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TWO FOSSIL SHARK TEETH FROM LOWER EOCENE SHALES OF THE KHUIALA FORMATION, JAISALMER BASIN, INDIA

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ABSTRACT

Two fossil shark teeth (*Galeorhinus* and *Physogaleus*), recorded from Lower Eocene sediments of the Khuiala Formation Jaisalmer Basin, are being described and illustrated. This is the first record of *Physogaleus* from the Jaisalmer Basin. The record of *Galeorhinus* from the Jaisalmer Basin suggests subtropical sea condition during Early Eocene time.

Keywords: Shark teeth, Eocene, Jaisalmer, India

INTRODUCTION

Despite fossil richness in the Paleogene sediments of the Jaisalmer Basin along the western margin of the Indian craton, only a few vertebrate fossils have been recorded till date (Kumar *et al*., 2007). Notably, while fossil shark teeth are ubiquitously found in the Paleogene sediments, they are rarely recorded from the Jaisalmer Basin. This study describes the recovery of two separate shark teeth assigned to the genera *Galeorhinus and Physogaleus*. Our study is potentially the first to record of the genus *Physogaleus* from the Jaisalmer Basin. Both the aforesaid shark genera potentially display dignathic and/or gynandric heterodonty, where the former is commonly observed among sharks (Cappetta, 1980: 37; Ward and Bonavia, 2001; Reinecke *et al*., 2005: 57-59, 138; Padilla *et al*., 2018) and hence the identification is a little complicated.

The present article describes and illustrates these two shark teeth from the Jaisalmer Basin and provides a review of their stratigraphic distribution in the Indian Subcontinent. Both the specimens have been recorded from a marly shale bed (Lower Eocene) of the Khuiala Formation (Fig. 1).

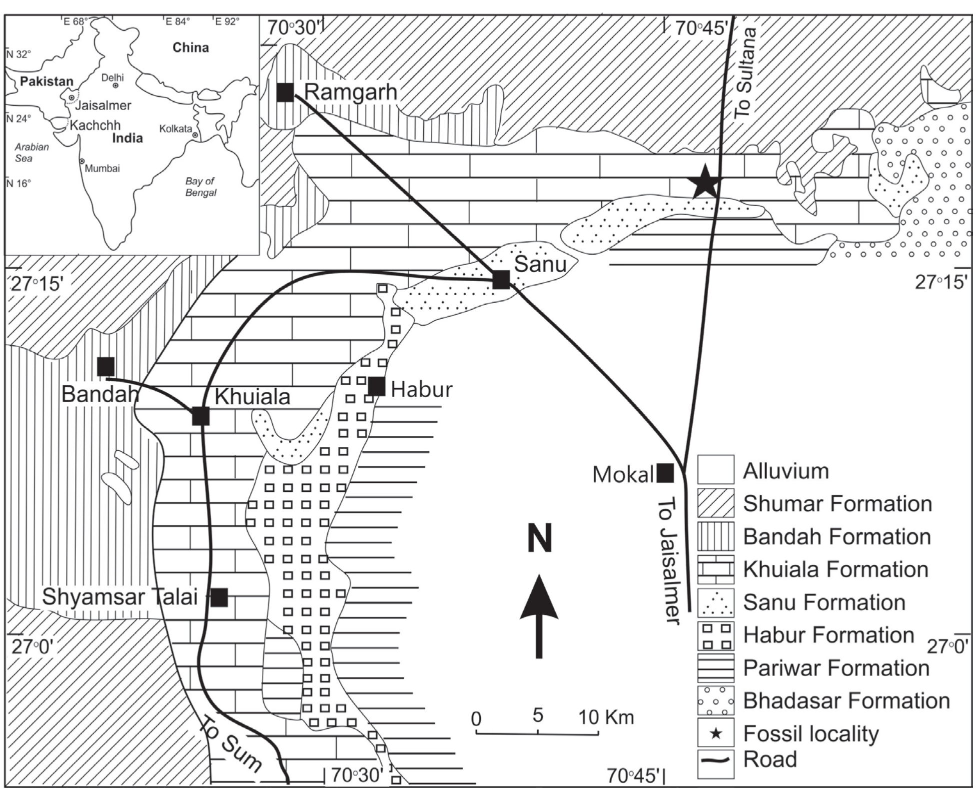


Fig. 1. Geological map of Khuiala-Sanu-Habur-Sultana areas of the Jaisalmer Basin showing Cenozoic outcrops and fossil locality (map modified after Kumar *et al*., 2007).

GEOLOGICAL SETTING OF THE JAISALMER BASIN

The Jaisalmer sedimentary basin is a shelf basin situated at the western margin of the Indian craton (Fig. 1, Das Gupta, 1975; Pandey *et al*., 2014). The sedimentary horizons of the basin are richly fossiliferous and easily accessible, however, the successions show several sedimentary gaps and are partly hidden under recent sand cover. Nevertheless, the rocks of the Jaisalmer Basin range from Precambrian to Holocene. Broadly, the sedimentary sequences overlying the basement rocks, the Malani Igneous suite, can be grouped into three. The oldest strata, assigned to Precambrian/Early Cambrian and Permian/Triassic age, have no outcrop in the basin, rather have been discovered in subsurface only. The middle group of strata, representing Jurassic and Cretaceous, covers the major part of the basin from southeast to northwest, whereas, the upper group of strata, corresponding to Paleogene and Quaternary, are exposed in the north-western part of the basin. Lithostratigraphically, the Paleogene strata consist of Sanu, Khuiala and Bandah formations (Fig. 1). The exposed part of the Khuiala Formation has been further divided into two members; Te-Takkar Limestone Member and Khinsar Shale members (Singh, 1984, 2007). These Tertiary formations are very rich in large foraminifera and subordinately ostracods, lamellibranchs, gastropods, echinoids and fish teeth have also been recorded, Accordingly, Late Paleocene to Middle to Late Eocene age has been assigned (Bhandari, 1996, 1999; Chatterji, 1960; Das Gupta, 1974, 1975; Kalia and Chakraborty, 1985; Khosla, 1973; Kumar *et al*., 2007; Lukose, 1974; Pareek, 1984; Sigal *et al*., 1971; Singh, 2003, 2007).

Due to change in latitudinal position of the Indian craton during the Paleogene, fluctuating nature of relative sea-level, and consequently palaeoenvironmental parameters, there has been a rapid change in lithology and faunal content. Generally, lower part of the Sanu Formation is exclusively siliciclastic and has been considered non-marine (Pandey and Bhadu, 2009, 2010a, b). The overlying younger part of Sanu Formation, all Khuiala and Bandah formations consist of dominantly carbonates and subordinate siliciclastic sediments of different marine sedimentary cycles (Pandey and Bhadu, 2010b). There are sharp chronological changes in the lithology, body fossil composition and bioturbation index. This uniqueness of the Jaisalmer Basin has attracted the palaeontologists and sedimentologists from all over the world (Pandey *et al.*, 2014).

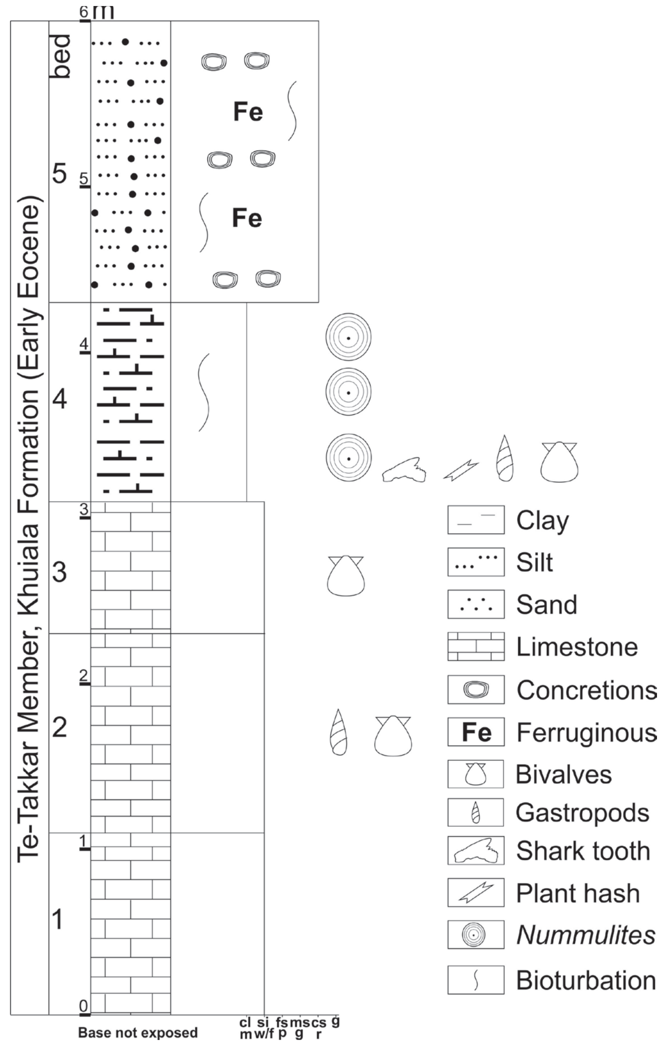


Fig. 2. Litholog of Tertiary succession yielding shark teeth, exposed 50 km north of Jaisalmer and 16 km south of Sultana village (Coordinates: 27º 19.133' N:70º 48.364' E; also see Fig. 1), in the Jaisalmer Basin; cl: clay, si: silt, fs: fine sand, ms: medium sand, cs: coarse sand, g: granule, m: mud, w/f: wackestone/floatstone, p: packstone, g: grainstone, r: rudstone.

MATERIAL AND METHODS

The specimens were collected during the months of November and December 2017 from a small domal outcrop (coordinates: 27°19.133'N:70°48.364'E) 50 km north of Jaisalmer and 16 km (milestone) south of Sultana village on the left side of Mokal – Sultana road. A 1.5. m thick marly shale bed (Figs. 1 and 2) of the Te-Takkar Limestone Member of the Khuiala Formation (Singh, 1984, 2007) is exposed at the base of a small dome has yielded two shark teeth along with large foraminifera (*Nummulites*), small to moderate-sized bivalves, gastropods, small fragments of teeth, coprolites, plant-hash, etc. The first specimen (MCNS2017Jaisalmer 1) could be observed in the field but other (MCNS2017Jaisalmer 2) could only be visible after overnight soaking and decomposing the marly shale sample in H_2O_2. The teeth specimens were measured under NSZ-606 binocular stereo zoom microscope and photographs were taken by Apple I phone 6+ mobile. The images were processed using Adobe photoshop and coral draw software. The specimens have been deposited in Manipal Centre for Natural Sciences (MCNS), Manipal Academy of Higher Education, Manipal (Karnataka).

DISTRIBUTION OF FOSSIL SHARK TEETH IN INDIAN SUBCONTINENT

Shark teeth have been commonly recorded from Miocene and Eocene sediments of the Indian Subcontinents (Sahni and Choudhary, 1972; Mehrotra *et al*., 1973; Sahni and Mishra, 1975; Mishra, 1980; Sahni and Mehrotra, 1981; Kumar and Loyal, 1987, Bajpai and Thewissen, 2002; Rana *et al*., 2004, 2005, 2006, a; Kumar *et al*., 2005, 2007; Mondal *et al*., 2009; Ralte *et al*., 2011; Sharma, 2013; Sharma and Patnaik, 2014; Patnaik *et al*., 2014; Smith *et al*., 2016; Kumar *et al.*, 2017). Nevertheless, the genus *Galeorhinus* is known from Cambay Shale of the Cambay Basin (Rana *et al*., 2004), Kapurdi Formation in the Barmer Basin (Rana *et al*., 2006a), Te-Takkar Member of the

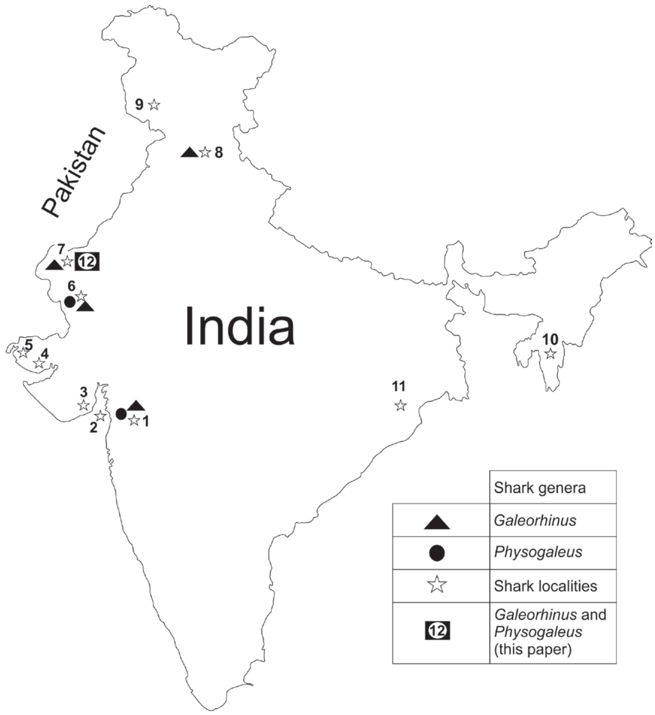


Fig. 3. Outline map of India showing distribution of Paleogene fossil shark teeth recorded by earlier workers. Note the record of *Galeorhinus* and *Physogaleus* along the northwestern margin; 1. Eocene, Cambay Shale of the Cambay Basin (Rana *et al*., 2004), including *Galeorhinus and Physogaleus*, 2. Miocene, Limestone, Piram Island (Mehrotra *et al*., 1973), 3. Miocene, Ghogha coast, Bhavnagar, southern Gujarat (Sahni and Mehrotra, 1981), 4. Eocene, Panandro Lignite mine, western Kachchh (Bajpai and Thewissen, 2002), 5. Eocene and Miocene, western Kachchh (Mehrotra *et al*., 1973; Sahni and Mishra, 1975; Mishra, 1980; Sahni and Mehrotra, 1981; Sharma and Patnaik, 2014; Patnaik *et al*., 2014), 6. Eocene, Kapurdi Formation of the Barmer Basin (Rana *et al*., 2006a; Smith *et al*., 2016) including *Galeorhinus* and *Physogaleus*, 7. Eocene, Khuiala Formation, Jaisalmer Basin (Kumar *et al*., 2007) including *Galeorhinus*, and Eocene, Bandah Formation (Kumar *et al*., 2017), 8. Eocene, Subathu Formation, Bilaspur (HP), Himalaya (Sahni *et al*., 1981; Singh, 1985; Kumar and Loyal, 1987) including *Galeorhinus*, 9. Eocene, Subathu Formation, Kalakot (J&K) (Khare, 1976), 10. Miocene, Bhuban Formation, Surma Group of Mizoram (Ralte *et al*., 2011), 11. Miocene, Baripada Beds, Orissa (Sahni and Mehrotra, 1981; Mondal *et al*., 2009; Sharma, 2013; Sharma and Patnaik, 2014), 12. *Galeorhinus* sp. and *Physogaleus* aff. *secundus* from the lower part of the Khuiala Formation (Lower Eocene) of the Jaisalmer Basin (this paper).

Khuiala Formation in the Jaisalmer Basin (Kumar *et al*., 2007), and from the Subathu Formation of the Himalayas (Kumar and Loyal, 1987). *Physogaleus*, hitherto, is known only from the Kapurdi Formation (Eocene) in the Barmer Basin and Cambay Shale in the Cambay Basin along the west coast of India (Rana *et al*., 2004, 2006a; Smith, *et al*., 2016) (Fig. 3).

From the Jaisalmer Basin, Kumar *et al*. (2007) reported for the first time a new Lower Eocene (Ypresian) assemblage of fish fossils from the lower part of the Khuiala Formation. The fish assemblage also includes *Galeorhinus*.

PRESENT FINDING

Two well preserved shark teeth (*Galeorhinus* and *Physogaleus*) have been recorded from the Te-Takkar Limestone Member of the Khuiala Formation (Early Eocene) of the Jaisalmer Basin. This is the first record of *Physogaleus* Cappetta (1980) from the Jaisalmer Basin. *Galeorhinus* (houndshark) is distributed worldwide in temperate seas at depths down to about 800 m. *Physogaleus* (sharpnose shark) is an extinct genus of shark, ranges in age from Late Paleocene to Middle Miocene (Reinecke and Hoedemakers, 2006). It would be interesting to highlight distinctions between these shark genera and the commonly recorded genus *Galeocerdo* Müller and Henle (1837) from marine Paleogene and Neogene strata of the Indian subcontinents and the comparable genus *Pachygaleus* Cappetta (1992), which although has not been recorded from India, but occur together with above mentioned genera and has been found a comparable genus (see Müller, 1999). The teeth of these four genera show some similarities in shape and inclination of principle cusps. However, they can be easily distinguished on the basis of combination of a set of morphological features, such as, size of teeth, shape of mesial margin of main cusp, size and number of distal denticles and relative difference in the size of principle cusp and distal crenulations (Table 1).

SYSTEMATIC PALAEONTOLOGY

Class **Chondrichthyes** Huxley, 1880
Subclass **Elasmobranchii** Bonaparte,1838
Order **Lamniformes** Berg, 1937
Family **Triakidae** Gray, 1851
Subfamily **Galeorhinidae** Gill, 1862
Genus ***Galeorhinus*** Blainville, 1816

Type species Squalus galeus Linnaeus, 1758, Recent, "European seas"

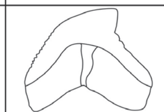
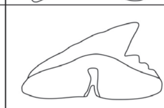
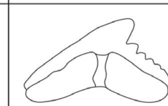
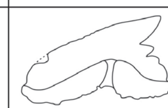
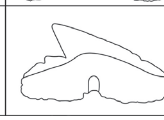
Remarks: *Galeorhinus* is a Cenozoic shark, although the fossil record of *Galeorhinus* goes back to Upper Cretaceous (Popov and Lapkin 2000, Marramà *et al*., 2018). *Galeorhinus* is distributed today in temperate and subtropical seas between 68°N - 55°S latitude. The teeth of *Galeorhinus* show dignathic heterodonty, therefore the identification is a little complicated.

Galeorhinus sp.
(Fig. 4A, B)

Description: Tooth small (width: 5 mm, height: 3.5 mm), low, triangular, consists of distinct root and crown. Base of root concave with median nutritional groove and lateral square-like lobes. Labially root low and lingually high. Principle cusp obliquely triangular, distally inclined, margin smooth, anterior margin almost straight, without distinct mesial heel, apex sharp, acutely rounded. Serrations limited to lower part of mesial edge of principle cusp numbering five, course, rounded and unequal. Distal shoulder possesses five simple, coarse, conical, sharp denticles, reducing in size distally. Lower part of lingual surface of principle cusp covered with longitudinal striations.

Remarks: The size, shape mesial edge and distal denticles in the specimen described here match *Galeorhinus* Blainville (1816). The closely comparable species, such as *G. duchaussoisi* Adnet and Cappetta (2008: 235, fig. 2A–J) from Eocene of Prémontré Abbey, Prémontré (Aisne, northern France) matches in size of teeth (width up to 7 mm), number and size of divergent distal denticles (up to 6), less number of mesial serrations, but differs in thicker and narrower principle cusp and concave mesial edge. *G. glickmani* Popov (Popov and Lapkin, 2000: 336, fig. 1) from Upper Cretaceous of Volga River Basin, Russia match in general shape but differs in having less size difference between

Table 1. Comparison chart showing distinguishable morphological features between *Galeocerdo*, *Physogaleus Pachygaleus* and *Galeorhinus*.

Genera	size range (width in mm)	shape of mesial margin of principle cusp	Size and number of distal denticles	nutritional groove	size comparison between principle & distal cusps	references	
Galeocerdo cuvier	Large, 29	serrated, convex serrations on the whole extent, rather unequally	fine and more in number	shallow	large	Pimiento *et al.*, 2012; Gibbes, 1849; Purdy *et al.*, 2001; Reinecke & Hoedemakers, 2006	
Physogaleus secundus	moderately large, 6 - 15	smooth, straight, slightly arched, sigmoid	coarse and 1-4	absent or shallow at base of the root only	large	Cappetta, 2012; Reinecke & Hoedemakers, 2006	
Pachygaleus lefevri	moderately large, up to 10	smooth, slightly arched to straight serrated at the basal part	coarse and less in number	deep	small	Bor, 1985; Stanley, 1999; Adnet & Cappetta, 2008; Case *et al.*, 2015	
Galeorhinus galeus	small, 2.2 - 7	smooth, slightly arched, concave to straight, sigmoid	coarse and less in number (3-5)	deep to shallow	large	Rana *et al.*, 2006; Carrillo-Briceno *et al.*, 2015; Adnet & Cappetta; 2008	
Galeorhinus sp. MCNS2017Jaisalmer 1	small, 5	smooth, almost straight, serrations limited to lower part of mesial edge	coarse, 5	shallow	large	Present work	
Physogaleus secundus MCNS2017Jaisalmer 2	moderately large,6.4	smooth, slightly arched, serrations on lower side, shallow	coarse, 3	shallow	large	Present work	

principle cusp and distal denticles, slightly arched mesial cutting edge and two nutrient furrows. The less size difference between principle cusp and distal denticles is like that in *Pachygaleus* (see Table 1). In addition, presence of two nutrient furrows in Upper Cretaceous shark teeth may be interesting from functional point of view.

Galeorhinus sp. 1 recorded from the Lower Eocene Kapurdi Formation in the Barmer Basin neighbouring to the Jasalmer Basin (Rana *et al*., 2006: 512, figs. 2.7-2.10, 3.3; pl. 1, figs. 3-9) exhibits coarse mesial serrations. Whereas. *Galeorhinus* sp. 2 recorded from the same horizon by Rana *et al*. (2006: 515, figs. 2.11, 3.1; pl.1, figs. 10a-b) shows higher width and height ratio (width: 11 mm and height 5 mm), flattened labial face of crown, gently convex posterior part of principle cusp, cusp having a "nipple-like" apex and moderately coarse distal denticles. The posterior teeth of *Galeorhinus* sp. illustrated by Rana *et al*. (2004: 1727, Fig. 2: 1-4) differ in showing less width-height ratio, extended root beyond the anterior and posterior extremities of the crown, and thick base of the crown overhangs root. *Galeorhinus* sp., figured and described by Kumar *et al*. (2007: 556, fig. 2: 19-20) from the Lower Eocene part of the Khuiala Formation, similar to the horizon of present specimen but from different locality, more on the eastern side in the basin, match tooth described here in width and angle of inclination of principle cusp, and width height ratio, differs in extended root beyond the anterior and posterior extremities of the crown, sigmoidal mesial cutting edge and showing down-turned distal part of principle cusp after mid-height, consequently, convex mesial cutting edge. Moreover, the tooth is broken from the distal side and exact number of distal denticles are unknown. The examples of *Galeorhinus* from Subathu (Eocene of Himalaya) (Kumar and Loyal, 1987: 66, pl. 1, figs. 23-24) show more width height ratio (teeth as high as broad), broader root than crown, and less distally inclined principle cusp. In view of the upper discussions and broken state of present specimens it has been assigned to *Galeorhinus* sp.

Material: One tooth (MCNS2017Jaisalmer 1).

Horizon and locality: 1.5. m thick shale bed of the Khuiala Formation (bed no. 4, see fig. 2), 50 km north of Jaisalmer and 16 km south of Sultana village on the left side of Mokal – Sultana road (Fig. 1).

Family **Carcharhinidae** Jordan and Evermann, 1896

Genus ***Physogaleus*** Cappetta, 1980

Type species Physogaleus secundus (Winkler, 1874)

Remarks: *Physogaleus* ranges from the late Palaeocene to middle Miocene in tropical to temperate neritic marine environments (Reinecke and Hoedemakers, 2006). The teeth of *Physogaleus* show dignathic heterodonty (Padilla *et al*., 2018). In addition, the genus is characterized by a strong sexual dimorphism (Cappetta, 1980: 37).

Physogaleus aff. *secundus* (Winkler, 1874)
(Fig. 4 C, D)

aff. 1874 *Trigonodus secundus* Winkler, p. 5, pi. 1, figs 4-5.
aff. 1980 *Physogaleus secundus* (Winkler, 1874) - Cappetta, p. 38, fig. 5.
aff. 1985 *Physogaleus secundus* (Winkler, 1874) – Bor, p. 95, pl. 3, figs. 3-8.

Description: Tooth small (width: 6.4 mm, height: 3.1 mm), low, triangular, consists of distinct root and distally inclined sigmoid crown with compressed labiolingually, labial and lingual faces arched. Principle cusp obliquely triangular, distally inclined, margin smooth, slightly arched mesial cutting edge runs smoothly from the apex to the anterior margin of the mesial heel, apex sharp, acutely rounded. Distal shoulder possesses

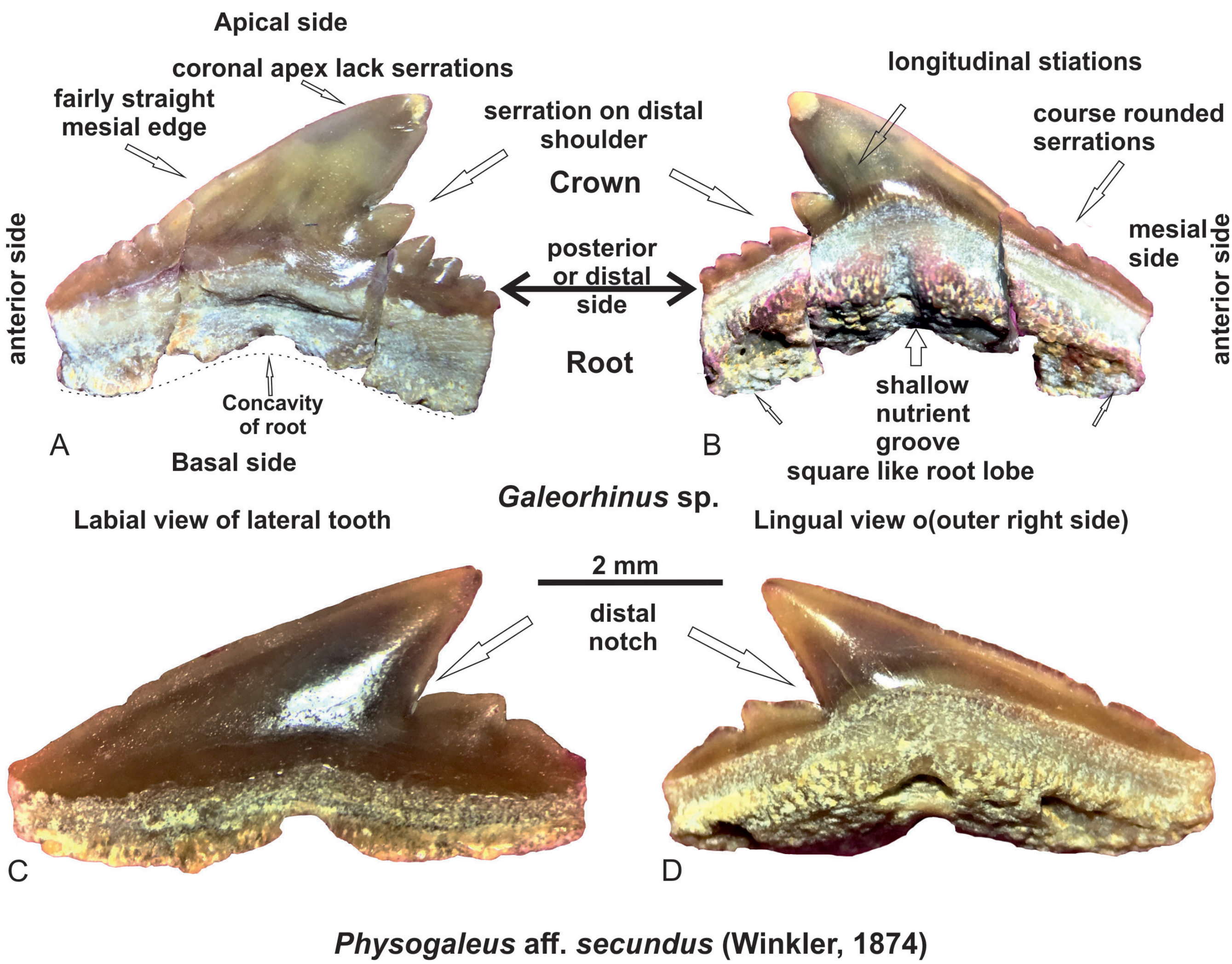


Fig. 4. (A-B) *Galeorhinus* sp.: A. labial view, B. lingual view, (C-D) *Physogaleus* aff. *secundus* (Winkler): C. labial view, D. lingual view.

three simple, distally inclined coarse, conical, sharp denticles, reducing in size distally, distal most less conspicuous, Serrations on lower mesial side of principle cusp shallow. Labially root low and lingually high. Base of root straight with median shallow nutritional groove and lateral square-like lobes.

Remarks: The morphological feature of tooth match anterior-lateral teeth of upper jaw of *Physogaleus hemmooriensis* Reinecke and Hoedemakers (2006, pl. 2, figs 8-11), however, median grove is narrower or not well developed and root is slightly extended anteriorly, *Physogaleus* sp. described and illustrated from white Mountain Formation (Middle Eocene), near the Aktau Mountains, Kizylkum Desert, Uzbekistan, C.I.S. by Case *et al*. (1996: 110, pl 7, figs. 128-143) exhibits higher and less inclined main cusp with narrow apex. *Physogaleus secundus* (Winkler, 1874) (Bor, 1985: 95, pl. 3, figs. 3-8) shows quite a similar outline and morphological feature of the lateral tooth figured as 6a, b. The outline sketch of upper lateral tooth (both inner and outer faces) of this species from Eocene of Méra-el-Arech, Basin, Quled Abdoun, Morocco, illustrated by Cappetta (1980: 38, fig, 5B, B') shows more arched mesial edge.

Material: One tooth (MCNS2017Jaisalmer 2).

Horizon and locality: 1.5. m thick shale bed of the Khuiala Formation (bed no. 4, see fig. 2), 50 km north of Jaisalmer and 16 km south of Sultana village on the left side of Mokal - Sultana road.

Faunal biodiversity of the shark tooth bearing bed

The faunal content of the shark tooth bearing bed of the Te-Takkar Limestone Member of the Khuiala Formation shows moderate biodiversity. Shark teeth (*Galeorhinus* and *Physogaleus*) have been found together with coprolites (small, tubular, helically coiled, flask-shaped), bivalves (Pterioids, cartiditids), gastropods (small turreted), echinoderms, plant hash and large foraminifers (*Nummulites*). All these fossils suggest open marine depositional environment. *Galeorhinus* is distributed today in temperate and subtropical seas at depths down to about 800 m between 68°N - 55°S latitude. *Physogaleus*, is an extinct genus of shark, ranges in age from Late Paleocene to Middle Miocene and has been recorded from tropical to temperate neritic marine environments (Reinecke and Hoedemakers, 2006). The *Galeorhinus* suggests the geographical location of the Jasialmer Basin was already in subtropical to temperate zone.

CONCLUSION

The shark tooth of *Physogaleus* has been recorded for the first time from the Jaisalmer Basin. The earlier record of *Galeorhinus* from the Lower Eocene sediments of Cambay, Barmer and Jaisalmer basins and Subathu Formation (Himalaya) *and an* additional record of *Galeorhinus* from the Jaisalmer Basin suggest that western margin of Indian subcontinent was already witnessing subtropical sea condition during Early Eocene time interval.

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2. Mani Shanker Shukla Gold Medal to a young research worker (below 40 years of age) in recognition of his outstanding contributions on Indian material in the field of micropalaeontology.
3. Prof. M. R. Sahni Gold Medal for a post graduate Student of University of Lucknow securing highest percentage of marks in the examination in Palaeontology Paper.
4. Prof. S. N. Bhalla Gold Medal for outstanding contributions in the field of micropalaeontology.
5. Prof. S. K. Singh Memorial Gold Medal for best research paper published in the immediate past volume of the Journal of the Palaeontological Society of India.
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