PALÆO VERTEBRATA

First report of *Cylindracanthus* (Osteichthyes) from the Eocene of India

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Abstract: Fossils of the endangered sturgeons and peddlefishes are widely distributed. We here report for the first time the presence of one of the extinct osteichthyes genus *Cylindracanthus* (Liedy 1856a) from the Early Eocene lignite-bearing successions of the Kutch Basin, India. The present well preserved rostrum is characterised by numerous wedge-shaped components encircling the central canal that runs along its length, paired at the base and each wedge contributing to the formation of a ridge. The rostrum lacks teeth. The present find extends the palaeobiogeographical distribution of *Cylindracanthus* considerably and supports its Eocene age as dental remnants preserved in *Cylindracanthus* sp. shows a decrease in remanent dentition and tooth bases from the Cretaceous to the Eocene. *Cylindracanthus* is an useful palaeoenvironmental indicator as it has been found associated typically with deposits of nearshore marine environments.

Keywords: *Cylindracanthus,* Eocene, rostrum, histology, Umarsar mine

Submitted 6 January 2023, Accepted 7 December 2023
Published Online 27 March 2024, doi: 10.18563/pv.47.1.e2

INTRODUCTION

The extinct genus of *Cylindracanthus* fish is known only by its preserved cylindrical bilaterally symmetrical partial rostrum, mostly found broken at both the ends (Fallaw 1964). *Cylindracanthus* dates from Cenomanian (Upper Cretaceous) found in a limestone layer that is now considered as marking the base of the La Cabaña Formation, near Oviedo in Asturias (northern Spain) (Vullo et al. 2009) to Eocene (Leriche 1905; Fierstine 2001; Adnet et al. 2010) in age, and is thought to be a member of the Acipenseriformes (Parris et al. 2001; Ciobanu and Trif 2016).

Cylindracanthus has been reported from the Upper Cretaceous of New Jersey and Alabama, and the Eocene of New Jersey, Virginia, South Carolina, Georgia, Alabama, and Mississippi, in the United States of America. It has also been reported from Europe and Africa (Gibbes 1850; Cope 1870; Fowler 1911; Romer 1945; Richards 1955; White 1956; Becker et al. 2009). Fowler (1911) diagnosed his *C. ornatus* specimens, using Cope's (1870) description of the *C. acus* species. Case and Borodin (2000) reported *Cylindracanthus* cf. *rectus* (Dixon) from the Late Eocene of the Irwinton Sand Member, Georgia. *Cylindracanthus* is also known from the Middle Eocene of Morocco (Zouhri et al., 2018); possible Lower Eocene of Mali (O'leary et al. 2019); Tertiary deposits of Senegal (Gorodiski and Lavocat 1953); Eocene of Togo (Cappetta and Traverse 1988); Eocene of Nigeria (White 1926); Lower Eocene of United Kingdom (Harrison and Walker 1975); Paleogene of Ukraine (Udovichenko 2009), Eocene of Italy (De Zigno 1882) and Middle Eocene of Uzbekistan (Nessov et al. 1987).

The unusual structure of the *Cylindracanthus* sp. rostrum is comprised of several wedge-shaped segments encircling the central canal (paired at the base) that runs the length of the rostrum. Fossils that Agassiz (1833-1843) classified as likely rostral components were given the name *Coelorhynchus*. The name *Cylindracanthus* was independently given by Leidy (1856a) to fossils from Alabama and New Jersey that he thought to be dorsal fin spines. Later in (1856b) he noted that Dixon's (1850) *Coelorhynchus* figures closely resemble his *Cylindracanthus* fossils. Since *Coelorhynchus* was previously occupied with a chimaeroid, Leriche (1905) suggested the name *Glyptorhynchus* to replace it. He also recognised that *Glyptorhynchus* resembles *Blochius*' rostrum (swordfish genus). *Cylindracanthus* and *Glyptorhynchus* are now considered junior synonyms (Purdy et al. 2001). *Cylindracanthus* (*Coelorhynchus*) was regarded by Woodward (1888, 1891) as a fin spine. Williamson (1849) and Carter (1927) in their histologic studies, did not convincingly identify these fossil fragments as fin spines or rostra. Carter (1927) investigated an Eocene *Cylindracanthus* rostrum from Nigeria and found that it was histologically comparable to both a *Blochius* rostrum fragment and the dermal spine of an unrelated extant trunkfish (*Ostracion*). Carter (1927) came to the conclusion that the *Cylindracanthus* sp. specimen was most likely a bill of an extinct swordfish related to *Blochius*. Most other ichthyologists and palaeontologists agreed on this relationship (Berg 1940; Darteville and Casier 1943, 1949; Casier 1946, 1958; Leriche 1942; Gregory 1951; Romer 1966). Woodward (1942) however, placed *Cylindracanthus* (=*Coelorhynchus*) in *incertae sedis*. Therefore, *Cylindracanthus* anatomical and taxonomic interpretations are still debatable (Friedman 2012).

The systematic history of *Cylindracanthus* has been tumultuous. Sturgeons are the most recent addition to the long and winding list of taxonomic families to which *Cylindracanthus* has been linked. Previously, it was thought to be related to billfishes, tetraodontiforms, chimaeroids (a group of chondrichthyans related to sharks and rays) (Parris et al. 2001). Fragments of *Cylindracanthus* have been variously labelled as spines or rostra based on their morphological interpretations, further complicating the classification of this genus. *Cylindracanthus* has been placed in the order Acipenseriformes despite a complicated taxonomic history (Parris et al. 2001, 2007). *Cylindracanthus* is currently thought to consist of three species (Becker et al. 2010). Compared to *Cylindracanthus ornatus*, *Cylindracanthus acus* Cope, 1870 has greater ossification and smaller tooth remains (Kemp et al.

1990), whereas *Cylindracanthus rectus* Agassiz, 1843 lacks the bilateral symmetry of *Cylindracanthus ornatus* (Arambourg 1952; Kemp et al. 1990). There is no conclusive evidence supporting any of these hypotheses, and no *Cylindracanthus* specimen has ever been unearthed with additional bone fragments that would have provided additional information about the animal's systematic placement or anatomical identity.

The partial rostrum of *Cylindracanthus* described here was collected from the Umarsar lignite mine managed by the Gujarat Mineral Development Corporation (GMDC) in the Kutch district of Gujarat, India. Umarsar mine is the northernmost lignite mine in the Kutch Basin. The Naredi Formation deposits from the early Eocene are exposed in this mine, together with multiple thick and thin lignite seams (Singh 2021). The Umarsar section appears to be contemporaneous with some of the lignite bearing strata found in Cambay Basin Gujarat (Mandal 1999; Singh et al. 2010, 2015; Tripathi and Srivastava 2012; Rao et al. 2013), Kutch Basin (Kar and Saxena 1976; Kar 1978, 1985; Mathews et al. 2013; Sharma and Saraswati 2015; Mathews et al. 2018), Barmer (Kar 1995; Tripathi 1995, 1997; Singh 2015) and Bikaner Basins in Rajasthan (Singh and Dogra 1988). The lignites formed after and during heat episodes associated with the Paleocene and Eocene ages, just before India collided with Asia, when it was at an equatorial location (Prasad et al. 2009; Srivastava et al. 2019). The foraminifers *Assilina spinosa, Lockhartia, Nummulites burdigalensis*, as well as the rare *Guembelitria, Chiloguembelia, Globigerina,* and *Globorotalia*, are among the abundant microfauna that occur in the formation. A diverse fauna comprising bivalves, gastropods and corals have also been found in addition to the foraminifers (Catuneanu and Dave 2017). The foraminiferal assemblage suggests that the lignites belong to the early Eocene (Dutta et al. 2011). The palynoassemblage from this mine contains moderate amounts of sulphur, dinoflagellate cysts and mangrove pollen, indicating that the lignites were likely concentrated near coast or in areas that are impacted by the sea (Mathews et al. 2018). Palaeoenvironmental reconstructions of all the known mines point to a near-shore coastal setting with substantial mangroves and evergreen tropical rain forests (McCann 2010).

This paper describes and compares in detail the histological characteristics of the *Cylindracanthus* rostrum being reported for the first time from the Eocene of the subcontinent, extending its geographical distribution considerably.

GEOLOGICAL SETTING

The Kutch basin, located near the northern end of India's western coastline (Fig. 1a), is the most western pericratonic-rift basin and marks the earliest rift that occurred during the split of Africa and India. It has preserved a somewhat complete record from Triassic to the present, with gaps between transgression cycles (Biswas 1980). Nearly all Mesozoic rocks in Kutch are encased by Tertiary sediments (see Fig. 1b). The Tertiary rocks of Kutch consist of the lower most Deccan Traps, followed by marine transgression facies and river environment deposits (Krishnan 1982). Tertiary vertebrates, including both terrestrial and marine mammals, have been recovered from the Kutch region of Gujarat, since the 19th century (Wynne 1872; Lydekker 1880). In the Kutch basin, there are a number of potential open-pit lignite mines with varying lithostratigraphic thicknesses. The lignite mines in the Kucth basin contain fossiliferous sedimentary layers that preserve both microfloral and megafloral records (Shukla et al. 2019). The lignite mine at Umarsar is thought to be a continuation of the mine at Panandhro. Saraswati and Banerjee (1984) have given the name Panandhro Formation to the lignite deposits found in the Panandhro-Lakhpat province. Dinoflagellate cysts and a comparable assemblage of spores and pollens were used by Agrawal et al. (2017) to date the lignitic seams at Panandhro to the early Eocene (Ypresian age; 56 - 48 Ma). The majority of the lignitic successions found in these mines have been dated by fossils and a handful of isotopic analyses to the Ypresian period (Khozyem et al. 2021; Punekar and Saraswati 2010; Samanta et al. 2013).

MATERIALS AND METHODS

The rostrum (PU/KTU-1) is housed at the Department of Geology, Panjab University, Chandigarh, India. The terminology of Parris et al. (2007) was used to describe the partial rostrum, with a few additional terms adopted from Williamson (1849).

The fossilized rostrum was discovered in the Umarsar lignite mine's middle seam in Gujarat's Kutch region (23°43'52.48"N, 68°49'22.29"E) (Fig. 1b). Its preservation is adequate to show morphological characteristics. Photographs of the rostrum were taken using stereozoom microscope (RSMr-8, Radical) and SEM (JEOLJSM-6490, magnification: 15x) at the Department of geology, Panjab university Chandigarh.

For histological study, the fossil rostrum was sliced into thin transversal section using a BeuhlerIsomet 1000. Thin sections were polished, and Araldite Klear was used to mount them to glass slides. Further, the thin section was studied under a petrographic microscope i.e. Zeiss Axiocam and microphotographs were taken (magnifications: 2.5x and 5x; under both plane polarized light and cross polarized light). Additional images were also taken using a confocal microscope (Nikon-A1R, magnification; 10x) to get higher resolution images of the internal structure of the rostrum.

Geological field work was undertaken at the Umarsar lignite mine and a section was measured (Fig. 1c, d). The Umarsar lignite mine, that belongs to the early Eocene Naredi Formation, is situated between Matanomadh and Brahma Nagar (Fig. 1b).

SYSTEMATIC PALAEONTOLOGY

Class Osteichthyes Huxley, 1880
Order *incertae sedis*
Genus *Cylindracanthus* Leidy, 1856
Cylindracanthus sp. (Figs. 2-3)

Material: Isolated rostrum (PU/KTU-1).
Locality and horizon: Umarsar lignite mine, Naredi Formation, Early Eocene.
Description: This specimen is merely a fragment, most probably from the rostrum's anterior portion. The recovered rostrum fragment appears cylindrical and contains longitudinal ridges that are evenly spaced, but lack ventral tooth-bearing grooves. The rostrum fragment is 62 mm long and has a diameter of 6.5 mm at its widest end and 5.75 mm at its narrowest (Fig. 2a, b). The external surface appears to be a thick, deeply fluted enamel-like layer with 30-32 longitudinal ridges. The circular cross-section reveals a central canal (Fig. 2e). Some longitudinal ridges of the rostrum unite into single ones (Fig. 3c, d). The rostrum fragment has a cogwheel like appearance and is symmetrical in cross section (Fig. 2e, f).

Figure 3 shows a profile representation of ridges, revealing their internal structure. The growth lines which are almost exactly parallel to the surface of the ridge, are also visible

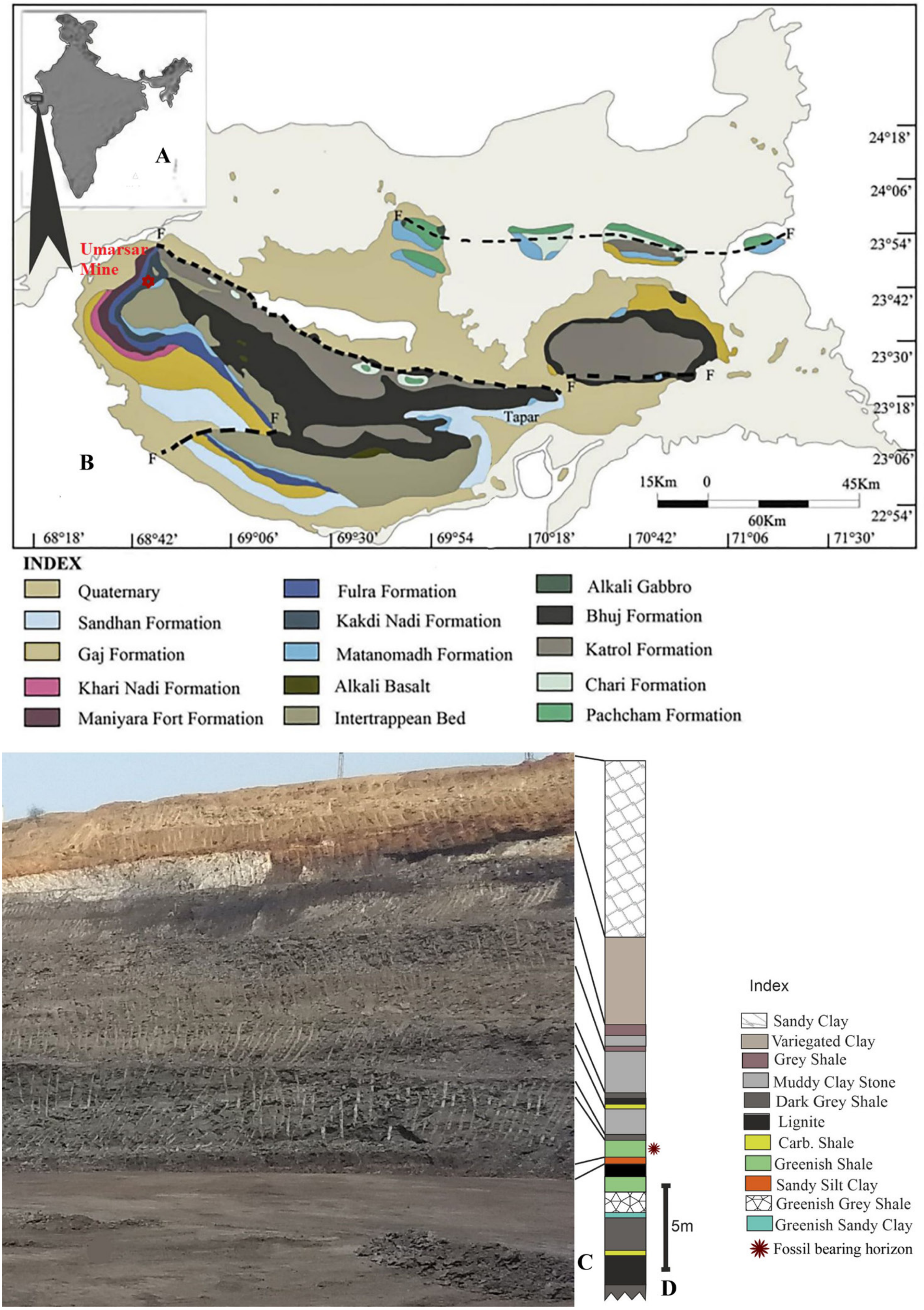

Figure 1. (A) Physical map of India showing the study area. **(B)** Geological map of Kutch (modified after GSI 2012) showing the distribution of mesozoic and cenozoic rocks (Red star: study area Umarsar mine). **(C)** Field photograph of the exposed upper portion of the Naredi Formation along Umarsar mine (23°43'52.48"N, 68°49'22.29"E). **(D)** The Umarsar lignite mine generalised litholog, showing the fossiliferous horizon from which the rostrum was collected.

from the top to the bottom of the segment (marked as GM in Fig. 3d, f). In the transverse section, each ridge is separated from its neighbour by a thin vertical network of small canals that open along the narrow groove separating the convex ridges (Williamson 1849) (Fig. 3f). The segmented orifices of the canals constituting this network are visible along the vertical line of demarcation between the ridges (marked as C in Fig. 3f). From each side of this line, a vast number of minute kosmine tubes can be seen arching downwards and inwards towards the plate's centre (marked as KT in Fig. 3f) displaying a feather-like pattern.

Remarks: *Cylindracanthus* Leidy is a marine, 'billfish-type' snouted fish recognised by its elongate, columnar rostrum with multiple longitudinal ridges and grooves and likely belonged to Acipenseriformes (Parris et al. 2001; Ciobanu and Trif 2016). The descriptions of several *Cylindracanthus* species are noticeably lacking in information. The common description of these remains is that they are cylindrical, somewhat conical, and covered with external ridges that run the length of the rostrum. We noticed a characteristic feature that was also mentioned by Leidy (1856a), that several ridge pairs combine into a single ridge (Fig. 3c, d). The specimen bears a passing resemblance to the central cavity reported by Leidy (1856a) and afterwards shown by various authors, including Fowler (1911) and Schultz (1987).

Transverse thin section of the rostrum shows the growth lines described by Williamson (1849), which run roughly parallel to the ridge surface (Fig. 3d, f). Numerous micro kosmine tubes, as reported by Williamson (1849) or the organization of calcified tissue, as described by Parris et al. (2001), can be seen bending downwards and inwards toward the centre of the plate. We concur with Woodward (1942) in placing *Cylindracanthus* (=*Coelorhynchus*) in *incertae sedis*. Thus, our specimen is conservatively defined as *Cylindracanthus* sp.

DISCUSSION

The occurrence of *Cylindracanthus* sp. in the Eocene deposits of Kutch basin, India provides new insights into its distribution during the early Eocene. This genus was widely distributed from the Cretaceous to the late Eocene in North America, Africa and Europe (Fig. 4). However, there is just one record from Asia (Fig. 4). Arambourg and Joleaud, (1943) reported *Cylindracanthus* sp. from Cretaceous strata of New Jersey. It is only during the Eocene that this genus reached its maximum geographic distribution. Breard (1991) noted that the extensive geographic occurrence of this fossil fish supports a pelagic habitat, for instance *Cylindracanthus* are extremely rare in nearshore deposits (Mississippi) and quite widespread in more open-ocean deposits (Louisiana and Alabama). According to Becker et al. (2009), *Cylindracanthus* can typically be discovered in deposits that are connected with shallow nearshore marine habitats. *Cylindracanthus* most likely became extinct when Eocene billed fishes with more modern appearance outcompeted them (Parris et. al. 2001). The occurrence of *Cylindracanthus* sp. in coastal deposits

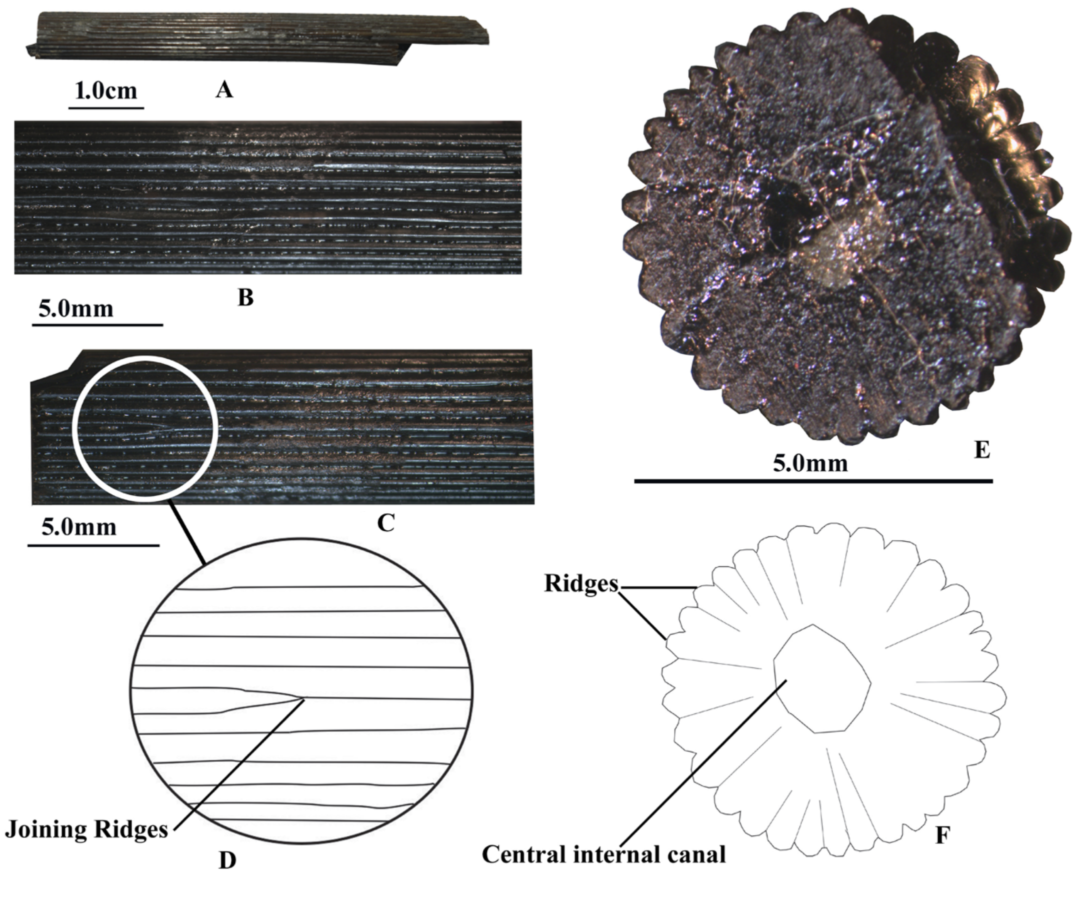

Figure 2. The fossil specimen referred to *Cylindracanthus* sp. (PU/KTU-1). **(A)** Lateral view of the rostrum. **(B)** Magnified section of lateral view. **(C)** Details of joining longitudinal ridges, with **(D)** illustrative drawing. **(E)** Specimen's natural transverse section, with **(F)** illustrative drawing.

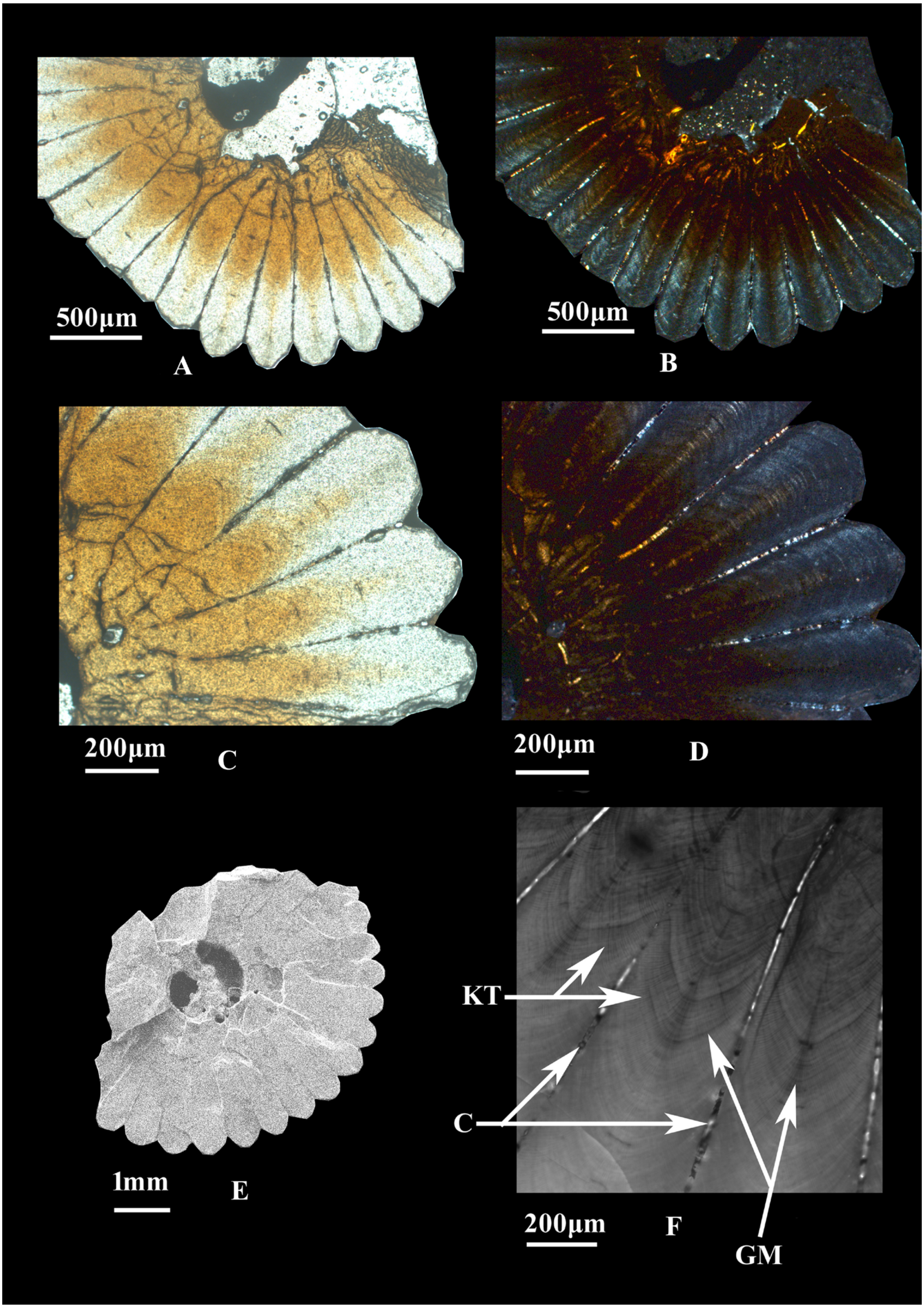

Figure 3. Rostrum cross section displaying ridge patterns and the central internal canal (magnification 2.5x), **(A)** under plane polarized light **(B)** under cross nicols. Magnified cross section of the rostrum (magnification 5x), **(C)** showing ridges in plane polarized light; **(D)** ridges and growth marks under cross nicols. **(E)** SEM image of transverse section of the rostrum showing arrangements of ridges and central internal canal (magnification 15x). **(F)** Confocal microscope image of ridges showing growth marks. GM= Growth Marks, C= canals, KT= kosmine tubes.

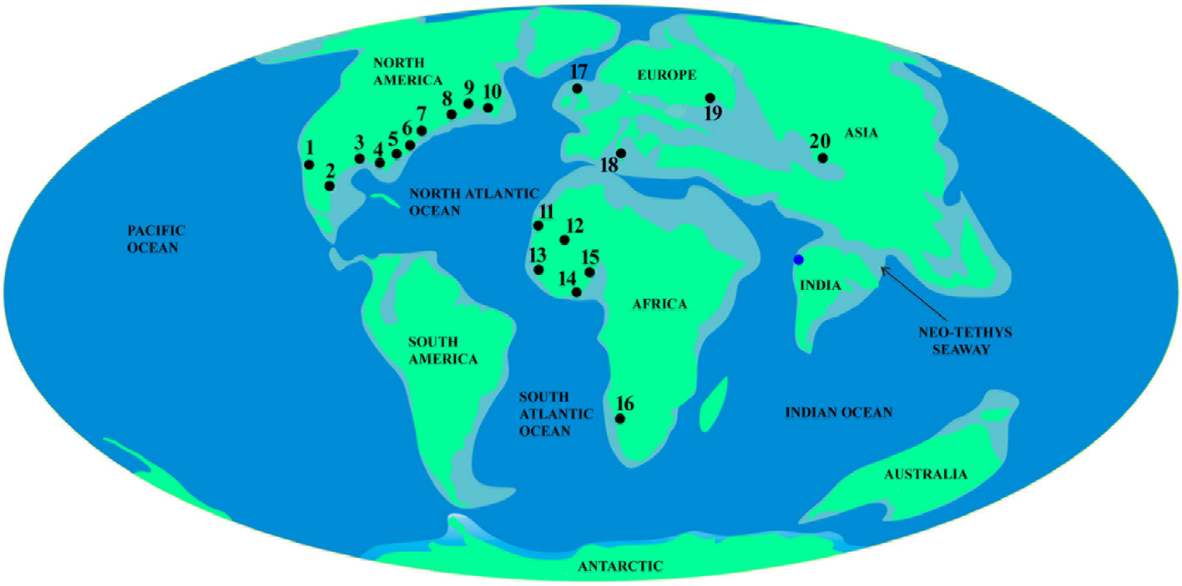

Figure 4. Paleogeographic sketch map of the world during the early Eocene (Modified after Scotese 2013), blue circle represents the fossil locality in the Kutch region, India. The figure depicts the distribution of *Cylindracanthus* sp. during early Eocene. North America: (1) California (Walsh 1996); (2) Texas (Westgate 2008); (3) Louisiana (Breard et al. 1995); (4) Mississippi (Fierstine and Starnes 2005); (5) Alabama (White 1956); (6) Georgia (Hulbert et al. 1998); (7) North Carolina (Fallaw 1964); (8) Virginia (Leriche 1942); (9) Maryland (Weems and Horman 1983); (10) New Jersey (Cope 1870). Africa: (11) Western Sahara (Zouhri et al. 2018); (12) Mali (O'leary et al. 2019); (13) Senegal (Gorodiski and Lavocat 1953); (14) Togo (Cappetta and Traverse 1988); (15) Nigeria (White 1926); (16) Namibia (Boehm and Weisfermel 1913); Eurasia: (17) The United Kingdom (Harrison and Walker 1975); (18) Italy (De Zigno 1882); (19) Ukraine (Udovichenko 2009); (20) Uzbekistan (Nessov et al. 1987).

formed during the Eocene transgression period in the Kutch region indicates a nearshore marine habitat.

Parris et al. (2001, 2007) commented on the biostratigraphic significance of *Cylindracanthus* rostrum. They found that *Cylindracanthus* with teeth belonged to the Cretaceous while teeth were highly reduced or absent in the Eocene forms. The Eocene *Cylindracanthus* specimen described here lacks teeth and therefore fits well with the hypothesis of Parris et al. (2001, 2007). The importance of *Cylindracanthus* in biostratigraphy is of particular interest, as this marine fossil is relatively frequent and broad throughout the Cretaceous/Tertiary boundary. It is hoped that further finds of better specimens will continue to improve our understanding of this interesting fish.

CONCLUSIONS

The fossilized rostrum reported here shows features diagnostic of the genus *Cylindracanthus* (Leidy 1856a) and is the only record of this disputed taxon from the Eocene strata of the Kutch region in Gujarat, India. The discovery of *Cylindracanthus* in the Indian subcontinent adds a new understanding about the paleobiogeographic distribution of this peculiar fossil fish. Since the rostrum lacks teeth, the present *Cylindracanthus* sp. supports an Eocene age to the deposits of Umarsar lignite mine in Kutch. In addition to the above significance, the taxon also lends support to the existence of a nearshore marine environment during the Early Eocene of Kutch.

ACKNOWLEDGMENTS

We are grateful for the kind assistance provided by Mr. Rajat Kumar Dash, General Manager of Umarsar Lignite Mine (GMDC), Ahmadabad, during the collection of the fossil material. Pankaj Kumar expresses gratitude to the Chairperson, Department of Geology, Panjab University, Chandigarh for providing necessary assistance as well as the Council of Scientific and Industrial Research (India) for the financial support in the form of a Junior Research Fellowship with grant no. (file no. 09/135(0920)/2020-EMR-I). RP expresses gratitude to SERB (HRR/2018/000063) for the financial assistance. The authors are thankful to Prof. M. G. Thakkar of K. S. K. V. Kachchh University, India for his help during the fieldwork. We also thank Alison Murray and an anonymous reviewer for their constructive comments, which helped us to improve the manuscript.

Author's contribution:
PK and RP have made major contributions to the writing of the manuscript. DC, RK and WAW assisted in the field and lab, beside contributing towards the manuscript.

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