m1	9.3	5.8	Palasava (India)	<i>Present study (Figure 9)</i>
m1	11.0	6.8	Siwaliks (Pakistan)	Pilgrim 1926
m1	9.0	6.5	Chinji (Pakistan)	Colbert 1935
m2	10.5	7.2	Palasava (India)	<i>Present study (Figure 9)</i>
m2	12.5	7.5	Chinji (Pakistan)	Colbert 1935
m2	11.0	8.0	Kushalghar (Pakistan)	Von Meyer 1866
m3	17.1	7.3	Palasava (India)	<i>Present study (Figure 9)</i>
m3	18.0	8.1	Sind (Pakistan)	Lydekker 1879

Table 4. Measurements (in mm) of the calcaneum [BSIP41793 (PSV 129'15)] attributed to *Sanitherium schlagintweiti* recovered from Palasava, Rapar Taluka, Kutch (Kachchh) District, Gujarat State, western India.

Calcaneum (Specimen no. BSIP41793)	Measurements (mm)
Total length	37.4
Tuber height	28.0
Talar facies height	11.2
Tuber antero-posterior breadth at mid height	9.6
Tuber minimal medio-lateral breadth	5.0
Antero-posterior diameter of sustentaculum	7.2

that blocks the lingual end of the transverse valley. The mesial and distal cingula in P4 are well-developed. The right upper molar (M1) is comprised of three lophs, and strong mesial and distal cingula. The lingual side of the crown in the M1 (BSIP41805) is convexly curved, and the buccal side is straighter with poorly expressed paracrista and metacrista. The left upper molar (M2) is bilophodont with a well-developed mesial cingulum. The paracrista and metacrista in the M2 (BSIP41807) are weakly developed. However, the postprotocrista and the posthypocrista in M2 are well-developed and are oriented obliquely towards the centre-line of the tooth. M2 has a small convolute on the distal aspect of the second loph.

Palaeoecology and palaeoenvironment

Overall, the fish elements from Palasava suggest the presence of freshwater, estuarine and marine taxa. The Selachimorph *Carcharinus* sp. and Myliobatiformes *Myliobatis* sp. quite likely dwelled in estuarine and marine water while pristids *Pristis* sp. may have preferred both estuarine and freshwater habitats. The exclusively freshwater fish fauna in the Palasava assemblage is represented by Cyprinids. The presence of chelonians comprising cyclanorbids, trionychids and pelomedusids; and the recovery of *Crocodylus* sp. and/or *Tomistoma* sp., and several snake vertebrae (Figure 5) attributed to Acrochordidae (*Acrochordus* sp.) are indicative of a riverine system connected to a shallow marine environment. A wet and highly productive aquatic ecosystem is also indicated by the possible presence of phoenicopterid birds at Palasava that generally feed on algae, molluscs and freshwater fishes.

The cetacean *Schizodelphis* is known from the Middle Miocene deposits at Wadi Moghara, Egypt (Fourtau 1920; Gingerich 2010) as well as occurring widely in the Miocene deposits of Europe (Gervais 1853; Abel 1901; Lambert 2005; Benoit et al. 2010). The elongated rostrum of the genus *Schizodelphis* suggests that it was adapted to estuarine

environments (Gingerich 2010) which accords with its presence at Palasava along with a mixed marine and freshwater molluscan assemblage comprising gastropods and bivalves [*Turritella* sp. (marine), *Bellamya* sp. (freshwater), oysters (marine) and mutelid bivalves (freshwater)].

Overall, the terrestrial mammalian assemblage comprising a sanitheriid *Sanitherium schlagintweiti*, an anthracothere (*Sivameryx palaeindicus*), a tragulid, two rhinocerotids (*Brachypotherium perimense* and a long-limbed species) and three genera of proboscideans (*Zygodolophodon*, *Gomphotherium* and *Deinotherium*) attests to the prevalence of a wooded habitat (experiencing humid, warm, tropical to sub-tropical conditions) close to semi-aquatic to fully aquatic (freshwater to marine) niches. In particular, the lophodont morphology of the cheek teeth of the genus *Zygodolophodon* appears to be related to a diet featuring a predominance of leafy material (Sanders et al. 2010). The same can be said of the genus *Deinotherium*. In addition, recovery of deciduous teeth of *Zygodolophodon* at Palasava indicates that the animal was breeding at or near the locality.

The palaeoenvironmental interpretations of Palasava based on the vertebrate fossil assemblage are in agreement with the published palaeobotanical evidence from the locality. The presence of a dominantly angiospermous palynomorph assemblage comprising *Spinizonocolpites*, *Spinomonocolpites*, *Retitrescolpites*, *Meliapollis*, *Ctenolophonidites*, *Palaeomalvaceaeapollis*, *Graminidites*, and *Ericipites* within the Palasava sedimentary succession, led Verma et al. (2013) to infer the existence of mangroves within the vicinity of tropical to subtropical forests that experienced warm and humid climatic conditions. Based on the palaeobotanical investigations of the permineralized fossil woods (*Bauhinium palaeomalabaricum* and *Ebenoxylon indicum*) from Palasava, Shukla et al. (2014) suggested the prevalence of tropical forests experiencing high precipitation, but little seasonality (in terms of temperature) in the Palasava area during the Miocene. Overall, the present and previous fossil finds from Palasava suggest that a rich diversity of fauna and flora sustained in a warm, humid/wet, tropical to sub-tropical environmental conditions during the Middle Miocene (~14 Ma).

Biostratigraphy

A preliminary correlation of fossil mammal localities of western India with the Siwalik succession of the Potwar Plateau, Pakistan is provided in Figure 18. The tragulid remains from Palasava are compatible in dimensions with *Dorcabune sindiense* (Pilgrim 1915) which, in the Potwar Plateau, ranges in

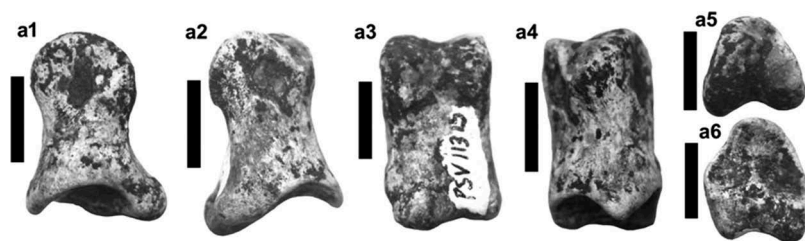


Figure 8. Suiform artiodactyl (*Suidae* gen. et sp. indet.) remains from Palasava, District Kachchh (Kutch), Gujarat State, western India. **a1-a6:** second phalanx; BSIP41791 (PSV 113'15) (**a1:** axial view; **a2:** abaxial view; **a3:** volar/plantar view; **a4:** dorsal view; **a5:** distal view; **a6:** proximal view). Scale bar equals 1 cm for all.

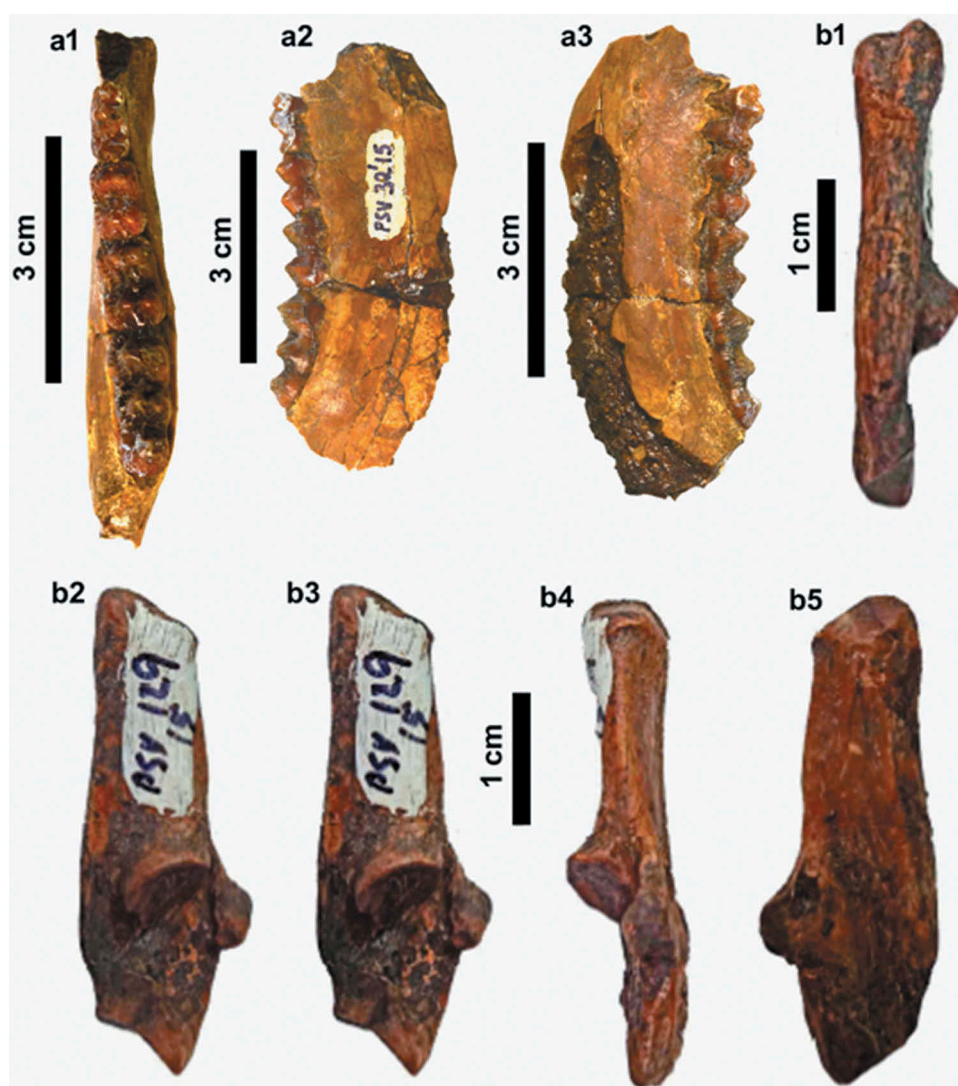


Figure 9. Remains of *Sanitherium schlagintweiti* (*Artiodactyla*; *Suidae*; *Sanitheriidae*) from Palasava, District Kutch (Kachchh), Gujarat State, western India. **a1-a3:** left mandible with p4-m3; BSIP41792 (PSV 32'15) (**a1:** occlusal view; **a2:** buccal view; **a3:** lingual view), **b1-b5:** left calcaneum; BSIP41793 (PSV 129'15) (**b1:** posterior view; **b2-b3:** stereo medial view; **b4:** anterior view; **b5:** lateral view). Scale bar equals 3 cm for **a1-a3**; 1 cm for **b1-b5**.

age from ca 16.8–13.6 Ma (Kamlial to lower Chinji levels). In the Sind region, the family Tragulidae occurs in the upper part of the Gaj Formation and the lower part of the Manchar Formation, which could be older than the Potwar occurrences (see Barry 2014). The genus *Zygodon* was widespread in the Old World during the Middle Miocene, being known from southern Africa, East Africa, Egypt, and Tunisia (Sanders et al. 2010) and many parts of Europe and Asia.

Zygodon (*Z. turicensis*) has a long time range in Europe, spanning the period from MN 3b to MN 10 (i.e. ca 20–10 Ma according to Garevski et al. 2012, but probably somewhat shorter, 18–10 Ma). *Deinotherium sindiense* from Palasava is a medium-sized deinothere. However, the previously known Sind deinothere material suggests the presence of two size groups. For instance, large specimens are known from Manchar, Shali Nala, Barai Nala and Dakko Nala [which are



Figure 10. Global (European, African, Indo-Pakistan region) distribution of the fossil record of the family Sanitheriidae. The index for localities is as follows – 1: Palasava (present study; marked by a red star), 2: Sind, 3: Bugti, 4: Chinji, 5: Kushalghar, 6: Leoben, 7: Chalkidiki, 8: Chios, 9: Wadi Moghara, 10: Gebel Zelten, 11: Langental, 12: Nyakach, 13: Napak, 14: Bukwa, 15: Loncherangan, 16: Nachola, 17: Kipsaraman, 18: Maboko, 19: Ombo, 20: Chianda Uyoma, 21: Karungu and 22: Rusinga.

as big as material from Chinji in the Salt Range (i.e. MN7/8 equivalent)] and comparatively small specimens are known from Bagathoro and Dakko Nala that are equivalent in dimensions to the Bugti assemblage (MN4-5) (Lydekker 1876, 1880; Pilgrim 1908, 1912; Sahni and Tripathi 1957). Medium-sized deinotheres were widespread in the Old

Table 5. Measurements (in mm) of the teeth [BSIP41794 (PSV 29'15); BSIP41795 (PSV 135'15)] of *Sivameryx palaeindicus* from Palasava, Rapar Taluka, Kutch (Kachchh) District, Gujarat State, western India.

Specimen (<i>Sivameryx palaeindicus</i>)	Meso-distal length (mm)	Bucco-lingual breadth (mm)
left M1 or M2 (BSIP41794)	21.0	-
left M3 (BSIP41795)	18.2	19.7

Table 6. Measurements (in mm) of the tragulid talus [BSIP41796 (PSV 128'15)] from Palasava, Rapar Taluka, Kutch (Kachchh) District, Gujarat State, western India.

Talus (Specimen no. BSIP41796)	Measurement (mm)
External length	28.8
Internal length	26.4
Proximal breadth	12.0
Distal breadth	14.8

Table 7. Measurements (in mm) of the teeth in the specimen [BSIP41797 (PSV 34'15)] of *Brachypotherium perimense* (Perissodactyla: Rhinocerotidae) from Palasava, Rapar Taluka, Kutch (Kachchh) District, Gujarat State, western India. *Estimate.

Specimen	Tooth	Length (mm)	Max. Breadth (mm)
BSIP41797	M1	55.6*	62.6
BSIP41797	M2	54.3	70.1
BSIP41797	M3	53.6	58.5

World during the Middle Miocene and were replaced by large to gigantic forms during the Late Middle Miocene (MN8 and MN9 in Europe) and the Late Miocene (MN10 – MN12) (Pickford and Pourabrishami 2013). The dimensions of the Palasava deinotheres teeth are compatible with an age range of 18 to 13 Ma. Overall, we infer that the Palasava terrestrial mammal assemblage likely correlates to MN6, approximately 14 Ma (Figure 19).

Based on a deinotheres tooth from the locality Samda (known previously as 'Sambera'), Lydekker (1876) correlated the Kutch deposits at Samda (Kutch District, Gujarat State, western India) to the Early Miocene, approximately equivalent to the Burdigalian of Europe or the Lower Siwaliks of Pakistan. In the 1960s, Prasad (1964) described two mammal species from the locality Fatehgarh (Kutch District, Gujarat State, western India), which he correlated to the Manchar series of Pakistan, approximately equivalent to the Lower Siwaliks of the Potwar Plateau. The works of Biswas and Raju (1973) and Biswas (1992) on the Kutch marine fossil records in the context of proposing a lithostratigraphic correlation of the late Palaeogene succession (best exposed in the west of the Kutch Peninsula near the localities of Pipar and Khari Nadi) were certainly influential. However, these authors did not focus much on the biostratigraphic correlation of the Neogene succession of Kutch. Nonetheless, Bhandari et al. (2010) while recording mammals from Pasuda (Kutch District, Gujarat State, western India) accepted an Aquitanian age proposed earlier by Biswas (1992) concerning the ferruginised conglomerates of Eastern Kutch belonging to the Khari Nadi Formation. However, as some of the fossil mammals from Pasuda hinted at a younger age, Bhandari et al. (2010) correlated the deposits at Pasuda to the base of the Langhian. Subsequently, the two localities (i.e. Pasuda and Tapar) in the Kutch region yielded mammalian fossils [*Hipparion*, a hominoid (*Sivapithecus*), rodents and suids] within the conglomerates indicating a basal Late Miocene age i.e. close to the Chinji-Nagri Boundary (ca 11–10 Ma) (Bhandari et al. 2018 and references therein). It should be noted that the first Asian occurrence of *Hipparion* is well established in the Potwar Plateau (Pakistan) where it occurs in the normal-polarity interval Chron C5n dated to ~ 10.7 Ma. Further, the earliest appearance of hominoid fossils within the Chinji Formation (Potwar Plateau, Pakistan) occurs close to 12.7 Ma (Kappelman et al. 1991). Thus, the inclusion of the conglomerates of the Pasuda-Tapar region (yielding *Hipparion*, a hominoid and associated mammalian remains) within the Khari Nadi Formation is very likely unsustainable. Recent palaeobotanical investigations at Palasava by Verma et al. (2013) and Shukla et al. (2014) led the authors to correlate the Chhasra Formation (which is reported to overlie the Khari Nadi Formation) to the Early Miocene (Burdigalian) and the Sandhan Formation to the Pliocene, as did Raju (2014), following the prior results of Biswas (1992). However, based on the mammalian assemblage recovered from Palasava (present investigation), we here correlate the Palasava sedimentary succession to the Lower Siwaliks (~14 ± 2 Ma; Langhian-Serravallian). In contrast to earlier reports, the Sandhan Formation is probably older than previously envisaged, i.e. basal Late Miocene rather than Pliocene. We believe that a more detailed, concerted remapping of the geology and stratigraphy of the Kutch Peninsula and the collection of stratigraphically controlled fossil samples is required to clarify the succession and timing of geological and

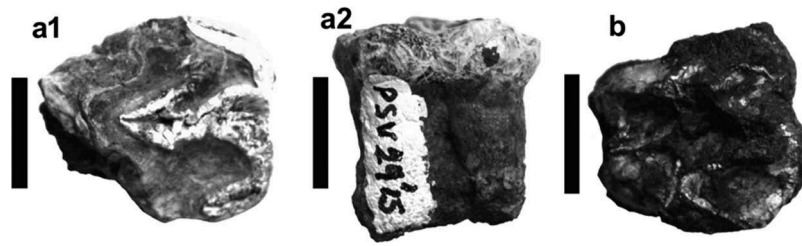


Figure 11. Remains of *Sivameryx palaendicus* (Artiodactyla; Anthracotheriidae; Bothriodontinae) from Palasava, District Kutch (Kachchh), Gujarat State, western India. **a1-a2:** fragmentary left upper molar (M1 or M2); BSIP41794 (PSV 29'15) (**a1:** occlusal view; **a2:** lingual view), **b:** left upper molar (M3); BSIP41795 (PSV 135'15); occlusal view. Scale bar equals 1 cm for all.

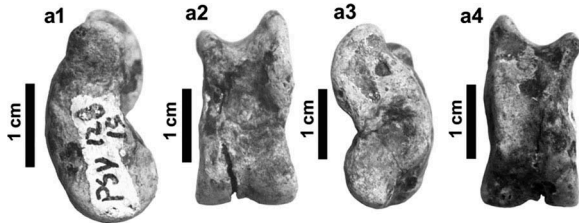


Figure 12. Remains of ruminant (Tragulidae gen. et sp. indet.) from Palasava, District Kutch (Kachchh), Gujarat State, western India. **a1-a4:** left talus; BSIP41796 (PSV 128'15) (**a1:** medial view; **a2:** anterior view; **a3:** lateral view; **a4:** posterior view). Scale bar equals 1 cm for all.

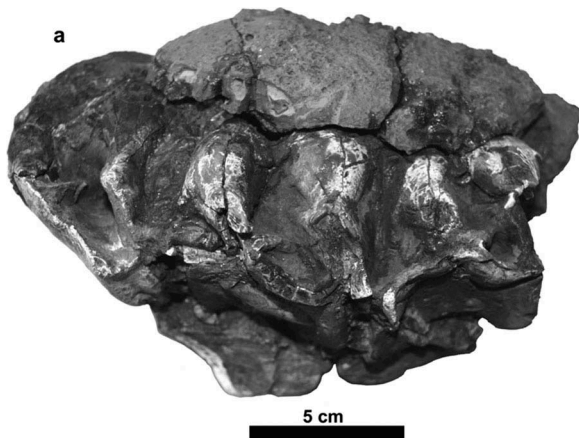


Figure 13. Remains of *Brachypotherium perimense* (Perissodactyla; Rhinocerotidae) from Palasava, District Kutch (Kachchh), Gujarat State, western India. **a:** left maxilla with M1-M3; BSIP41797 (PSV 34'15); occlusal view.

palaeontological events in the region. Available data suggest that there is a considerable span of time represented in the Neogene strata of the Kutch Basin. Considering the Neogene ossiferous localities within the Kutch Basin, the two localities (Fatehgarh and Pipar) likely correlate to the Burdigalian (ca. 18–19 Ma), and the two localities (Pasuda and Tapar) most likely correlate to the base of the Middle Siwaliks (ca. 10–11 Ma), while several localities (Samda, Junagia and Jangadia) and the presently investigated locality (Palasava) correlate to the Lower Siwaliks (ca. 14–16 Ma). Considering the Neogene deposits of the PIRAM Island (Gulf of Cambay, located south of Kutch), it best correlates to the upper part of the Middle Siwaliks (ca. 7–8 Ma), i.e. equivalent to the Turolian of Europe, thereby extending the representation of the

biostratigraphic column of Western India upwards into the late Miocene.

Palasava mammalian assemblage and its correlation to sea-level changes linked to Eustacy

A correlation of the fossiliferous localities of Kutch (Gujarat State, western India) with the Eustatic curves of the Mediterranean and Paratethyan megabasins as envisaged in the present investigation is provided as Figure 20. Considering the data on sedimentary accumulations linked to Eustatic changes (rather than to regional tectonics; although the latter cannot be completely ruled out) numerous studies have been undertaken within the Mediterranean and Paratethys regions (Steininger et al. 1976; Rögl and Steininger 1983; Ginsburg 1984, 1990, 2000; Pickford 1998; Rögl 1999a, 1999b). These studies show similar depositional histories linked to sea-level changes (regressions and transgressions) as a consequence of Eustacy. Barry et al. (1985), Rögl (1999a) and Harzhauser et al. (2007) have previously suggested that a major transgression event occurred close to the late Burdigalian that led to the accumulation of Early and Middle Miocene fluvio-marine and littoral sediments of the Bugti and Sind (Pakistan), Kutch region (western India) and in the low-lying areas of the Irrawaddy (Myanmar) (Figure 20). On the basis of the faunal correlations, the Kutch deposits most likely correlate with the Neogene transgressions i.e. Sea Level cycle TB 2.2 (Woodburne and Swisher 1995) and the C5 and C6 highstands in the Tagus Valley succession, Portugal (Rögl and Steininger 1983; Bhandari et al. 2010; also refer to Figure 20, present article). With regards to the inferred ~14 Ma age of the Palasava faunal assemblage, it correlates to the regression cycle R5 within the C5 and C6 highstands in the Tagus Valley succession (Rögl and Steininger 1983).

Discussion and conclusions

The Kutch region of western India is taking on renewed importance for Neogene palaeontology of India with the realisation that it possesses a richly ossiferous series of marine and continental strata that spans the Early, Middle and Late Miocene periods. Our present and recent investigations on

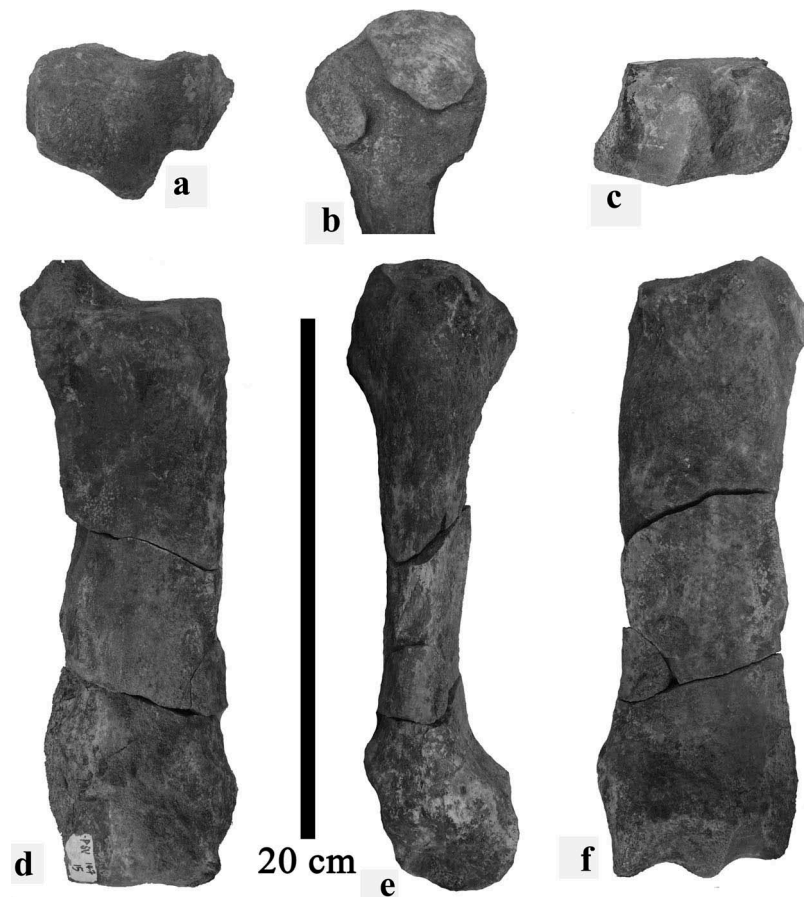


Figure 14. Various views of right metacarpal III of a large running rhinocerotid [BSIP41798 (PSV 147'15)] from Palasava. (a) proximal view, (b) axial view of proximal end, (c) distal view, (d) volar view, (e) abaxial view, (f) dorsal view. Scale bar equals 20 cm.

Table 8. Measurements (in mm) of the isolated tooth [BSIP41799 (PSV 83'15)] of *Zygodolophodon* sp. (Proboscidea: Mammutiidae) from Palasava, Rapar Taluka, Kutch (Kachchh) District, Gujarat State, western India.

Specimen	Length (mm)	Breadth (mm)		
		1st loph	2nd loph	3rd loph
left D2 (BSIP41799)	29.0	18.2	20.1	-

Table 9. Measurements (in mm) of the teeth [BSIP41800 (PSV 4'15); BSIP41801 (PSV 42'15)] of *Gomphotherium* sp. (Proboscidea: Gomphotheriidae) from Palasava, Rapar Taluka, Kutch (Kachchh) District, Gujarat State, western India.

Specimen	Breadth (mm)		
	1st loph	2nd loph	3rd loph
Left M3 (BSIP41800)	-	83.6	70.4
Right m2 (BSIP41801)	-	-	63.0

fossil vertebrates from the Kutch Basin highlight the significance of the Neogene palaeontology of the region in palaeoenvironmental, palaeoecological and biostratigraphic contexts linked to Eustatic changes during the Neogene. Concerted palaeontological efforts in the region have led to the delineation of several vertebrate-bearing (including mammal) deposits and/or localities including Palasava (present study). The Palasava vertebrate assemblage comprising fishes, reptiles,

birds and mammals (including the genera *Zygodolophodon* and *Deinotherium*) is indicative of a Middle Miocene, 14 ± 2 Ma (Langhian to Serravallian) age for the sedimentary succession at the site. The presence of *Hipparion*, the hominoid *Sivapithecus*, and associated mammalian remains (rodents and suids) at Pasuda indicate a correlation to the Chinji-Nagri zones of the Potwar Plateau, Pakistan (ca 11–10 Ma). In addition, the two ossiferous localities (Fatehgarh and Pipar) which correlate to the Burdigalian (ca. 18–19) and the deposits of the PIRAM Island (Gulf of Cambay) which correlate to the upper part of the Middle Siwaliks (ca 7–8 Ma) extend the biostratigraphic column of Western India from the basal Miocene upwards into the late Miocene. The potential for further discoveries of vertebrates is evident at Palasava and elsewhere in the Kutch Peninsula. We reiterate that our field investigation at Palasava resulted in the recovery of numerous unidentified post-cranial remains quite likely belonging to giraffids and bovines; however, these specimens certainly warrant a separate detailed investigation.

The Neogene biogeographic aspects pertaining to the mammalian records from the Indian subcontinent have been previously discussed by many works (see Patnaik 2016 and references therein). As presently understood, the genus *Gomphotherium* was amongst the first large mammal from Africa to cross into the Indian subcontinent via the Afro-

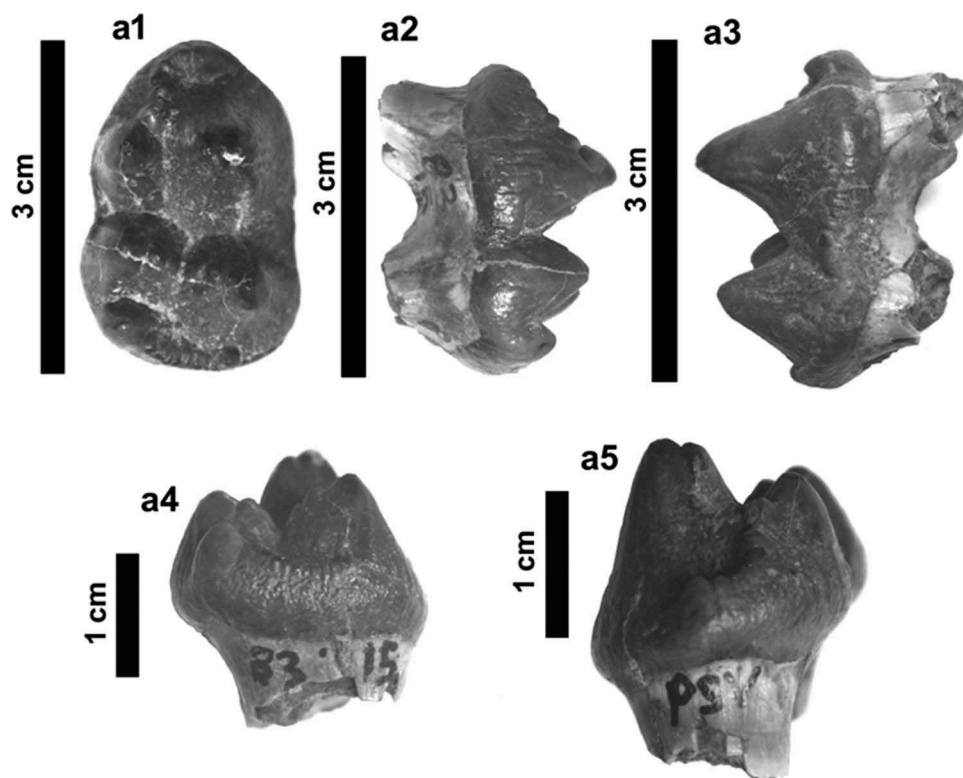


Figure 15. Remains of *Zygodon* sp. (Proboscidea; Mammutidae) from Palasava, District Kutch (Kachchh), Gujarat State, western India. **a1-a5:** left upper deciduous tooth (D2); BSIP41799 (PSV 83'15) (**a1:** occlusal view; **a2:** lingual view; **a3:** buccal view; **a4:** distal view; **a5:** mesial view). Scale bar equals 3 cm for **a1-a3**, 1 cm for **a4** and **a5**.

Arabia-Eurasia Landbridge (also known as the 'Gomphotherium Land Bridge') during the early Miocene (~18 Ma). However, an agile swimming capability of *Gomphotherium* has also been argued in favour of an earlier (i.e. close to ~22 Ma) Out-of-Africa migration of *Gomphotherium* prior to the establishment of Afro-Eurasia Land Bridge. Neogene fossil records of the genera *Sanitherium* and *Zygodon* within the Indian subcontinent (including the ones reported herein from Palasava), Africa and Europe clearly suggest intermittent biotic exchanges within these landmasses. Orliac et al. (2010) argued in favour of origin of sanitheres within the Indian subcontinent with subsequent dispersal to Africa. In general, it is considered that the intermittent mammalian dispersals between Africa, Europe and Indian subcontinent were linked to sea-level fluctuations during the Neogene (particularly Miocene) time-interval. As already discussed, the Neogene (particularly Miocene) sedimentary sequences of the Kutch region certainly hold potential in yielding additional mammalian finds. Thus, any new mammalian discoveries from the Oligocene-Miocene intervals would surely help in enhancing our understanding of the Neogene historical biogeographic and allied aspects of the Indian subcontinent.

In the context of palaeoenvironment, the faunal assemblage from Palasava is indicative of the prevalence of a warm, humid/wet, tropical to sub-tropical environmental conditions during the Middle Miocene (~14 Ma). As such, the overall fauna (dealt with in the present study) supports

previous palaeobotanical interpretations of Palasava about the presence of a forest in the vicinity of a riverine-estuarine system linked to the sea. Furthermore, an envisaged ~14 Ma age for the Palasava fauna indicates a correlation to regression cycle R5 in the Tagus Valley succession of Portugal.

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Disclosure statement

No potential conflict of interest was reported by the authors.

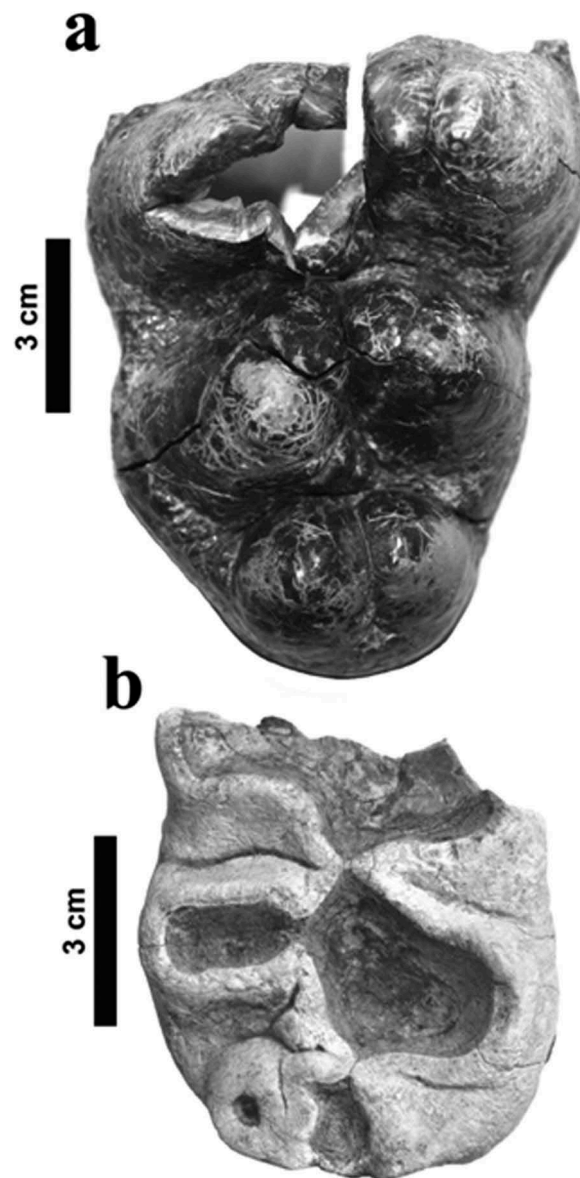


Figure 16. Dental remains of *Gomphotherium* sp. (Proboscidea: Gomphotheriidae) from Palasava, District Kutch (Kachchh), Gujarat State, western India. **(a)** distal loph of left upper molar (M3); BSIP41800 (PSV 4'15); occlusal view, **(b)** distal loph of right lower molar (m2); BSIP41801 (PSV 42'15); occlusal view). Scale bar equals 3 cm for **(a-b)**.

Table 10. Measurements (in mm) of the teeth of *Deinotherium sindiense* (Proboscidea: Deinotheriidae) from Palasava, Rapar Taluka, Kutch (Kachchh) District, Gujarat State, western India.

Specimen	Mesio-distal length (mm)	Bucco-lingual breadth (mm)
Left P3 (BSIP41802)	41.5	42.0
Right P3 (BSIP41803)	41.3	41.5
Left P4 (BSIP41804)	51.5	56.5
Right M1 (BSIP41805)	74.5	51.4
Left M2 (BSIP41807)	75.6	72.6
Left P3 (BSIP41806)	41.5	44.5
Right m3 (PSV 100' 15)	77.0	60.6

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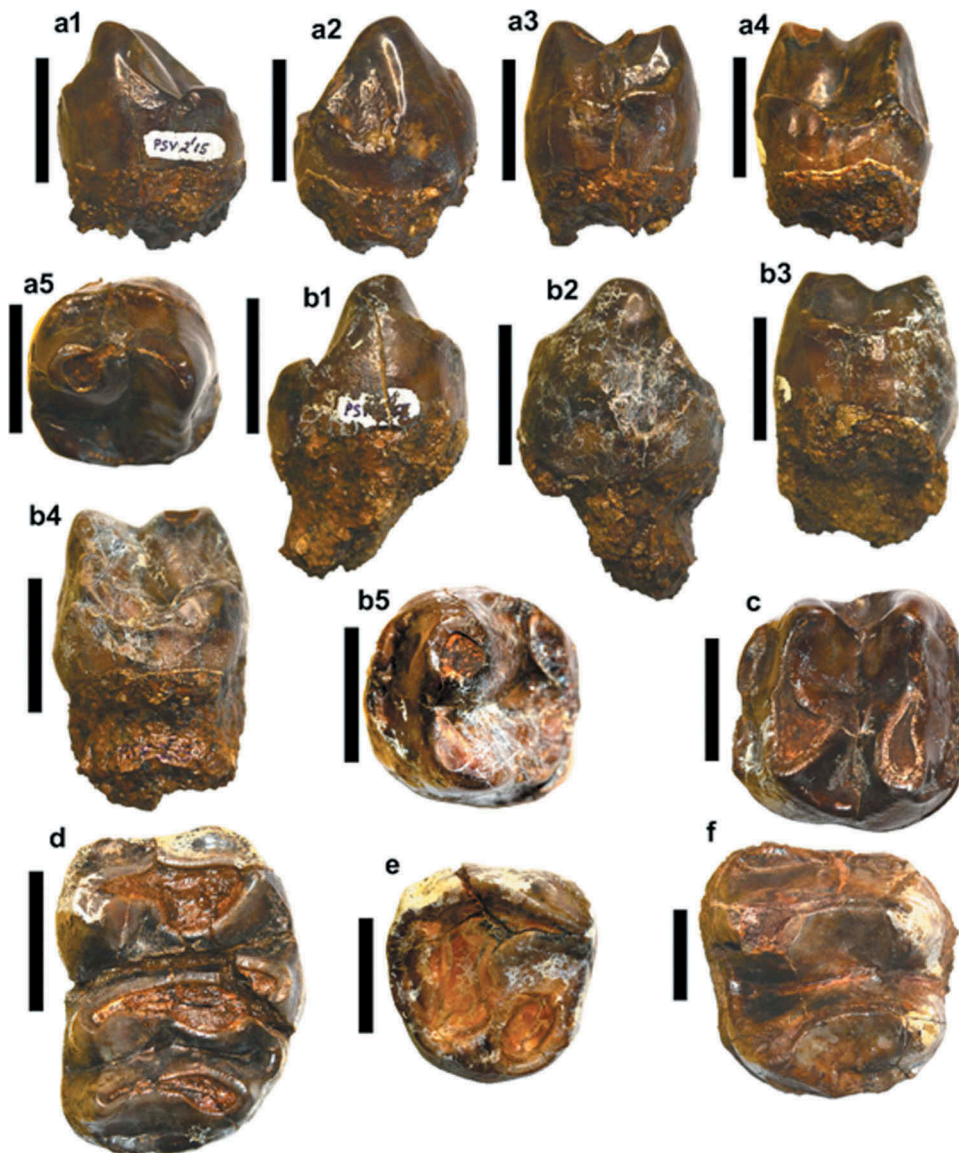


Figure 17. Remains of *Deinotherium sindiense* (Proboscidea: Deinotheriidae) from Palasava, District Kutch (Kachchh), Gujarat State, western India. (a1-a5: left upper premolar (P3); BSIP41802 (PSV 2'15) (a1: lingual view; a2: buccal view; a3: anterior view; a4: posterior view; a5: occlusal view, b1-b5: right upper premolar (P3); BSIP41803 (PSV 2'15) (b1: lingual view; b2: buccal view; b3: anterior view; b4: posterior view; b5: occlusal view), c: left upper premolar (P4); BSIP41804 (PSV 2'15); occlusal view, d: right upper molar (M1); BSIP41805 (PSV 2'15); occlusal view, e: left upper premolar (P3); BSIP41806 (PSV 41'15); occlusal view, f: left upper molar (M2); BSIP41807 (PSV 3'15); occlusal view. Scale bar equals 3 cm for all.

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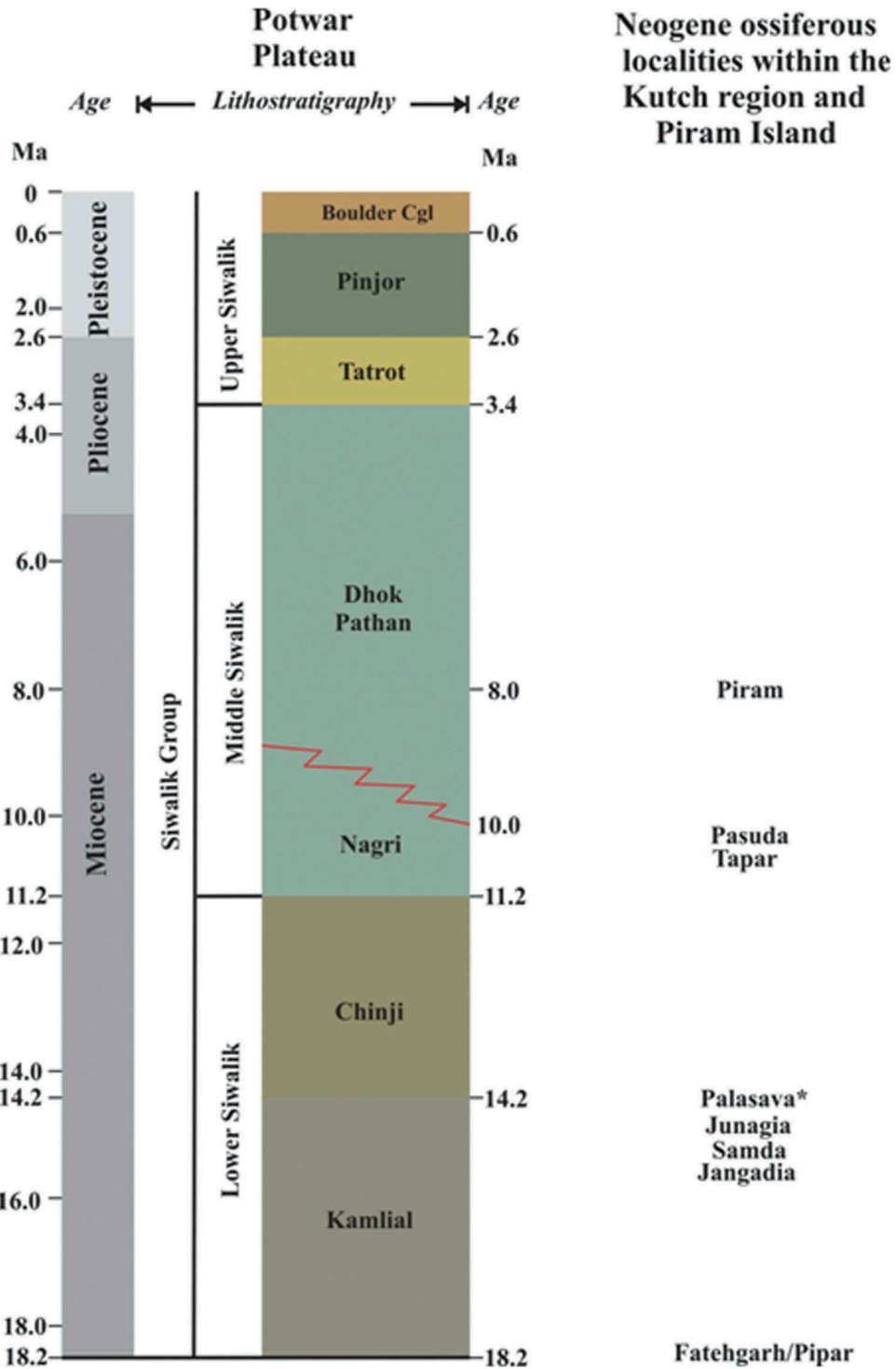


Figure 18. Correlation of fossil mammal localities of western India with the Siwalik succession of the Potwar Plateau, Pakistan.

Note: Siwalik succession modified after Johnson et al. (1982) and Barry et al. (2005). Asterisk (*) marks the studied locality (Palasava).

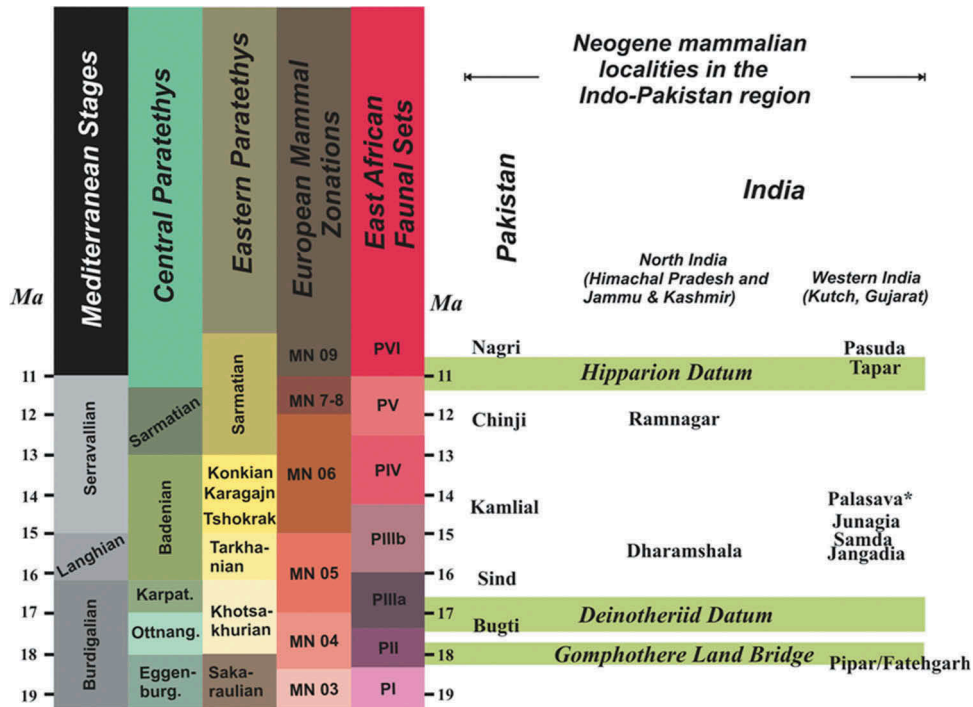


Figure 19. Correlations of the Indo-Pakistan (including Kutch region) Neogene fossil mammal localities with the European, African and Central & Eastern Paratethyan sedimentary sequences.

Note: Palasava is most likely to be about 14 ± 2 Ma, and if so, then it helps to fill the gap between the late Early Miocene deposits at Pipar, Fatehgarh and Samda on the one hand, and the basal Late Miocene deposits at Pasuda and Tapar on the other (all within the Kutch Basin). Asterisk (*) marks the studied locality (Palasava).

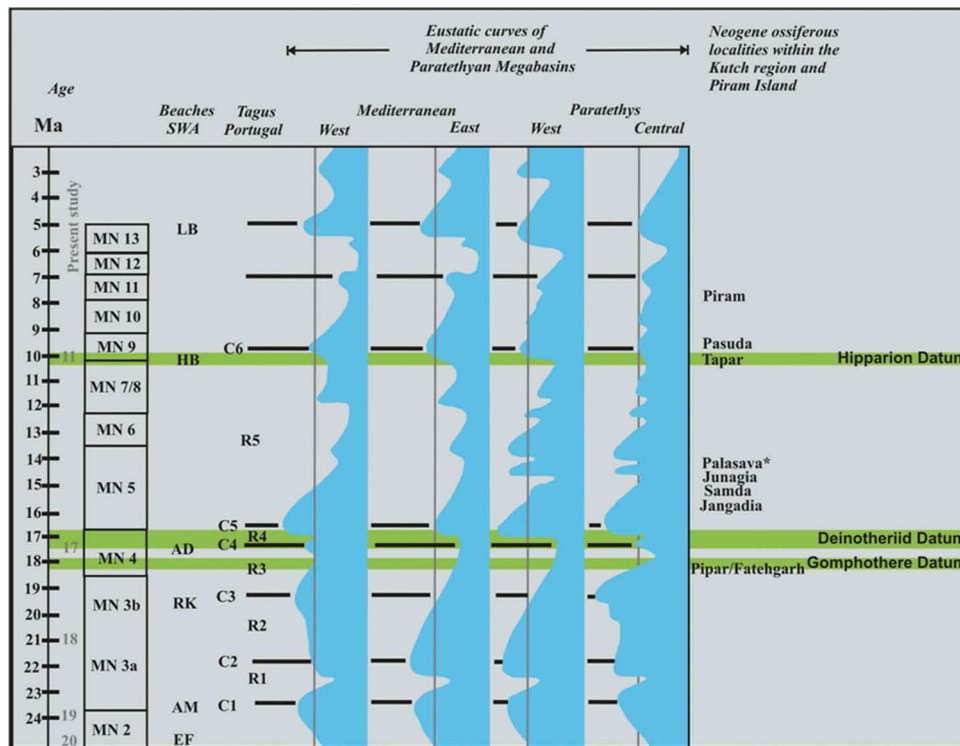


Figure 20. Correlation of the Kutch (Gujarat State, western India) fossiliferous deposits with the Eustatic curves of the Mediterranean and Paratethyan megabasins. Note: European phases after Steininger et al. (1976); Time-Scale adjusted to Gradstein et al. (2004). Asterisk (*) marks the studied locality (Palasava).

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