

Biostratigraphy and Paleoenvironmental Interpretation Along Eastern Margin in Gamij Area of Cambay Basin, Gujarat, India*

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Introduction

The Cambay Basin is an elongated and narrow intracratonic rift graben which trends roughly in a north–south direction (Figures 1, 2, 3, and 4). The basin originated during Late Cretaceous with the development of extensional faults along the margins followed by Deccan volcanic activity. It is filled with Tertiary sediments which were deposited over the Deccan Trap volcanic basement.

The eastern margin of Cambay Basin is the focus area for exploration in the Ahmedabad block. Recent hydrocarbon discoveries in horst blocks in the Gamij field have upgraded the prospectivity of the area and added impetus to exploration activities. New pools and hydrocarbon finds have opened up the area for Paleocene-Eocene prospects. Integrated laboratory studies were carried out to precisely delineate the biostratigraphic and lithostratigraphic boundaries between Deccan Trap basement, overlying volcanoclastic sediments of Olpad and Cambay formations, and reconstruct the paleoecology of the area.

The Olpad sediments of Paleocene age, the first sedimentary units deposited on the Deccan basalt, consist of two major lithofacies: conglomeratic trapwacke and silty trapwacke. The conglomeratic trapwacke was deposited in both middle and distal parts of a fan in a coastal to brackish environment. The silty trapwacke is more clayey, was deposited in distal fan as levee to floodplain deposits under coastal, tidal and brackish conditions, and has poor reservoir characteristics. The upper part of Cambay Formation is mainly sideritic in nature, composed mainly of reddish brown, ooidal shale that marks an unconformity surface between the Cambay Formation and over-lying Kalol Formation.

The palynological assemblages of a variety of spores, pollen and dinoflagellate cysts in the Olpad, Cambay and the lower part of Kalol formations, precisely mark the age boundaries between Early Paleocene/Eocene and Early Eocene/Middle Eocene. The stratigraphic ranges of various marker taxa enabled the dating and correlation of the sediments in the area. Two palynozones corresponding to the

Olpad Formation of Paleocene age and Cambay Formation of Early Eocene age have been demarcated in the subsurface. The top of the Paleocene and Early Eocene is marked by first downhole appearance of the index marker taxa *Rhombipollis geniculatus* and *Pellicieripollis langenheimii*, respectively.

The palynofloral assemblage indicates a subtidal to inner shelf environment during the deposition of the Olpad Formation and the overlying Cambay Formation, respectively. The microfaunal assemblages composed of *Nummulites burdigalensis* and *Baculogypsinoidea*, together with *Operculina* sp. and *Cibicides* sp. in the Cambay Formation, suggest a shallow bathymetry. The integrated studies have helped in reconstructing a paleoecology of the area and facilitated in locating suitable reservoir and cap rock facies for further hydrocarbon exploration.

Previous work

Abbasi et al. (1994) studied the lithofacies and depositional environment of Paleogene pay sands in Gamij area. Shanmukhappa et al., (1994) carried out palyno-stratigraphy and paleoenvironment analysis of Paleogene sequence in this area and divided the sequence into three palynozones. Dhruvendra Singh et al. (1997) conducted a sedimentological study in some of the selected wells in Gamij area. Singh et al (2003) studied the biostratigraphy and paleo-bathymetry of the Eocene Pays (EP-III pay sands) on the basis of faunal assemblages. Bhat Padoor et al. (2003) studied the microfacies, mineralogy and reservoir characterization of Eocene Pay sands (EP - III pays) in this area. The present study deals with standardization of the biozones, paleoenvironment reconstruction, and demarcation of Olpad and Cambay formation boundaries.

Geological Setup and Stratigraphy

The Gamij field is north-south trending elongated field, parallel to the trend of the eastern margin fault. The beds dip about 6-8° to the west. A number of hydrocarbon pays have been identified in the Olpad and Kalol formations in the area (Ashok Kumar *et al.*, 2004). The generalized stratigraphy of the studied area is as follows (after Pandey et al., 1993):

Age	Formation
Middle Eocene	Kalol
Early Eocene	Cambay
Paleocene	Olpad
Late Cretaceous	Deccan Trap

Material and Methods

About 350 samples of conventional cores and well cuttings from nine wells in the Gamij area were studied for their palynofloral content. The samples were processed by using standard palynological techniques and examined at 5m intervals to demarcate the age

boundaries and interpret the depositional environment of sedimentary sequences. Sedimentological studies were carried out to examine the lithological attributes, microfacies and mineralogy of the Olpad and Cambay formations. Samples were analyzed for microfaunal assemblages in the selected wells of Gamij area; however, very poor populations of larger benthics, micro-gastropods, and ostracod assemblage were observed.

Biostratigraphy

The palynofloral assemblage record consists of a variety of spores, pollen and dinoflagellate cysts. The stratigraphic ranges of various marker taxa have been used for dating and correlation of the sediments in different wells. The top of the Paleocene and Early Eocene has been marked by the first downhole appearance of the index marker taxa (Table 1). Based on the study, two palynozones have been demarcated (Table 2).

Rhombipollis geniculatus-Peninsulapollis gillii zone-I: The lower limit of this palynozone has been taken as the top of the Deccan trap. The top of the this zone is marked by the first downhole appearance of *Rhombipollis geniculatus*, *Peninsulapollis gillii*, *Yegupollis prolatus*, *Spinizonocolpites adamanteus*, *Milfordia homeopunctata*, *Polycolporopollenites calvus*, *Nuxpollenites sp.*, *Mulleripollis bolpurensis*, *Echitriporites sp.*, *Kapurdipollenites sp.*, *Cricotriporites vimalii*, *Plicatopollis sp.*, *Apectodinium augustum*, and *A. parvum*. Other associated taxa include *Palmaepollenites kutchensis*, *P. nadhamunii*, *Florschuetzia sp.*, *Zonocostites ramonae*, *Proxapertites operculatus*, *Proxapertites cursus*, *Lycopodiumsporites sp.*, *Lygodiumsporites sp.*, *Cyathidites sp.*, *Couperipollis rarispinosus*, *Longapertites vaneedenburgi*, *Margocolporites tsukadai*, and *Marginipollis concinnus*.

The above assemblage has been correlated with the known stratigraphic distributions from the Upper Paleocene Patala Formation of the Surghar and Salt ranges of northern Pakistan (Frederiksen, 1994). It is suggestive of a Paleocene age and corresponds to the Olpad Formation.

Pellicieiroipollis langenheimii, Triangulorites bellus zone-II: The top of this zone is marked in all the studied wells. The base of this zone is characterized by the first downhole appearance of Paleocene marker palynotaxa. This palynozone is characterized by the first downhole appearance of *Pellicieiroipollis langenheimii*, *Triangulorites bellus*, *Striacolporites striatus*, *Polybrevicolporites cephalus*. The other associated taxa include *Ctenolophonidites sp.*, *Meliapollis sp.*, *Lakiapollis ovatus*, and *Triorites communis*. This assemblage has been earlier reported by Venkatachala et al. (1988) from the Paleocene-Eocene marker pollen from Kutch, Cambay, Assam, Meghalaya and Tropical Africa. It is suggestive of Early Eocene age and corresponds to the Cambay Formation. The micropaleontological studies have revealed the occurrence of *Operculina sp.*, *Cibicides sp.*, gastropods, *Baculogypsinoides*, ostracods, *Nummulites staminus*, *Nummulites fabianii*, *Nummulites acutus* and bivalve shell fragments in the Cambay Formation. The assemblage is suggestive of Early Eocene age.

Depositional Environment

The palynofloral assemblage recorded from different wells has been grouped into eight floral ecological complexes. These complexes are inland, freshwater, fern, fungal, palm, low-salinity water-plant complex, mangrove and marine phytoplankton (Mathur and Chowdhury, 1976). The micropaleontological studies reveal the presence of larger and smaller benthics in moderate frequency, thereby suggesting shallow paleobathymetry for selected intervals of the subsurface sedimentary sequence.

The palynofloral assemblage recorded from the lower part of the Olpad Formation in the Gamij area is dominated by inland complex, fresh-water complex, fern complex, low-salinity water complex, low frequency of mangrove and marine phytoplankton complex. In the southern part of the Gamij area, low frequency of marine phytoplankton along with very low frequency of mangrove pollen have been observed in the palynofloral assemblage suggesting that the sediments were deposited under an intertidal environment. In the middle part of the Gamij field, during the deposition of the Olpad Formation similar complexes continued to occur except for the fact that there was an absence of marine phytoplankton. This is attributable to supratidal conditions during the Middle to Late Paleocene period. As deposition continued, intertidal conditions again prevailed in the upper part of the Olpad Formation towards the end of Paleocene age. Towards the northern part of Gamij area subtidal followed by intertidal conditions continued during the deposition of lower part of Cambay Formation in Early Eocene times. The sediments of the upper part of Cambay Formation show dominance of marine phytoplankton and low frequency of mangrove complex, suggesting an inner shelf environment towards the end of Early Eocene period.

Discussion

Palynofloral studies by Shanmukkhapa et al., (1994) indicated that the Olpad Formation ranges in age from Paleocene to early part of Early Eocene based on the presence of *Meliapollis sp.*, *Lakiapollis ovatus*, *Triorites communis* and *Apectodinium sp.* The lower most part of the Olpad Formation, in general, is marked by a lateritic red claystone. The present study reveals the occurrence of characteristic index marker taxa, namely *Rhombipollis geniculatus*, *Peninsulapollis gillii*, *Yeguapollis prolatus*, *Spinizonocolpites adamanteus*, *Milfordia homeopunctata*, *Polycolporopollenites calvus*, *Nuxpollenites sp.*, *Mulleripollis bolpurensis*, *Echitriporites sp.*, *Kapurdipollenites sp.*, *Cricotriporites vimalii*, *Plicatopollis sp.*, *Apectodinium augustum*, and *A. parvum* suggesting a Middle to Upper Paleocene age.

The criteria adopted in the present study to decipher the paleoenvironment are: the absence of mangrove and marine phytoplankton complex suggests supratidal conditions; absence of only marine phytoplankton indicates intertidal conditions; moderate frequency of marine phytoplankton and rare occurrence of mangroves suggests subtidal conditions; and low frequency of mangroves and dominance of marine phytoplankton are suggestive of inner neritic environment.

Olpad Formation

The Olpad Formation is the first sedimentary unit overlying the Deccan Trap with a reported unconformity at the base. However, no other direct evidence of an unconformity could be found, due to the low frequency of microfossils in the studied wells. The average thickness of the Olpad Formation is 315m in the study area. It has been dated as Paleocene age on the basis of occurrence of *Rhombipollis geniculatus*, *Peninsulapollis gillii*, *Yeguapollis prolatus*, *Spinizonocolpites adamanteus*, *Milfordia homeopunctata* and *Apectodinium augustum*. The Olpad Formation in the Gamij area is characterized by two laterally extensive lithofacies, conglomeratic trapwacke and trapwacke (Figure 5). The other facies include volcanic tuff, shale and pebbly sandstone that have limited lateral extension.

In the conglomeratic trapwacke, the palynological assemblage is dominated by palm complex; namely, *Palmaepollenites kutchensis*, *P. nadhamuni*, *Couperipollis rarispinosus*, and *Longapertites vaneedenburgi*, low-salinity water complex; namely, *Proxapertites operculatus* and *Spinizonocolpites echinatus*, thus indicating coastal environment under supratidal regime.

Cambay Formation

The overlying Cambay Formation is characterized by finer clastic facies dominated by shale. The palynological studies indicate a subtidal to inner neritic condition of deposition, based on the occurrence of mangrove palynotaxa; namely, *Marginipollis concinnus*, *Zonocostites ramonae* and *Florschuetzia* and marine phytoplankton; namely, *Apectodinium augustum*, and *A. parvum*.

The micropaleontological studies have revealed the occurrence of *Operculina* sp., *Cibicides* sp., gastropods, *Baculogypsinoidea*, ostracods, *Nummulites staminus*, *Nummulites fabianii*, *Nummulites acutus* and bivalve shell fragments, suggesting a fluctuating environment.

Conclusions

The Olpad Formation, assigned a Paleocene age on the basis of diagnostic palynoflora, was deposited under supratidal to intertidal conditions with little subtidal influence towards the upper part. The Cambay Formation has been dated as Early Eocene, and it was deposited under subtidal to inner neritic conditions.

The microfaunal assemblages composed of *N. burdigalensis* and *Baculogypsinoidea*, *Operculina* sp. and *Cibicides* sp. in Cambay Formation suggest an Early Eocene age and shallow to inner neritic bathymetry. Based on the lithological attributes, microfaunal and diagnostic floral assemblages, the lithostratigraphic and biostratigraphic boundaries in the area have been demarcated; this helped in integrating the age boundaries with seismic markers for regional correlation. Two laterally correlatable facies in the Olpad Formation, namely, conglomeratic trapwacke and fine to medium-grained trapwacke, have been delineated in the subsurface well sections.

The studies helped in understanding of the paleoenvironments and prospectivity of Olpad and Cambay formations for future exploration leads in the Gamij area.

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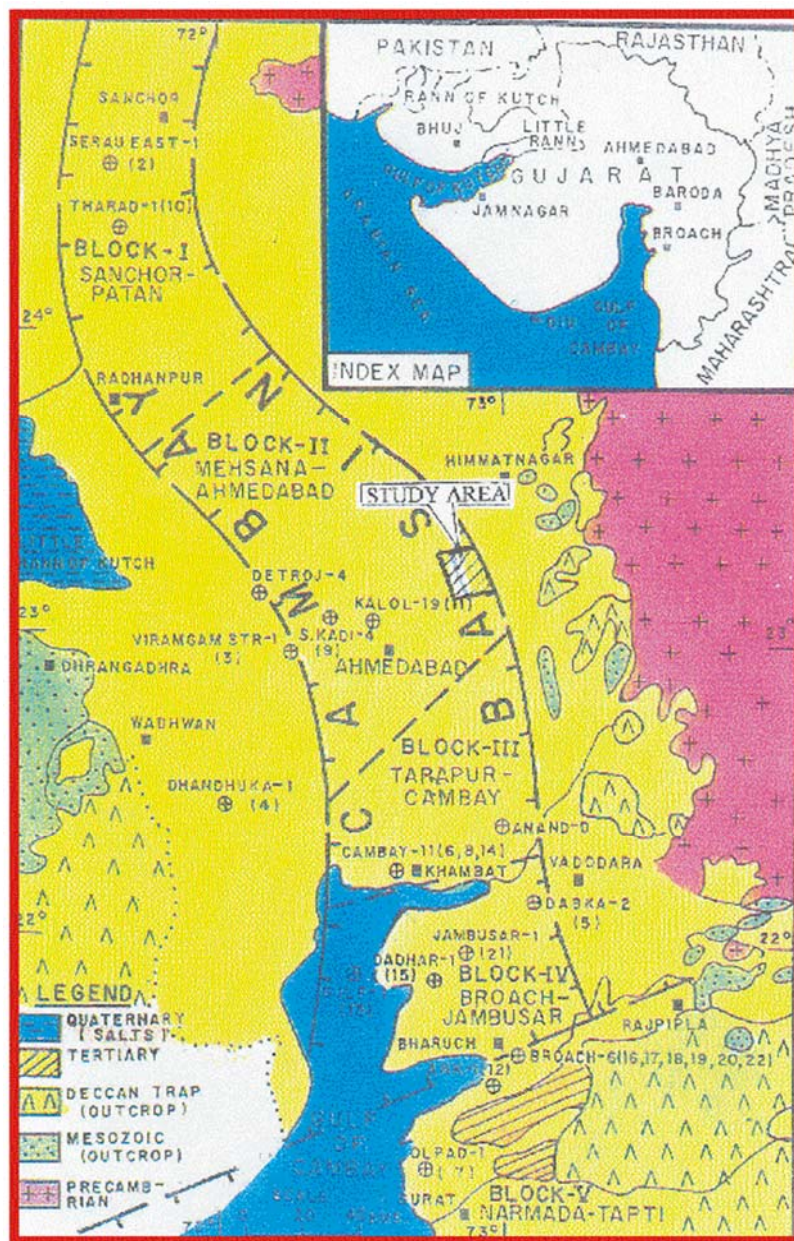


Figure 1. Geologic map of Cambay Basin.

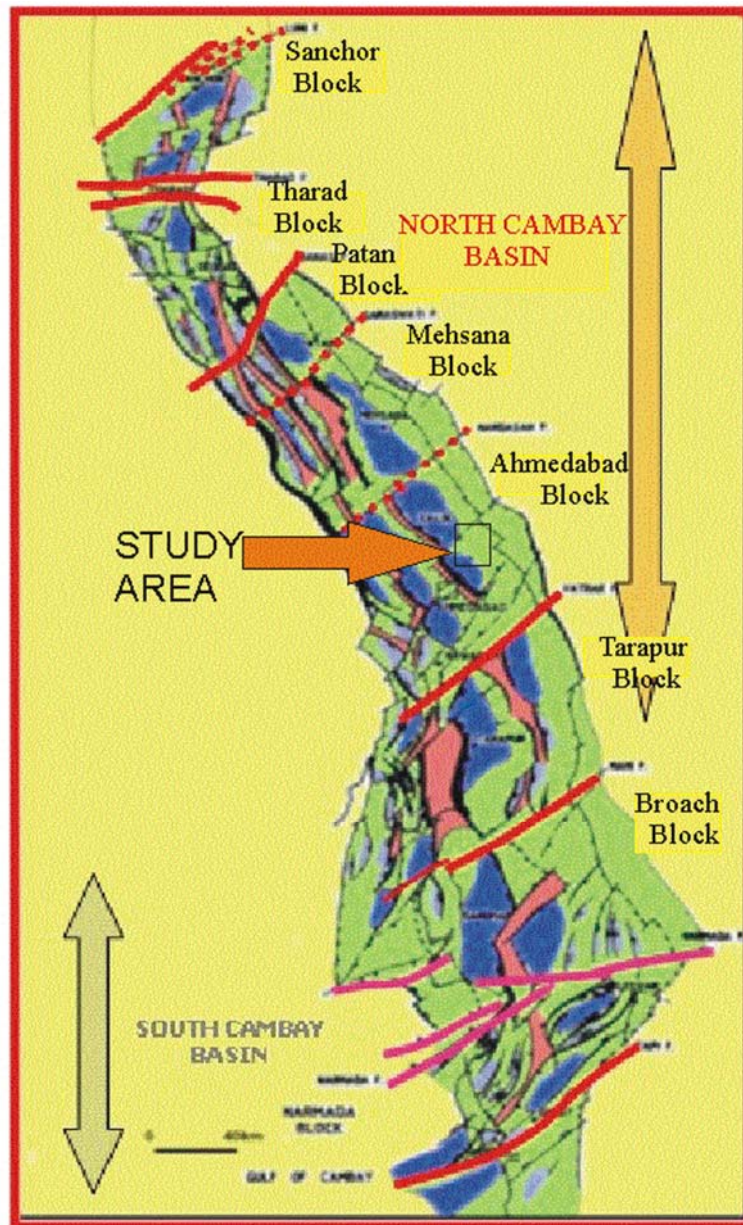


Figure 2. Generalized tectonic map of Cambay Basin.

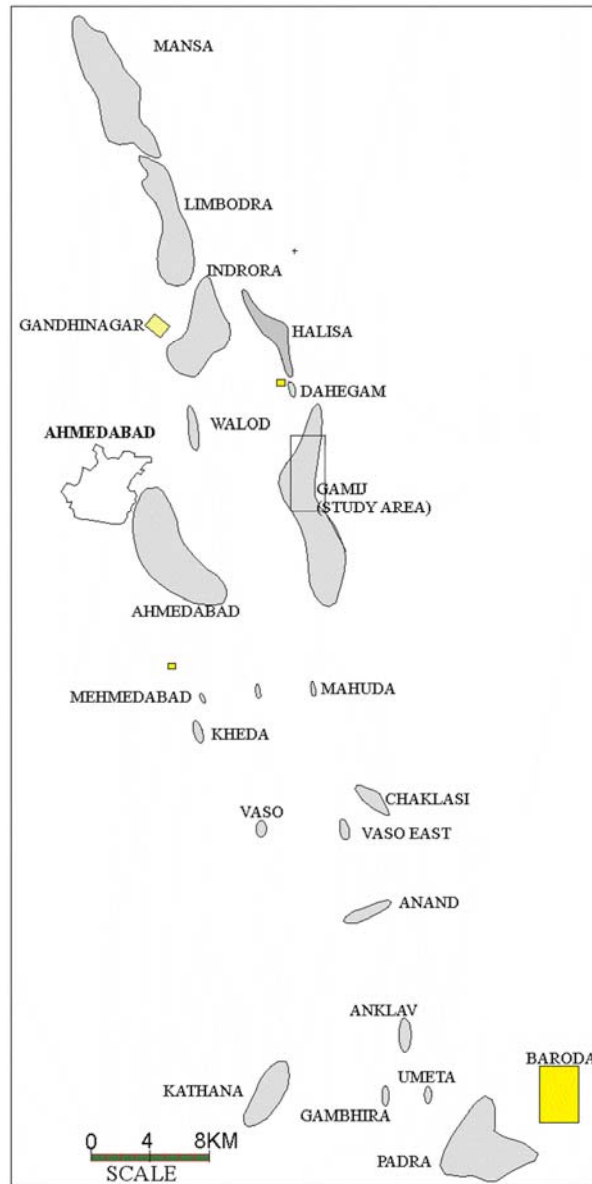


Figure 3. Location map of important structures along Eastern Margin in Cambay Basin.

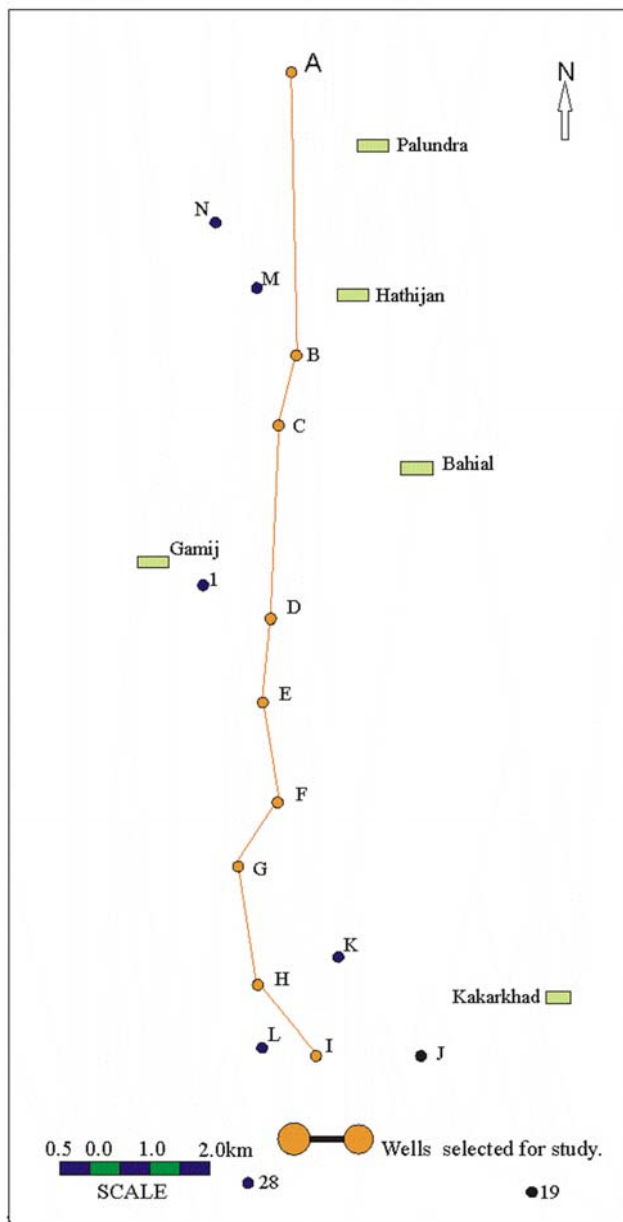


Figure 4. Map showing location of wells studied in Gamij area.

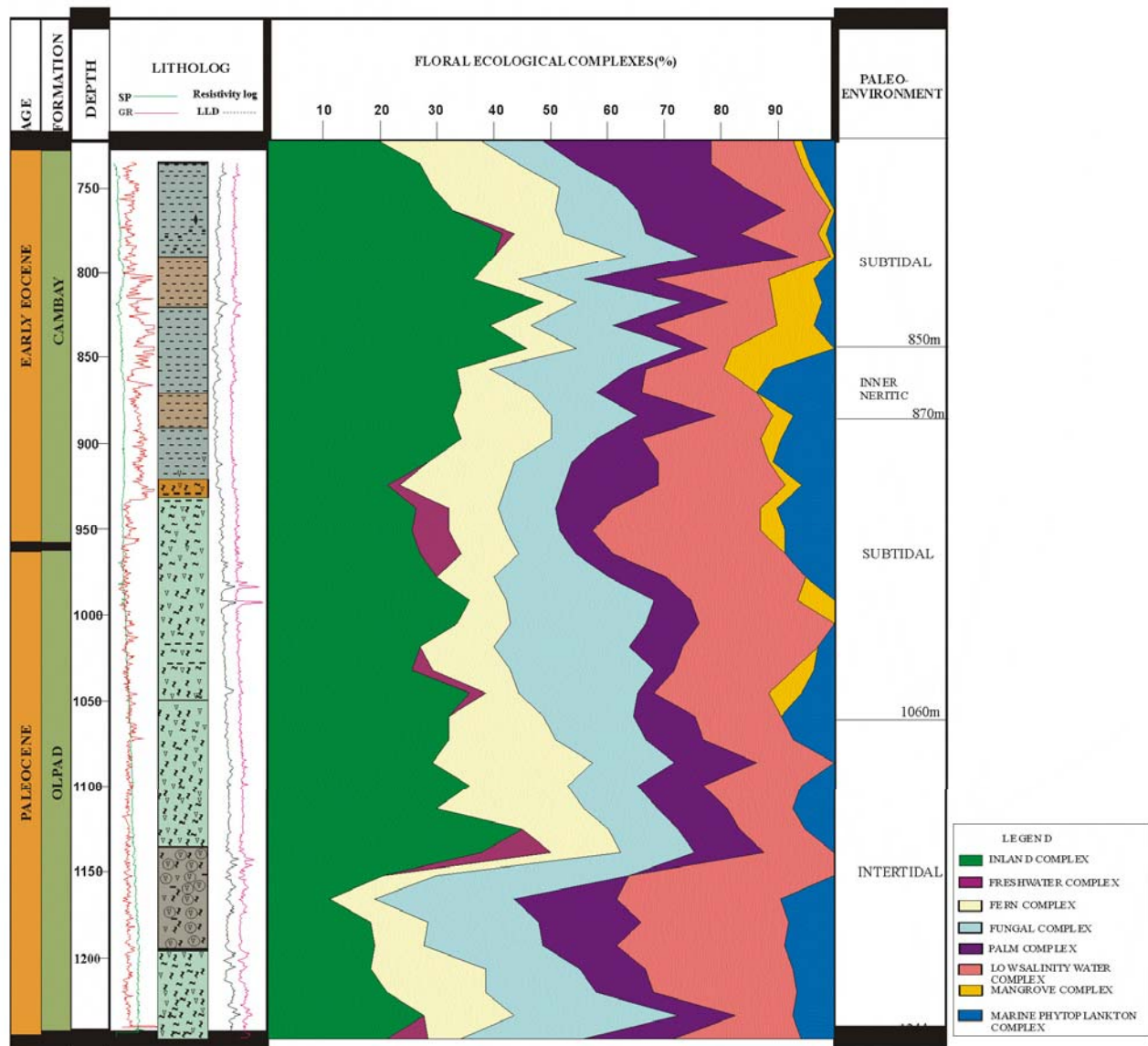


Figure 5. Paleodepositional environment of Gamij area.

WELLS Nos.	GAMIJ #A	GAMIJ #B	GAMIJ #C	GAMIJ #D	GAMIJ #E	GAMIJ #F	GAMIJ #G	GAMIJ #H	GAMIJ #I
Interval Studied (m)	700-1245	710-1345	730-1395	700-1205	740-1370	700-1200	800-1295	800-1395	625-1260
Early Eocene Top (m)	705	770	760	740	745	725	840	840	700
Paleocene Top (m)	960	1010	970	890	965	870	1040	1100	1030

Table 1. Top of Paleocene and of Lower Eocene, based on the first downhole appearance of Paleocene and of Early Eocene index marker taxa, respectively.

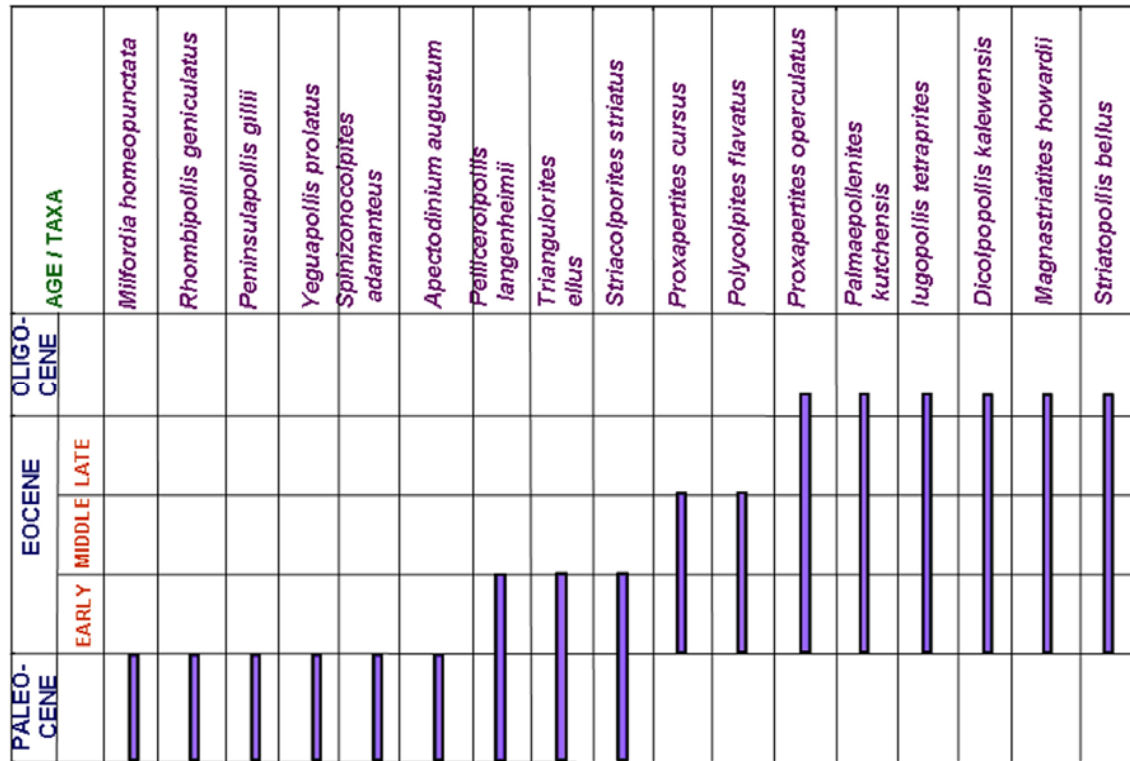


Table 2. Stratigraphic ranges of age marker taxa in Cambay Basin.