S. D. SINGH, SUJAY SINHA, SUDHIR SHUKLA, ANAND GUPTA AND M. SHANMUKHAPPA
KDM IPE, ONGC, 9, Kaulagarh Road, Dehradun, India
Email: swarndeep@yahoo.com

Refinement of Paleobathymetric Curves of Paleocene - Early Eocene Sequences in Selected Wells of Cambay Basin

ABSTRACT

Micropaleontological and palynological data pertaining to Paleocene-Early Eocene sequences is generated in three wells of Cambay Basin namely, A-1, B-1 and C-1. Besides re-interpreted the already generated data for more precise age determination, paleoenvironmental interpretation and estimation of paleobathymetry of the subsurface sequences in nine wells namely, D-1, E-1, F-1, G-1, H-1, I-1, J-1, K-1 and L-1 The paleobathymetric curves have also been compared with the eustatic sea level curve to know the relationship of local bathymetric changes with those of eustatic curves. In some wells the local paleobathymetric curves are not matching with the eustatic sea level curves which can be attributed to the local tectonics.

INTRODUCTION

The Cambay Basin is an intracratonic rift graben situated in the western part of Indian Peninsula and covers an area of about 59,000 sq. kms. It is a proven petroliferous basin having commercial production from Tertiary sediments. It is a linear NNW- SSE trending Tertiary rift graben filled with more than 7 km of sedimentary rock overlying the Deccan Trap (volcanic rocks). It is a narrow, elongated, intra-cratonic rift. This rift is bounded by near meridional boundary faults both on the eastern and western margin and divisible into several discrete tectonic blocks or grabens with respective transfer zones delineating the blocks, from north to south. The basin has several north-south trending normal faults and east – west trending transfer faults. These faults have divided the basin into several smaller tectonic blocks. Four tectonic blocks having well defined structural setting have been recognized from south to north:

- the Narmada Block,
- the Jambusar/Broach Block,
- the Cambay-Tarapur Block,
- the Ahmedabad- Mehsana Block.

Biostratigraphic studies utilizing foraminifera, ostracoda, spore pollen and dinoflagellates have been carried out on Paleocene-Early Eocene of wells A-1, B-1 and C-3. KDMIPE for age determination, paleoenvironmental interpretation and estimation of paleobathymetry for the Paleocene–Early Eocene sequence. Biostratigraphic data pertaining to Paleocene-Early Eocene sequences of nine studied wells of Cambay Basin

by the ONGC laboratories viz. D-1, E-1, F-1, G-1, H-1, I-1, J-1, K-1 and L-1 (Fig.1) has also been reinterpreted to refine the paleobathymetric curves and compared with the eustatic sea level curve.

MICROFOSSILS RECORD IN CAMBAY BASIN:

FORAMINIFERA

Microfaunal occurrences of Cambay Basin have been discussed by various workers including Dutta (1964, 1965), Sastri *et al* (1964) , Raju *et al* (1970), Bhandari (1990) Bhandari *et al* (1998), Chaube (1980), Guha and Singh (1980), Datta and Mehrotra (1974) Govindan (1987,1989), Kumar, (1983), Sharma (1987, 1989), Singh *et al* (1978, 1979) , Mohan (1982) and Pandey *et al* (1993) Shukla *et al* (2006) amongst others.

PALEOCENE: Dutta and Mehrotra (1974) firstly reported *Globorotalia inconstans, G. pseudobulloides, Smoutina* sp., *Pararotalia* sp., *Spirosigmoilina* sp. with other miliolids and rotalids. Pandey *et al* (1993) opined that only one major transgression existed in the Cambay Basin and discounted the existence of *A. granulosa, N. thalicus, Globorotalia inconstans* and *G. pseudobulloides*.

EARLY EOCENE: Raju *et al* reported *Assilina granulosa* and *Nummulites* Zone from the lower most part of the Early Eocene. Mohan (1982) and Pandey *et al* (1993) reported *Nummulites burdigalensis* Zone in Early Eocene with its LAD demarcating the Early Eocene top along with *Assilina spinosa*.

OSTRACODA

Presence of fresh water to brackish water ostracodes have been reported by earlier workers e.g. Singh and Porwal (1999), Bhandari, A. (1990, 1998). In general, the Olpad Formation has yielded fresh water ostracodes represented by *Darwinula gujaratensis, Paracypris cambayensis, Paracypris siddiquii, Ovocytheridea mahiae, O. chaklasiensi, Moenocypris* sp., *Frambocythere colini* and a brackish water *ostracode Neocyprideis raoi.*

The younger cambay shale has yielded marine foraminifera and ostracoda equivalent to the *Nummulites burdigalensis* Zone. The ostracodes include *Alocopocythere abstracta, A. longilinea, Gyrocythere grandilavis, Buntonia boldi, Paracypris* sp. and *Neocyprideis* sp.

SPORE-POLLEN AND DINOFLAGELLATES

Venkatachala (1977) has reviewed the available data from the Cambay Basin. Earlier important contributions are from Venkatachala and Chowdhary (1974), Rawat *et al.* (1974) and Mathur and Chowdhary (1974). Venkatachala and Chowdhary (1974) recorded a rich assemblage of palynofossils from the different formation of Cambay Basin. Shanmukhappa (1991) worked out the palynostratigraphy and paleoenvironment analysis of subsurface sequence of different wells in Gandhar area. He, based on rich assemblages mainly spore-pollen and dinoflagellates identified five palynozones in the Eocene to Miocene sections and established correlation in Gandhar area. Shanmukhappa

and Koshal (1993) further elaborated on the paleoenvironment of Eocene sediments in Gandhar area.

BIOSTRATIGRAPHIC STUDIES

MICRO-PALEONTOLOGICAL STUDIES

Micro-paleontological studies have been carried out on wells A-1, B-1 and C-1.

Well A-1

Cutting samples pertaining to well A-1 between the interval 1950 to 2300m have been studied. Late Paleocene age is assigned for the interval 2295-2300m, Early Eocene for the interval m. 2295-1985m and Middle Eocene for the interval 1985 to 1950m (Fig.4). The biostratigraphy of the well is discussed below:

Interval: 2295-2300m
Fauna: *Nummulites* sp. cf. *N. indicus*
Age: Late Paleocene
Paleoenvironment: Based on the presence of *Nummulites* sp. cf. *N. indicus*, inner shelf paleoenvironment is inferred for the interval.

Interval: 1985-2295-m
Fauna: *Nummulites burdigalensis, Bulimina* sp., Costate *Uvigerina* sp., *Quinqueloculina* sp., *Operculina* sp, *Heterolepa* sp., *Eponides* sp., , *Eponides* sp., *Cibicides* sp., *Nonion* sp., *Melonis* sp., *Lenticulina* sp., other smaller benthics, Molluscan shells/ shell fragments, Rotalids, miliolids, *Pseudohastigerina micra, Globigerina* sp., *Chiloguemblina martini, Chiloguemblina* sp., broken/ juvenile planktics, pyritised microgastropods, sideritic bodies, fish teeth, *Alocopocythere* sp. cf. *abstracta, Costa (Paracosta) declivis, Cytherepteron guhai, Cytherella bhaladaensis, Ganeshella parvatiae, Paijenborchella* sp. and A, *paijenborchella* sp. B
Age: Early Eocene
Paleoenvironment: Based on the faunal assemblage inner shelf paleoenvironment is inferred for the interval.

Well B-1

Cutting samples pertaining to well B-1 between the interval 1795 to 2870 m have been studied. Late Paleocene age is assigned for the interval 2165 to 2870m and Early Eocene for the interval 1795-2165m (Fig. 5). The bistratigraphy of the well is discussed as below:

Interval: 2165-2870 m
Fauna: *N. indicus, N. exilis planulatus, N. planulatus, N. globulus, N. burdigalensis, N.* sp. c.f. *N. thalicus, N.* sp., *Assilina ranikoti, Assilina prespira* fragments, *Assilina* sp. fragments, *Epistomaria* sp., *Operculina* sp., miliolids, *Pararotalia* sp., *Amphistegina* sp., *Rotalia* sp., Broken *Ammonia* sp., *Globigerinoides* sp., and *Cibicides* sp., *Neocyprideis raoi, Buntonia boldi, Ganeshella parvatiae, Alocopocythere* sp., *A. lunejensis, A.*

abstracta. A. rajasthanensis, Ovocytheridea mahiae, O. chaklasiensis, Paracypris nadaensis, P. siddiquii, Cytherella bhaladaensis, Cytherella sp. and an *Indet* ostracoda sp.

Remarks: *Alocopocythere abstracta. A. lunejensis, A. rajasthanensis, Buntonia boldi, Ovocytheridea mahiae, Paracypris nadaensis* and *Cytherella bhaladaensis* are caved forms.
Age: Late Paleocene age has been assigned to the interval on the basis of index fauna *Nummulites indicus.*
Paleoenvironment: Based on the faunal assemblage inner shelf paleoenvironment is envisaged for the interval.

Interval: 1795-2165m
Fauna: *Nummulites burdigalensis, N. exilis-planulatus, N. planulatus, N. praelucasi. N. globulus, N.* sp., *Sphaerogypsina* sp., *Pellatispira* sp., *Discocyclina* sp., *Operculina* sp., *Operculinoides* sp., *Rotalia* sp., *Cibicides* sp., *Pararotalia* sp., *Amphistegina* sp., *Lenticulina* sp., , miliolids and *Nonion* sp., *Alocopocythere abstracta. A.* sp., *A. lunejensis, A. minuta, Ovocytheridea chaklasiensis, O. mahiae, Trachyleberis* sp., *Cytherella bhaladaensis, Cytherelloidea cambayensis, Paracypris nadaensis, P. cambayensis, Ganeshella shankari, Bairdia* sp. (broken), *Schizocythere* sp., juvenile ostracoda and an indet. ostracoda sp.
Age: Early Eocene is assigned to the interval on the basis of index fauna *Nummulites burdigalensis* and *Alocopocythere abstracta.*
Paleoenvironment: Based on the faunal assemblage inner shelf paleoenvironment is inferred for the interval.

Well C-1
Cutting samples pertaining to depth intervals between 1950-2095m, 2505-2610m and 2800-3000m were examined for their microfaunal content. No microfauna were recorded from the studied intervals. Therefore, no age or paleoenvironmental analysis could be carried out on this well on the basis of foraminifera and ostracode studies.

PALYNOLOGICAL STUDIES

Selected cuttings from well C-1 (1770-3770m) and A-1 (1950-2300m) have been analysed for palynological contents. Samples were examined at 10m intervals. Sometimes even at closer interval for demarcating the age boundary and to recognize the changes in depositional conditions of the sediments, the standard processing techniques were used for recovery of spore- pollen and dinoflagellates.

Well C-1

Interval: 2915-3700m

Zone: **Palynozone II:**
It is the lowermost zone in this well. The top of this zone is marked at 2915m depth, corresponding to the LAD of *Netothyrites paleocenicus* which disappear close to the Late Paleocene-Early Eocene boundary. *Netothyrites paleocenicus shows* its first occurrence in Early Paleocene (Danian) in Indian tertiary sediments making the base of the Informal zone II. (Fig.4)

Palynological contents of this zone include common occurrence of *Spinizonocolpites bulbosus, Callimothallus pertusus, Intrareticulites brevis, Raceimonocolpites ramonus, Proxapertites assamicus, Proxapertites emendatus* and *Neotrichotomosulcites faveolatus.*

This assemblage also includes the moderate to rich occurrence of fungal spores such as *Netothyrites paleocenicus, Phragmothyrites eocenica, Callimothallus pertusus, Dicellaesporites popovii, Diporisporites hammenii, Fusiformisporites crabii, Multicellaesporites elsikii, Palaeocirrenalia elegans.*

Age: The record of LAD of *Netothyrites paleocenicus* at the upper boundary of this zone, which disappear close to the Paleocene-Eocene boundary. In the K.G. Basin *Netothyrites* is very common in *Raceimonocolpites ramonus - Spinizonocolpites bulbosus* and *Muleripollis bolpurensis-Psittacopollis circularis* zones (Misra *et al 1996*). The above spore-pollen zones are identified in Modi–A (3342-3420m), Palalkollu–A (2550-2685m) and Razole-A (3360-65m). *Netothyrites* in AN-42-A well (1200-3275m) of Andaman Basin occur in association with Paleocene spore pollen assemblages dominated by *Proxapertites cursus, Psilodiporites hammenii* and *Spinozonocolpites baculatus* (Shanmukhappa 1990,1991). Similarly, the occurrence of *Netothyrites* in the well A-66-A, SM-79-A and B-163-A wells of Bombay Offshore Basin is also recorded. Therefore, a Late Paleocene age has been inferred for this zone.

Paleoenvironment: Palynozone-II (Late Paleocene) corresponding to Olpad Formation has encountered only in the well C-1 around 2875m depth. Sediments between 2875-3100m are poor in back mangrove but moderate to rich in fungal spores. The depth interval from 3100 to 3700m shows the occurrence of fungal spores only. The presence of black organic matter (Coal/lignite?) with association of back mangrove and fungal spores in lower delta plane conditions indicates intertidal (foreshore) condition of deposition (Regressive phase).

Interval: 1770-2915m
Zone: **Palynozone-I:**

This zone, recorded in Cambay Formation in the well C-1, conformably overlies the Zone-II. The base of this zone has marked by the first occurrence of *Pellicieroipollis langenheimii, Dandotiaspora plicata, Striatricolporites cephalus, Polycolpites pedaliaceoides* and *Ephedra volut* (Fig. 4).

Palynological contents of this zone include common occurrence of *Psilodiporites hammenii, Dandotiaspora dilata, Draceanoipollis circularis, Pseudonothofagidites kutchensis, Iugopollis tetraporoites, Striatricolporites ovatus, Polygalacidites clarus,*

Palmaepollenites nadhamunii, P. ovatus P. eocenicus, Proxapertites operculatus, Lakiapollis ovatus, Longapertites vaneedenburgi, L. punctatus, Margocolporites sahanii and *Polycolpites granulates.*

This assemblage zone also includes the rare occurrence of dinoflagellates like *Apectodinium homomorphum, Wetzeliella articulate, Alisocysta circumtabulates,* and *Biconidinium longissimum.*

Age: The zone includes characteristic Palynoflora of *Pellicieroipollis langenheimii*, which occurs at top of Early Eocene, *Dandotiaspora plicata, Striatricolporites cephalus, Polycolpites pedaliaceoides* and *Ephedra volute* are known to occur in Paleocene to Early Eocene age in Kutch and South Shillong plateau of Meghalaya (Sah and Dutta,1974) and Cambay basin (Shanmukhappa,1990, 1991).The zone has thus been dated as Early Eocene. However, the record of *Apectodinium homomorphum, Wetzeliella articulate, Alisocysta circumtabulates, Biconidinium longissimum* a strongly corroborates the Early Eocene age of this zone.

Paleoenvironment : Palynozone-II (Late Eocene) corresponding to Cambay Formation encountered in the well. In well C-1 (1770-2875m) shows the dominance of pteridophytic spores, palm pollen and low salinity water elements. Mangrove pollen and phytoplankton are rare to absent. This indicates brackish water condition of deposition

Well A-1

Interval: 1950-2300
Zone: **Palynozone-I:**

This zone, recorded in Cambay Formation in the well A-1. The base of this zone has marked by the first occurrence of *Pellicieroipollis langenheimii, Dandotiaspora plicata, Striatricolporites cephalus, Polycolpites pedaliaceoides* and *Ephedra volute.*(Fig.5)

Palynological contents of this zone include common occurrence of *Psilodiporites hammenii,Dandotiaspora dilata, Draceanoipollis circularis, Pseudonothofagidites kutchensis, Iugopollis tetraporoites, Striatricolporites ovatus, Polygalacidites clarus, Palmaepollenites nadhamunii, P.ovatus P. eocenicus, Proxapertites operculatus,Lakiapollis ovatus,Longapertites vaneedenburgi, L.punctatus, Margocolporites sahanii* and *Polycolpites granulates.*

This assemblage zone also includes the moderate occurrence of dinoflagellates viz. *Thalassiphora pelagic, Apectodinium homomorphum, Spiniferites* spp., *Cordosphaeridium funiculum, Adnatosphaeridium multispinosum, Glaphrocysta exuberans, Hystricospaeridium tubiferum, Homotryblium tenuispinosum, Polysphaeridium* spp., *Cleistosphaeridium* spp..

Age: The zone includes characteristic Palynoflora of *Pellicieroipollis langenheimii*, which occurs at top of Early Eocene, *Dandotiaspora plicata, Striatricolporites cephalus*

and *Polycolpites pedaliaceoides* are known to occur in Paleocene to Early Eocene age in Kutch and South Shillong plateau of Meghalaya (Sah and Dutta, 1974) and Cambay basin (Shanmukhappa, 1990, 1991).The zone has thus been dated as Early Eocene. However, the record of *Thalassiphora pelagic, Apectodinium homomorphum, Adnatosphaeridium multispinosum, Glaphrocysta exuberans, Homotryblium tenuispinosum, Wetzeliella articulate, Alisocysta circumtabulate,* and *Biconidinium longissimum* strongly corroborates the Early Eocene age of this zone.

Paleoenvironment: Palynozone-I (Early Eocene) corresponding to Cambay Formation. The presences of marine phytoplankton with mangrove floral elements indicate under subtidal (inner shelf) regime.

PALEOEBATHYMETRIC REFINEMENTS

In the present study, an attempt has been made to reconstruct the paleobathymetric curves and T/R facies cycles by reinterpreting the data already generated by previous workers. Paleobathymetric curves of nine wells have been refined, reinterpreted and compared with the eustatic cycles of Haq. *et al.* (1987) as discussed below:

1. **WELL D-1:** In the well D-1 characteristic microfauna comprising foraminifera and ostracoda at two levels 1700 to 1800m and 1300 to 1350m suggests transgressive pulses where the bathymetry is of the order of upto 30m. Depending on the fossiliferous and unfossiliferous intervals paleobathymetric curves, minor T/R facies cycles are prepared and compared with the eustatic curve. After reinterpretation of data, two T/R facies cycles are observed as shown in figure no. 6.

2. **WELL E-1:** In this well the earlier paleobathymetric studies suggested one T/R facies cycle in the Cambay shale. The reinterpreted data indicates three T/R facies cycles in the Cambay shale.

3. **WELL F-1:** In this well the occurrence of characteristic ostracoda and dinoflagelates at 1920m, 1845m, 1780m, 1750m and 1550 to 1600m suggests transgressive pulses where the bathymetry is of the order of upto 20m. In this well, previously, two T/R facies cycles were interpreted in the interval of study. The reinterpreted data indicates two T/R facies cycles with minor pulses.

4. **WELL G-1:** In the well Nawagam-94 characteristic microfauna comprising foraminifera and ostarcoda at two levels 2010 to 2035m and 1820 to 1830m suggests transgressive pulses where the paleobathymetry is of the order of upto 30m. Two minor transgressive pulses are observed at 1950 and 1970m. Previously, based on paleobathymetric studies, three T/R facies cycles were

interpreted. After reinterpretation of data two T/R facies cycles with minor pulses in between are observed as shown in figure no. 6.

5. **WELL H-1:** In this well characteristic foraminifera and ostracoda at two levels 1500 to 1580 and 1275 to 1320m suggests transgressive pulses where the bathymetry is of the order of upto 30m as shown in figure no. 6. Two T/R facies cycles are interpreted in the study.

6. **WELL I-1:** In the well I-1 characteristic foraminifera comprising *Nummulites burdigalensis* between 1110 to 1130m suggests transgressive pulse where the bathymetry is of the order of upto 30m. In this well, based on paleobathymetric studies, one T/R facies cycle was interpreted in the earlier work. However, reinterpretation of the paleobathymetric data suggests one T/R facies cycle with minor pulse as shown in figure no. 6.

7. **WELL J-1:** In this well characteristic foraminifera, ostracoda and dinoflagelates between the intervals 1925 to 2010m and 1800 to 1870m suggests transgressive pulses where the bathymetry is of the order of upto 30m. Previous studies on this well interpreted only non-marine to marginal marine environment in the interval 1775 to 2100m. However, reinterpretation of paleobathymetric data suggests the presence of two T/R facies cycles in the interval as shown in as shown in figure no. 6..

8. **WELL K-1:** In this well characteristic foraminifera comprising *Nummulites burdigalensis* at 475m and *Operculinoides* sp. at 380 to 390m suggests transgressive pulses where the bathymetry is of the order of upto 30m (as shown in figure no. 6.). Based on the reinterpretation of paleobathymetric curves two T/R facies cycles with minor pulse are interpreted. Previous studies indicated only two T/R facies cycles.

9. **WELL L-1:** In this well, the paleobathymetric studies indicate a bathymetry of upto 30m in the interval 3015 to 3100m based on the presence of *Nummulites burdigalensis* in the Early Eocene as shown in as shown in figure no. 6.. One T/R facies cycle in the Early Eocene is interpreted in the present study.

CONCLUSIONS

1. In the southern part of Cambay Basin, marine influences in Cambay Shale is best evident in well B-1, as foraminiferal occurrence is prolific. On the basis of foraminifera the Late Paleocene/ Early Eocene boundary has been demarcated at 2165m. Paleobathymetric fluctuations within inner shelf paleoenvironment have been inferred in the form of bathymetric curves and T/R facies cycles.

2. In well A-1, cutting samples between the interval 1950 to 2300m have been studied for their faunal and floral contents. The pollen spores and phytoplankton studies suggest Early Eocene age for the interval 1950 to 2300m. However, based on the foraminiferal and ostracoda studies the Late Paleocene/ Early Eocene boundary has been demarcated at 2295m and inner shelf paleoenvironment has been inferred.

3. In the well C-1, two Palynozones are characterized by *Netothyrites paleocenicus* and *Pellicieroipollis Langenheimii* which are assigned Late Paleocene (2915-3700m) and Early Eocene age (1770-2915m) corresponding to Olpad and Older Cambay Shale Formation respectively. Late Paleocene/ Early Eocene boundary has been demarcated at 2915m. The interval 2915 to 3770m indicates foreshore condition of deposition and the interval 1770 to 2915m indicates backshore (supratidal) paleoenvironmental conditions.

4. Biostratigraphic data pertaining to Paleocene - Early Eocene sequences of nine already studied wells viz. D-1, E-1, F-1, G-1, H-1, I-1, J-1, K-1 and L-1 has been reinterpreted to refine the paleobathymetric curves. The reinterpretation of faunal and floral data including bathymetry at certain levels helped identification of minor T/R facies cycles and/or pulses.

5. Paleobathymetric curves as observed in studied wells have also been compared with the eustatic sea level curve (Haq *et al,* 1987). The first marine transgressive pulse during Early Eocene has been observed in wells H-1, B-1, K-1, A-1 and D-1. In the other studied wells the effect is not clearly observed. The difference in matching the paleobathymetric curves with the eustatic sea level curve can be attributed to the local tectonics.

6. The observed T/R facies cycles attribute to fluctuations in bathymetry as suggested by the presence or absence of microfossils in rift and post rift depositional setup, often strongly affected by the local tectonics. Although more data points are required to make precise conclusions for such a vast basin, however, the present study provides point leads to further integrate results on electrolog correlations and possibly comparing with the available seismic horizons.

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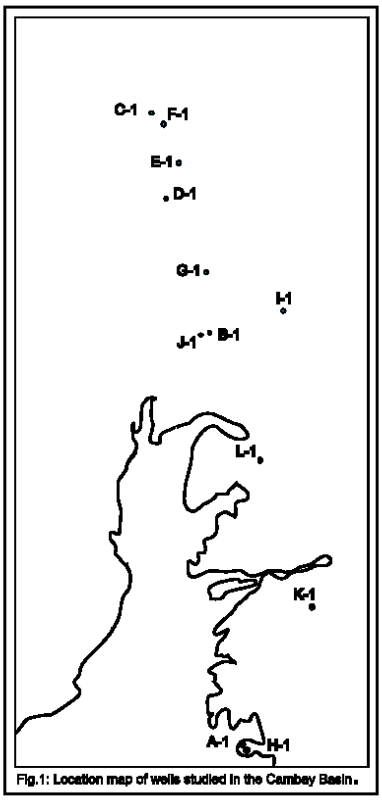

Fig.1: Location map of wells studied in the Cambay Basin.

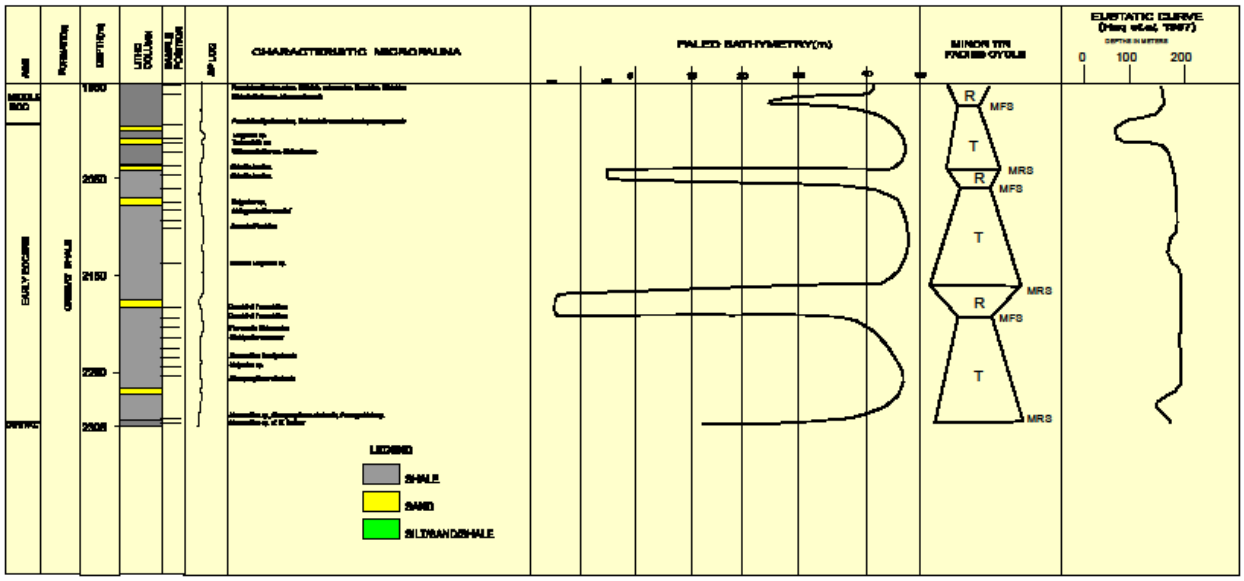

FIG.2 : BIOSTRATIGRAPHY, PALEOBATHYMETRY, T/R FACIES CYCLE & EUSTATIC CURVE OF WELL A-1, CAMBAY BASIN

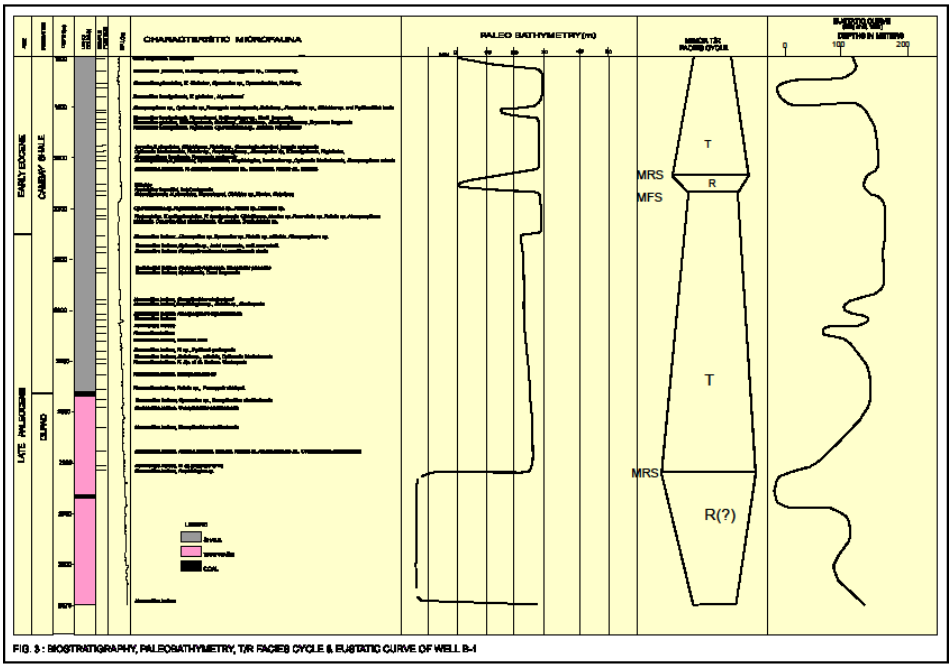

FIG. 3 : BIOSTRATIGRAPHY, PALEOBATHYMETRY, T/R FACIES CYCLE & EUSTATIC CURVE OF WELL B-1

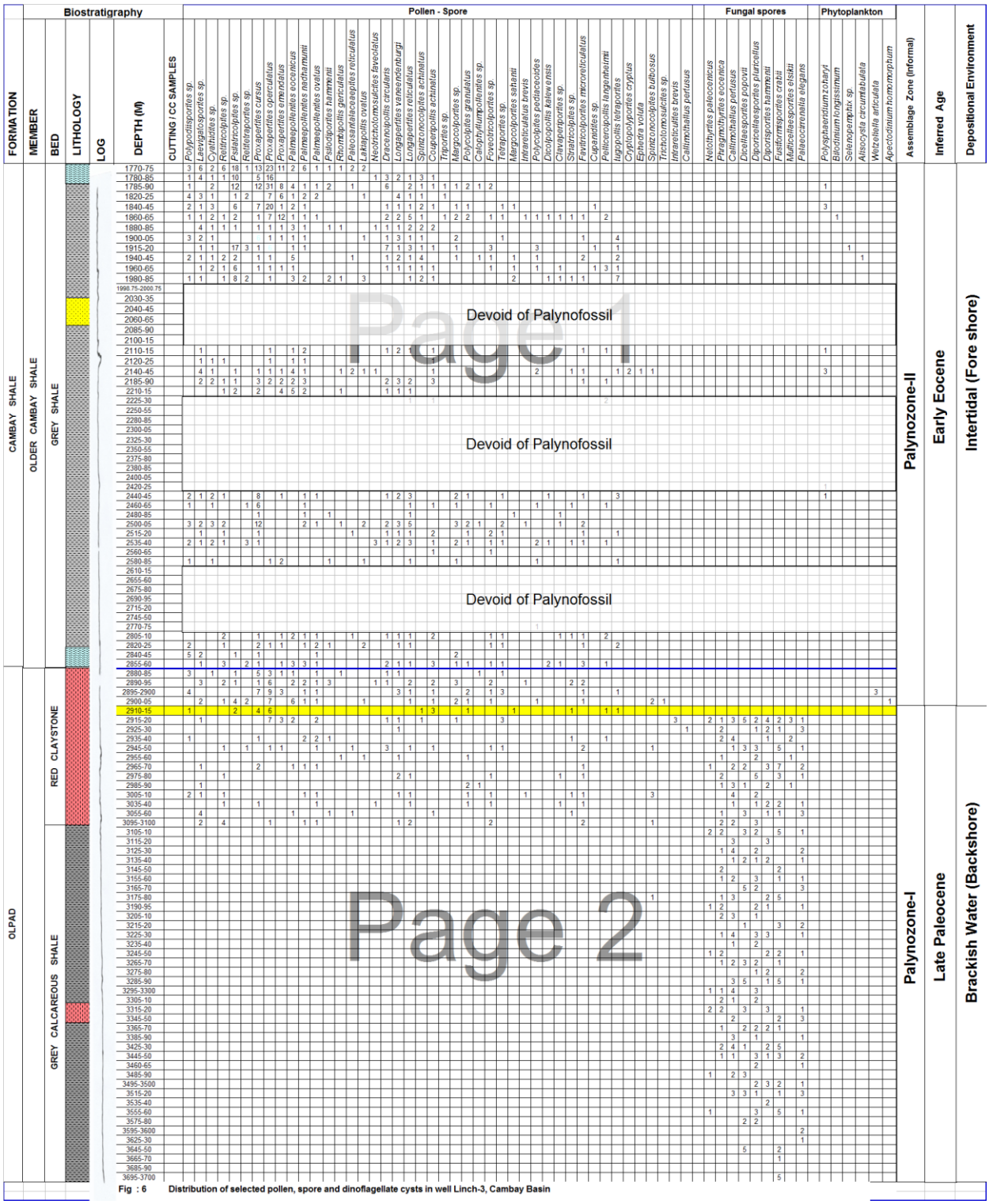

Fig : 6 Distribution of selected pollen, spore and dinoflagellate cysts in well Linch-3, Cambay Basin

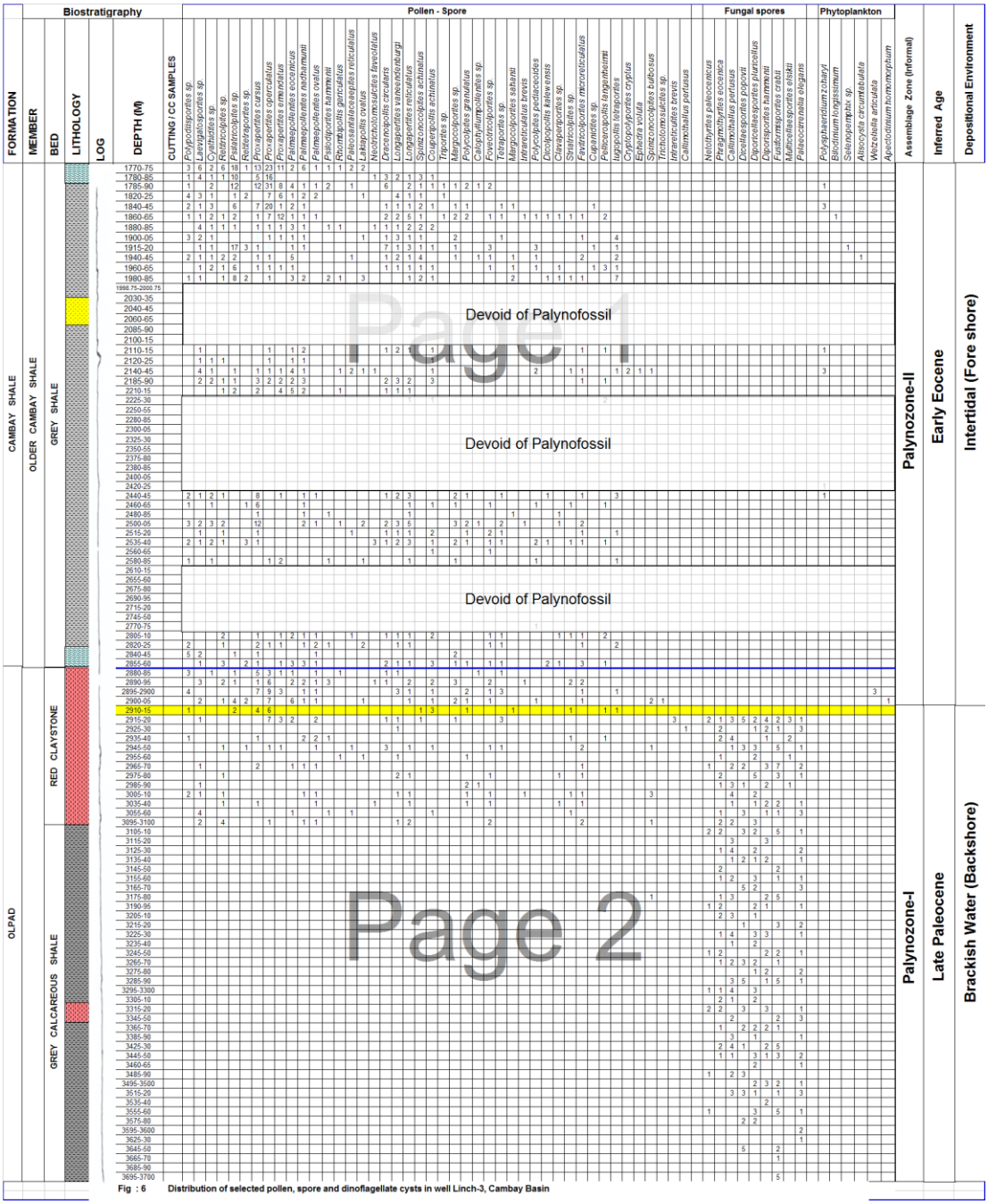

Fig : 6 Distribution of selected pollen, spore and dinoflagellate cysts in well Linch-3, Cambay Basin

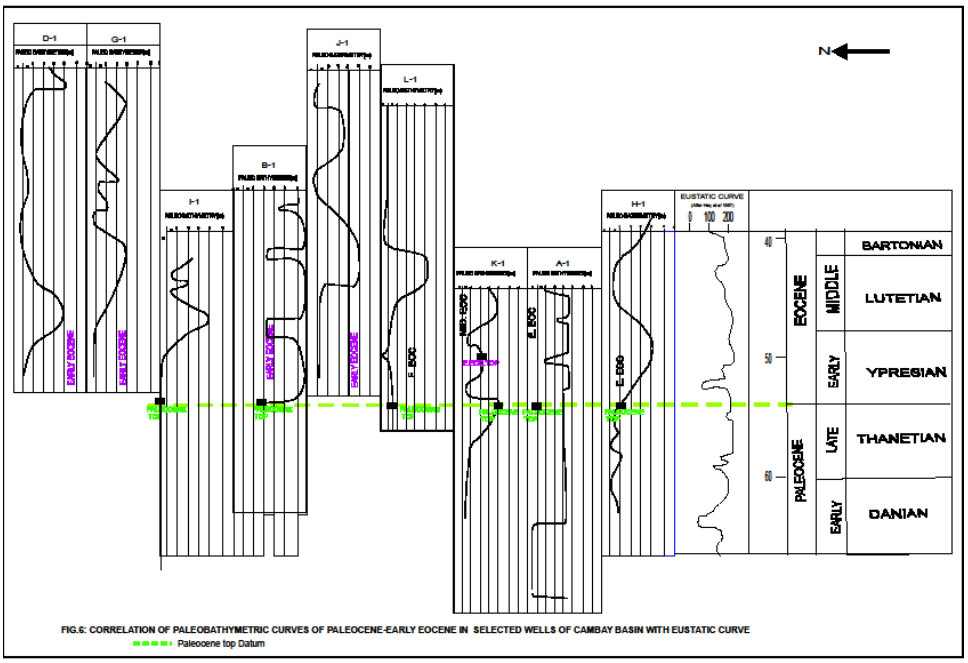

FIG.6: CORRELATION OF PALEOBATHYMETRIC CURVES OF PALEOCENE-EARLY EOCENE IN SELECTED WELLS OF CAMBAY BASIN WITH EUSTATIC CURVE