

# Foraminiferal biostratigraphy of lignite mines of Kutch, India: Age of lignite and fossil vertebrates

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**Abstract** The lignite deposits of Kutch, India are stratigraphically referred to the Naredi Formation and considered to be Early Eocene in age. The biostratigraphy of the older mine at Panandhro and a newly opened mine at Matanomadh has constrained the upper age limit of lignite to the early Bartonian. Its lower age may extend to the late Lutetian. Temporally the formation of lignite corresponds to the warming event of the Middle Eocene and suggests a humid climate at the onset of the warming. The previous palynological studies have already suggested dominance of tropical angiospermic pollen. A diverse assemblage of fossil whales and other vertebrates, many of them supposedly the oldest representatives, were reported from Panandhro mine. These were initially assigned to the Early Eocene and later to the Lutetian age. The present biostratigraphic study revises their age to the Early Bartonian.

**Key words** Eocene vertebrates, Kutch, India, lignite, biostratigraphy

## 1 Introduction

The Cenozoic succession of Kutch, West India is known for its commercial deposits of lignite. Stratigraphically, lignite deposits referred to the Naredi Formation (Table 1) were initially assigned to the Early Eocene (Biswas and Raju, 1971) and later revised to the Late Paleocene to the Early Eocene in age (Biswas, 1992). The recent biostratigraphic study refutes the revised age of the formation and suggests that it ranges from the shallow benthic zone SBZ 5/6 to SBZ 11 of the Early Eocene (Saraswati *et al.*, 2012). In the type locality the Naredi Formation is not associated with lignite and in the mine section of Panandhro no definite age could be assigned to lignite due to poor faunal control. However, due to the subsurface occurrence of lignite just south of the type locality of the Fulra Limestone (Middle Eocene) and the absence of the characteristic foraminiferal

*Nummulites obtusus* of the Harudi Formation, probably led earlier workers to believe that the lignite belongs to the Naredi Formation and it is of Early Eocene age.

The Eocene period was marked by hyperthermal events in the Early Eocene (Zachos *et al.*, 2001) and the Middle Eocene (Bohaty *et al.*, 2009). Several hyperthermal events lasting for a few tens of thousands of years are recorded in the Early Eocene, prominent among which are the PETM (Palaeocene Eocene Thermal Maximum), ETM2 (Eocene Thermal Maximum 2) and EECO (Early Eocene Climatic Optimum). The hyperthermal event of the Middle Eocene lasted for about 750 kyrs and is known as the MECO (Middle Eocene Climatic Optimum). In western India, lignite deposition corresponding to the Early Eocene warming event is found in the Cambay Basin near Surat (Punekar and Saraswati, 2010). A carbon isotope excursion reported in this section is referred to one of the events, called ETM2 (Clementz *et al.*, 2011). Lignite deposition was extensive during this period in western India and the Indus Basin in Pakistan. In Pakistan lignite occurs in the Bara Member

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Received: 2013–06–05 Accepted: 2013–10–09

**Table 1** The Eocene stratigraphy of Kutch, India

Epoch	Age	Formation	Member
Oligocene	Chatian	Maniyara fort	Bermoti
	Rupelian		Coral limestone
			Lumpy clay
			Basal member
Eocene (Middle)	Bartonian	Fulra Limestone	-
	Lutetian(?)–Bartonian	Harudi	-
Eocene (Early)	Ypresian	Naredi	Ferruginous clay
			Assilina limestone
			Gypseous shale
Upper Paleocene	Thanetian	Matanomadh	-

and Lakhra Member of the Ranikot Formation. The former is biostratigraphically assigned to planktic foraminiferal zone P4 and the latter to P4–P7 (Jones, 1997; Afzal *et al.*, 2009). The Early Eocene lignite in western India occurs in Cambay Basin, Barmer Basin, Bikaner Basin and Kutch Basin (assuming the presently held age of lignite). In comparison, the lignite deposits of the Middle Eocene are few. The lignite of Barmer and Bikaner occur in formations that extend to the Middle Eocene in age (Raju and Mathur, 2013). Further detail is not available if it is of Lutetian or continues to the Bartonian. In Pakistan, a minor occurrence of lignite is reported from the upper part of the Domanda Formation (nannoplankton zone NP15–NP16; Afzal *et al.*, 2009). While there are a number of lignite deposits corresponding to the Early Eocene hyperthermal events in this part of the subcontinent, was there lignite deposition during the Middle Eocene warming period in the early Bartonian?

The stratigraphy of the lignite mine section also has implication for the age of the fossil vertebrates recorded from the mine. An assemblage comprising snakes, fishes, turtles, crocodiles and whales was recorded from the strata overlying lignite in Panandhro mine (Bajpai and Thewissen, 2002; Rage *et al.*, 2003). Considering the Early Eocene age of the lignite, the vertebrate fossils in the overlying strata were also assumed to be of the same age and, as a result, some of them were initially regarded to be the earliest representatives of respective fauna in Asia or the Indian subcontinent (Rage *et al.*, 2003). Later, Thewissen and Bajpai (2009) supposed the Panandhro fauna to have been washed down from the overlying Harudi Formation and thus assigned them a Lutetian age. In our recent study of the stratigraphically equivalent Matanomadh mine sec-

tion we observed the Middle Eocene larger benthic foraminifera comparable with those of the Fulra Limestone (of Bartonian age) directly overlying lignite (Khanolkar and Saraswati, in press). This led us to re-investigate the Panandhro mine section to establish the stratigraphic position of lignite with the aim to (1) determine the period of lignite deposition in relation to the Middle Eocene warming interval and (2) verify the reported age of the vertebrate fossils.

## 2 Methodology

The rock samples were collected from Panandhro (23°42'N; 68°46'E) and Matanomadh (23°30'N; 68°57'E) (Figure 1) mines and macerated to separate foraminifera by standard procedure. The litholog, sample positions and foraminiferal taxa in the two mine sections are shown in Figure 1. Scanning electron micrographs and oriented sections of the biostratigraphically important species are illustrated in Figure 2.

## 3 Results

The lignite-bearing succession overlies the Deccan basalt. In Panandhro mine, it consists of sandstone, carbonaceous shale and lignite in the lower part and shale, siltstone and limestone in the upper part. The shale interbedded with lignite is practically barren and did not yield any age-diagnostic foraminifera. The shale immediately overlying lignite consists of *Nummulites spectabilis*, *N. pinfoldi* and *N. cf. discorbinus*. These Middle Eocene species are reported from the upper part of the Harudi Formation in other sections of Kutch (Samanta *et al.*, 1990;

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