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Record of Additional Middle Eocene Vertebrate Remains from the Mikir Hills, NE India: Implications on Paleoenvironment and Paleobiogeography

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Abstract

The fossiliferous middle Eocene deposits of Sylhet Limestone of Mikir Hills have yielded vertebrate and invertebrate faunas. The fossil assemblages recorded in this contribution consist of shark, ray, crocodile, conical tooth, broken fragments and echinoderm spines. Ray and crocodile tooth are reporting for the first time from the Mikir Hills. Paleoenvironmental analysis based on the fossil fish assemblage in association with invertebrate (foraminifera) remains and sedimentogical observations suggest a shallow marine environment ranging from open marine, inner neritic to more proximal coastal settings. Also, the presence of common marine elements (similar faunas) from Kutch, Rajasthan, Himachal Pradesh, Assam (India), New Hampshire, Libya, Iraq, Iran, North Western Sahara (Algeria), Tanzania (East Africa), Italy, Germany, Southern North Sea basin (Europe) based on previous published works and the present finding testifies to the connection of the Tethys Sea during Lutetian-Bartonian of middle Eocene.

Keywords

Eocene, Fish Teeth, Mikir Hills, Paleoenvironment, Ray, Sylhet Limestone

1. Introduction

Mikir Hills in Assam and Shillong Plateau in Meghalaya (Figure 1) are the northeastern extension of the Indian peninsular shield [1] [2] [3] [4]. The Mikir Hills lie in the East Karbi Anglong district of Assam, and the NW-SE trending Kopili Fault separates it from the Shillong Plateau [1] [2] [5] [6]. The Mikir Hill which is the uplifted part of a Precambrian crustal block constitutes a part of the Assam Shelf [7]. The sediment deposition in this region was controlled mainly

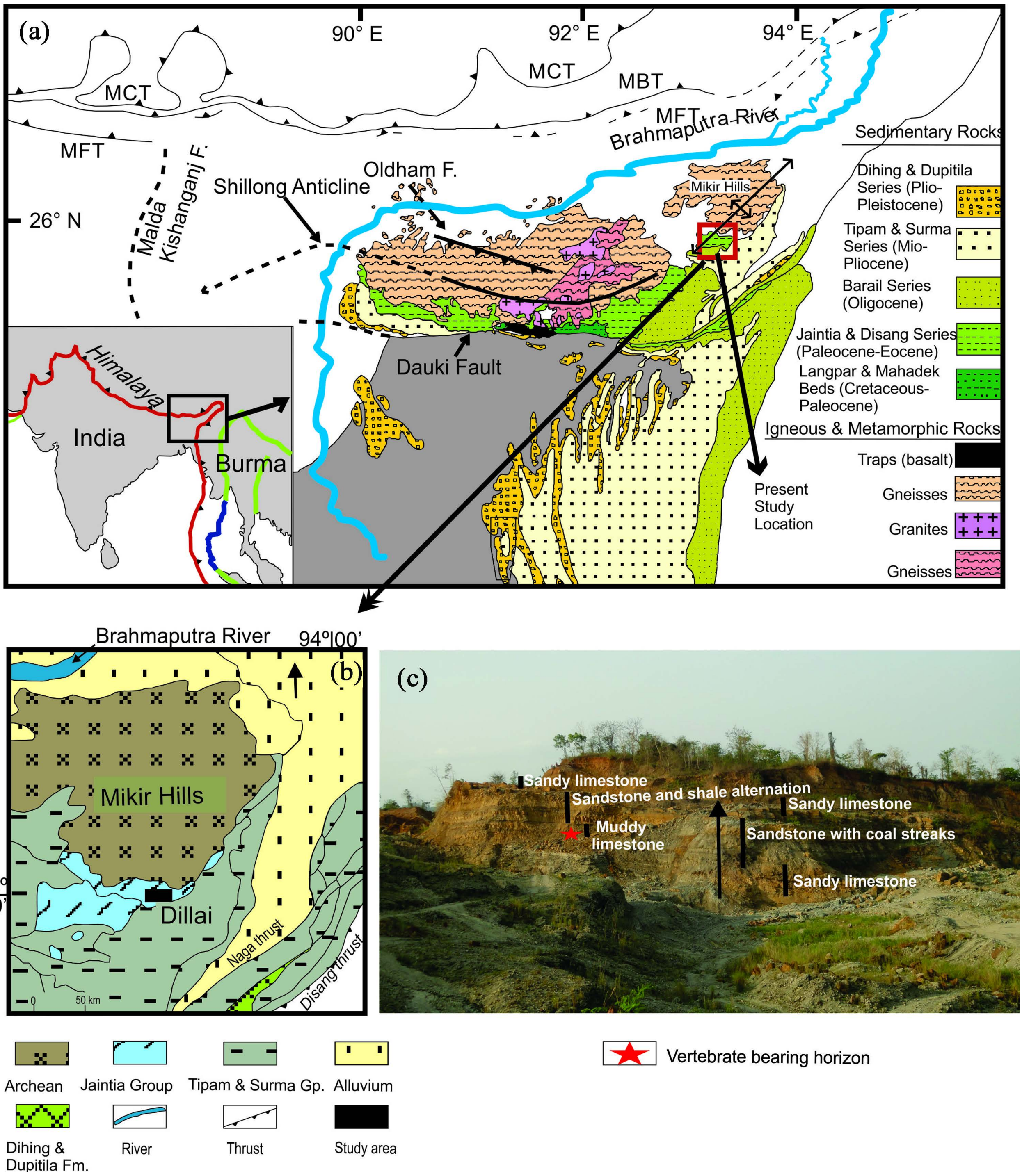

Figure 1. (a) Geological map of the Mikir Hills (modified after [79] [80]); (b) enlarged geological map of the study area where the vertebrates were collected [13]; (c) field photo of the outcrop with the vertebrate bearing horizon.

by tectonic activities along the fault zones and by the collision of India-Asia plates during the late Paleocene and early Eocene [3] [8] [9] which is reflected in the contrasting lithofacies of limestone, sandstone and shale in the Paleogene sequence of the Assam Shelf, Garo, Khasi, Jaintia, and in Mikir Hills. Existing knowledge of the fossils which is significant in relative age dating of sediments and revealing of paleoenvironment is scanty from the Mikir Hills of Assam compared to the Shillong Plateau in Meghalaya although they fall in similar tectonic regime separated by a Kopili fault. New fossil discoveries can greatly affect our understanding of evolutionary history, by revealing previously unseen amalgamations of primitive and derived characters, [10]. The present paper aims to put into record the finding of vertebrate remains from the Mikir Hills, Assam and its implications on the paleoenvironment and paleobiogeographic distribution of the Tethys Seaway during the middle Eocene.

For many years, fossil shark teeth have been objects of curiosity and study. Sharks and their families are known as "living fossils" and they are part of an ancient clade of vertebrates. They are the most common vertebrate fossils found in rocks ranging in age from the Devonian till date. [11], recorded fossil denticles which are scale-like bony pieces embedded in or on the skin that resemble chondrichthyan scales from the late Ordovician rock of Colorado. According to [12], there are approximately 1200 known living and valid species of shark-like fishes of the class Chondrichthyes with 10 orders, 60 families, and 186 genera. Shark and ray teeth, sometimes calcified vertebrae, are common fossils in many Cretaceous and Cenozoic deposits. The profusion of shark teeth as fossils is due to their denseness and mineral composition of calcium phosphate and to their rapid, continual replacement in the shark's jaws. Old teeth drop from their jaws to the sea floor where they are often buried by sediments because of this reason shark teeth are common as fossils. Myliobatid (eagle rays) are mostly seen along sandy beaches in shallow waters at a depth of up to 30 m. The shape of their teeth is flattened and they feed on mollusks and crustaceans. In the Paleogene sediments of Dillai Parbat, Mikir Hills, only a few vertebrate fossils consisting of a mammalian lumbar vertebra belonging to an archaeocete cetacean, and a shark teeth belonging to order Selachii and Batoidea have been recorded by [13] prior to this study. Considering the paucity of Eocene vertebrate faunal records from the northeastern region of India particularly from the Mikir Hills, it was realized that a lot more studies were needed to be undertaken in the area in order to determine the paleoenvironment and paleobiogeographic reconstruction of the Neo-Tethys seaway. In this study shark, ray, spines of echinoderms and a broken tooth of crocodile are described here associated with conical tooth and broken fragments. All the specimens have been recovered from a muddy limestone horizon in the studied section of sample No. 20 (**Figure 2**).

2. Stratigraphy of the Region

The first detailed stratigraphy of the Tertiary sediments of the Assam-Arakan

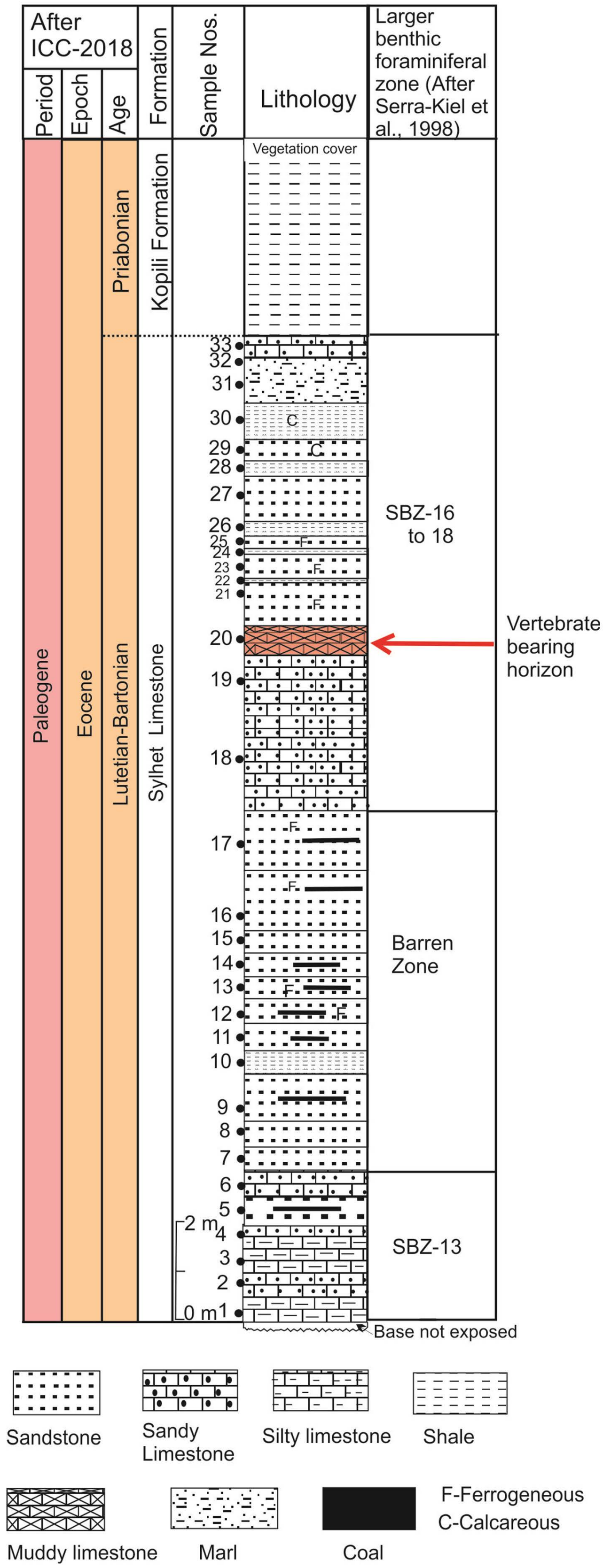

Figure 2. Measured litholog of the studied section at Dillai Parbat highlighting the vertebrate-yielding horizon.

Basin was given by [14] in his classic work "Tertiary Succession in Assam". He designated the shelfal facies of the Paleocene-Eocene beds as the Jaintia Series which was divided into the lower Sylhet Limestone Stage and upper Kopili Stage. The Sylhet Limestone which is found in the Mikir, Garo, Khasi and Jaintia Hills, was deposited in shallow, warm water, open marine environment [15] [16]. It consists of alternating limestones and sugary white sandstones with mineable coal seams. The present study area is confined to the upper part of the Sylhet Limestone on the south-eastern edge of the Mikir Hills, Assam. These beds yield an admixture of faunal assemblages of foraminifers, including larger benthic foraminifers (mainly *Nummulites*), smaller benthic foraminifers (*Quinqueloculina* sp., *Triloculina* sp., *Cibicides* sp., *Turrilina* sp., and *Lagena* sp.) [17] [18] was the first to study in detail the microfaunal assemblages of the area. On the basis of stratigraphic ranges of planktonic foraminiferal species, [19] identified five biozones of middle to late Eocene age from the Kopili Formation of Mikir-North Cachar Hills, Assam: *Truncorotaloides topilensis* Zone, *Truncorotaloides rohri* Zone, *Globigerapsissemi involuta* Zone, *Cribrohantkenina inflata* Zone, *Globigerina gortanii* Zone. Two varieties of glauconites were found in the carbonates of Mikir Hills [20] [21] [22] reported *Planorotalites palmerae,* which denotes the base of planktonic foraminiferal Zone P9 in the lower succession of the Sylhet Limestone Formation. Four larger benthic foraminiferal zones ranging in age from early Eocene to latest middle Eocene occur in the Sylhet Limestone Formation of Mikir Hills [23] along with mammalian lumbar vertebra and fish teeth from Dillai Parbat of Mikir Hills [13]. Lately, [17] delineated Shallow Bethic Zones (SBZ) 13-18 with a barren zone in the middle of the section which suggests that it might correspond to SBZ 14-15.

3. The Vertebrate and Invertebrate Yielding Section and Its Age

The studied section (**Figure 1(a)**, **Figure 1(b)**) is located in Dillai Parbat Limestone mine, Karbi Anglong District of Assam. In this paper we describe the vertebrate fauna recovered from the Eocene succession of the Sylhet Limestone exposed in a quarry (26˚01'00"N; 93˚35'50"E), (**Figure 1(c)**). This succession comprises of alternating limestones and sandstones with few coal streaks and shale beds. Our recent investigation on Sylhet limestone resulted in the collection of fossil fish teeth (crocodile, shark and ray) from the yellow muddy limestone horizon exposed in the upper part of the succession.

Based on the previous investigation of larger benthic foraminifers, the Sylhet Limestone of Mikir Hills has been assigned an age from early Eocene to upper Middle Eocene [23]. The occurrence of *Planorotalites palmerae [22]* in the lower part of the Sylhet Limestone is significant as its first appearance datum denotes planktonic foraminiferal zone P9, which is equivalent to the late part of the early Eocene. The larger foraminifers include *Nummulites verneuili, N.* aff. *millecaput*, *N. lehneri*, *N. praediscorbinus*, *N. striatus*, *N. discorbinus*, *N. praegarnieri*, *N.* cf. *ptukhiani*, *N. vicaryi* and *Assilina papillata* [17]. The horizon containing the vertebrate assemblages described here comes from larger benthic foraminiferal Zone SBZ 16-18 which corresponds to late Middle Eocene age (Bartonian) of [17]. In view of the poor preservation of fossils, specific identifications in some cases have not been attempted, and only tentative identifications are made (**Figure 3**, **Figure 4**). Collection of more specimens are planned for detailed and elaborative studies.

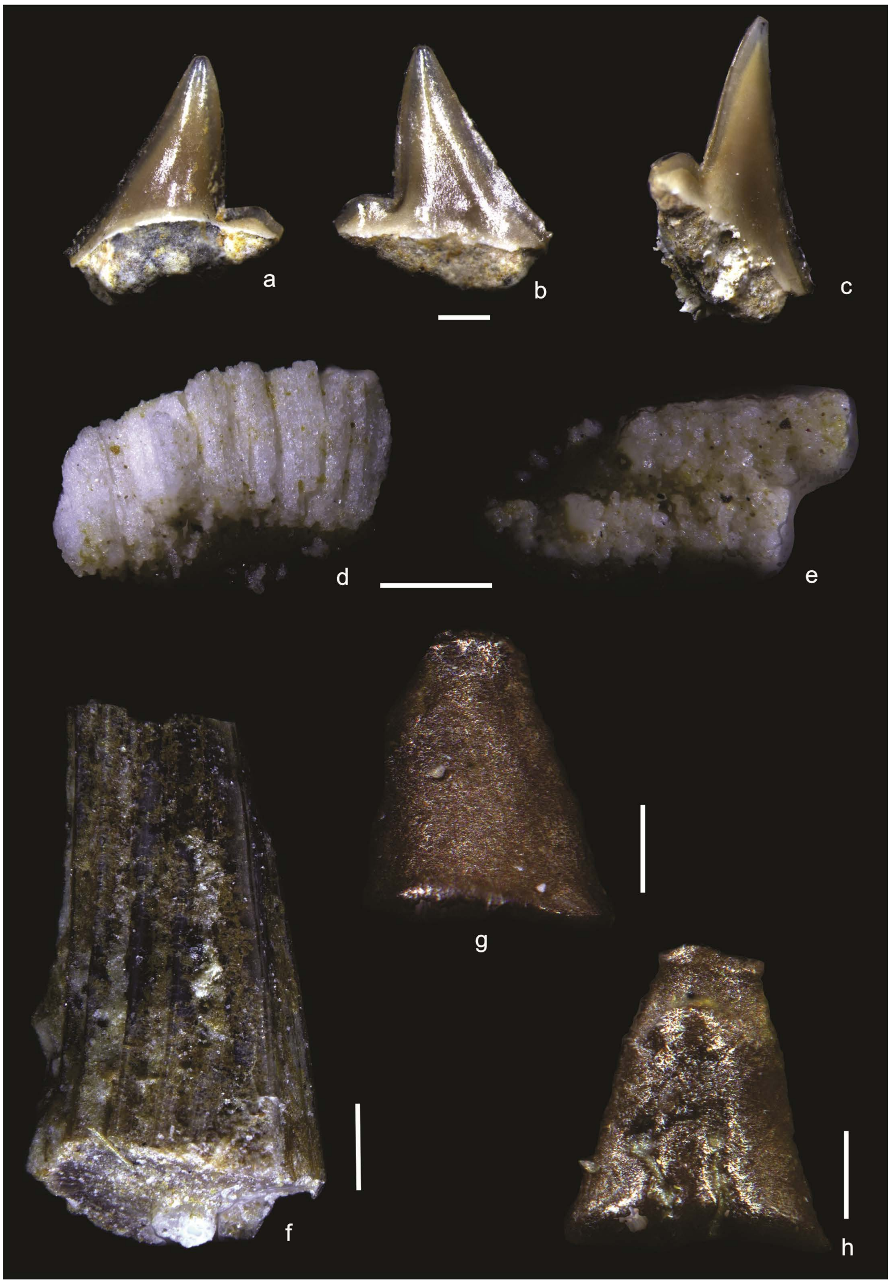

Figure 3. Shark and Ray tooth from the Mikir Hills. (a) Lingual views of Shark tooth; ((b), (c)) labial views of shark tooth; ((d), (e)) ray tooth (median tooth fragment); (f) crocodile broken tooth; ((g), (h)) conical tooth. Scale for all is 200 um (d)-(h) except for (a)-(c) (500 um).

Figure 4. (a)-(i) Spines of echinoderms; (j)-(k) broken fragments; (l) broken tooth fragment. Scale for all is 500 um (a), (b), (d), (h) & (i) except for (c), (j) & (l) (200 um), (e), (f), (g) & (k) (1 mm).

4. Material and Methods

The fossils described here were mainly collected from the samples taken from the surface outcrops of the Dillai Parbat Limestone Mine, Assam. All the materials required for the present study were collected through spot sampling in the field. The following methods were followed for the recovery of the fossils in the lab. The fossils were recovered from the rock samples through mechanical processing. Fish teeth and other vertebrate remains, echinoderm spines were recovered by washing with simple water (as the lithology is muddy Limestone). Initially, 150 gm of each rock sample were broken to a diameter of 1 to 10 mm and kept in a heat resistant bowl with 500 ml water. The sample bowls were kept on a hot plate with temperature of 60˚C. Sample solution was allowed to boil with the water level occasionally topped up for a few days until the rock showed no further signs of breaking down. Once disaggregated, the samples were washed with a gentle jet of water from tap to remove clay and silts over a sieve set of 40, 60, 80, 100 and 120 mm meshes (ASTM), which correspond to 400, 250, 177, 149, 125 microns. Alizarin blue was used in checking contamination. The samples were then air dried naturally. Dried samples were sorted and the fish teeth, other vertebrate remains, echinoderm spines were picked under the stereo zoom microscope. The photographs of fossils were taken with a Leica M205A stereo zoom microscope and digital imaging system. The measurements of the fossils were also taken. The illustrated specimens are housed in Wadia Institute of Himalayan Geology, Dehradun as WIMF/A 4871-4884. The teeth commonly found here are not white because they were covered with sediments from fossilization.

5. Systematic Palaeontology

Class: Chondrichthyes Huxley, 1880
Subclass: Elasmobranchii Bonaparte, 1838
Order: Selachii
(**Figures 3(a)-(c)**)

Material and Horizon: An isolated tooth from upper Sylhet Limestone Formation of CCI Mikir Hills, Assam (WIMF/A 4871; Length × width, 2.585 mm × 2.055 mm).

Description: WIMF/A 4871; (**Figures 3(a)-(c)**) is an incomplete medium-sized tooth of a shark with triangular shaped cusp. The cusp is narrow elongated and blunt apex and broad. A notch is present in the distal base of the cusp and basal edge is separated from the cusp by a well-developed notch. The crown cutting edge is smooth without presence of serration at the heels. Root is broken from one end. The triangular cusp has a flat labial face and convex lingual face. The specimen is longer than wide.

Remarks: The tooth is comparable to the *Lamna* sp. described by [24] [25] [26] from Kutch, Mizoram and Odisha respectively. The present tooth is characterized by large cusplets on each lateral side where there are two cusplets but broken on one side.

Phylum: Chordata
Class: Chondrichthyes Huxley, 1880
Order: Rajiformes Berg, 1940
(**Figures 3(d)-(e)**)

Material and Horizon: Isolated tooth from upper Sylhet Limestone Formation of CCI Mikir Hills, Assam (WIMF/A 4872) (Length × width, 0.330 mm × 0.626 mm).

Description: The specimen is small, incomplete tooth, hexagonal in shape although slightly broken from one end with thick crown and root. Crown height is nearly equal to the height of the root. Smooth crown and smooth occlusal surface with minor tubercle present. Distinct longitudinal grooves present on basal side of the root and separated the root and crown portion. The root of WIMF/A 4872 is having 10-11 prominent ridges and grooves. The distance between two chambers is less.

Remarks: The present tooth is similar in shape and morphology to those of *Myliobatis* sp. described from Miocene sediments of Kutch [27] and several occurrences of the genus *Myliobatis* sp. has been described from the Eocene of Kutch [24], Subathu Formation of Himachal Pradesh [28], Cambay Shale of Vastan lignite Mine, Gujarat [29] and Kapurdi Formation of Rajasthan [30]. It is also known from the Miocene Baripada beds of Odisha [31]. Mylobatid rays prefer shallow marine water of tropical to temperate climate, feeding on invertebrates and small fishes.

Order: Crocodilia Gmelin, 1788
Suborder: Eusuchia Huxley, 1875
Family: Crocodylidae Cuvier, 1807
Genus: *Crocodylus* Laurenti, 1768
(**Figure 3(f)**)

Material and horizon: An isolated tooth from Sylhet limestone Formation of CCI Mikir Hills, Assam. WIMF/A 4873; Length x Width, 0.387 mm × 0.290 mm (**Figure 3(f)**).

Description: The isolated tooth is slender and slightly curved (**Figure 3(f)**). Here vertical striations are prominent and present on both the sides of the tooth.

Remarks: Isolated crocodile tooth (**Figure 3(f)**) has been found from Mikir Hills, and referred to the genus *Crocodylus* (**Figure 3(f)**). The crocodile teeth were also recorded from Tripura [32] and Garo Hills in Meghalaya [33] in northeastern part of India.

In addition to these sharks and rays, we have also collected broken fragments **Figures 4(j)-(k)**, and a tooth fragment **Figure 4(l)** and spines of echinoderm (**Figures 4(a)-(i)**). From the same horizon, crocodile tooth has also been found (**Figure 3(f)**) and having some prominent ridges on both sides of the tooth and basal part is broader than apex which is broken from tip. While another specimen in our collection is conical tooth having a smooth surface on both sides with length 1.197 mm and width 0.666 mm (**Figure 3(g)** & **Figure 3(h)**).

6. Paleobiogeographical and Paleoevironmental Implications

The Sylhet Limestone in the Mikir Hills is composed of physically and lithologically distinct Sandstone, Shale and Limestone lithofacies associations [17]. These lithofacies are repetitive in nature and occur at different levels forming a 33 m thick succession. Lithologically, it is represented by sandy and silty limestones, buff to gray coloured with laminae rich in silt and fine sand. At places, limestone is nodular with diffused bedding planes. As a whole, limestones may be identified as wackestone and packstone in Dunham's classification [34] in the succession, the former is succeeded by the latter. Limestones occurring at different levels contain abundant larger foraminifera represented by *Nummulites* and *Assilina* floating in the micritic or sparitic groundmass. Characteristically, at 29 m level, the limestone is muddy (micrite) and full of *Nummulites* forming packstone [17]. The present vertebrate and invertebrate faunas were recovered from this horizon. In the upper part of the succession (38.5 m level), marly limestone contains abundant fossil shells, mostly fragmented, forming packstone to wackestone.

Two varieties of glauconite (*i.e.*, dark grass green and yellow green) occur in the carbonates of Mikir Hills [20] [21]. These two varieties are also found in foraminiferal tests in the present study area [17]. Presence of glauconite suggests that the carbonates were formed on continental shelves in subtidal inner neritic environments. Fossil assemblages from the present study and previous studies on glauconites from Mikir Hills suggest that Sylhet Limestone was deposited in shallow, fairly warm agitated water in neritic environment. Herringbone cross-bedding and other structures in sandstones suggest intertidal-subtidal conditions of sedimentation. The supply of clastics and carbonaceous matter from land was huge, which caused sea level regression [17]. Coastal progradation took place, sand was transported to subtidal conditions and occasionally below in transitional part of the inner neritic zone [35] [36] [37], where it was deposited in tidal channel sand shoaling bars. In subtidal neritic zone, the Shale Lithofacies Association containing microfossils of smaller benthic foraminifers was deposited under rather low energy conditions [38] [39]. The Limestone Lithofacies Association containing abundant *Nummulites* represents deposition during sea level rise (transgression), [40] [35] [41]. The limestone, varying from wackestone to packstone, is impure, containing sand and silt, which implies that during deposition the clastic supply from land was drastically reduced or became negligible preventing salinity dilution and inducing limestone sedimentation [41] [38] [42]. Wackestones were deposited in the lower shoreface to inner neritic conditions whereas, packstones in upper shoreface sedimentation. Presence of the muddy limestone at 29 m level, and marl at 38.5 m level forming packstones which have yielded extensive population of *Nummulites* testifies the high stand sea levels attaining maximum flooding (MF) [40] [35]. Marl sedimentation took place in intertidal conditions of deposition. So, during the deposition of the 33 m thick succession, the relative sea level continuously oscillated in response to sediment supply from the land.

Varieties of Eocene whales have been reported from Kutch, Western India, northern and central Pakistan [43]. In India, various assemblages of Eocene cetaceans have been described from the Harudi Formation of Kutch, Gujarat [44]-[52]. A solitary mammalian vertebra lumbar with few associated fish teeth has been reported from the marine Eocene strata (Jaintia Group) of the Mikir Hills [13]. Moreover, the oldest known fossil whale, *i.e.*, *Himalayacetus* [53] and the closest terrestrial ancestor of cetaceans, *i.e.*, *Indohyus [54]* [55] are also known from the Subathu Formation of NW Himalaya. In Pakistan, a much more diversed assemblage of archaeocetes (Pakicetidae, Ambulocetidae, Protocetidae, Remingtonocetidae, Basilosauridae) have been described from horizons ranging in age from late early Eocene (Ypresian) to late middle Eocene (Bartonian) [56] [57] [58]. Overall, studies on the Indian and Pakistani archaeocetes taxa have explained the drastic evolutionary transformation of cetaceans from a four-footed land ancestor to a marine mammal [57] [59] [60] [61].

Myliobatis has been reported from the Tertiary deposits of India like Eocene of Kutch [24], Subathu Formation of Himachal Pradesh [28], Cambay Shale of Vastan lignite Mine, Gujarat [29], and Kapurdi Formation of Rajasthan [30]. It is also known from the Miocene Baripada beds of Odisha [31]. [27] have also recorded *Myliobatis* from Khari Nadi Formation (early Miocene) of Kutch.

Crocodilian teeth are also known from the Eocene of Kutch [62], Siwaliks [63] and the Eocene Kuldana Formation of Pakistan [64]. In the present study, we recovered a broken crocodilian tooth (**Figure 3(f)**).

A preliminary report based on several vertebrate faunal assemblages like shark, rays, crocodiles and mammals were described by [65] from the Bandh Formation (Middle Eocene) of Jaisalmer Basin. However detail studies of these vertebrate faunal assemblages along with Archaeocete cetaceans (archaic whales) were described later by [43]. Sharks and rays (chondrichthyes, elasmobranchii) were also recorded from the Miocene sediments of Kutch, Gujarat [27]. Fossil batoid and teleost fish remains were reported from the Bhuban Formation (Lower to Middle Miocene) of Surma Group, Aizwal, Mizoram [66]. In Shandong province, the terrestrial Cretaceous stratigraphic succession is dominated by dinosaurs, including five vertebrate fauna (bone fossil assemblages) beds from bottom to top in the Cretaceous succession, which is an ideal area with diverse information on paleoenvironment and paleoecology [67]. [28] recorded the shark teeth of *Galeorhinus* from the Subathu Group of northwestern Himalaya. Globally, similar Middle Eocene vertebrate faunas were reported from North Sea basin in Europe [68], Libya [69], Kazakhstan [70], Italy [71], Iran [72], Germany [73], North West Madagascar [74], Tanzania [75], Pakistan [76], Southern England [77], North Western Sahara, Algeria [78] (**Figure 5**). This global distribution of middle Eocene vertebrates gives an insight of open Tethys Sea connection during the middle Eocene.

7. Conclusion

The middle Eocene deposits of Sylhet Limestone of Mikir Hills have yielded both invertebrate and vertebrate faunas. The present faunal assemblages (shark, ray, crocodile, and echinoderm spines) were recovered from Shallow Benthic Zone (SBZ) 16 - 18 in the upper part of the succession of Sylhet Limestone corresponding to late middle Eocene age. All these fossils were recovered from the muddy limestone horizon of the succession containing full of *Nummulites* forming packstones. Presence of muddy limestone at 29 m level forming packstones which

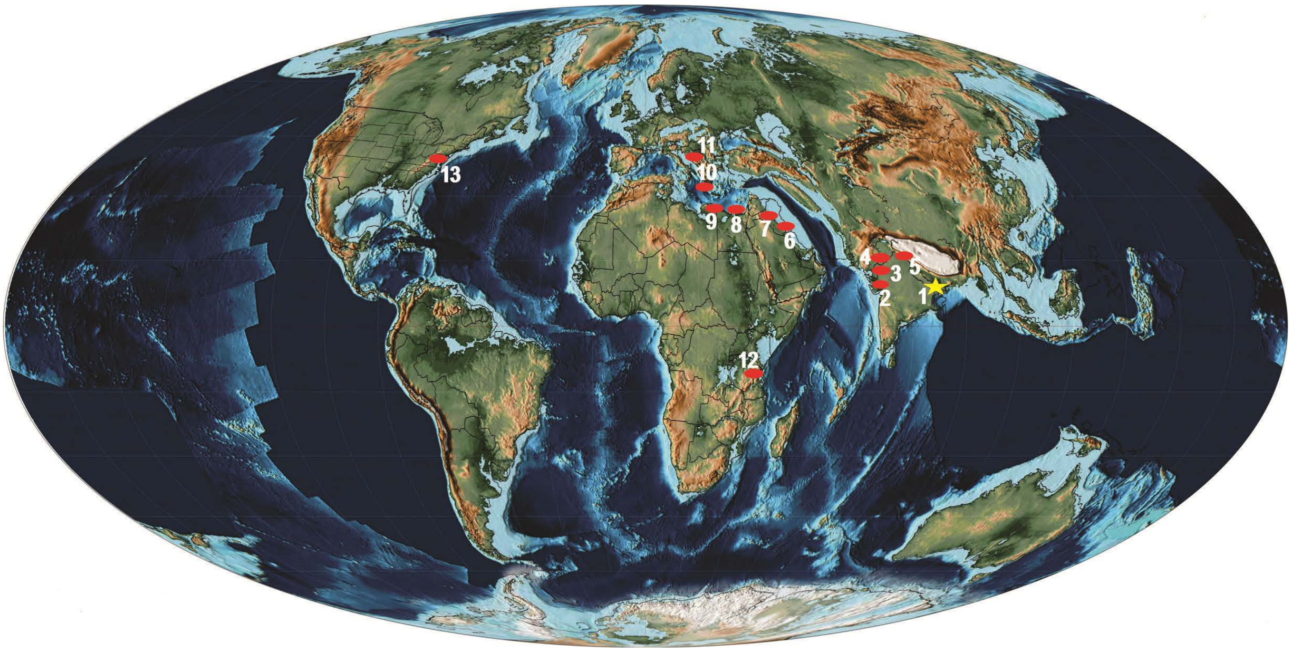

Figure 5. Paleogeographic map of late middle Eocene (Bartonian) showing distribution of fish teeth over the world in red dots and yellow star for the present study (map after [81]). 1. Mikir Hills; 2. Kutch; 3. Rajasthan; 4. Pakistan; 5. Himachal Pradesh; 6. Iran; 7. Iraq; 8. Libya; 9. Algeria; 10. Italy; 11. Germany; 12. Tanzania; 13. New Hampshire.

have yielded extensive population of *Nummulites* and other faunas testifies the high stand sea levels attaining maximum flooding surface (MF). The collected invertebrate and vertebrate fossils and sedimentological observations imply a typical shallow marine environment for Sylhet Limestone Formation of Mikir Hills. Also, as indicated by remains of sharks and ray in the present study, which mostly prefer shallow marine water of tropical to temperate climate and they feed on invertebrates and small fishes. This faunal yielding horizon of Mikir Hills may be of considerable use in understanding the paleoenvironment, paleobiogeography and paleobiodiversity. More detailed and elaborated studies will be carried out in future. The recovery of shark, ray fish and crocodile in this study have a common feature with many marine middle Eocene formations of the world, in particular middle Eocene of Kutch, Subathu, Rajasthan (India), New Hampshire, Libya, Iraq, Iran, North Western Sahara (Algeria), Tanzania (East Africa), Italy, Germany, and Southern North Sea basin (Europe). The present discovery of middle Eocene shark and ray in this region with other published data from other parts of India and world signifies an open connection of the Tethys Sea during middle Eocene age.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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