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Stratigraphic Harudi signatures at the Umarsar Lignite Mine, Kutch Basin, Gujarat, India

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The data focus on the recent stratigraphic evidence which support the age of the Kutch Lignites to be Lutetian to Bartonian, younger to the Cambay Lignite deposits dated Ypresian in age. Of significance is a Harudi marker Coquina Limestone bed investigated from the open-cast Umarsar Lignite Mine of the Kutch Basin, Gujarat. The irregular and unassorted accumulation of bivalves in the Harudi Coquina bed indicates deposition under high energy storm-like events during the Middle Eocene Climatic Optimum (MECO), unlike the Early Eocene Climatic Optimum (EECO) warming event experienced by the Cambay Lignites. The study also suggests possibilities of tracing biotic lineages from the Ypresian to the end of Lutetian time period.

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INTRODUCTION

The lignite deposits of Gujarat and Rajasthan mostly occur as coastal peat deposits and were traditionally dated using palynological data (Samant and Tapaswi, 2001; Dutta *et al*., 2011; Tripathi and Srivastava, 2012; Singh *et al*., 2010; Prasad *et al*., 2018, 2020) to be of Palaeocene-Eocene in age. However, the work of Saraswati and coworkers from IIT Bombay questioned the temporal co-equivalence of the lignites deposits in a series of papers published within the last decade (Saraswati *et al*., 2012, 2014, 2018; Khanolkar *et al*., 2017; Khanolkar and Saraswati, 2019). Khanolkar and Sharma (2019) specifically arranged the Rajasthan and Gujarat sequences in a chronological order placing Akli as Palaeocene to Eocene, Cambay sequences to Lower Eocene while assigning a Lutetian to Bartonian age to the Panandhro and Matanomadh sequences of Kutch. This view of temporal differentiation of the Gujarat lignite mines has added implications for researchers studying fossil biota in these open-cast mines, especially those dealing with amber inclusions. The new ages will, hence, allow lineages to be traced from the Lower Eocene to the end of the Lutetian.

The Kutch Lignite sequences exposed in the three principal lignite mines, namely Panandhro, Matanomadh and Umarsar, are the westernmost exposures to the Cambay and Khadsaliya Lignite Mines (Fig. 1). So far, most detailed stratigraphic studies have been conducted on the Panandhro Lignite Mine (Bajpai and Thewissen, 2002; Dutta *at el*., 2011; Saraswati *et al*., 2014, 2018; Sharma and Saraswati, 2015; Khanolkar *et al*., 2017; Khanolkar and Sharma, 2019), which lies in close proximity and stratigraphic continuation to the Umarsar Lignite Mine. For this reason, both Panandhro and Umarsar Lignite Mines are considered to be stratigraphically coeval (Agnihotri and Singh, 2020).

Traditionally, the Kutch Lignites (Fig. 3) exposed in the Panandhro and Matanomadh Mines were dated Lower Eocene, equivalent with the Naredi Formation (Biswas, 1965, 1992; Biswas and Raju, 1971, 1973). This view remained a threshold for all geological investigations of the Kutch Lignites for quite some time until the later work of IIT Bombay put forward an alternate viewpoint in the context to the age equivalence of the Kutch and Cambay Lignites. The Cambay Lignite successions from the Vastan Mine have the occurrence of *Nummulites burdigalensis burdigalensis*, which determines the age of the Cambay Lignites to be concordant with the Early Eocene Naredi Formation (Khanolkar and Saraswati, 2019). Although no such Early Eocene marker foraminifera has been found in the Kutch Lignite sequences, bio-zonations based on foraminifers, dinoflagellates and pollen led Khanolkar and Sharma (2019) to establish that the Kutch Lignites are substantially younger than the Cambay ones.

Saraswati *et al*. (2014, 2018), based on his work on biomarker foraminifers of Kutch, demarcated different levels in the concept of Shallow Benthic Zones (SBZ) from the Panandhro and Matanomadh Lignite Mines respectively. According to the information by Saraswati *et al.* (2018), the marine transgression SBZ 5/6 is part of the Early Eocene Naredi Formation. SBZ 12 to SBZ 16 constituted a gap, which was followed by the deposition of Harudi Formation-Fulra limestone during the Bartonian in SBZ 17. The Naredi and Harudi Formations constitute carbonate platforms that developed during warm intervals, whereas the gaps between the SBZs formed during a cooling time period (Saraswati

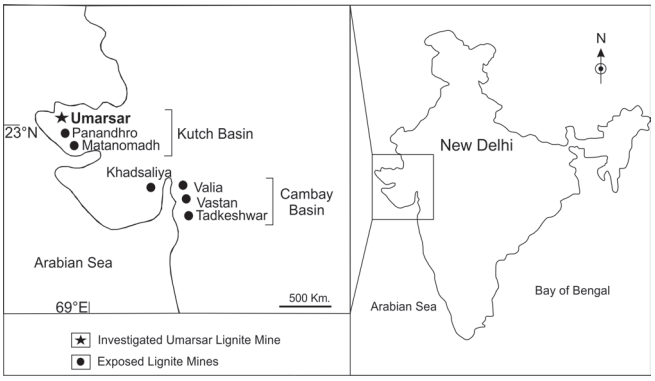

Figure 1. Investigated Lignite mines in the Kutch and Cambay Basins of Gujarat, Western India.

et al., 2018). These warm intervals correlate to the Middle Eocene Climate Optimum (MECO), which spanned the planktic foraminifer zone E11 to E12 (Edgar *et al*., 2010) and SBZ 17 (Whidden and Jones, 2012). The event was also identified by Khanolkar *et al.* (2017) and Khanolkar and Sharma (2019) based on their study on the increased dinoflagellate cyst assemblage during the MECO in the Matanomadh and Panandhro mine sections.

Following the perceived idea of the age sequences, several isotopic studies have also contributed to distinguish different thermal events experienced by the Kutch and Cambay Lignites. Agrawal *et al*. (2017) described an EECO event experienced by the Kutch and Cambay Lignites with 2.7 % and 3% negative carbon isotopic event (CIE) respectively. Khozyem *et al*. (2021) supported the Ypresian age of the Kutch Lignites based on a similar misconception. However, Khanolkar *et al*. (2017) for the same section reported a 1.5% negative CIE in the later part of the planktic foraminiferal zone E11 from the Panandhro Lignite section, and have tried to relate the response of the foraminiferal assemblage to the MECO warming event. The authors cite dinoflagellate and larger foraminferal data from beds immediately overlying the Panandhro Lignites in support of a largely Lutetian age for the Panandhro sequences (Khanolkar and Sharma, 2019). Recently, Mitra *et al.* (2022) identified several thermal events starting from Palaeocene-Eocene Thermal Maximun (PETM), Eocene Thermal Maximum event 2 (ETM2), H2, I1 and I2 respectively, based on isotopic parameters and assured a Lower Eocene age of the Umarsar Lignite Mine, equivalent to the Naredi Formation without any independent palaeontological evidences.

Significant to the Harudi stratigraphy of Kutch, Biswas (1992) identified two characteristics of the Harudi Type section, a signature Harudi Limestone section to the west of Harudi village and the presence of *Nummulites obtusus* charactersitc marker bed within the Formation. Recently, in one of the field visit to the Umarsar Lignite Mine (year 2022), one of the authors (H.S.) reported a well-developed Coquina Limestone bed. The Coquina Limestone bed at Umarsar directly correlates with the Rato River and Harudi Cliff sections. The Harudi Cliff section studied by Saraswati *et al*. (2014) and Srivastava *et al*. (2019) and Rato River section by Bajpai and Thewissen (1998) and Banerjee *et al*. (2012) share resemblance with the recently reported Coquina Limestone bed at Umarsar. Saraswati *et al*. (2014) reported Coquina Limestone bed, typical of Harudi Formation from the exposed section near Harudi village, containing foraminifer marker *Nummulites obtusus*. Srivastava *et al*. (2019) published data on facies characteristics and depositional environment of the Middle Eocene Harudi Formation on the ESE-WNW Cliff section across the Harudi-Baranda road of the Kutch Basin. He presented both clastic and carbonate facies of the Harudi Formation, of which the carbonate facies comprise Coquina Limestone bed. The Coquina bed of the Cliff section contains gastropods and bivalves arranged in a non-linear trend. A similar Coquina bed with *N. obtusus* has been reported in the outcrops near the Rato River section along with evidences of glauconite in shale samples (Banerjee *et al*., 2012). Bajpai and Thewissen (1998) reported abundant Lutetian Cetacean fossils namely *Remingtonocetus*, *A. kutchensis*, *Indocetus* and *Gaviacetus* from the Harudi Chocolate Limestone unit of the Rato River section of Kutch. The Chocolate Limestone bed has also been identified by Kumar and Sahni (1986) as one of the potential Cetacean yielding unit from the Lutetian.

Amongst the few palaeontological researches from the recently exposed Umarsar Lignite Mine, significant works include amber associated arthropod fossils, comparative study between pollen from sediments and in amber nodules (Singh 2020; Agnihotri and Singh, 2020) and record of fossil wood *Hopeoxylon umarsarensis* (Shukla *et al*., 2019). Sedimentary samples have also been investigated to study thermal maturity, oil generation potential and geochemical properties (Akanksha *et al*., 2020). The ongoing palaeontological studies suggests that the amber inclusions from the Umarsar Lignite Mine are equivalent to similar taxa reported from the Baltic and Cambay amber and adapted to similar environmental conditions (Singh, 2020; Agnihotri and Singh, 2020, Bickel *et al*., 2022). It appears that the palynology based chronological data are much better in describing the depositional environment rather than the age of the sedimentary sequences.

GEOLOGICAL SETTING

The Harudi marker Coquina Limestone bed has been discovered from the open-cast lignite deposits of the Umarsar Lignite Mine (Latitude 23° 43’ 22.97’’ N; Longitude 68° 50’ 23.82’’ E), approximately ten kilometers from the Panandhro Lignite Mine in the South West. The Umarsar Mine has four lignite seams ranging from a few centimeters to roughly two meters. The upper lignite seams are thinner than the basal seams. Shale and sandy clay sedimentary strata alternate with lignite seams incorporating amber nodules (Agnihotri and Singh, 2020). The Harudi marker Coquina Limestone bed has been recovered between the Grey Shale strata (B-10) above Lignite Seam III (L-3) during section measurement in the year 2022 (Fig. 2). The Coquina bed is composed of irregularly piled and fragmented molluscan shells and vertebrate fossils including rostral fragments and pectoral spine of silurids (Fig. 4) in a calcareous matrix. This provides strong support to assign the Umarsar Lignite sequence under the Harudi Formation, overlying the Ypresian Naredi

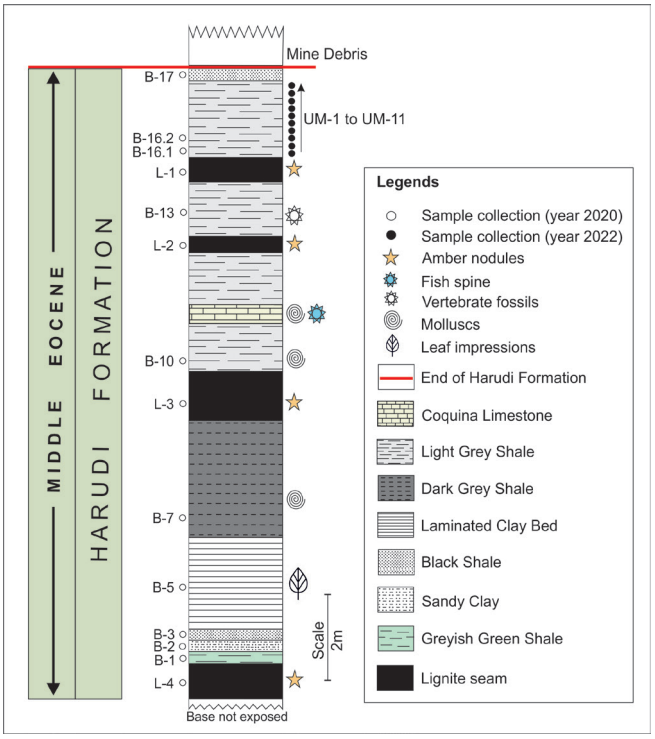

Figure 2. Lithological section of Umarsar Lignite Mine, site exposed in the South-East direction (Stratigraphy largely based on Khanolkar and Sharma, 2019).

Formation, proposed in multiple articles (Saraswati *et al*., 2014, Srivastava *et al*., 2019; Khanolkar *et al*., 2017) (Fig. 3).

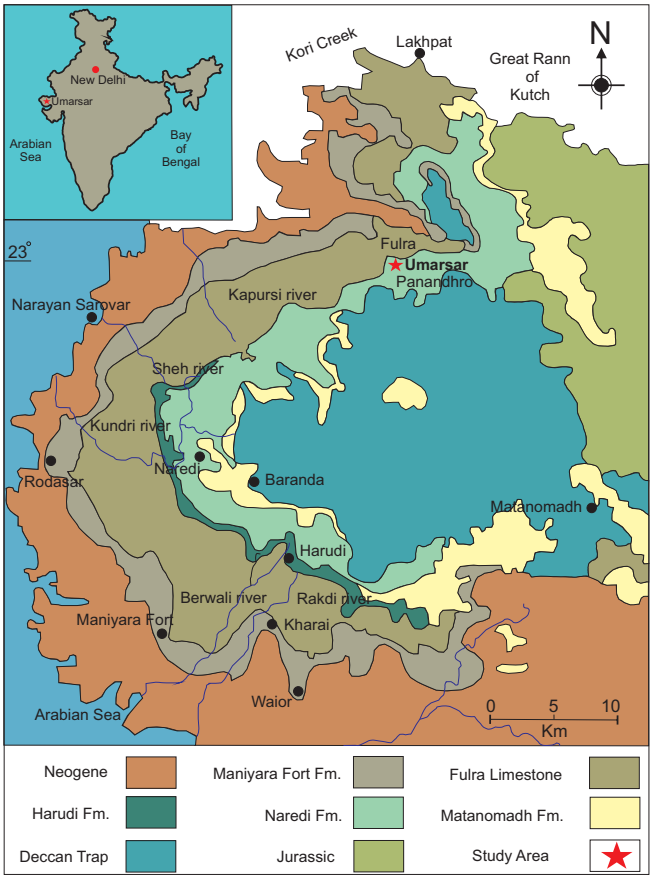

Figure 3. Regional geology of Kutch (modified after Saraswati *et al*., 2018).

DISCUSSION

Stratigraphic data from the open-cast Umarsar Lignite Mine supports the recently revised age of the Kutch Lignites to be Lutetian to Bartonian, corresponding to the Harudi Formation (Saraswati *et al*., 2018; Khanolkar and Sharma, 2019). In the recent field investigation by H.S. in the year 2022, it has been established that one of the signature beds of the Harudi Type section exposed in the Cliff Section as well as in the Rato River sections is also found in the Umarsar Lignite Mine (Fig. 2). The Umarsar Lignite Mine also abuts the Panandhro Mine in the Southwest. With the find of a Limestone Coquina at Umarsar showing similarities in nature, composition and fabric and mollusc assemblages with the Harudi Type Section, the contention that the Panandhro and Umarsar Mine sections are Lutetian and slightly younger, is strongly supported. In several papers, Saraswati *et al.* (2018) and Khanolkar and Sharma (2019) have also re-emphasized that the Panandhro Mine sequence is largely Lutetian in age. Evidence of vertebrates 8-10 meters above the topmost lignite seam at Panandhro (Bajpai and Thewissen, 2002; Rage *et al*., 2003; Bajpai, *et al*., 2006; Thewissen and Bajpai, 2009), and report of *Kutchicetus*, an archaeocete taxon known earlier from the Lutetian (Bajpai and Thewissen, 2000; Spoor *et al*., 2002) provides additional support for the younger age of the adjacent Umarsar Lignite Mine. Silurid fragments recovered in the Coquina deposit at Umarsar are related to the Middle Eocene silurid fishes identified from the Harudi locations of the Berwali Series in Western Kutch, which are comparable to those discovered in Nigeria and Egypt (Sahni and Mishra, 1975).

During the Middle Eocene, there was a warming trend from ~40.6 to 40 Ma, called the MECO (Bohaty and Zachos, 2003; Sexton *et al*., 2006; Bohaty *et al*., 2009). Records of the MECO have contributed to the facies development and formation of the Harudi section under the effect of a rapid sea-level rise and subsequent carbonate deposition, like the Coquina beds. The presence of irregularly stacked molluscan shells in the Harudi Coquina matrix of the Umarsar Lignite Mine from the Kutch Basin (Fig. 4) is suggestive of a high-energy storm-like wash over deposits in a lagoonal depositional condition (Kidwell 1991; Kumar *et al*., 2009). Traces of glauconite in grey shale sequence below the Coquina layer (Fig. 4) are indicative of a slow rate of sedimentation in a shallow marine to coastal environment.

Amber nodules with biotic inclusions are well recorded from the Cambay Lignite Mines as well as the Kutch Lignite Mines. This occurrence is fortunate in many ways as it now appears that the Cambay Basin Lignite deposits are characterized by *Nummulites burdigalensis burdigalensis*, a marker larger foraminifera for the Lower Eocene, (Punekar and Saraswati 2010; Sahni *et al*., 2006) while the Kutch localities are much younger and Middle Eocene in age. This will allow, in the future to trace diverse biotic lineages

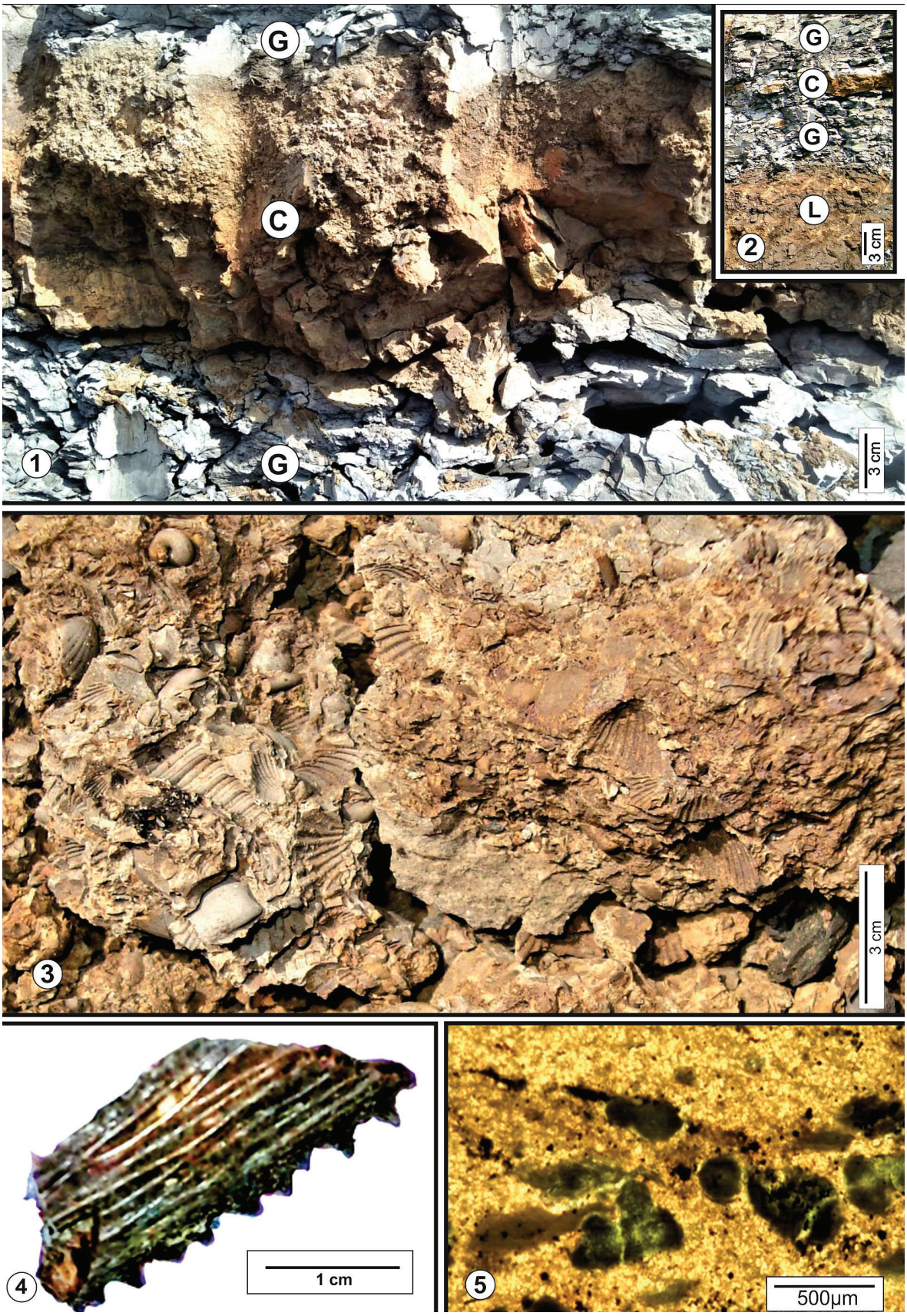

Figure 4. Fossils from the sedimentary sequences of the Umarsar Lignite Mine, Kutch Basin. (1 and 2) Harudi Limestone bed (C) between Shale (G) sequence B-10, overlying the Lignite (L) bed; (3) Bivalve mollusc impressions in coquina limestone sequence; (4) pectoral spine of a Silurid fish; (5). Thin section of Glauconite infillings from Grey Shale sequence B-10, (BSIP Slide no. 17183).

between pre-collision and post-collision history of the Indian Plate that are preserved in amber for about 10 million years or slightly less (Bickel *et al*., 2022).

CONCLUSIONS

1. Discovery of the Coquina Limestone bed at the Umarsar Lignite Mine of the Kutch Basin in the early 2022 adds support to the viewpoints of Saraswati *et al*. (2014, 2018), Sharma and Saraswati (2015), Khanolkar *et al*. (2017), Khanolkar and Sharma (2019), for championing a younger age for the Kutch Lignites.
2. The younger age for the Kutch Lignites raises the opportunity of tracing faunal and floral lineages for a range of nearly 10 million years. The Cambay Lignites would approximately correspond to the Fushun Lignites of China, while the Kutch Lignites would be coeval to the Baltic and Bitterfield Lignites.
3. The carbon isotopic excursion (CIE) event recorded by Khanolkar *et al*. (2017) in the Panandhro Lignite Mine which abuts the Umarsar Lignite Mine, relates to the Middle Eocene Climate Optimum (MECO) event.
4. In general, the Umarsar Lignite sequences resemble the Harudi Cliff section and other sections of the Rato Nala in its common biotic content.

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